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Abstract

Concerns about climate risk suggest it should affect risk assessment and pricing of corporate securities, particularly for firms facing potential regulatory restrictions. Employing a shock to expected climate regulations, we find support for this hypothesis given our evidence that climate regulatory risks causally affect bond credit ratings and yield spreads. Moreover, a structural credit model indicates the increased spreads for high carbon issuers, especially those located in stricter regulatory environments, derive from changes in firms' asset volatilities rather than asset values, highlighting that regulatory uncertainty affects security pricing. The results have important implications for corporate decisions, portfolio management, and policymaking.

Key words: climate risk, regulatory risk, fixed income

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1. Introduction

Investors and policymakers consistently raise their concerns about environmental and climate risks embedded in investor portfolios.[1] Of the three primary components of climate risk (physical, technological, and regulatory), regulatory risk is the one that investors, policymakers, and others in the finance community believe has the most immediate relevance (Krüger, Sautner, and Starks, 2020; Stroebel and Wurgler, 2021), particularly because environmental regulatory costs can significantly affect firms' operating costs and cash flows (Karpoff, Lott, and Wehrly, 2005; Meng, 2017). Moreover, uncertainty about future regulation itself poses costs to firms and their investors (Pindyck, 1993; Brogaard and Detzel, 2015).[2] In fact, even if a country is not currently issuing new climate change legislation, regulatory risks can still get embedded in firms' cost of capital through the channel of regulatory uncertainty.

Researchers have examined the effects of climate and environmental risk, particularly climate regulatory risk, on asset prices, but this work has focused primarily on equity prices.[3] In this paper we argue that analyzing corporate bonds can provide valuable insights into climate regulatory risk and its effects on firms' securities more generally. This approach is important for at least three reasons. First, regulatory risk entails added uncertainty to both a firm's equity and debt, but as pointed out by Campbell and Taksler (2003), volatility can have opposite effects on stock and bond prices. In particular, volatility can increase the optionality of a company's equity, adding value to the stock price. At the same time it can increase the probability of default for the company's bonds (that is, it can entail more downside risk), thus, lowering the bond price. These relationships imply increases in climate regulatory risk can have mixed effects on equity prices, but more straightforward effects on bond prices. Thus, it is important to understand the effects on debt instruments as they may be even greater due to the downside risk inherent in such securities. Second, by studying how bond prices respond to changes in climate regulatory risk in conjunction with equity prices, we are

[1] See, for example, Shultz (2017), Smith (2021), Jourde and Kone (2023), and Maloney (2023).

[2] In theoretical models such as Pastor and Veronesi (2013), political uncertainty regarding climate regulations affects asset prices. Empirically, Kaviani, Kryzanowski, Maleki, and Savor (2020) find a strong relationship between policy uncertainty and corporate credit spreads when they employ the Baker, Bloom, and Davis (2022b) economic policy uncertainty index. Further, Brogaard and Detzel (2015) conclude that government economic policy related to regulation can have market-wide effects that are largely non-diversifiable and further, that policymakers can increase risk through "generating an environment of uncertainty about their future economic policy decisions."

[3] See, for example, Zerbib (2019), Monasterolo and de Angelis (2020), Ramelli et al. (2021), Bolton and Kacperczyk (2021), and Mukanjari and Sterner (2023). For climate risk research on other security prices, see for example, Pastor et al. (2022), and Goldsmith-Pinkham et al. (2023).

able to employ a structural credit model to tease out the impact from asset value shocks versus volatility shocks. This is a contribution to the literature where extant studies typically examine the asset pricing effect of climate and environmental risk on a single asset class. Finally, as pointed out by Gourio (2013), for many corporations, the bond market, rather than the equity market, is the marginal source of finance.

In considering the effects of regulatory risks on corporate bond ratings and pricing, we also examine whether the effects are compounded when firms' operations are located in places with more stringent regulatory enforcement. In the United States, significant environmental legislation exists at the federal level with implementation arising from rulemaking by the EPA. However, state governments generally hold the primary responsibility for enforcing these laws, and the states vary widely in their enforcement practices. Further, some states impose additional environmental restrictions beyond those required by the EPA.[4] We estimate regulatory risk exposure through aggregating measures of the regulatory stringency a firm faces depending on the geographical locations of the firm's establishments. Thus, even when two firms have objectively similar levels of environmental impact, depending on the local regulatory conditions of their facility locations, the regulatory risks they face can differ.

In initial analyses, we use a sample of newly-issued corporate bonds to examine whether bond credit ratings and yield spreads are associated with firms' environmental profiles, the regulatory risk exposures of their facilities, and the interaction between the two. These analyses reveal several important empirical relationships. First, we find that firms' environmental profiles, whether measured using third-party environmental ratings or through the firms' carbon footprints, are unconditionally reflected in bond credit ratings and yield spreads. Firms with lower environmental scores, higher levels of carbon emissions, or higher carbon intensities (carbon emissions scaled by firm revenue) exhibit lower credit ratings and higher yield spreads, on average. These findings echo previous results in the equity market that carbon risk is priced into average stock returns and the tail risk of stocks (Bolton and Kacperczyk, 2021, 2023; Ilhan, Sautner, and Vilkov, 2021). Second, and more importantly, there exists a statistically and economically significant interaction effect

[4] Prior studies have documented uneven enforcement across states (e.g. Konisky, 2007; Mattera and Baggaley, 2021; Gulen and Myers, 2024). As Mattera and Baggaley (2021) point out, *"Frequently overlooked is the fact that the country's enforcement system is actually divided between the EPA and the states. This shared responsibility, which in the academic literature is known as environmental federalism...has at times been a source of tension between levels of government."*

on credit ratings (and alternatively, yield spreads) between a firm's environmental profile and its regulatory environment. The differences in credit ratings and yield spreads for low environmental score firms or high-emission firms (as compared to other firms) become more pronounced when the firms operate in states with more stringent enforcement of environmental regulations. This result suggests that regulatory risk is an important channel through which firms' environmental profiles affect their credit risks.

Recognizing the potential endogenous relationship between firms' environmental profiles and market participants' perceptions of firms' risks, we consider a setting in which expectations regarding future climate regulations receive an exogenous shock, namely the December 2015 Paris Agreement, under which world governments pledged to take actions to limit future global temperature increases. When the Agreement was announced, a natural implication for rating agencies and bond investors to draw was that governments—including U.S. federal and state governments—would tighten their environmental regulations related to the mitigation of climate change.[5] In fact, consistent with this presumption, at least one rating agency adjusted their baseline scenarios to include expectations of increased regulations after the Paris Agreement (Moody's, 2016). Survey results also suggest that firms upwardly revised their beliefs about future regulation intensity in their disclosure to the CDP around the time of the Agreement (Ramadorai and Zeni, 2024). The Paris Agreement shock implies that firms would face greater climate regulatory risk, especially those firms more exposed to this risk because of their business activities. The importance of this event is reflected in the fact that it is the third highest spike in the Engle, Giglio, Kelly, Lee, and Stroebel (2020) climate change news index.[6]

To test the hypothesis that the Paris Agreement had greater effects on the U.S. corporate bonds more exposed to climate regulatory risks, we employ difference-in-differences analyses of firms' credit ratings and yield spreads in the months around the Agreement. The treated bonds are those issued by firms that have poor environmental scores, high carbon emissions, or high carbon intensities prior to the Agreement, or that belong to a top 15 carbon-emitting industry.

