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Physical and transition risk premiums in euro area corporate bond markets

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Abstract

The European Union plays a prominent role in climate regulations initiatives, this commitment likely implies that climate risk premiums look different in Europe compared to the rest of the world. This paper examines the pricing implications of climate risks in euro area corporate bond markets, focusing on physical and transition risk. Using climate news as a gauge for systematic climate risk, we find a significant pricing effect of physical risk in long-term bonds, with investors demanding higher returns on bonds exposed to physical risk shocks. The estimated physical risk premium is 34 basis points, indicating increased awareness and hedging demand after the Paris Agreement. Transition risk premiums are smaller and less significant, reflecting the ongoing transition to a low-carbon economy. Our findings contribute to understanding climate risk pricing in the European bond markets, highlighting the importance of physical risk and the evolving nature of investor demand for climate-resilient assets.

JEL codes: G12, G14, G28, Q51, Q54

Keywords: Climate physical risk, climate transition risk, corporate bonds, news index, intertemporal hedging demand

Non-technical summary

The European Union (EU) plays a prominent role in climate regulations initiatives, this commitment likely implies that climate risk premiums look different in Europe compared to the rest of the world.

This paper examines the pricing implications of climate risk in euro area corporate bond markets, focusing on the period before and after the Paris agreement. Using climate news as a gauge for systematic climate risk, we investigate the relationship between physical and transition risk betas and future bond returns, offering insights into how the demand for protection against climate risks influences bond pricing (*hedging hypothesis*). The study contributes to the existing body of literature by shedding light into the pricing of climate risk in euro area corporate bonds, which has been largely unexplored compared to equity markets.

The findings reveal that since the Paris agreement, there is a significant negative relationship between the physical news risk beta and future returns on long-term bonds. This suggests that investors demand higher future returns on bonds that are more vulnerable to physical risk shocks, as reflected by a relatively low physical news risk beta. Even short-term bonds exhibit a pricing effect, although the premium is smaller in magnitude and less significant. Additionally, we observe a negative relation between transition risks and returns, although not statistically significant. When compared to some US-centered studies, which failed to confirm the *carbon risk premium hypothesis* in the US corporate bond market (Duan et al., 2021), our results serve as an indicator that the stricter environmental standards in the Euro Area enhance the pricing of climate risk in the corporate bond market.

Our results have implications for both market participants and European policymakers, emphasizing the need for a comprehensive understanding of climate risk and its impact on bond pricing. The significant pricing of physical risk premiums in long-term bonds indicates that investors are increasingly concerned about the potential impact of physical risk on bond returns. Additionally, the negative relation between transition risks and return suggests that the enforcement of environmental regulations enhance the pricing of risks. This in turn, has important substantial and positive implications for climate mitigation policies and financial stability.

1 Introduction

Investors are wary of climate change. This is because climate change, through physical and transition risks, can have a negative effect on the financial system and the wider economy. Physical risk reflects the impact of chronic and acute physical events, whereas transition risk arises from the costly adjustment towards a low-carbon economy, typically prompted by changes in climate and environmental policies, technological advances, and/or shifts in public preferences.[1] Research documents the negative effect of physical events and mitigation polices on consumption and investment opportunities (see Batten, 2018; Tol, 2018), suggesting the desire of investors to hedge against these undesirable states of the economy. With the EU expected to become the first continent with a net-zero emissions balance, it is important to understand the relationship between Europe, specifically, and climate change risks. In this paper, we test the pricing impact on euro area corporate bonds stemming from the demand for assets that hedge against climate physical and transition risk.

Recent theoretical work focuses on the link between asset price returns (expected and realized) and firm's climate characteristics, suggesting different channels are at play (see Pástor et al., 2021; Engle et al., 2020; Pedersen et al., 2021).

According to risk-based asset pricing theory, the *intertemporal hedging hypothesis* developed by Merton (1973) predicts that investors prefer assets that hedge against unfavourable shifts in their opportunities set and that state variables that are correlated with such changes are priced in capital markets (Merton, 1973). Since climate change affects future investment and consumption opportunities, investors have incentives to hedge against climate change risks by holding assets today that deliver higher returns during events of adverse climate shocks (Engle et al., 2020; Huynh and Xia, 2021b). By implication, investors may be willing to accept lower future returns for assets that are good hedges against climate change. Our study focuses on this hypothesis. In addition, within the risk-based asset pricing theory, the *carbon risk premium hypothesis* also predicts a positive relation between carbon-intensive assets and expected returns. This theory focuses on transition risks and moves from the assumption that carbon-intensive firms are riskier than firms with lower carbon intensity, because they are more exposed to the increase in the cost of fossil fuel energy and the depreciation of assets foster by mitigation policies (such as carbon taxes). Given that investors want to be remunerated for holding this risk, assets issued by more polluting firm earn higher expected returns (see Bolton and Kacperczyk, 2021; Duan et al., 2021; Pástor et al., 2021). The model developed by Pástor et al. (2021) also predicts a negative relation

[1] Examples of chronic physical events are gradual shifts in wind and precipitation in the shorter-term, or sea levels, desertification and ocean temperatures in the longer-term, while examples of acute physical events are floods, droughts and wildfires.

between green assets and expected returns. They add to the previous risk-framework, suggesting that the lower expected return earned by green assets reflects a taste premium rather than a risk premium. Green assets have lower expected returns because investors enjoy holding them and because green assets hedge climate risk. The model, however, also explains that green assets can outperform brown assets (have higher realized returns) when agents' demands shift unexpectedly in the green direction. In other words, in an empirical settings, the relationship between greenness and returns can also be positive if, over the period under analysis, investors' concern for climate change strengthen sufficiently and unexpectedly. This positive relation between lower carbon emission intensity and higher return has been referred to as the *investor preference hypothesis* (Duan et al., 2021).[2] More recently, Pedersen et al. (2021) have developed a model where the relation between expected returns and ESG performance in equilibrium differs, depending on the investors preference and the ESG potential to predict firm fundamentals. In this framework, the green assets deliver lower expected returns, if investors have preferences for ESG, however they deliver higher expected returns if ESG is a good gauge of higher future return, but investors are unaware of ESG score *(investor underreaction hypothesis)*.

While there is a fast-growing literature that studies the pricing of climate change in equity markets (Giglio et al., 2021),[3] the literature on pricing climate risks in corporate bond markets is scarce. To our knowledge, while Seltzer et al. (2022), Huynh and Xia (2021b,a) and Duan et al. (2021) are the only studies to investigate climate risk premiums in US corporate bond markets, no study has so far focused on euro area corporate bond markets. Additionally, results for the US are mixed. Huynh and Xia (2021b) focus on the *hedging hypothesis* and test the pricing implication of excess demand for assets that hedge against climate risk. Using climate news as a gauge for systematic climate risk, they find that investors in US corporate bond markets accept lower future returns on bonds that are good hedges against climate risk. Duan et al. (2021) focus on the *carbon risk premium hypothesis* and test whether carbon-intensive firms pay higher expected returns as compensation for higher exposure to transition risks. Contrary to the theory, they find that more carbon-intensive firms earn significantly lower returns. Seltzer et al. (2022) look at pricing of regulatory risks. Using the Paris Agreement as exogenous shock, they find that after December 2015, changes in yield spreads are more pronounced for environmentally problematic firms mainly located in states with stricter environmental regulations. Finally, Huynh and Xia (2021a) focus on physical climate risk and find that when a firm is exposed to disasters, its future

[2](Pástor et al., 2022) are able to show that outperformance of green minus brown portfolios disappears when accounting for climate-concern shocks, suggesting that most of the performance is unanticipated.

[3]While a large number of authors find significant transition risk premiums (see Alessi et al., 2019; Bolton and Kacperczyk, 2021; Ardia et al., 2020; Bua et al., 2021; Faccini et al., 2021; Görgen et al., 2020) and physical risk premiums (see Addoum et al., 2019; Hong et al., 2019; Kruttli et al., 2021), especially after the Paris agreement, other authors find opposite evidences (see In et al., 2019; Pástor et al., 2022). Pástor et al. (2022), for example, show that green assets outperform brown assets when investors are surprised by climate concern.

bond returns are higher.[4] Overall, these studies have focused either on climate change as a single risk factor, without distinguishing between physical and transition risks (Huynh and Xia, 2021b) or have captured sub-dimensions of physical and transition risk, e.g. natural disasters or climate policies, ignoring relevant aspects of these complex risks leading to restricted results.[5]

Examining corporate bonds specifically is important for a number of reasons. First, while equity and bonds are both contingent claims on the same firm fundamentals, it is not clear whether findings in equity markest can be extended to bond markets, given e.g. the nature of predominant investors (Duan et al., 2021). Second, exposure to climate risk may be different for corporate bonds than for equities (Bai et al., 2019). Third, bonds differ along multiple characteristics, such as maturity, allowing to capture differential pricing for short and long term instruments.

Additionally, pricing of climate risk in corporate bond markets is especially relevant for the euro area. The European Union plays a leading role in climate regulations initiatives, and there is evidence of a *self-driven* policy approach that that sets the EU apart from other countries in terms of climate regulation. In fact, the European Council has established ambitious targets, aiming to reduce the EU greenhouse gas emissions by 55% by 2030, compared to 1990, and reach climate neutrality by 2050. With these commitments, the EU is expected to be the first continent to attain a net-zero emissions balance. This commitment likely implies that climate risk premiums look different in Europe compared to the rest of the world. This unique context provides an opportunity to delve deeper into the relationship between Europe, in particular, and climate change risks. This may also have important policy implications. The identification of physical and transition risk premia in European debt markets may in fact highlights the need for integrating climate risks into the core of financial risk management and regulatory supervision (Bua et al., 2021). Further, relative to GDP, market-based debt finance plays a more prominent role in the euro area than in the US.[6] While corporate debt has increased as a financing source on both sides of the Atlantic since the Global Financial Crisis (Berg et al., 2021), the increase in the relative share of bond financing is particularly pronounced in the euro area (e.g. Cappiello et al., 2021; Darmouni and Papoutsi, 2022).