[5]The fact that so many nations would sign on to the Paris Agreement does not appear to have been foreseen far in advance of the United Nations Climate Change Conference, which began on November 30, 2015. For example, a headline in a British newspaper on November 1, 2015 stated "Why climate treaty will be the flop of the year." In mid-November there still existed divisions among the world's leading countries regarding a deal. As late as November 23, the EU's climate and energy czar warned that an agreement was far from certain.

[6]See Engle, Giglio, Kelly, Lee, and Stroebel (2020), Figure 2, p. 1193.

Tracking bonds traded during the testing period, we find that after the Agreement, bonds from the treated firms experience an average decrease in credit ratings of 0.48 to 0.63 notch relative to bonds from other firms. These results support the hypothesis that changes in climate regulatory risk affect bond credit ratings for firms with more significant carbon footprints. Further, the results corroborate the anecdotal evidence that credit rating analysts consider expected regulatory changes when evaluating how climate risk affects firms' default risks. In addition, we find that the yield spreads of treated bonds increase significantly after the Paris Agreement, suggesting that beyond the credit rating analysts, bond investors also react to potential regulatory changes. For example, yield spreads increased by about 30 bps for bonds issued by firms with high total carbon emissions relative to bonds issued by other firms. Similarly, bonds issued by firms in a high carbon emitting industry, firms with high carbon intensities, or low environmental scores also experience a significant increase in yield spreads after the Paris Agreement.

Given that the expected tightening of environmental regulations following the Paris Agreement would presumably be carried out under the state-enforcement regime that currently exists, we hypothesize that any effects on credit ratings and yield spreads should be stronger for issuers operating in high-enforcement states. Consequently, we conduct a triple-difference analysis in which we include an indicator variable for firms operating in states with relatively more enforcement actions. The results indicate that, following the Paris Agreement, the changes in credit ratings and yield spreads for environmentally problematic firms are more pronounced if a firm's establishment locations are in states with stricter enforcement of environmental regulations.

While existing literature provides evidence that the value of equities also dropped for carbon-intensive firms after the Paris Agreement, we note that the drop in equities as found, for example, in Monasterolo and de Angelis (2020) and Mukanjari and Sterner (2023) seems small and more transitory relative to the yield spread changes we observe for corporate bonds. To jointly examine the change in equity markets with the change in bond markets, we use a structural credit model based on Merton (1974) to study the drivers of the observed credit spread changes for high-carbon issuers. Indeed, the analysis shows that under the assumption of constant volatility, the observed surge in credit spreads is too large based on the model-implied sensitivity of bond yields to changes in equity values (Schaefer and Strebulaev, 2008). In other words, the underlying structural parameters must change around the Paris Agreement to account for the change in both equity values and credit spreads. We hence estimate the asset value and asset volatility for bond issuers both before and after the announcement of the Paris Agreement. Our results reveal a modest drop in asset value and a significant increase in asset volatility for the high carbon firms relative to the control firms. While the high carbon firms' decrease in asset value quickly reverses within a few months after the Paris Agreement, the increase in asset volatility remains persistent.

Based on the structural credit model, we calculate the default probabilities for the treated and control firms and observe a significant increase in the treated firms' default probabilities of around 2.1 percentage points shortly after the Paris Agreement, relative to control firms. The counterfactual analysis suggests that the increase in asset volatility contributes more to this change in default probability than the change in asset value. This result is consistent with the evidence in Goldsmith-Pinkham et al. (2023) that suggests uncertainty rather than changes in asset value is the primary driver of changes in municipal bond yields. Our analyses demonstrate that climate regulatory risks can raise the probabilities that corporate bond issuers default, underscoring their potential role in generating systemic risks. Furthermore, given that critical financial institutions hold corporate bond securities on their balance sheets (Boyarchenko et al., 2021; Papoutsi et al., 2022), the results imply that climate regulatory risks can adversely affect these institutions, which could have financial stability implications.

The structural model and the empirical results suggest that after the 2015 Paris Agreement some investors would reevaluate their holdings in bonds more exposed to climate risk. Substantial theoretical and empirical research provides evidence that various segments of the institutional investor population employ differing investment strategies regarding ESG risks, including climate risks.[7] Consequently, we hypothesize that after the Paris Agreement reactions should differ between the two major institutional investor types in the corporate bond market, mutual funds and insurance companies, primarily due to the variations in their typical investment horizons (Massa et al., 2013). Using difference-in-differences analyses, we find after that insurance companies, which tend to have longer investment horizons, lower their holdings in the treated bonds after the Paris Agreement. Mutual funds, which tend to have shorter investment horizons, either keep their portfolio holdings in the treated bonds constant or increase their holdings.

[7] See, for example, Heinkel et al. (2001); Krüger et al. (2020); Pedersen et al. (2021); Oehmke and Opp (2024); Goldstein et al. (2024); Dyck et al. (2019); Ilhan et al. (2023); Starks et al. (2024).

Our analyses and results contribute on a number of dimensions. First, we contribute to the literature on the pricing of firm securities with respect to climate and environmental risks and news about those risks.[8] Our evidence that corporate bond investors demand higher yield spreads from issuers with poor environmental performance is consistent with earlier work on bank loans (Chava, 2014), municipal bonds (Painter, 2020; Goldsmith-Pinkham et al., 2023), and equities (Bolton and Kacperczyk, 2021, 2023). Previous work on environmental news or environmental policy changes focus primarily on the stock market response (e.g., Krüger, 2015; Karpoff et al., 2005; Ramelli et al., 2021), although some work examines the effects on fixed income instruments such as bank loans (e.g., Ivanov et al., 2024). Our analysis considers not only how credit rating analysts and bond investors respond to changes in perceptions of firms' environmental regulatory risks, but also whether the responses affect firms' asset values and asset volatilities. In addition, through our examination of firm's exposures to EPA regulatory enforcement, we can tease out the degree to which the regulatory environment affects the risk. Thus, we are able to highlight regulatory risks as a mechanism through which climate and environmental risks and news affect security pricing.

Our paper also contributes to the literature on investor preferences for environmentally friendly securities such as the work on green bonds (Zerbib, 2019; Tang and Zhang, 2020; Flammer, 2021; Baker et al., 2022a; Pastor et al., 2022; D'Amico et al., 2023), and the pricing effect of ESG on sovereign bonds (Margaretic and Pouget, 2018; Capelle-Blancard et al., 2019). We show that ratings and spreads for corporate bonds as well as their institutional investor ownership are affected by not only a firm's environmental activities but also their regulatory risk exposures.

Previous research shows the relation between firms' costs of debt and the liability and political uncertainty risks that they face (Gormley and Matsa, 2011; Bradley et al., 2016; Kaviani et al., 2020; Ilhan et al., 2021). Our paper is particularly complementary to that of Ilhan, Sautner, and Vilkov (2021), who examine the effects of the Trump election on firms' tail risk by using out-of-the-money put options on firms' equity securities. They conclude that the election was followed by significantly decreased tail risks for the top polluting industry firms. Our results not only demonstrate how policy uncertainty can increase firms' risk, but also through a structural model we decompose the effects of the Paris Agreement into asset volatility and asset value channels. The

[8] For reviews of the climate finance literature, see Giglio et al. (2021); Gasparini and Tufano (2023); Pastor et al. (2024).

dominance of the volatility channel over the asset value channel carries important implications for understanding how climate policy uncertainty affects financial markets. Against the backdrop of the U.S. political landscape where administrations oscillated their stance on global climate pacts, we provide insights that the mere presence of substantial regulatory uncertainty can materially increase the cost of capital for high emission firms in bond markets, even in the absence of concrete policy implementation.