In this paper, we fill the gap and estimate climate risk premiums in corporate bond markets for the euro area. Our study is close in spirit to Huynh and Xia (2021b) in that we are motivated by the *hedging hypothesis* developed by Merton (1973) and we test whether demand for hedging against

[4]Recently,Amiraslani et al. (2023) look at the importance of trust in the US corporate bond market. They employ a firm s investments in environmental and social activities (ES) as a proxy for social capital and find that when the market and the economy faced a severe shock to overall trust, high ES firms had bond spreads that were substantially lower than those of low ES firms.

[5]Duan et al. (2021) and Seltzer et al. (2022), for example, focus only on carbon emissions or intensity, while Huynh and Xia (2021a) investigate only extreme physical events, without considering chronic events.

[6]See for example the BIS debt securities statistics.

physical and transition risk is priced in the bond markets. Building on their work, we contribute to the literature in multiple ways. First, by using the two novel text-based climate risk indicators developed by Bua et al. (2021), we are able to assess whether climate risk premiums in euro area corporate bond markets stem mostly from physical or transition risks. Different from previous studies that have used textual analysis to identify climate risk (Engle et al., 2020), and with the corporate bond literature thus far focusing on climate change only as a single risk factor (Huynh and Xia, 2021b), our indices exploit news content to identify physical and transition risk shocks separately. Studying the individual effects of physical and transition risks is important, as climate risks affect companies through different channels.[7] Additionally, our risk indicators are based on vocabularies that capture the multifaceted characteristics of each climate risk type and also their interconnections. For example, the physical risk vocabulary includes multiple dimensions of physical risk such as both extreme and chronic hazards directly caused by climate change, excluding natural disasters attributable to other sources. This enhances previous studies that mainly capture sub-dimensions of physical and transition risk, e.g. natural disasters or climate policies, ignoring relevant aspects of these complex risks leading to restricted results (Bua et al., 2021).[8] Second, focusing on the euro area, we exploit the intuition of Seltzer et al. (2022) who show that climate risk is priced differently by investors in states where environmental regulation is stricter. Third, different from most of the literature on corporate bonds, our analysis uses daily instead of monthly data on climate risk shocks and corporate bond prices. Daily data improve the identification of climate risk shocks using textual analysis, since the news coverage of climate change fluctuates rapidly. Moreover, daily data also provide for a more accurate quantification of climate risk premiums, because monthly data lack power to identify abnormal returns (see also Bessembinder et al., 2009). Finally, we investigate climate risk pricing in corporate bond markets using portfolio analysis and Fama-Macbeth cross-sectional regressions (Fama and MacBeth, 1973). In contrast to the fixed effects panel estimation approach by Huynh and Xia (2021b), our empirical asset pricing strategy aligns our work with the corporate bond market literature, which relies on a combination of bond and stock market factors for the estimation of abnormal returns (e.g. Lin et al., 2011; Bali et al., 2017; Bai et al., 2019; Bali et al., 2021).

Using data from January 2005 until September 2021, this study employs three steps to estimate physical and transition risk premiums in the euro area corporate bond markets.

In the first step, we estimate the loading on the climate news risk factors, i.e. climate news risk betas, by analyzing the sensitivities of bond excess returns to physical and transition news risk

[7] Companies exposed to physical risk can be affected through damaged assets and disruption of business operations. Depending on how fast and orderly the decarbonisation process occurs, companies exposed to transition risk may be affected by large swings in cost of input factors, stranded assets and cost of financing.

[8] Duan et al. (2021); Bolton and Kacperczyk (2021)for example focus only on carbon emissions or intensity

shocks using daily data on corporate bond prices. We interpret the betas as the "ability to hedge against climate risk". This follows the work of Huynh and Xia (2021b) and Engle et al. (2020). According to Huynh and Xia (2021b), since bonds with high beta provide high returns as the climate change news increases, they serve as good hedge against climate change risk. The implicit assumption is developed by Engle et al. (2020), who state that the number of climate change discussions increase when climate risk is elevated. In other words, the climate index embeds the view that, when it comes to climate change, no news is good news (Engle et al., 2020). Bonds with negative or low physical and transition news risk betas, indicate low returns during periods of heightened climate news risk. Such bonds are regarded as poor hedges against physical and transition risks, suggesting that investors should demand higher expected returns to compensate for the additional risk associated with holding them in their portfolios. Conversely, bonds with positive or high climate news risk beta perform well during periods of increased climate news risks, offering a potential hedge against climate change risks. Investors should require lower expected return to include them in their portfolio. It is probable that companies opposed to new climate regulations or heavily dependent on climate stability may be characterised by a negative transition or physical climate beta, respectively.

Moving to the second step, we utilize monthly data to categorize corporate bonds into portfolios based on their climate risk betas, specifically using quintiles. This categorization enables us to explore the cross-sectional relationship between climate risk and the future excess returns of bonds at the portfolio level. We also estimate risk-adjusted return measures for each portfolio by incorporating bond and stock market factors.

Finally, in the third step, we examine the intertemporal relationship between climate risk betas and future monthly bond returns through Fama-Macbeth cross-sectional regressions. These regressions allow us to assess the persistence of climate risk premiums by focusing on out-of-sample cumulative returns several months ahead.

In line with the literature, we study the periods before and after the year of the Paris agreement separately. Our study reveals compelling insights regarding the pricing of physical risk beta in euro area corporate bonds, particularly after the year of the Paris agreement. Notably, we find a significant relationship between physical risk beta and the pricing of corporate bonds with longer maturities. In contrast, bonds with shorter maturities exhibit a smaller and less significant physical risk premium. When considering bond characteristics, we observe a negative physical risk premium for long-term bonds. Specifically, our estimations indicate a 15 basis points decrease in the physical risk premium one month ahead and a 34 basis points decrease over a period of 2 to 6 months. This negative premium implies that investors demand higher future returns on bonds that provide inadequate protection against physical risk. Importantly, this result stems primarily from the underperformance of bonds with low physical risk betas. Interestingly, our findings align with the stock market literature, as we observe that corporate bonds did not exhibit significant physical risk premiums before 2015. This suggests that investors' motivation to hedge against physical risk intensified following the implementation of the Paris agreement. In contrast, although the transition risk premium is also negative, our estimations generally do not reach statistical significance. Nonetheless, these findings collectively highlight the identification of a new risk factor that contributes to predicting the cross-sectional variation in future bond returns.

Our study mainly contributes to a growing strand of literature which focuses on understanding the impact of physical and transition climate risk on asset prices.[9] Focusing on bond markets, we contribute to Huynh and Xia (2021b), as we acknowledge that climate risks arise from different sources that need to be analyzed separately. While they find that investors are concerned about climate risk, they suggest that the small coefficient points to the fact that market has not fully priced in climate risk. However, given that their climate risk indicator does not distinguish between physical and transition risks, they are not able to identify the source of the premium. Using our two novel indicators, we are able to show that the significance of the result may be driven by demand for hedging against physical risks, while the results on transition risk are less evident. We also add to the work of Duan et al. (2021) who find that the *carbon risk premium* is not verified in the US bond market. We expand on their work in multiple ways. First, Duan et al. (2021) focus on the *carbon risk premium* while we test the *hedging hypothesis*. Second, they focus on US while we look at the Euro Area. Third, they measure transition risk as one single factor, i.e. GHG firms emissions, while we consider a more complete measure of transition climate risk. All these factors may explain why the carbon risk premium is not verified in their paper, while the relation between the beta climate and future return is negative in ours, while still not significant. In particular, our results may suggest that the jurisdiction where climate change mitigation plan is more stringent, e.g. the Euro Area, markets have started pricing transition risks. We also add to Seltzer et al. (2022) who find that after December 2015, changes in yield spreads are more pronounced for environmentally problematic firms, located in states with stricter enforcement of environmental regulations. Compared to them, our study aims to explore the financial impacts of transition risks in a more comprehensive manner. In fact, whereas Seltzer et al. (2022) focus one specific regulatory event, namely the Paris Agreement, our paper considers a wide range of transition climate risk events that we integrate into a comprehensive index. Finally, we contribute to the work of Huynh and Xia (2021a) , who focus on firms directly exposed to natural disasters, by considering the pricing effect of the demand for hedging against both extreme and chronic physical risks.

[9]for a more complete review see Hong et al. (2020) and Giglio et al. (2021)

Our study, as a whole, offers valuable insights into the pricing dynamics of climate risk beta and its impact on the euro area corporate bond market. These findings carry significant implications for both investors seeking to navigate climate-related risks and for policy makers. The identification of physical and transition risk premia in European debt markets underscores the need for integrating climate risks into the core of financial risk management and regulatory supervision in so far as possible. In particular, the identification of the negative relation between transition risks and returns, though not statistically significant, and previously undocumented in some US-centered studies, serves as an indicator that the stricter environmental standards in the Euro Area enhance the pricing of climate risk in the corporate bond market. This in turn, has important substantial and positive implications for climate mitigation policies and financial stability.

The rest of this paper is organised as follows. Section 2 describes the data. Section 3 discusses the results. Section 4 concludes.

2 Data

2.1 Corporate bond data

The analysis includes daily ISIN-level data on investment grade (IG) and high yield (HY) bonds issued in the euro area by non-financial and financial corporates. The sample starts in January 2005 and ends in September 2021. We combine data on individual bond price returns with information on bond characteristics that are commonly used in the literature, including remaining maturity, rating, outstanding amount (log) and illiquidity (indicated by bid-ask spreads). The bond- and firm-level data are taken from Bloomberg, while European market-level data are taken from iBoxx and the Kenneth French's data library. All bonds are traded in euros.

The selection of bonds is based on the ICE Bank of America (BofA) Global Corporate and High Yield indices (i.e. G0BC and HW00). Corporate bonds are qualified for the BofA indices when they have (1) a rating (provided by S&P, Fitch and Moody's), (2) more than 1 year to maturity, (3) at least 18 months to maturity at issuance, and (4) a fixed coupon schedule. Different from the literature focusing on the US, which generally uses the Financial Industry Regulatory Authority's Trade Reporting and Compliance Engine (TRACE) enhanced database, we do not include information on corporate bond transactions due to data constraints. While investigating the cross-section of corporate bond returns using transaction data is preferable, the BofA indices are used actively in derivative trading, which provides a strong incentive for accurate price data. We exclude matrix prices from the sample, as these are considered less reliable than dealer quotes.[10]

Following Bao et al. (2011), bonds are dropped when they are traded relatively little so as to facilitate the reliable estimation of a bond's exposure to climate risk. The trading activity of a bond is gauged from the availability of Bloomberg data on a bond's daily bid/ask spreads, since data on bid/ask spreads can only be available when the bond has been traded that day. More specifically, a bond is dropped when data on the daily bid/ask spreads is missing for more than 25 percent of the bond's life span. In line with Bali et al. (2021) and others, the sample is further restricted by excluding bonds that (i) are issued by non-publicly listed firms, (ii) are convertible, backed by mortgages or other assets, or linked to equity, (iii) are structured notes, (iv) have once traded below €5, and (v) price a floating coupon rate. Similar to Huynh and Xia (2021b), bonds with a rating lower than B- are also excluded from the main regression analysis, since junk bonds generally are less liquid, which can lead to pricing errors (see for example Gebhardt et al., 2005; Lin et al., 2011).

In line with the literature, the corporate bond price returns are calculated as:

$$r_{i,t} = \frac{(P_{i,t} + AI_{i,t}) + C_{i,t} - (P_{i,t-1} + AI_{i,t-1})}{(P_{i,t-1} + AI_{i,t-1})} \quad (1)$$

where $P_{i,t}$ is the bond price, $AI_{i,t}$, represents accrued interest, $C_{i,t}$ indicates the coupon payment, if any in the respective time period, and the subscripts i and t denote the bond and time period. Subsequently, to determine the excess price returns of corporate bonds, we subtract the 1-month OIS rate (based on €STR) - an indicator of the risk-free rate - from the individual corporate bond returns.[11]

2.2 Climate change shocks

To determine the corporate bond pricing effects of climate change, we use climate news as a gauge for systematic climate risk. We update the daily text-based indicators of transition and physical climate risk shocks developed by Bua et al. (2021). The text-based indices exploit news content to identify physical and transition risk shocks. Investors use news as a source of information to update beliefs on climate change risks, with the assumption that news coverage on climate change intensifies amid rising climate risks. In other words, the climate index embeds the view that, when it comes to climate change, no news is good news (Engle et al., 2020). Different from previous studies that have identified climate change as a single risk factors (e.g Engle et al.,

[10] In the final sample, excluding matrix-priced bonds, which are bonds that have no market price and are priced using the quoted prices of similar bonds, eliminates the observations of 2 bonds only.

[11] Data on the 1-month OIS rates start in August 2005. For the months before that, we use short-term German bond yields as an indicator of the risk-free rate.

2020), these indices have the advantage of distinguishing between physical and transition risks, allowing the assessment of the different effects of physical and transition risk shocks on financial markets. Additionally, our risk indicators are based on vocabularies that capture the multifaceted characteristics of each climate risk type and also their interconnections. For example, the physical risk vocabulary includes multiple dimensions of physical risk such as both extreme and chronic hazards directly caused by climate change, excluding natural disasters attributable to other sources. Accordingly, the transition risk vocabulary includes various aspects of this climate risk such as technological advances and environmental policies (Bua et al., 2021).

The textual identification of the climate risk shocks can be summarized in four main steps.[12] First, in order to detect physical and transition risk separately, scientific and authoritative text documents on climate change topics are aggregated into physical and transition risk vocabularies. Similarly, an analogous list of term frequency scores is documented for daily aggregations of real-time European Reuters news, referred to as daily Reuters news documents.[13] Second, term frequency – inverse document frequency *(tf-idf)* scores are constructed for both the vocabularies and Reuters news documents, which indicate the extent to which a term is frequent in a specific document, while infrequent in other documents (see also Gentzkow et al., 2019). Third, physical and transition risk concern series are then constructed using *cosine similiarity* between the *tf-idf* scores of the vocabularies and Reuters news documents.[14] The concern indices roughly represent the portion of daily news corpus dedicated to either the topic of physical risk or transition risk.[15] Fourth, following the literature (e.g Engle et al., 2020), we estimate physical and transition risk shocks as the residuals from autoregressive regressions of order 1 (i.e. an AR(1) process). Positive, zero, or negative values of our climate risk indicators indicate an above-expected, expected, or below-expected level of discourse regarding climate risk issues, whether related to physical or transition risks (Bua et al., 2021).

Figure 1 and Figure 2 show the daily physical and transition media concerns (i.e. not the estimated shocks) with the major risk shock topics (vertical bars) from January 2005 to September 2021. The physical risk concern index peaked on 19 September 2018, amid large discussions revolving

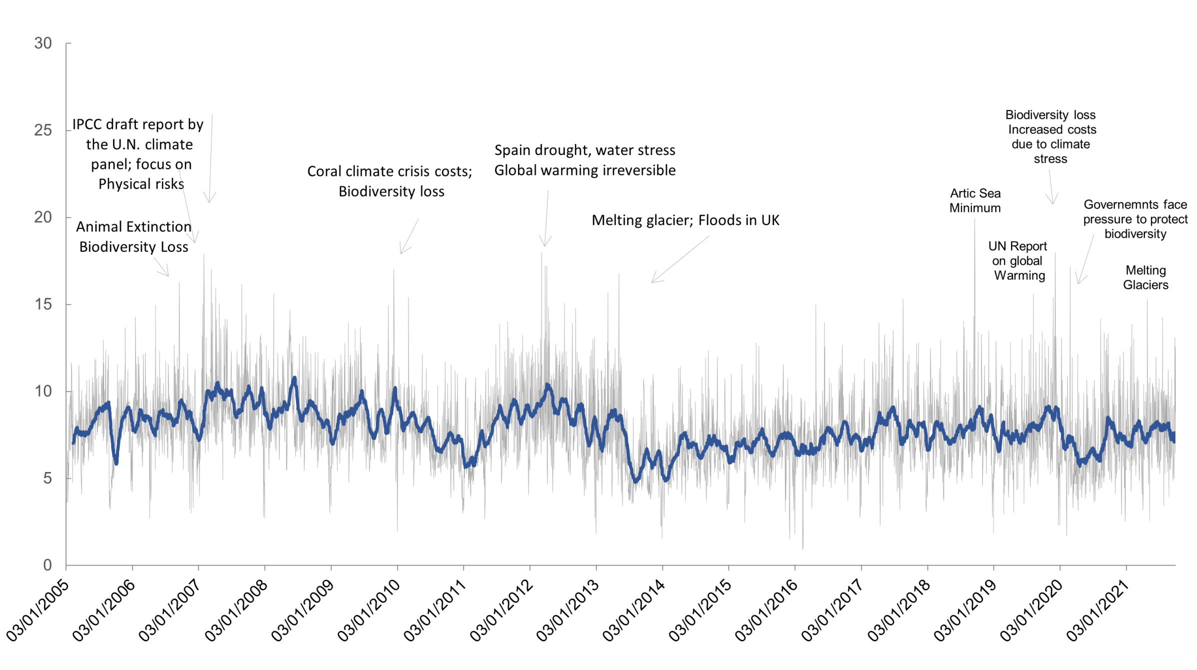
[12]For a detailed description of the indices please refer to Bua et al. (2021).

[13]We use Reuters News filtered for a European regional focus via the Factiva database interface. In this fashion, we ensure our news sample consists of news related to Europe, or any of the European countries, obtaining a suitable Europe-focus media coverage

[14]Cosine-similarity is a technique used in textual analysis to evaluate the similarity between pairs of texts. It expresses the angular distance between two pairs of text, where, the smaller the angular distance, the higher the cosine, and the higher the similarity. Put differently, we consider our physical and transition risk dictionaries as vectors, the direction of which depends on the intensity of each element, given by the *tf-idf* of vocabulary terms. This means that daily news which point in the same direction as the physical and transition risk vectors are assessed to discuss the physical and transition risk topics, respectively.

[15]'Daily news' is broadly defined such that, in addition to actual climate-related events, the concern indices can for instance also reflect speculation by the public, which is expected to drive asset prices.