Our findings have broader implications given the corporate bond market's significant role in the economy through its relationship with firm investment (Philippon, 2009) and potential feedback effects during market distress (Gilchrist and Zakrajšek, 2012; Gilchrist et al., 2014). Policymakers have begun monitoring corporate bond markets for financial stability reasons (Boyarchenko et al., 2021), and some central banks now purchase corporate bonds as an important policy tool. In this light, our work provides guidance for regulators in understanding the connection between climate regulatory uncertainty and the real economy through bond pricing. Further, our results are consistent with the arguments of Stiglitz et al. (2017) and Berg et al. (2023) that the uncertainty in the regulatory framework and path used by governments in the transition to combat climate change can harm the efficiency of both financial institutions and financial markets.

2. Data

2.1. Sample construction

Our sample includes bonds issued by U.S. public non-financial companies over the 2009-2017 period, which are classified as corporate debentures and corporate medium term notes with maturities ranging from one month to 30 years.[9] We obtain data on these bonds and their issuing firms from a number of sources: Mergent FISD, FINRA's Trade Reporting and Compliance Engine (TRACE), CRSP, Compustat, Sustainalytics and CDP.

We use the Mergent FISD database for characteristics of the bonds such as offering terms, maturity, the principal amount outstanding, and credit ratings (which originate from Moody's, Standard and Poor's (S&P) and Fitch). We employ the Moody's ratings as the primary source

[9] We omit any non-standard corporate bonds such as Yankee bonds, convertible bonds, puttable bonds, exchangeable bonds, Canadian bonds, bonds listed in foreign currency, private placements, variable rate bonds and zero coupon bonds.

of credit ratings and transform the qualitative rating to a quantitative measure by assigning each rating a numerical value, giving a 1 to the lowest rating (D) and increasing by 1 for each notch such that the Moody's Aaa rating (or the S&P and Fitch equivalent) receives a value of 22.[10] This approach has the advantage that when a credit rating is downgraded, the representative number is lower.

Using the Mergent FISD offering terms, we define a bond's offering yield spread as the difference between a bond's offering yield and the yield of a cash flow-matched synthetic Treasury bond. In this measure the discount rates of varying maturities derive from the U.S. Treasury yield curve provided by Gürkaynak et al. (2007), where the yield of the synthetic Treasury bond is inverted from its price.

We combine the Mergent FISD bond characteristics data with data on secondary market pricing for corporate bonds from the TRACE database.[11] We calculate a bond's monthly yield as the median yield on all trades of that security occurring on its last active-trading day of a given month.[12] When possible, we linearly interpolate yields for months with missing yields. We then calculate trading yield spreads and the difference between a bond's trading yield and the yield of the Treasury bond with the same maturity in that month. Data on characteristics of the issuing companies are obtained through the CRSP and Compustat databases where we use the six-digit CUSIP to link companies across databases. We drop observations for which we are unable to obtain information on either the firm's headquarters location or the SIC industry code.[13]

Our first measure of the issuing firm's environmental profile relies on Sustainalytics Environmental Scores from their ESG rating service, which during this period are based on 57 environmental indicators and range from 0-100, with a higher score indicating stronger environmental performance. We employ the summary Environmental Score, which is calculated as a weighted average of the indicators, where the weights used are industry specific and proprietary, that is, the environmental scores are industry adjusted. We merge the corporate bond data with the Sustainalytics data at

[10]If Moody's did not rate the security, we use the S&P rating and if that rating is also unavailable, we employ the Fitch rating.

[11]We adopt the procedure suggested in Dick-Nielsen (2009) to clean the TRACE data.

[12]Based on the suggestion in Edwards, Harris, and Piwowar (2007), all trades that deviate from the security daily median price by greater than 10% are dropped. Additionally, all price reversals greater than 10% are dropped.

[13]Headquarters location and SIC industry code are obtained from Compustat. Since Compustat provides only current headquarter locations, we use historic headquarter locations provided by Gao (2020). Only 0.2% of the bonds in the sample are dropped because of missing headquarter or industry information.

the issuer-year level using firm ticker symbols.

We derive three additional measures of a firm's environmental profile using firms' carbon emissions provided by CDP. Firms submit their carbon emissions data to CDP at the end of June each year, covering emissions for the previous year.[14] The data includes information on Scope 1 emissions (direct emissions produced by the firm), Scope 2 emissions (indirect emissions from purchased energy) and Scope 3 emissions (indirect emissions that arise from the firm's supply chain). We focus on Scope 1 emissions since not all firms reporting to CDP provide the Scope 2 and Scope 3 emissions, the firm has the most direct control over Scope 1, and these emissions are measured with the most precision. Using the Scope 1 emissions data, we also calculate carbon intensity by dividing carbon emissions (in tons) by firm revenue (in thousands of dollars). We employ both total carbon emissions and carbon intensity in our tests.

Because not all firms submit their carbon emissions to CDP, we identify the highest carbon emission industries in the sample and for the difference-in-differences tests we employ an additional measure according to a firm's industry. Specifically, we rank industries by total carbon emissions within our sample, and define the industries with the top 15 carbon emissions as top carbon emission industries. We employ total industry emissions for this definition because political attention for climate regulations seems to focus on the size of total emissions rather than the carbon intensity.[15]

2.2. Environmental regulations data

U.S. environmental policy is designed as a shared responsibility between the federal government and the individual states—in general, federal environmental policies are established through laws passed by Congress and rules developed by the EPA. According to federal enforcement protocols, the individual states are authorized and expected to enforce EPA regulations for violations within the state. Thus, for most states, state government personnel evaluate compliance with the EPA regulations and issue enforcement actions if they conclude that compliance standards are not being met. In addition, although states can create and enforce laws stricter than EPA regulations, they

[14] Given the data reporting lag in the CDP (Zhang, 2024), we use a one year lag of the data release date and adjust for restatements in reported variables.

[15] These industries are electricity, gas and sanitary, oil and gas extraction, transportation by air, petroleum and coal, chemical and allied products, primary metal, railroad transport, food and kindred products, paper and allied products, motor freight transportation, metal mining, general merchandise stores, stone, clay and glass, non-classifiable establishments, and transportation equipment.

are expected to govern compliance at least as strictly as EPA standards. Since some states enforce regulations with minimum standards while others enforce them more stringently, this allows us to observe cross-sectional variation in regulatory standards.