Figure 1: Physical risk concern



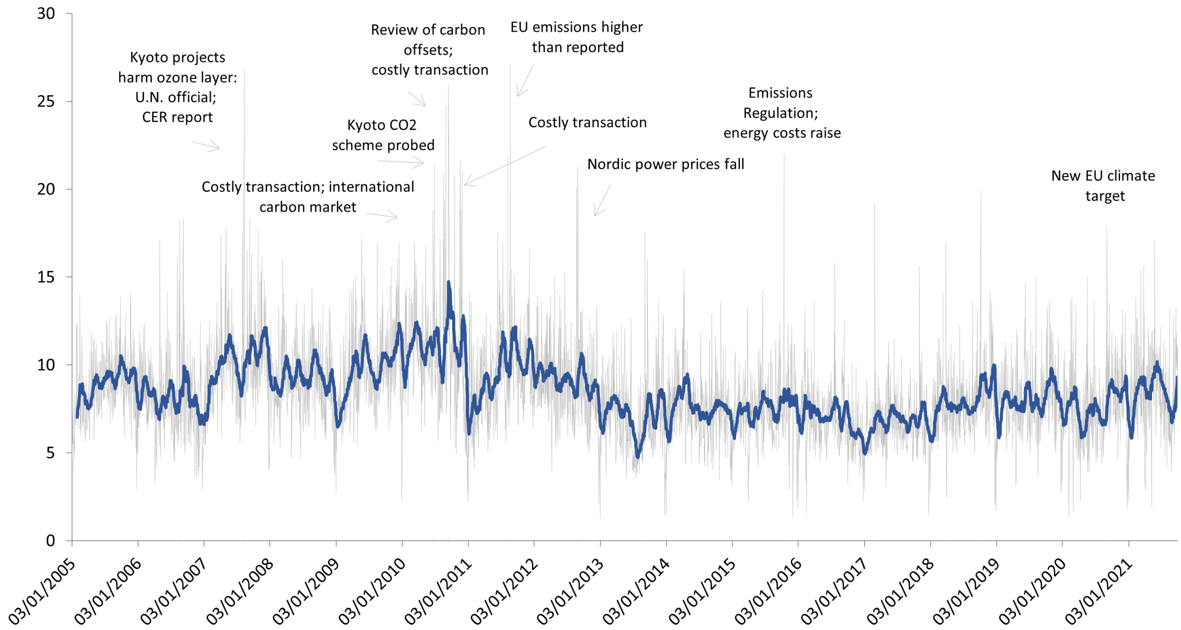
Notes: Daily physical risk concern with the major risk shock topics (vertical bars) for the period Jan 2005-Sep2021.

the loss of arctic sea. Other spikes in physical risk concerns generally related to the loss of biodiversity, becoming more concentrated toward the end of the sample. The transition risk index peaked on 24 August 2011, with news on high levels of EU GHG emissions. The transition risk index furthermore peaked following news concerning climate regulation and measures to curb GHG emissions (e.g. news regarding the EU carbon reform deal or the Kyoto Protocol, as well as news concerning the costs associated to the transition and the advances of technological innovation and renewable energies).

2.3 Cross-sectional climate change sensitivities

Different from the corporate bond literature, which has so far only identified a bond's climate risk exposure using monthly data over longer rolling windows, we calculates a bond's daily exposure to our measures of climate risk to improve the identification of bond price performance in the event of climate risk news shocks. In contrast to monthly returns, daily return data provide sufficient information to detect the abnormal performance of bonds (Bessembinder et al., 2009). More specifically, we determine each bond's daily sensitivities to the transition and physical risk shocks by estimating the 7-factor model by Chung et al. (2019) over rolling windows of 3 months. Similar to Faccini et al. (2021), the estimation windows are fixed and move forward by

Figure 2: Transition risk concern



Notes: Daily transition risk concern with the major risk shock topics (vertical bars) for the period Jan 2005-Sep2021.

one month at each iteration. The following model is run bond-by-bond:

$$\begin{aligned} r_{i,t} = \alpha_{i,t} + \beta_{i,t}^{\prime climate} ClimateShock_t + \beta_{i,t}^{market} r_t^{market} + \beta_{i,t}^{term} Term_t + \beta_{i,t}^{default} Default_t \\ + \beta_{i,t}^{SMB} SMB_t + \beta_{i,t}^{HML} HML_t + \beta_{i,t}^{liquidity} liquidity_t + \beta_{i,t}^{VIX} \Delta VSTOXX_t + \varepsilon_{i,t} \end{aligned} \quad (2)$$

where $r_{i,t}$ is the bond's excess return, $ClimateShock_t$ represents either the transition or physical climate risk shock, r_t^{market}, $Term_t$, $Default_t$, SMB_t, HML_t, $liquidity_t$ and $\Delta VSTOXX_t$ are the bond market factors, including the value-weighted return of the broader corporate bond market, the term spread (i.e. the difference between the monthly value-weighted return in 10-year euro area government bonds and the 1-month OIS rate), the default spread (the difference between the value-weighted returns in euro area 10-year corporate and government bonds), the Small Minus Big (SMB) factor (i.e. the average return of small versus big stock market portfolios), the High Minus Low (HML) factor (i.e. the average return of value versus growth stock market portfolios), the bond liquidity risk factor (i.e. market weighted bid-ask spread) and the market volatility factor (i.e. innovations in the VSTOXX using an AR(1) process), respectively, and the subscripts i and t denote the bond and daily time period.[16,17] As a robustness check, and similar to Huynh and Xia (2021b), we also estimate the climate risk betas using the 5-factor model (based on Fama and French, 1993; Elton et al., 1995), which excludes the liquidity risk and the market volatility factors. The loading on the climate news risk factors, i.e. $\beta_{i,t}^{climate}$ are our climate news risk betas. By construction, a bond's return reacts positively to an increase in climate news risk shocks when the sign of $\beta_{i,t}^{climate}$ is positive and negatively when the sign of $\beta_{i,t}^{climate}$ is negative. This implies that bonds with a negative exposure to the climate news risk shocks provide bad hedges against the risk of climate change. The implicit assumption is that the number of climate change discussions increase when climate risk is elevated. In other words, the climate index embeds the view that, when it comes to climate change, no news is good news (Engle et al., 2020).

The final sample includes 3,874 bonds issued by 970 firms. 82% of all observations represent IG bonds, while the remaining 18% are HY bonds. Table 1 shows the descriptive statistics. In total, there are 167,952 bond-month observations for excess price returns. The mean excess return is approximately 0.11% while the median excess return is 0.43%. On average, bonds have a remaining maturity of approximately 5 years, a credit rating of 8 (which translates to BBB+), a face value of 815 million euros and a bid-ask spread of 0.5 percentage points. The standard deviations suggest there is sufficient variation in all variables.

Table 1: Descriptive Statistics

						Percentiles			
Variables	Source	Obs	Mean	Median	Std Dev	5th	25th	75th	95th
Dependent variable									
Excess return (percentage)	Bloomberg	167,952	0.11	0.43	2.65	-4.04	-0.44	1.03	3.08
Climate variables									
Transition risk beta	Author calculations	178,890	-0.0008	-0.0005	0.0225	-0.0235	-0.0044	0.0033	0.0205
Physical risk beta	Author calculations	178,890	-0.0012	-0.0004	0.0247	-0.0301	-0.0048	0.0037	0.0233
Bond characteristics									
Remaining maturity (years)	Bloomberg (ICE BofA)	190,277	5.52	4.79	3.89	1.43	2.99	7.09	11.27
Rating (numerical)	Bloomberg (composite)	190,277	8.04	8	2.52	4	6	9	12
Amount outstanding (millions)	Bloomberg (ICE BofA)	190,277	815.94	750	399.57	387	500	1,000	1,500
Bid-ask spread	Bloomberg	189,983	0.50	0.42	0.43	0.14	0.26	0.63	1.14

Notes: This table shows the summary statistics of the monthly time series. The first variable is the monthly excess return (in percentages), calculated as a bond's price return minus the 1-month OIS rate. The second and third variables are the monthly transition and physical climate risk betas. The last four variables are, at the bond-level, remaining maturity in years, credit rating (average of S&P, Fitch and Moody's) in numerical scores, where 1 refers to AAA and 21 to C, face value in millions of euros and bid-ask spreads, respectively.

[16]The time variation in the regression coefficients, denoted by subscript t, is not by unit of time observation. Within the rolling window, coefficients are constant over time.

[17]We do not use the liquidity measure proposed by Bao et al. (2011) – who compute illiquidity as $cov_t(\Delta P_{i,t,d}, \Delta P_{i,t,d+1})$, where $P_{i,t,d}$ is the daily log change in a bond's price at day d – since this measure requires intraday data on transaction prices, which our analysis does not include.

3 Empirical results

We examine the cross-sectional association between the climate risk betas of bonds and their future returns through two sequential approaches: univariate portfolio-level analyses and Fama-Macbeth cross-sectional regressions. Consistent with prior research on climate change pricing in risky asset markets, we analyze the periods before and after the Paris agreement independently. Furthermore, to account for the potentially stronger price impact of physical risk, particularly on bonds with longer maturities, we distinguish between long-term and short-term bonds. Bonds with maturities of up to 7 years are categorized as short-term, while those with longer remaining maturities are classified as long-term. Notably, our conclusions remain largely unchanged when considering bonds with remaining maturities above 5 years as long-term.

3.1 Univariate portfolio-level analysis

We create univariate portfolios by sorting individual bonds into quintiles based on their physical or transition risk betas at the end of each month. The portfolios are constructed using equal-weighting, although similar patterns emerge when using value-weighting with face values as weights (details available upon request). The lowest quintile comprises bonds with the lowest betas, while the highest quintile represents bonds with the highest betas. Additionally, we construct a high-minus-low portfolio (HML), which involves taking a long position in the lowest quintiles and a short position in the highest quintiles. Bonds with negative or low climate news risk beta are regarded as poor hedges against physical and transition risks, suggesting that investors should demand higher expected returns to compensate for the additional risk associated with holding them in their portfolios. Conversely, bonds with positive or high climate news risk beta perform well during periods of increased climate news risks, offering a potential hedge against climate change risks. Investors should require lower expected return to include them in their portfolio. It is probable that companies opposed to new climate regulations or heavily dependent on climate stability may be characterised by a negative transition or physical climate beta, respectively. It follows that a high-minus-low transition (physical) climate beta portfolio should therefore earn negative excess returns in case a climate risk premium exists.

Accordingly, for each portfolio, we calculate the 1-month ahead excess return (raw return) and the risk-adjusted return (alphas) using bond and stock market factor models following Fama and French (1993); Elton et al. (1995); Bessembinder et al. (2009). We estimate the 3-factor bond alpha by regressing the future excess portfolio returns on the corporate bond market return, term spread and default spread, and the 6-factor alpha by additionally regressing the excess portfolio returns on the broader stock market return and the SMB and HML stock market factors. In all portfolio tables, the first two columns report the average physical risk beta for the quintile portfolios, while the next columns show the average one-month ahead excess returns and the alphas (in percentages), and the parentheses include Newey and West (1987) adjusted t-statistics.

3.1.1 Physical risk

Table 2 presents portfolios of corporate bonds sorted by their physical risk betas during the period from 2015 until September 2021, starting from the year of the Paris agreement. The results demonstrate that the future returns on portfolios of long-term bonds with physical risk exposure decrease from 0.92% in the lowest quintile to 0.68%, 0.66%, and 0.68% in the third, fourth, and fifth quintiles, respectively. Consequently, there is a significant difference of 0.24% in future returns between the highest and lowest quintiles, significant at the 5% level. The higher returns in the two lowest quintiles suggest that investors demand greater future returns on portfolios of bonds that offer limited protection against physical risk shocks (i.e., bonds with low $\beta^{climate}$). Similarly, the risk-adjusted returns (alphas) of long-term bond portfolios, computed using the 3-factor bond and 6-factor bond and stock models, also decrease monotonically from the lowest to the highest quintile, with declines of -0.79% and -0.84%, respectively, both significant at the 1% level. In contrast, the difference in future returns between the lowest and highest quintiles of portfolios consisting of short-term bonds is smaller. Furthermore, for short-term bonds, the alphas do not decrease monotonically from the lowest to highest quintile. While the alphas using the 3-factor bond and 6-factor models in the highest quintiles are significantly lower than those in the lowest quintiles of short-term bond portfolios, the high-minus-low differences are more than three times smaller compared to the portfolios of long-term bonds, suggesting that physical risk beta has less significance for bonds with shorter maturities.[18]

As a robustness check, for the period after 2014, Table 3 sorts corporate bond portfolios by the physical risk beta estimated using the 5-factor instead of the 7-factor model (i.e. excluding the liquidity risk and the market volatility factors from Model 2 in Subsection 3.3). Similar to Table 2, the results show that the future returns on portfolios of long-term bonds in the highest quintile are significantly lower than in the lowest quintile, while there are no significant differences between the returns on portfolios of short-term bonds in the highest and lowest quintiles.These results are in line with Huynh and Xia (2021a) who find higher bond returns for firms directly exposed to natural disasters. We add to their studies showing that market participants in the Euro Area are able to distinguish different type of physical risks and to incorporate them in their investment decisions.

[18]Table 2 shows negative alpha for all portfolios suggesting an overall under-performance of their expected returns based on the risk factors included. Although negative alphas are less common than positive alphas, results may be affected by the specific period selected, characterized by negative interest rate, squeezed risk premium and search for yield.

Table 2: Portfolios sorted by the physical risk beta since the Paris Agreement

Quintiles	Physical risk beta		Future return		3-factor bond alpha		6-factor alpha	
	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Low	-0.0149	-0.0179	0.69	0.92	-0.41	-0.63	-0.43	-0.58
			(6.28)	(4.76)	(-0.64)	(-0.66)	(-0.71)	(-0.68)
2	-0.0025	-0.0033	0.59	0.76	-0.44	-0.83	-0.45	-0.75
			(6.33)	(4.06)	(-1.08)	(-0.99)	(-1.17)	(-1.00)
3	-0.0002	0.0003	0.54	0.68	-0.28	-0.96	-0.29	-0.91
			(7.20)	(3.58)	(-0.77)	(-1.19)	(-0.84)	(-1.22)
4	0.0028	0.0041	0.54	0.66	-0.21	-0.98	-0.23	-0.96
			(6.61)	(3.30)	(-0.54)	(-1.19)	(-0.63)	(-1.23)
High	0.0171	0.0202	0.68	0.68	-0.66	-1.42	-0.66	-1.42
			(4.94)	(2.69)	(-1.04)	(-1.42)	(-1.13)	(-1.48)
High - Low	0.0320	0.0381	-0.01	-0.24**	-0.25***	-0.79***	-0.23***	-0.84***
			(-0.50)	(-2.14)	(-2.93)	(-3.78)	(-2.68)	(-3.60)

Notes: This table shows univariate quintile portfolios of corporate bonds sorted by the physical risk beta. The physical risk beta is estimated using the 7-factor model based on Chung et al. (2019) (see Model 2 in Subsection 3.3). The portfolios are equally weighted. For each portfolio, the table shows the average of the physical risk beta, the 1-month ahead excess price return, and the 3-factor bond and 6-factor alphas. The averages are shown for short- and long-term bonds separately. Bonds with times to maturities of up to 7 years are classified as short-term, while bonds with longer remaining maturities are considered long-term. The data cover the time period from January 2015 until September 2021, after the (anticipation of the) Paris Agreement. The parentheses include Newey and West (1987) adjusted t-statistics. Significance levels are provided for the high-minus-low portfolio: * p<0.1, ** p<0.05, *** p<0.01.

Table 3: Portfolios sorted by the physical risk beta using the alternative 5-factor model

Quintiles	Physical risk beta		Future return		3-factor bond alpha		6-factor alpha	
	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Low	-0.0137	-0.0136	0.70	0.90	-0.57	-0.79	-0.58	-0.75
			(5.84)	(4.52)	(-0.78)	(-0.78)	(-0.84)	(-0.82)
2	-0.0024	-0.0033	0.57	0.73	-0.54	-0.82	-0.55	-0.75
			(5.78)	(4.14)	(-1.11)	(-0.94)	(-1.20)	(-0.96)
3	-0.0002	0.0005	0.54	0.70	-0.30	-0.92	-0.32	-0.89
			(6.98)	(3.71)	(-0.82)	(-1.09)	(-0.89)	(-1.13)
4	0.0019	0.0043	0.56	0.68	-0.14	-1.03	-0.15	-0.97
			(7.36)	(3.40)	(-0.41)	(-1.29)	(-0.47)	(-1.33)
High	0.0169	0.0184	0.67	0.69	-0.44	-1.27	-0.46	-1.26
			(5.30)	(2.66)	(-0.89)	(-1.38)	(-1.00)	(-1.44)
High - Low	0.0306	0.0320	-0.03	-0.21*	0.13	-0.47*	0.12	-0.51**
			(-0.71)	(-1.77)	(0.49)	(-1.84)	(0.48)	(-2.30)

Notes: The physical risk beta is estimated using the 5-factor model based on Fama and French (1993); Elton et al. (1995) (see also Subsection 3.3). The data cover the time period from January 2015 until September 2021, after the (anticipation of the) Paris Agreement. See also the notes to Table 2.

The results look different for the period before the Paris agreement. Table 4 shows the corporate bond portfolios sorted by the physical risk beta for the period from February 2005 until December 2014.[19] The results indicate a non-linear relationship between the average returns across the portfolios. More specifically, for both short- and long-term bonds, the future return and alphas consistently decrease from quintile 1 to quintile 3, while increasing again from quintile 3 to quintile 5. While the (risk-adjusted) returns on the portfolios in the highest quintiles are lower than in the lowest quintiles, the differences are for none of the return estimate significant. Together, in

[19]Due to the minimum window size of 40 valid return observations in the rolling estimation of the climate risk betas, there are no climate risk betas estimated for January 2005 (see also Subsection 3.3).

line with the existing literature on climate risk pricing, these findings indicate that investors had a lower level of awareness regarding climate risks during the period preceding the Paris agreement.

Table 4: Corporate bond portfolios sorted by the physical risk beta before the Paris Agreement

Quintiles	Physical risk beta		Future return		3-factor bond alpha		6-factor alpha	
	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Low	-0.0339	-0.0465	-0.31	-0.58	0.91	1.62	1.03	1.73
			(-1.54)	(-0.88)	(2.78)	(2.59)	(3.05)	(2.74)
2	-0.0055	-0.0103	-0.58	-0.93	0.48	0.94	0.54	1.04
			(-2.24)	(-1.63)	(3.80)	(3.78)	(4.11)	(4.49)
3	-0.0010	-0.0005	-0.68	-0.94	0.30	0.80	0.35	0.86
			(-2.53)	(-1.76)	(3.42)	(3.99)	(4.11)	(4.92)
4	0.0027	0.0067	-0.67	-0.86	0.32	0.98	0.38	1.06
			(-2.48)	(-1.56)	(2.95)	(3.85)	(3.87)	(4.98)
High	0.0245	0.0323	-0.46	-0.84	0.66	1.10	0.81	1.27
			(-1.92)	(-1.43)	(2.84)	(3.11)	(3.36)	(3.69)
High - Low	0.0584	0.0788	-0.15	-0.26	-0.25	-0.52	-0.22	-0.46
			(-1.20)	(-1.22)	(-1.26)	(-1.41)	(-1.29)	(-1.31)

Notes: The data cover the time period from February 2005 until December 2014, before the (anticipation of the) Paris Agreement. See also the notes to Table 2.