We obtain EPA enforcement data from the Integrated Compliance Information System for Federal Civil Enforcement Case Data. Employing these data we construct a measure of state-level environmental regulatory stringency that captures compliance and enforcement actions for the Clean Water Act (CWA), Clean Air Act (CAA) and Resource Conservation and Recovery Act (RCRA) in a given state and year. Our measure, which we adopt from the political science literature (Konisky, 2007), uses the number of enforcement actions, both informal enforcement actions with no pecuniary penalty (notifications of violation) and formal enforcement actions resulting in a pecuniary penalty (fines and administrative orders). We normalize the number of enforcement actions by the total number of facilities subject to EPA regulations in that state (measured in thousands), which is obtained from the Facility Registry Services (FRS).[16]

Because firms often have facilities in multiple states, we adapt the state-level EPA measures to firm-specific measures to capture the regulatory environment for individual firms. In order to determine each firm's aggregate exposure to state-level EPA enforcement, we use the National Establishment Time Series Database (NETs). The NETs is produced by Wall & Associates based on the Dun & Bradstreet dollar-directory database, and provides establishment-level information on firms, which we use to calculate each firm's revenue within each state in the United States. We then define the firm-level regulatory stringency as the weighted-average state-level environmental regulatory stringency across all of a firm's establishments.[17]

$$RegStringency_{j,t} = \sum_{s \in S_j} \left(\frac{StateRevenue_{j,s}}{TotalRevenue_j} \times EPAEnforcements_{s,t}\right), \quad (1)$$

where $TotalRevenue_j$ is total revenue by firm j in all states, $StateRevenue_{j,s}$ are total revenue by firm j in state s and $EPAEnforcements_{s,t}$ are total EPA enforcement actions in state s

[16] If states fail to enforce regulations at the minimally acceptable level, the EPA has the option to enforce the laws themselves through their regional offices. States for which this is relevant are detailed at https://www.epa.gov/compliance/state-review-framework-compliance-and-enforcement-performance. Since we cannot observe whether the EPA or the state is the lead investigator on a given case, we drop all enforcement actions occurring in the few states in which the EPA is responsible for enforcement.

[17] For firms for which we cannot observe establishments in the NETs data, we use the total number of EPA enforcement actions for the state in which the firm's headquarters are located. We have also constructed alternative regulatory stringency measure based solely on the state in which the firm's headquarters reside. Our results hold.

scaled by the number of EPA-registered facilities (in thousands) in state s at time t. Therefore, $RegStringency_{j,t}$ captures firm j's exposure to environmental regulatory enforcement at time t across the states within which the firm operates.

2.3. Sample construction

Our initial data set covers 5,548 bonds and 830 issuers included in the Mergent and TRACE databases over the 2009-2017 sample period. After merging the bond data with Sustainalytics environmental ratings data on the issuers, the sample size reduces to 4,235 bonds from 478 issuers. For the tests that employ the CDP carbon emissions data, the merger with initial bond data reduces the sample to 3,368 corporate bonds, corresponding to 287 issuers. Table 1 reports the sample summary statistics.

3. Credit risk, environmental profile, and regulatory stringency

3.1. Regression specifications

We first examine the relationship between bond credit risks and the issuing firms' environmental profiles, and test whether that relationship appears to be heightened by the firms' exposures to differing regulatory risks across states. We employ bond credit ratings and offering yield spreads as separate dependent variables that capture credit risk. The key independent variables in these regressions are firms' environmental profiles, the level of regulatory enforcement intensity each firm faces, and the interactions between these two variables. In this set of analyses, we focus on at-issue bonds to better capture the relation between environmental regulatory risk exposure and firms' costs of debt because the offering spreads reflect the costs of issuing debt. For bond i issued by firm j at time t, we examine its credit rating or yield spreads using the following specification:

$$Y_{ijt} = \beta_1 EnvProf_{jt-1} + \beta_2 RegStringency_{jt-1} + \beta_3 EnvProf_{jt-1} \times RegStringency_{jt-1} + \beta_4 X_{jt-1} + \beta_5 Z_{it} + FE + \epsilon_{it}, \quad (2)$$

where $EnvProf_{jt-1}$ is firm j's environmental profile at time $t-1$, which we proxy for using three separate measures: the firm's Sustainalytics Environmental Score, the firm's total carbon emissions (in millions of tons), or the firm's carbon intensity (tons of emissions divided by revenue in thousands of dollars). $RegStringency_{jt-1}$ is the regulatory stringency for firm j at time $t-1$, proxied by the revenue-weighted average state EPA enforcement intensity across a firm's establishments (Equation (1)). X_{jt-1} are firm j's characteristics at time $t-1$, which include book leverage, pre-tax interest coverage, the natural log of total assets, cash-to-assets ratio, profitability, tangibility of assets, annual stock returns and standard deviation of stock returns. When employing credit ratings as the dependent variable, we also control for the weighted-average maturity of the firm's outstanding bonds at time t. When employing bond yield spreads as the dependent variable, we include Z_{it} to additionally control for bond characteristics such as the principal amount, time to maturity, and an indicator if the bond is callable. For all specifications, we include time fixed effects to control for macroeconomic trends. In some specifications, we also include industry fixed effects to control for time-invariant industry characteristics.

In Equation (2), the primary coefficient of interest is β_3, which captures the interaction effect between firms' environmental profiles and their regulatory conditions. If firms with poor environmental scores tend to have higher regulatory risk exposures, we expect β_3 to be positive when employing credit ratings as the dependent variable and environmental scores as the measure of the firms' environmental profiles. Alternatively, when we proxy for the firm's environmental profile with one of the carbon emission measures, we expect β_3 to be negative since higher carbon emissions indicate a weaker environmental profile. When we employ a bond's offering yield spread as the dependent variable in Equation (2), we expect opposite signs on β_3 because yield spreads are increasing in a bond issuer's risk exposure.

We are also interested in the coefficient of $EnvProf_{jt-1}$, β_1, as it captures the unconditional effect of a firm's environmental profile on the firm's credit risk. Recent studies have established relationships between carbon emissions or carbon intensity and equity prices.[18] Assuming bond investors also care about carbon risk, we expect credit ratings and yield spreads to differ across issuers with different environmental profiles, even when issuers are exposed to average levels of regulatory risk.

[18]There exists an active debate on whether the correct measure to employ for judging the risk premia on high carbon stocks is total carbon emissions or carbon intensity. We employ both measures as well as a firm's identity as being part of a high carbon emissions industry. See, for example, Bolton and Kacperczyk (2021, 2023); Aswani et al. (2023); Bolton and Kacperczyk (2024); Zhang (2024).

3.2. Results

In columns (1) through (3) of Table 2, we report the results for the regressions in which credit ratings are the dependent variables. In column (1), using the firms' Sustainalytics environmental scores, we find that bonds issued by firms with higher environmental scores tend to have higher ratings. In particular, an increase in a firm's environmental score of one point is associated with a statistically significant 0.027 notch increase in credit ratings for firm-years with an average regulatory stringency.[19] Importantly, the interaction term between a firm's environmental score and the weighted-average regulatory stringency the firm faces is positive and statistically significant. When an increase in a firm's environmental score of one is combined with a one standard deviation increase in the firm's regulatory stringency, ratings increase by 0.047 notch ($0.027 + 0.020$). The results suggest that a firm's environmental profile affects its credit rating, particularly through the channel of regulatory risks.

In the next two columns, we employ alternative proxies for the firm's environmental profile: the firm's absolute carbon emissions (column (2)) and its carbon intensity (column (3)). For both of these measures, we find a strong negative effect on the firm's credit rating from the interaction of the carbon emissions measure and the average regulatory stringency the firm faces. Consistent with the results using the firm's environmental score, we find strong relationships between the firms' credit ratings and their environmental profiles when using carbon intensity. Examining the coefficient reported in column (3), if carbon intensity increases by one (ton per $1,000 revenue), a firm's credit rating decreases by 0.514 notch. This result suggests that carbon risk affects credit ratings unconditionally. Moreover, when combined with a one standard deviation increase in $RegStringency$, the same increase in carbon intensity is associated with a 0.797 notch decrease in credit ratings ($-0.514 - 0.283$). We include industry fixed effects in the regression specifications reported in columns (4) through (6) of Table 2 in order to examine whether the relationship between a firm's environmental profile and credit risk is also present within a given industry. The results are qualitatively similar to those without industry fixed effects.