3.1.2 Transition risk

Table 5 presents portfolios of corporate bonds categorized by transition risk betas during the period spanning from January 2015 to September 2021. The first two columns show that moving from decile 1 (low-$\beta^{climate}$) to decile 5 (high-$\beta^{climate}$), there is cross-sectional variation in the average values of $\beta^{climate}$; the average transition risk betas increases from -0.013 to 0.014 for short term bonds and from -0.015 to 0.017 for long term bond, subsequent to the Paris agreement. Another notable point in Table 5 is that the raw future returns for long term bonds decrease from 0.84% to 0.80%, when moving from the lowest to the highest quintile. The average return difference between quintile 5 and quintile 1 is - 0.04% per month, although the estimates do not reach statistical significance. This result indicates that bonds in the lowest quintile generate slightly higher annual returns compared to bonds in the highest quintile. We do not observe the same patter for short term bonds, as the high-minus-low portfolio reveals a positive association between transition risk betas and future returns. In addition to the raw returns, Table 5 presents the risk-adjusted returns (alphas) from the 3-factor bond and 6-factor bond and stock models. In both models the difference in alphas between the highest and the lowest quintile portfolios have the expected sign, although not significant. The negative relation between $\beta^{climate}$ and alphas suggest that investors are willing to accept lower future returns for bonds that are good hedges against transition risks. This result is in line with Huynh and Xia (2021b) who find a very small effect for the climate beta and suggest that the small coefficient may point to the fact that market has not fully priced in climate risk.

Furthermore, a more detailed examination of the returns and alphas provides additional insights. The future returns on transition risk portfolios for both short- and long-term bonds initially decrease from the lowest quintile to the third quintile, suggesting a negative relationship between transition risk and returns. However, they subsequently rebound towards the highest quintile, indicating a potential reversal of this relationship. This finding suggests that the impact of transition risk on bond returns may not follow a linear pattern. In contrast, the alphas (risk-adjusted returns) increase from the lowest quintile to the third or fourth quintile, indicating that bonds with higher transition risk betas may exhibit better risk-adjusted performance during these intermediate quintiles. However, in the highest quintile, the alphas significantly decrease, suggesting that bonds with the highest levels of transition risk may experience a decline in risk-adjusted returns. Overall, while there is some evidence of a negative relationship between transition risk and returns for longer-term bonds, the lack of statistical significance and the non-linear patterns observed underscore the complexity of the relationship between transition risk and future bond returns.

Table 5: Corporate bond portfolios sorted by the transition risk beta since the Paris Agreement

Quintiles	Transition risk beta		Future return		3-factor bond alpha		6-factor alpha	
	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Low	-0.0133	-0.0153	0.66	0.84	-0.56	-1.11	-0.59	-1.10
			(5.10)	(3.34)	(-0.82)	(-1.11)	(-0.91)	(-1.19)
2	-0.0023	-0.0035	0.59	0.66	-0.21	-1.07	-0.21	-1.02
			(6.81)	(3.28)	(-0.66)	(-1.30)	(-0.73)	(-1.32)
3	-0.0004	0.0001	0.52	0.64	-0.20	-0.78	-0.21	-0.75
			(7.41)	(3.68)	(-0.62)	(-1.00)	(-0.68)	(-1.00)
4	0.0016	0.0036	0.56	0.76	-0.36	-0.70	-0.37	-0.64
			(6.92)	(4.34)	(-0.78)	(-0.87)	(-0.84)	(-0.87)
High	0.0138	0.0172	0.71	0.80	-0.69	-1.22	-0.69	-1.16
			(5.42)	(3.69)	(-1.04)	(-1.16)	(-1.15)	(-1.23)
High - Low	0.0271	0.0325	0.05	-0.04	-0.13	-0.11	-0.11	-0.06
			(0.99)	(-0.60)	(-1.00)	(-0.29)	(-0.75)	(-0.14)

Notes: This table shows univariate quintile portfolios of corporate bonds sorted by the transition risk beta. The transition risk beta is estimated using the 7-factor model based on Chung et al. (2019) (see Model 2 in Subsection 3.3). The data cover the time period from January 2015 until September 2021, after the (anticipation of the) Paris Agreement. See also the notes to Table 2.

Table 6 provides insights into the pricing of transition risk in euro area corporate bonds before 2015. The results suggest that transition risk may have been partially incorporated into the bond prices during this period. Specifically, both the portfolio returns and alphas exhibit a decreasing trend from the lowest quintile to the third or fourth quintile, indicating a negative relationship between transition risk and bond performance. However, the returns and alphas start increasing again from the third or fourth quintiles onwards, suggesting a potential reversal of this relationship. Notably, the differences between the highest and lowest quintiles in terms of future returns and 6-factor alphas are statistically significant at the 10% level for short-term bonds. This indicates a weak but significant cross-sectional association between transition risk betas and the future returns of corporate bonds in the period preceding 2015. These findings further support the notion that the awareness and pricing of transition risk in euro area corporate bonds have evolved over time. The evidence of some pricing of transition risk before 2015 implies that investors may have started considering these risks to some extent.

Overall, our findings are consistent with Huynh and Xia (2021b), who find that bonds with a higher climate change news beta earn lower future returns, although the value is small. They suggest that while the negative sign is consistent with the asset pricing implications of demand for bonds with high potential to hedge against climate risk, the small coefficient may point to the fact that market has not fully priced in climate risk. Given that their climate risk indicator does not distinguish between physical and transition risks, our study shows that the significance of their overall result is likely driven by demand for hedging against physical risks, while the results on transition risk are less evident.

The findings of Duan et al. (2021) may also provide some insight on the insignificant relation between transition risk and expected returns, identified in our paper. Specifically, Duan et al. (2021) find that while bond of high carbon intensity are riskier than those of low carbon intensity, they underperform the low carbon intensity firms, suggesting that the carbon risk premium is not verified in the US bond market. While our findings do share common ground with Duan et al. (2021), it is important to note some distinctions. First, Duan et al. (2021) focus on the *carbon risk premium* while we test the *hedging hypothesis*. Second, they focus on US while we look at the Euro Area. Third, they measure transition risk as one single factor, i.e. GHG firms emissions, while we consider a more complete measure of transition climate risk. All these factors may explain why the *carbon risk premium* is not verified in their paper, while the relation between the beta climate and future return is negative in ours, while still not significant. In particular, in line with the work of Seltzer et al. (2022) who find that after December 2015, changes in yield spreads are more pronounced for environmentally problematic firms, located in states with stricter enforcement of environmental regulations, our results suggest that in the jurisdiction where climate change mitigation plan is more stringent, e.g. the Euro Area, markets have started pricing transition risks.

Table 6: Corporate bond portfolios sorted by the transition risk beta before the Paris Agreement

Quintiles	Transition risk beta		Future return		3-factor bond alpha		6-factor alpha	
	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Low	-0.0256	-0.0360	-0.25	-0.60	0.97	1.58	1.08	1.65
			(-1.43)	(-0.87)	(2.90)	(2.76)	(3.08)	(2.92)
2	-0.0041	-0.0079	-0.60	-0.87	0.46	1.08	0.51	1.12
			(-2.27)	(-1.51)	(3.51)	(3.53)	(3.94)	(3.69)
3	-0.0003	-0.0007	-0.69	-0.91	0.29	0.85	0.36	0.96
			(-2.54)	(-1.69)	(2.79)	(4.20)	(3.56)	(5.92)
4	0.0029	0.0057	-0.65	-0.96	0.36	0.81	0.42	0.93
			(-2.45)	(-1.80)	(3.03)	(3.46)	(4.00)	(4.76)
High	0.0188	0.0264	-0.51	-0.82	0.58	1.12	0.73	1.28
			(-2.03)	(-1.41)	(2.80)	(3.14)	(3.59)	(3.75)
High - Low	0.0444	0.0624	-0.26*	-0.22	-0.40	-0.46	-0.35*	-0.37
			(-1.66)	(-1.24)	(-1.64)	(-1.42)	(-1.76)	(-1.30)

Notes: The data cover the time period from February 2005 until December 2014, before the (anticipation of the) Paris Agreement. See also the notes to Table 5.

3.2 Fama-Macbeth cross-sectional regressions

Our analysis of the cross-sectional relationship between climate risk and future returns at the portfolio-level has the specific advantage of being non-parametric. However, one caveat of analysing portfolios of corporate bonds is that it excludes information at the bond-level and does not control for bond characteristics. We therefore also gauge the relationship between the climate risk betas and future returns at the bond-level using Fama-Macbeth cross-sectional regressions. The following model is estimated:

$$r_{i,t+1} = \alpha_t + \gamma'_{1,t}\beta^{Climate}_{i,t} + \gamma'_{2,t}Controls_{i,t} + \varepsilon_{i,t+1} \tag{3}$$

where $r_{i,t+1}$ is the one-month ahead future excess return, $\beta^{Climate}_{i,t}$ is a vector of the physical and transition risk betas, $Controls_{i,t}$ represents a vector of bond characteristics, including the sensitivity to the broader corporate bond market (i.e. β^{market}_{i}), remaining maturity, rating, outstanding amount (log) and bid-ask spread, and the subscript t denotes the last Friday of each month.[20] Using Model (3), we report the time-series averages of the intercept and the estimated slope coefficients γ'_1 and γ'_2. In parentheses, we include the Fama-Macbeth Newey-West adjusted t-statistics. Bold numbers reflect statistical significance below the 5% level.

3.2.1 Physical risk

Table 7 shows the results of the Fama-Macbeth cross-sectional regressions of the 1-month ahead excess return (in percentages) on the physical risk beta for the period starting in January 2015.

[20] The time period refers to the last Friday instead of the last working day of each month, as end-of-month portfolio reallocations can impact prices. When there is no trading on the respective Friday, then we take the last trading day prior to the last Friday of each month as the end-of-month date.

The results indicate that the relationship between the physical risk beta and the 1-month ahead returns on both short- and long-term bonds are significantly negative. This suggests that investors demand higher future returns on bonds whose returns are most adversely impacted by physical risk shocks, as reflected by a relatively low physical risk beta. Excluding control variables, the estimated average slopes equal -4.55 and -5.35 for short- and long-term bonds, respectively. The economic magnitude of these effects can be calculated by using the difference between the highest and lowest quintiles in the univariate portfolio analysis in Table 2. Table 2 reports a high-minus-low difference in the physical risk beta of 0.032 and 0.038 for short- and long-term bonds, respectively. Multiplying these differences with the average slope coefficients suggests a physical risk premium of 15 and 20 basis points for short- and long-term bonds, respectively. The significant cross-sectional relationship between the physical risk beta and future returns holds for when bond characteristics are controlled for, albeit their economic magnitude reduces to 14 for short-term bonds and 15 basis points for long-term bonds.