The results in Table 2 imply that credit rating agencies consider regulatory risk when evaluating how environmental concerns affect bond risk, which is consistent with rating agencies' policies.

[19] For reference, the standard deviation of the environmental score is 14.1.

According to methodology published in 2018, credit rating analysts at Moody's consider both direct environmental implications and regulatory costs when evaluating ESG effects on credit ratings. Specifically, they state that they consider regulation more closely because forecasting is easier (Moody's, 2018). These statements are consistent with our finding that the effects of detrimental environmental activities on bond credit ratings are sensitive to the strictness of states' EPA regulation enforcement.

In Table 3, we present regression results for the relationship between bonds' offering spreads and their issuers' environmental risk exposures. Regressions in columns (1) through (3) include results using only time fixed effects and columns (4) through (6) include both time and industry fixed effects. The results in column (1) indicate that a one unit increase in a firm's environmental score is associated with a 0.9 bp decrease in their bonds' offering yield spreads, holding the regulatory stringency a firm faces at the average level. Additionally, when a firm operates in states with a one standard deviation increase in regulatory stringency, the same increase in environmental score is instead associated with a 1.4 bps decrease ($-0.9 - 0.5$) in offering yield spreads. Considering that the standard deviation of the samples' environmental scores is 14.1, this effect is economically large. Our finding that firms with higher environmental scores have lower yield spreads is consistent with Chava (2014) who concludes that firms with higher environmental scores pay lower interest rates on their bank loans. Both our results and that of Chava (2014) imply that such firms face lower risks, which is an effect widely believed by many ESG investors.

The results in column (2) show that a one million ton increase in firm carbon emissions is associated with a 0.7 bp increase in yield spreads. When combined with a one standard deviation increase in *RegStringency*, the increase in emissions is associated with a 1.4 bps increase ($0.7+0.7$). Column (3) shows similar results when using carbon intensity as a carbon intensity increase of one (ton per $1,000 revenue) is associated with a 16.2 bps increase in bond spreads. These results are consistent with the argument that issuers with higher carbon emissions face higher costs in raising capital. In columns (4) through (6), we report broadly similar results when employing both time and industry fixed effects.

Our results reported in Tables 2 and 3 suggest that bonds from firms with poor environmental performance have both lower credit ratings and higher yield spreads. Importantly, these findings highlight that the effects become particularly pronounced when issuing firms face more stringent environmental regulation enforcement, implying that these firms face a higher probability of regulatory costs such as fines or possibly reputation losses, which in turn increases their credit risk. The results, which are also consistent with previous research showing the greater negative consequences for firms that pollute under stricter regulatory regimes, imply strictness in regulation forces firms to internalize the costs of pollution (Greenstone, 2002).

The results are also informative about the channel through which environmental regulations affect credit ratings and yield spreads. In particular, the findings provide evidence that environmental regulatory risk relates to credit ratings and yields spreads both across-industry and within-industry, which suggests that for the high carbon emission sectors, firms that operate in states with stricter regulatory enforcement likely bear even more credit risk than their counterparts in less stringent states.

4. The Paris Agreement announcement

A firm's environmental profile and its regulatory conditions may be jointly determined, thus, creating potential endogeneity issues. For example, state governments could impose stricter environmental regulations because the economic conditions in the state are favorable; these favorable economic conditions might in turn attract high carbon emitting firms to locate there. To mitigate such endogeneity concerns, we exploit an event that increases the climate regulatory risks faced by firms, without significantly changing the environmental profiles of these firms.

4.1. The Setting: The Paris Agreement

The setting we use in our research design is the announcement of the Paris Agreement on December 12, 2015. The Paris Agreement has the primary goal of limiting global temperature rise in this century to 1.5 degrees Celsius above pre-industrial levels. The Agreement calls for the signing countries to submit national action plans to reduce emissions with sufficient speed to limit their countries' emissions. To achieve the Paris Agreement goal, the national action plans would require new regulations to encourage firms to lower emissions, resulting in financial market expectations of more stringent environmental regulations in the future. However, the nature of these regulations was not explicitly determined at the time, which increased uncertainty regarding their timing and stringency.

Even prior to the December 2015 meeting, many countries were already preparing legislative and regulatory changes to combat climate change. For example, in the US, the Obama administration unveiled the Clean Power Plan on August 3, 2015, which used the EPA's authority under the Clean Air Act to regulate carbon emissions. Under this Plan, the EPA assigned each state a goal for limiting emissions from existing power plants. The Plan also increased regulatory requirements for new power plant construction, and in particular made it very difficult to build new coal plants. The EPA estimated this Plan would reduce greenhouse gas emissions from the power sector to 32 percent below 2005 levels by 2030.

We hypothesize that the Paris Agreement would have created expectations of more climate regulation stringency in the U.S., most immediately through the channel of the Clean Power Plan. Given the existence of the Clean Power Plan and the uncertainty surrounding its implementation, the announcement of the Paris Agreement would have elevated the climate regulatory risks for firms with high carbon footprints. The increased level of risks should then be reflected in firms' bond credit ratings and spreads. To test this hypothesis, we conduct difference-in-differences analyses to compare the credit ratings and yield spreads of bonds from firms with problematic environmental profiles versus those from other firms, both before and after the Paris Agreement.

4.2. Descriptive evidence of changes in bond credit ratings and spreads

We start by visually inspecting changes in the average credit ratings and spreads for bonds issued by firms in the 15 highest carbon-emitting industries. Figure 1(a) displays the average credit ratings for each of the top 15 carbon-emitting industries before and after the December 2015 Paris Agreement. Although we find large variation across these industries in their average creditworthiness, the figure demonstrates a clear pattern – the Paris Agreement is associated with a ratings decrease for firms in the high carbon emissions industries. Figure 1(b) shows the changes in average yield spreads for bonds issued by firms in the top 15 carbon-emitting industries before and after the Paris Agreement. As in the case of the credit ratings, substantial differences exist across industries in the magnitude of the yield spreads and their changes. Nonetheless, in most cases, large increases in spreads occur after the Agreement with the largest increases in oil and gas extraction, primary metals, and metal mining industries.

4.3. *Changes in credit ratings around the Paris Agreement*

We test changes in bond credit ratings in the two-year period around the December 2015 Paris Agreement through the following difference-in-differences regression at the monthly interval:

$$Rating_{it} = \beta_1 EnvProf_j \times AfterParis_t + \gamma_i + \kappa_t + \epsilon_{it}, \quad (3)$$

where $AfterParis_t$ is an indicator variable for the months starting in December 2015 and continuing through the following 12 months. We also include security fixed effects, γ_i and time fixed effects, κ_t. Since the Paris Agreement is a time-series shock, in order to capture changes in ratings affected by the Agreement, our sample in these tests consists of bonds issued before the Paris Agreement and traded during the period.[20] In constructing our test sample, we include a pre-event period of twelve months prior to the Agreement and a post-event period of twelve months following the Agreement. That is, the testing period runs from December 2014 through November 2016.

We employ four measures of a firm's environmental profile. First, we use an indicator variable equal to one if a firm is in the top-quartile in terms of firm-level total carbon emissions in 2014. Second, we use an indicator variable equal to one if a firm is in the top-quartile in terms of firm-level carbon intensity in 2014. Third, we use an indicator variable for whether a firm is in one of the top 15 carbon-emitting industries. Finally, we use an indicator variable equal to one if a firm has a below-median environmental score in December 2014.

In Equation (3), coefficient β_1 captures the change in bond risk assessments around the Paris Agreement for firms with a treated environmental profile relative to other firms, controlling for time-invariant bond characteristics and for macroeconomic trends that affect all bond issues. We double-cluster standard errors at the 3-digit SIC industry and month levels to account for correlated error terms within industries and across time.

Table 4 reports the results from the difference-in-differences regressions. Column (1) shows that after the Paris Agreement, bond ratings decrease by 0.55 notch for bonds issued by firms with top-quartile emissions relative to other firms. Based on this result, the Paris Agreement announcement results in an economically significant decrease in bond ratings for firms with higher

[20]Specifically, the sample includes bonds issued at least one year before the Paris Agreement, i.e., in December 2014 or earlier. We also require that the bonds do not mature before the end of the testing period.

emissions relative to other firms. Correspondingly, column (2) demonstrates that firms with top-quartile carbon intensity also exhibit a bond ratings decrease, in this case by 0.63 notch for those bonds relative to others. Employing the high emissions industry definition for firms in column (3) we find no statistically significant changes in credit ratings relative to other firms. Finally, in column (4) we examine bonds issued by firms with below median environmental scores and find that credit ratings decrease by 0.58 notch relative to bonds issued by firms with higher environmental scores. Moreover, as shown by the results using the environmental score, bond ratings decrease after the Paris Agreement for bonds issued by firms exposed to environmental risk more generally.

We examine the dynamics of the treatment effects on credit ratings in relation to the Paris Agreement event. Specifically, we construct a series of tests to examine the time series of differences between ratings for firms in the treatment and the control groups. We run the following regressions:

$$Rating_{it} = \sum_{k=-11}^{11} \beta_k[\mathbb{1}(t=k) \times EnvProf_j] + \gamma_i + \kappa_t + \epsilon_{it}, \tag{4}$$

where $\mathbb{1}(t=k)$ are indicators for periods that are k months before or after the Paris Agreement. The time indicator variable for the first month in our sample period (December 2014) is excluded, so the magnitude of all treatment effects are relative to December 2014.

Figure 2 shows the dynamics of the credit ratings of treated firms relative to control firms around the Paris Agreement. Panel (a) displays the treatment effects over time for bonds issued by firms with top-quartile emissions. The solid line and dots indicate the coefficient estimates, and the dashed lines represent bands of a 90% confidence interval around these estimates. We find no significant differences in the treatment effect in the entire period before the Agreement, indicating the parallel trends assumption appears to hold. In contrast, after the Agreement, the treated firms' bonds have significantly lower credit ratings, consistent with the results reported in Table 4. Figures 2 (b), (c) and (d) illustrate the results for Equation (4) when the treated firms as defined by being in the top-quartile of carbon intensity, in a top 15 carbon-emitting industry or with a below-median environmental score, respectively. All of the figures demonstrate that the parallel trends assumption appears to hold and they also all indicate a significant drop of the treated firms' credit ratings after the Paris Agreement.

Since the Paris Agreement increased the prospect of future environmental regulatory risks, we expect its effects to differ across companies in part due to variations across state governments in their enforcement of environmental regulations. In a scenario in which the U.S. government imposes new environmental regulation at the federal level, we hypothesize that credit ratings (and bond yield spreads) should change more for firms located in high-enforcement states where the new regulations would be enforced in a more stringent way. To examine this hypothesis, we run triple-difference regressions by including an indicator variable for firms facing stricter regulatory environments. To define the stricter regulatory environments, we sort firms by *RegStringency*, which is calculated as a firm's revenue-weighted average environmental regulatory stringency, from 2012 through 2015. Firms with a top-quartile *RegStringency* are defined as high regulatory enforcement firms.

Using these definitions, we run the following regression:

$$\begin{aligned} Rating_{it} = \gamma_i + \kappa_t &+ \beta_1 AfterParis_t \times EnvProf_j + \beta_2 AfterParis_t \times HighRegStringency_j \\ &+ \beta_3 EnvProf_j \times HighRegStringency_j \\ &+ \beta_4 AfterParis_t \times EnvProf_j \times HighRegStringency_j + \gamma_i + \kappa_t + \epsilon_{it}, \end{aligned} \tag{5}$$

where the outcome variable $Rating_{it}$ is the credit rating. The binary variable $HighRegStringency_j$ indicates high regulatory enforcement firms.

The primary parameter of interest, β_4, captures the effects of the Paris Agreement for firms with treated environmental profiles that operate in states with strict regulatory enforcement relative to firms that operate in less stringent states. If after the Paris Agreement firms with the treated environmental profiles become more exposed to climate regulatory risks in states where any potential new regulations are expected to be enforced more strictly, we expect β_4 to be negative. Such a result would suggest that regulatory risk is the channel through which the Paris Agreement affects bond credit ratings. We again use the four alternative measures to define the treated firms.

Table 4 provides the results of the triple-difference regressions where the dependent variable is the credit rating. The main parameter of interest is the coefficient for the triple-difference estimator $AfterParis_t \times EnvProf_j \times HighRegStringency_j$. In column (5) in which the environmental measure is the top-quartile emissions indicator, the results show that after the Paris Agreement, relative to the firms located in low regulatory stringency states, firms with the greatest amount of carbon emissions located in strict regulatory states experience credit rating decreases of an additional 1.37 notch. Results in other columns show that after the Paris Agreement, if an issuing company is located in a high regulatory enforcement state, credit ratings decrease by an additional 1.39 notch, 1.09 notch, and 0.99 notch for bonds issued by firms in the top-quartile of carbon intensity, in high carbon emissions industries and with below median environmental scores, respectively. These triple-difference results imply that the decrease in corporate bond ratings following the Paris Agreement is driven by firms with operations in states that have stricter regulatory enforcement.

Overall, the findings in this section imply a direct consequence of the Paris Agreement for firms with the treated environmental profiles. In particular, they provide evidence that credit rating agencies appear concerned about future regulatory changes when evaluating the effects of environmental risk, particularly climate risk, on a bond's default risk. Next, we examine whether bond yield spreads changed for bonds issued by firms with treated environmental profiles relative to other bonds after the Paris Agreement.

4.4. Changes in bond yield spreads around the Paris Agreement

To test for changes in bond yield spreads around the Paris Agreement, we use the following difference-in-differences regression:

$$Spread_{it} = \beta_1 EnvProf_j \times AfterParis_t + \gamma_i + \kappa_{tp} + \epsilon_{it}, \tag{6}$$

where we measure a firm's environmental profile using the same four measures as in Equation (3). We again include security fixed effects, γ_i, and matched-pair-by-time fixed effects κ_{tp}. Effectively, this test can be interpreted as comparing the change in spreads for a treated security to its matched control security after the Paris Agreement, controlling for time-invariant security characteristics.

We implement our matching procedure, one-to-one Mahalanobis matching with replacement, in order to better control for noise in spreads and to compare bonds with similar creditworthiness. With this matching approach we can identify and match each treated bond to its most similar control bond according to various covariates.[21] The procedure uses year-end 2014 credit ratings, bond principals outstanding, times to maturity, and the issuers' equity oil betas.

[21] We use a caliper of 1, meaning if for a given treatment firm there does not exist a control firm whose Mahalanobis distance is 1 or less, we drop the firm from the sample. We further address the potential bias in continuous variable matching using the methods proposed by Abadie and Imbens (2006).