The results of the Fama-Macbeth regressions confirm the finding that long-term bonds in portfolios with a relatively low physical risk beta have a higher expected return (Table 2 reports the high-minus-low difference in future returns equals 24 basis points for long-term bonds, which is close to the economic magnitude estimated by the Fama-Macbeth regressions). In addition, the Fama-McBeth analysis also indicates that the future return on short-term bonds may be significantly impacted by physical risk. By contrast, the results of the portfolio analysis in Table 2 indicate that the future returns on short-term bonds reduce consistently from the lowest to the fourth quintile, before increasing again from the fourth to the highest quintile. Accordingly, the estimation of cross-sectional Fama-Macbeth regressions does not capture this non-linearity.

Table 7: Fama-Macbeth cross-sectional regressions for the period after the Paris agreement

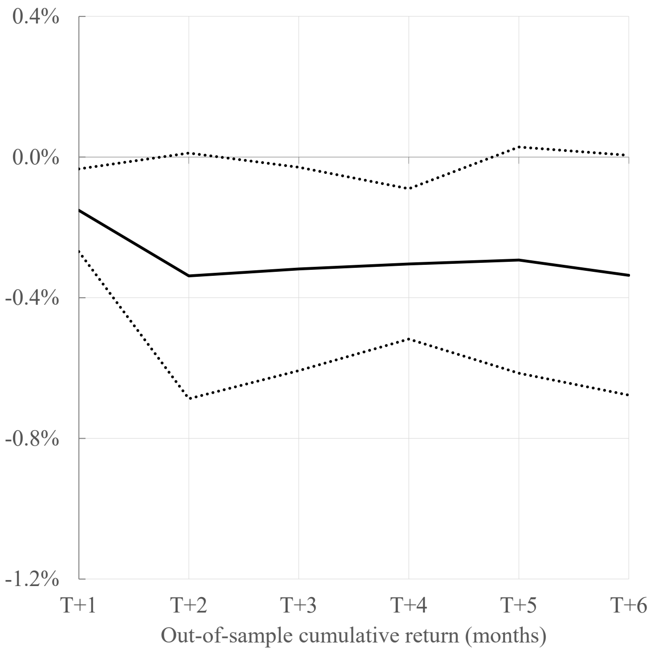
Maturity bucket	Intercept	Physical	β^{market}	Rating	Maturity	Value	bid-ask	Adj. R-sqr
Short-term	**0.59**	**-4.55**						0.03
	(6.89)	(2.17)						
Short-term	-0.69	**-4.25**	0.00	0.01	0.00	0.05	**0.27**	0.26
	(1.16)	(2.58)	(0.01)	(0.81)	(1.34)	(1.76)	(2.08)	
Long-term	**0.73**	**-5.35**						0.05
	(4.24)	(2.16)						
Long-term	0.14	**-3.89**	-0.01	0.02	0.00	0.01	0.19	0.29
	(0.17)	(2.29)	(0.43)	(1.11)	(0.38)	(0.35)	(1.74)	

Notes: This table shows average intercepts and slope coefficients estimated using Fama-Macbeth cross-sectional regressions. The dependent variable is the 1-month ahead excess price return in percentages (not decimals). Newey-West adjusted t-statistics are included in the parentheses. The data cover the time period from January 2015 until September 2021, after the (anticipation of the) Paris Agreement. Bold numbers reflect statistical significance below the 5% level.

The portfolio analysis and Fama-Macbeth regressions together suggest that investors demand higher returns on long-term bonds that are prone to physical risk. To gauge whether investors continue to demand higher returns further into the future, we additionally employ Fama-Macbeth regressions of the accumulated monthly sum of a bond's excess return - $\sum_{h=0}^{H} r_{i,t+h}$ for H = 1, 2, ..., 6 - on the right-hand side of equation 3 for the period starting in January 2015. Using the accumluated sum of returns, we determine the persistence of the intertemporal relationship between the physical risk beta and excess price returns of long-term bonds.

Figure 3 shows the results for when the control variables are included. Two observations stand out. First, the physical risk premium of long-term bonds increases from 15 basis points 1-month ahead to 34 basis points 2-months ahead, suggesting the impact of physical risk on corporate bond pricing becomes more pronounced over time. Second, the intertemporal relationship between the physical risk beta and excess returns of long-term bonds persists, with the physical risk premium continuing to stand at 34 basis points 6 months ahead.

Figure 3: Cumulative returns of long-term bonds regressed on physical risk beta after Paris agreement



Notes: This figure shows the results of Fama-Macbeth cross-sectional regressions of the future cumulative excess returns of long-term bonds. To facilitate the economic interpretation of the results, the y-axes show the average Fama-Macbeth slope coefficients multiplied by the differences in the average physical risk beta between lowest and highest portfolios (0.038; see Table 2). The data cover the time period from January 2015 until September 2021, after the (anticipation of the) Paris Agreement. The dotted lines represent the 90% confidence intervals using Newey-West adjusted standard errors.

Table 8 presents the findings of the Fama-Macbeth regressions, examining the relationship between the 1-month ahead excess return and the physical risk beta for the period spanning from February 2005 to December 2014. The results validate the observations from the portfolio analysis, indicating that there is no significant relationship between the physical risk beta and future return for long-term bonds during this pre-Paris agreement period.

However, the cross-sectional analysis reveals a significant relationship between the physical risk beta and the future return of bonds with short-term maturities. Excluding control variables, the estimated average slope coefficient is -2.38, emphasizing the direction and magnitude of this relationship.

To quantify the economic implications, we utilize the high-minus-low difference in future return observed in the portfolio analysis (Table 2). By leveraging this difference, we calculate the physical risk premium to be 8 basis points for short-term bonds before the Paris agreement. When controlling for the included variables, the estimated physical risk premium decreases to 7 basis points, although the relationship is no longer statistically significant at the 5% level but remains significant at the 10% level.

In summary, the Fama-Macbeth regressions confirm that there is no significant relationship between the physical risk beta and future return for long-term bonds before the Paris agreement. However, they highlight a significant relationship between the physical risk beta and the future return of bonds with short-term maturities. These findings indicate that short-term bonds were potentially influenced by physical risk factors during the pre-Paris agreement period.

Table 8: Fama-Macbeth cross-sectional regressions for the period before the Paris agreement

Maturity bucket	Intercept	Physical	β^{market}	Rating	Maturity	Value	bid-ask	Adj. R-sqr
Short-term	**-1.11**	**-2.38**						0.02
	(2.10)	(2.16)						
Short-term	**-2.38**	-2.16	0.13	0.02	0.00	0.04	0.15	0.24
	(3.65)	(1.80)	(1.76)	(1.15)	(1.37)	(1.37)	(0.80)	
Long-term	-0.98	0.12						0.04
	(1.52)	(0.07)						
Long-term	-2.21	-0.68	0.05	0.04	0.00	0.04	-0.06	0.21
	(1.71)	(0.43)	(1.24)	(1.49)	(0.33)	(0.87)	(0.41)	

Notes: The data cover the time period from February 2005 until December 2014, before the (anticipation of the) Paris Agreement. See also the notes to Table 7.

3.2.2 Transition risk

Table 9 and Table 10 present the findings of the Fama-Macbeth regressions, investigating the relationship between the 1-month ahead excess return and the transition risk beta. Table 9 focuses on the period preceding January 2015, while Table 10 examines the period following December 2014.

Consistent with the portfolio analysis, the results confirm that there is a negative relationship between transition risk and future returns on both short- and long-term bonds. However, this relationship is found to be statistically insignificant.

Taken together, the results from the portfolio analysis and the Fama-Macbeth regressions suggest that physical risk is more robustly and significantly priced in euro area corporate bond markets compared to transition risk. These findings underscore the importance of physical risk factors in shaping bond returns, indicating that investors are more sensitive to the impact of physical risk on bond prices.

Table 9: Fama-Macbeth cross-sectional regressions for the period after the Paris agreement

Maturity bucket	Intercept	Transition	β^{market}	Rating	Maturity	Value	bid-ask	Adj. R-sqr
Short-term	**0.59**	-0.48						0.03
	(6.70)	(0.23)						
Short-term	-0.73	-1.07	-0.01	0.01	0.00	0.05	**0.26**	0.25
	(1.23)	(0.58)	(0.43)	(0.96)	(1.59)	(1.82)	(2.06)	
Long-term	**0.72**	-0.36						0.06
	(4.10)	(0.15)						
Long-term	0.26	-2.15	-0.01	0.01	0.00	0.01	0.18	0.29
	(0.27)	(1.11)	(0.47)	(0.70)	(0.30)	(0.24)	(1.71)	

Notes: The data cover the time period from January 2015 until September 2021, after the (anticipation of the) Paris Agreement. See also the notes to Table 7.

Table 10: Fama-Macbeth cross-sectional regressions for the period before the Paris agreement

Maturity bucket	Intercept	Transition	β^{market}	Rating	Maturity	Value	bid-ask	Adj. R-sqr
Short-term	**-1.11**	-3.36						0.03
	(2.12)	(1.39)						
Short-term	**-2.36**	-1.99	**0.16**	0.01	0.00	0.04	0.16	0.25
	(3.97)	(1.33)	(2.26)	(0.76)	(1.20)	(1.54)	(0.86)	
Long-term	-0.96	-2.28						0.04
	(1.50)	(0.85)						
Long-term	-1.77	-1.42	0.07	0.04	0.00	0.02	-0.06	0.21
	(1.40)	(0.72)	(1.76)	(1.38)	(0.23)	(0.53)	(0.46)	

Notes: The data cover the time period from February 2005 until December 2014, before the (anticipation of the) Paris Agreement. See also the notes to Table 7.