We believe it is particularly important to match on the issuer's equity oil beta in order to alleviate a potential concern that changes in bond pricing may be driven by concurrent movements in the oil market, particularly given the volatile changes in oil prices over this period.[22] We use the following model to calculate firms' equity oil betas:

$$R_{it} = \alpha + \beta_{market} MktRet_t + \beta_{oil} OilRet_t, \tag{7}$$

where $MktRet$ is proxied by the CRSP value-weighted index and $OilRet_t$ is the monthly return on Brent Crude Oil for month t. We calculate this value for each firm in our sample for which we observe 36 months or more of stock price data before November 2015.

We construct four matched samples, one for each of our environmental measures, the below-median environmental score, the top carbon-emitting industry, the top emission quartile and the top carbon intensity quartile treatments, respectively. In Table A.1 we report the summary statistics for all matched samples (as of the matching date). The differences between the treated and the control groups are generally statistically insignificant and economically small. We therefore conclude that the treated and control groups are observationally similar.

Table 5 reports the results from the difference-in-differences regression from Equation (6). The effects of the Paris Agreement on the treated firms' spreads are both economically large and statistically significant. Column (1) indicates that after the Paris Agreement, bond yield spreads increase by 30.1 bps for bonds issued by firms with top-quartile emissions. Similar results are observed when examining bonds issued by firms with top-quartile carbon intensity or in high-emitting industries, as the yield spreads increase by 34.7 bps and 38.6 bps, respectively (columns (3) and (4)). Finally, column (4) displays results using the below median environmental score indicator, which shows that yield spreads increase by 39.4 bps for the treated bonds relative to other bonds. These results, which are consistent with the results employing bond credit ratings, provide evidence that regardless of the specific firm environmental profile measure used, after the Paris Agreement corporate bond spreads increase for bonds issued by firms with the treated environmental profiles relative to other firms.[23]

[22] Generally speaking, oil price volatility is seen as negatively predicting economic growth and aggregate equity prices, especially for the oil sector (Gao et al., 2022).

[23] To examine robustness of the results according to matching specification, Figure A.1 displays a sensitivity analysis varying the matching by caliper and controls. Details of the specifications are described in Table A.2.

We also provide visual evidence for the parallel trend assumption and the difference-in-differences results through the following dynamic difference-in-differences regression:

$$Spread_{it} = \sum_{k=-11}^{11} \beta_k[\mathbb{1}(t = k) \times EnvProf_j] + \gamma_i + \kappa_{tp} + \epsilon_{it}. \quad (8)$$

The excluded period is December 2014. Additionally, we use security and matched-pair-by-time fixed effects.

Figure 3(a) illustrates the changes in bond spreads around the Paris Agreement using firms with top-quartile emissions as the treated firms. Immediately after the announcement of the Paris Agreement, there exists a significant and sizable increase in yield spreads of bonds issued by treated firms relative to bonds from other issuers. Similar patterns are observed for high carbon intensity firms in Figure 3(b), firms in top carbon-emitting industries in Figure 3(c) and firms with below median environmental scores in Figure 3(d). We note, however, treated firms' yield spreads appear to show some anticipatory effect prior to the Paris Agreement, especially around August 2015. To further tease out the impact of the Paris Agreement on the treated firms' bond spreads more cleanly, we focus on the trading days more closely surrounding the Paris Agreement announcement and examine bond returns at a trading-week frequency.

In this analysis of the trading around the announcement of the Paris Agreement, we examine the two trading weeks before the UN Climate Change Conference (COP21) began on November 30, 2015, the duration of COP21 (which lasted two trading weeks), and a two-trading week period after COP21 concluded with the Paris Agreement announcement on December 12, 2015.[24] Weekly bond abnormal returns are calculated based on the methodology of Bessembinder et al. (2019), which is detailed in the Appendix. Figure 4 shows the cumulative abnormal returns of treated firms (the shaded area indicates the duration of COP21). The figure shows that, before COP21, there is no detectable difference in returns between treated bonds and other bonds. Throughout the length of the Paris climate talks, treated bonds experience significant negative abnormal returns. There is an additional decrease in returns following the announcement on December 12, 2015, at which point

[24]These trading weeks do not correspond precisely to calendar weeks. Since the COP21 meeting spanned ten trading days, we group the first five trading days as one trading week and the last five trading days as the second trading week. We then define the ten trading days prior to COP21 as two trading weeks and the ten trading days following the Paris Agreement announcement as another two trading weeks.

the decrease in returns stabilizes and persists for the two trading weeks after the Paris Agreement.

We calculate cumulative abnormal returns in the period leading up to the Paris Climate Talks (November 16, 2015 – November 27, 2015), during the talks (November 30, 2015 – December 11, 2015) and after the announcement (December 12, 2015 – December 28, 2015) and display them at the bottom of each panel in Figure 4. In the period leading up to the COP21, cumulative abnormal returns are not statistically distinguishable from zero for all treated groups except for the low environmental score group. However, consistent with the Paris Agreement contributing to negative treated bond returns, there exist negative abnormal returns of between 70 bps and 110 bps during the Paris Climate Talks, and additional negative abnormal returns of between 40 bps to 120 bps after the announcement of the Paris Agreement.[25]

Considering again the bond yield spread changes at a monthly horizon (Figure 3), we also note that the initial increase in the treated firms' yield spreads to a large extent reverses in the months after the Paris Agreement, beginning in February 2016. One explanation for the reversal is that, immediately after being announced in August 2015, the Clean Power Plan was challenged in the courts by 24 states with the support of industry groups. In response to this challenge, on February 9, 2016, with a 5–4 vote, the US Supreme Court ordered the EPA to suspend enforcement of the Plan until the lawsuit could be reviewed by the Appeals Court.[26] This Supreme Court ruling created uncertainty over whether the Plan would be enacted until after the 2016 presidential election to be held nine months later. Our yield spread figures show that the credit spread increase is muted but still detectable until November 2016. In November 2016, Donald Trump, who campaigned on pulling the U.S. out of the Paris Agreement, won the election. The new administration ultimately ordered the EPA to dismantle the Clean Power Plan, and also announced they would be withdrawing from the Paris Agreement, which provides an explanation for the eventual complete reversal of the yield spread effect.

Comparing the time series of the difference-in-differences results for the yield spreads with those of the credit ratings shows that the yield spreads largely adjust back to their levels before the Paris Agreement, while the credit ratings remain permanently lower. This divergence might be attributable to the dissimilarities in how changes in yield spreads and credit ratings arise. Yield

[25] Figure A.2 shows cumulative abnormal returns looks similar for alternative specifications, with alternative specifications detailed in Table A.3.

[26] See `https://www.climatecentral.org/news/obama-confident-climate-plan-court-setback-20014`.

spread changes originate from the ability of bond market participants to trade on a daily basis. In contrast, changes to credit ratings require reviews by the ratings analysts and their agencies. Moreover, credit ratings play multiple roles in financial markets, including being used in contractual arrangements such as loans. Thus, there exists a competitive expectation for credit ratings to be relatively stable.[27] This need for stability helps explain the well-documented conservatism of credit rating agencies (e.g., Altman and Rijken (2004); Löffler (2005); Baghai et al. (2014)). Importantly, in the context of the Paris Agreement, the major credit rating agencies began to more fully incorporate climate risk into their ratings after the Paris Agreement.[28] Consequently, it is not surprising that the credit rating agencies did not reverse their ratings for the high carbon emissions firms as quickly as the yield spreads changed.[29] In fact, even after the 2016 presidential election with the candidate's promise to withdraw from the Paris Agreement, in the February 16, 2017 Moody's Report "Shift in US Climate Policy Would Not Stall Global Efforts to Reduce Emissions," the agency notes that as of the time of publication, it was too early to tell exactly what climate policy would be reversed.