4 Conclusion

In conclusion, our study makes a significant contribution to the limited literature on the pricing of climate risks in corporate bond markets, particularly in the euro area. We address this research gap by examining the pricing implications of climate risk demand in euro area corporate bonds, focusing on the distinction between physical and transition risk.

It is worth noting that the existing literature primarily focuses on the pricing of climate change in equity markets, leaving the euro area corporate bond markets largely unexplored. By extending the analysis to corporate bonds, we offer valuable insights into the unique dynamics of bond pricing in relation to climate risk. This is particularly important because bonds and equities have different clienteles and bond investors face distinct downside risks.

Furthermore, our study is particularly relevant for the euro area due to the region's prominent role in climate regulation initiatives. The European Union's commitment to becoming a net-zero emissions continent implies that the pricing of climate risk premiums may differ from the rest of the world. Additionally, market-based debt plays a more significant role in financing European corporations compared to their American counterparts.

Consistent with the hedging hypothesis, our findings reveal that since the Paris agreement, physical risk beta is significantly priced in euro area corporate bonds, particularly those with longer maturities. Even short-term bonds exhibit a pricing effect, although the premium is smaller and less significant. Controlling for bond characteristics, we estimate a negative physical risk premium of 15 basis points for bonds with a 1-month horizon and 34 basis points for bonds with a 2- to 6-month horizon. This negative premium reflects investors' demands for higher future returns on bonds that provide poor hedges against physical risk.

Similarly, we find evidence of a transition risk premium, although the estimates are mostly insignificant. When compared to some US-centered studies which failed to confirm the *carbon risk premium hypothesis* in the US corporate bond market (Duan et al., 2021), the identification of the negative relation between transition risks and returns, though non significant, serve as an indicator that the stricter environmental standards in the Euro Area enhance the pricing of climate risk in the corporate bond market

To advance our understanding further, future research should investigate the transmission mechanisms through which climate risk affects bond prices, including the role of different climate-related news. Additionally, expanding the analysis to more geographical regions and asset classes, e.g. investment funds, would provide a broader perspective on climate risk pricing dynamics.

To re-cap, our study fills an important gap in the literature by shedding light on the pricing of climate risks in euro area corporate bond markets. Our findings provide valuable insights into the pricing dynamics of physical and transition risks, which have implications for investors, issuers, and policymakers. By considering the unique characteristics of corporate bonds and the context of the euro area, our study contributes to a better understanding of the intersection between climate change and financial markets.

References

J. M. Addoum, D. T. Ng, and A. Ortiz-Bobea. Temperature shocks and earnings news. *Review of Financial Studies*, 2019.

L. Alessi, E. Ossola, and R. Panzica. The greenium matters: Evidence on the pricing of climate risk. *University of Milan Bicocca Department of Economics, Management and Statistics Working Paper*, (418), 2019.

H. Amiraslani, K. V. Lins, H. Servaes, and A. Tamayo. Trust, social capital, and the bond market benefits of esg performance. *Review of accounting studies*, 28(2):421–462, 2023.

D. Ardia, K. Bluteau, K. Boudt, and K. Inghelbrecht. Climate change concerns and the performance of green versus brown stocks. *National Bank of Belgium, Working Paper Research*, (395), 2020.

J. Bai, T. G. Bali, and Q. Wen. Common risk factors in the cross-section of corporate bond returns. *Journal of Financial Economics*, 131(3):619–642, 2019.

T. G. Bali, A. Subrahmanyam, and Q. Wen. Return-based factors for corporate bonds. *Available at SSRN 2978861*, 2017.

T. G. Bali, A. Subrahmanyam, and Q. Wen. The macroeconomic uncertainty premium in the corporate bond market. *Journal of Financial and Quantitative Analysis*, 56(5):1653–1678, 2021.

J. Bao, J. Pan, and J. Wang. The illiquidity of corporate bonds. *Journal of Finance*, 66(3): 911–946, 2011.

S. Batten. Climate change and the macro-economy: a critical review. 2018.

T. Berg, A. Saunders, and S. Steffen. Trends in corporate borrowing. *Annual Review of Financial Economics*, 13:321–340, 2021.

H. Bessembinder, K. M. Kahle, W. F. Maxwell, and D. Xu. Measuring abnormal bond performance. *The Review of Financial Studies*, 22(10):4219–4258, 2009.

P. Bolton and M. Kacperczyk. Do investors care about carbon risk? *Journal of Financial Economics*, 142(2):517–549, 2021.

G. Bua, D. Kapp, F. Ramella, and L. Rognone. Transition versus physical climate risk pricing in european financial markets: A text-based approach. *SSRN*, 2021.

L. Cappiello, F. Holm-Hadulla, A. Maddaloni, S. Mayordomo, R. Unger, L. Arts, N. Meme, I. Asimakopoulos, P. Migiakis, C. Behrens, et al. Non-bank financial intermediation in the euro area: implications for monetary policy transmission and key vulnerabilities. Technical report, European Central Bank, 2021.

K. H. Chung, J. Wang, and C. Wu. Volatility and the cross-section of corporate bond returns. *Journal of Financial Economics*, 133(2):397–417, 2019. ISSN 0304-405X. doi: https://doi.org/10.1016/j.jfineco.2019.02.002. URL `https://www.sciencedirect.com/science/article/pii/S0304405X19300248`.

O. Darmouni and M. Papoutsi. The rise of bond financing in europe. 2022.

T. Duan, F. W. Li, and Q. Wen. Is carbon risk priced in the cross-section of corporate bond returns? *Available at SSRN 3709572*, 2021.

E. J. Elton, M. J. Gruber, and C. R. Blake. Fundamental economic variables, expected returns, and bond fund performance. *The Journal of Finance*, 50(4):1229–1256, 1995.

R. F. Engle, S. Giglio, B. Kelly, H. Lee, and J. Stroebel. Hedging climate change news. *The Review of Financial Studies*, 33(3):1184–1216, 2020.

R. Faccini, R. Matin, and G. S. Skiadopoulos. Dissecting climate risks: Are they reflected in stock prices? *Available at SSRN 3795964*, 2021.

E. F. Fama and K. R. French. Common risk factors in the returns on stocks and bonds. *Journal of financial economics*, 33(1):3–56, 1993.

E. F. Fama and J. D. MacBeth. Risk, return, and equilibrium: Empirical tests. *Journal of political economy*, 81(3):607–636, 1973.

W. R. Gebhardt, S. Hvidkjaer, and B. Swaminathan. The cross-section of expected corporate bond returns: Betas or characteristics? *Journal of Financial Economics*, 75(1):85–114, 2005.

M. Gentzkow, K. Bryan, and M. Taddy. Text as data. *Journal of Economic Literature*, 57(3):535–574, 2019.

S. Giglio, B. Kelly, and J. Stroebel. Climate Finance. *Annual Review of Financial Economics*, 13(1), nov 2021. ISSN 1941-1367. doi: 10.1146/annurev-financial-102620-103311. URL `https://www.annualreviews.org/doi/10.1146/annurev-financial-102620-103311`.

M. Görgen, A. Jacob, M. Nerlinger, R. Riordan, M. Rohleder, and M. Wilkens. Carbon risk. *Available at SSRN 2930897*, 2020.

H. Hong, F. W. Li, and J. Xu. Climate risks and market efficiency. *Journal of econometrics*, 208 (1):265–281, 2019.

H. Hong, G. A. Karolyi, and J. A. Scheinkman. Climate Finance. *The Review of Financial Studies*, 33(3):1011–1023, mar 2020. ISSN 0893-9454. doi: 10.1093/rfs/hhz146. URL `https://academic.oup.com/rfs/article/33/3/1011/5735309`.

T. D. Huynh and Y. Xia. Panic selling when disaster strikes: Evidence in the bond and stock markets. *Management Science*, 2021a.

T. D. Huynh and Y. Xia. Climate change news risk and corporate bond returns. *Journal of Financial and Quantitative Analysis*, 56(6):1985–2009, 2021b. doi: 10.1017/S0022109020000757.

S. In, K. Park, and A. Monk. *Is "Being Green" Rewarded in the Market? An Empirical Investigation of Decarbonization Risk and Stock Returns.* Number February. Stanford Global Projects Center Working Paper, 2019.

M. S. Kruttli, B. Roth Tran, and S. W. Watugala. Pricing poseidon: Extreme weather uncertainty and firm return dynamics. 2021.

H. Lin, J. Wang, and C. Wu. Liquidity risk and expected corporate bond returns. *Journal of Financial Economics*, 99(3):628–650, 2011.

R. C. Merton. An intertemporal capital asset pricing model. *Econometrica*, 41(5):867–887, 1973. ISSN 00129682, 14680262. URL `http://www.jstor.org/stable/1913811`.

L. Pástor, R. F. Stambaugh, and L. A. Taylor. Sustainable investing in equilibrium. *Journal of Financial Economics*, 142(2):550–571, 2021.

L. Pástor, R. F. Stambaugh, and L. A. Taylor. Dissecting green returns. *Journal of Financial Economics*, 146(2):403–424, 2022.

L. H. Pedersen, S. Fitzgibbons, and L. Pomorski. Responsible investing: The esg-efficient frontier. *Journal of Financial Economics*, 142(2):572–597, 2021.

L. H. Seltzer, L. Starks, and Q. Zhu. Climate regulatory risk and corporate bonds. Technical report, National Bureau of Economic Research, 2022.

R. S. Tol. The economic impacts of climate change. *Review of Environmental Economics and Policy*, 2018.

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