We also estimate the following triple-difference regressions to examine whether bond yield spreads increase more around the Paris Agreement for firms located in states with greater regulatory stringency regarding environmental violations:

$$
\begin{aligned}
Spreads_{it} = {} & \gamma_i + \kappa_t + \beta_1 AfterParis_t \times EnvProf_j + \beta_2 AfterParis_t \times HighRegStringency_j \\
& + \beta_3 EnvProf_j \times HighRegStringency_j \\
& + \beta_4 AfterParis_t \times EnvProf_j \times HighRegStringency_j + \gamma_i + \kappa_{tp} + \epsilon_{it}, \qquad (9)
\end{aligned}
$$

where $HighRegStringency_j$ is defined the same as in Equation 5. We expect the coefficient on the triple interaction variable $AfterParis_t \times EnvProf_j \times HighRegStringency_j$ to be positive if after the Paris Agreement firms with the treated environmental profiles become more exposed to

[27] See for example, Beaver et al. (2006).

[28] See, for example, Moody's Environmental Services June 28, 2016 report "Moody's to Analyse Carbon Transition Risk Based on Emissions Reduction Scenario Consistent with Paris Agreement."

[29] These findings also correspond to our structural model results discussed in the next section where we find increased asset volatility following the Paris Agreement that persists over time. This increased asset volatility reflects the increased uncertainty surrounding the credit regulatory risk from climate change.

climate regulatory risks in states where any potential new regulations are expected to be enforced more strictly.

Table 5 reports the triple-difference results on bond yield spreads. Columns (5) and (6) show that although the difference-in-difference coefficients for firms in either the top-quartile emissions group or the top-quartile carbon intensity group remain statistically significant, the triple-difference coefficients for these two groups of firms are statistically insignificant. Column (7) displays a marginally significant coefficient when we employ the high carbon emissions industry indicator. Bond spreads increase by an additional 70 bps for bonds issued by firms in high carbon emissions industries if the firm is located in stricter regulatory enforcement states. Further, using the below-median environmental score indicator in column (8), we find that bond spreads increase by an additional 91.1 bps for firms with poor environmental profiles that are located in stricter regulatory enforcement states, as compared with firms with poor environmental profiles located in less strict states. The triple-difference results for the bond yield spreads provide limited evidence suggesting that bond investors expected the Paris Agreement to lead to increased regulations for environmentally problematic firms and that the new regulations would most likely be enforced through the state governmental agencies. We examine this issue with further analysis.

Our results on treated firms' yield spreads are not contingent on the matching methodology. In Table 6, we include the full sample of bonds in a panel regression. Instead of matching, we sort bonds into high-dimensional bins and utilize fixed-effect regressions. Specifically, we use the fixed effects of size (two groups based on issuers' asset value, defined as market value of equity plus book value of debt) by value (two groups based on issuers' equity market-to-book ratio) by cash holdings (two groups based on issuers' cash and short-term investments scaled by total assets) by ratings (two groups based on investment grade vs. high yield) by time.

Columns (1) through (4) in Table 6 display the difference-in-differences results. When we regress bond yield spreads on the interaction between the post-Paris indicator and the treated issuer indicator, we find that bonds issued by treated companies experience an increase in yield spreads of about 26.2 to 43.9 basis points. The fixed effect setting effectively means that we are comparing bonds issued by similar-sized issuers with similar market-to-book ratio and similar cash holding ratios. The magnitude of the estimated diff-in-diff effect is quite similar to the estimates from our matching specification.

In columns (5) through (8), we further interact *After Paris* × *Env Prof* with the *High Reg Stringency* indicator, which is equal to one if a firm's plants are more exposed to EPA regulatory enforcement. With high dimensional fixed effects, we continue to find that the increase in yield spreads for treated issuers after the Paris Agreement is concentrated among companies whose plants operate in high regulatory enforcement states. The coefficients on the triple interaction are all positive and statistically significant across the specifications.

5. Paris Agreement results through a structural credit model

In this section we employ a structural model based on Merton (1974) to understand the underlying economic mechanisms that drive the yield spread changes we have observed around the Paris Agreement. Previous literature (e.g., Schaefer and Strebulaev, 2008; Huang, Shi, and Zhou, 2020) shows that structural credit models can be effective in fitting the elasticity of credit spreads to equity in the empirical data. This analysis allows us to interpret the observed yield spread changes for high carbon footprint firms jointly with their equity returns, which prior research shows to have declined following the Paris Agreement announcement (Monasterolo and de Angelis, 2020; Mukanjari and Sterner, 2023). Furthermore, this methodological approach facilitates a decomposition of yield spread changes into components attributable to variations in issuers' asset values and issuers' asset volatilities, which provides additional insights into the underlying dynamics.

5.1. The Merton (1974) Model

Consider the classic Merton model, in which the firm's asset value (V) follows a geometric Brownian motion assuming risk neutrality:

$$\frac{dV_t}{V_t} = (r - \delta)dt + \sigma dW_t, \tag{10}$$

where r is the asset return, σ is the asset volatility, and δ is the corporate payout ratio. A firm's equity can be considered a call option on the asset value in this context, where the value of the equity is:

$$V_E = VN(d_1) - Ke^{-rT}N(d_2), \tag{11}$$

and:

$$d_1 = \frac{ln(V/K) + (r - \delta + \sigma^2/2)\tau}{\sigma\sqrt{\tau}}, \tag{12}$$

$$d_2 = d_1 - \sigma\sqrt{\tau}, \tag{13}$$

where K is the face value of the option, and τ is the time to maturity of the option.

5.2. Do equity returns explain the change in yield spreads without structural breaks?

As a first pass, we evaluate whether the observed joint movements of poor environmental firms' securities in the equity and bond markets are driven by random shocks dW_t or by changes in structural parameters. If the underlying parameters of the model (i.e., the asset value V and asset volatility σ), do not change, then the sensitivity of a bond's credit spread CS with respect to the firm's equity return E can be expressed as follows:

$$h_E^{CS} := \frac{\partial(CS)}{\partial E/E} = -\frac{1}{\tau}(\frac{1}{N(d_1)} - 1)(\frac{1}{L} - 1), \tag{14}$$

where L is market leverage.

Under the assumption of no structural breaks, given the observed (percentage) equity return r_i^e of an issuer after the Paris Agreement, we should expect the same firm's bond issue to change its credit spread by the amount of ΔCS_i^*:

$$\Delta CS_i^* = \frac{1}{\tau}(\frac{1}{N(d_1)} - 1)(\frac{1}{L} - 1)r_i^e. \tag{15}$$

If the model-implied change in credit spreads greatly differs from the observed change in credit spreads after the Paris Agreement, this indicates a change in firms' asset values V and asset volatilities σ are necessary to explain the observed change in credit spreads.

To estimate each issuer's Merton model parameters for the period before the Paris Agreement, we employ the methodology of Vassalou and Xing (2004). Assuming that the relationship between issuer equity, debt and asset value adheres to the Merton (1974) model, we calculate σ through an iterative procedure, which uses daily equity return data from the past 12 months to calculate equity volatility as the initial value for estimating σ.[30] From Equation 11, with V_E as the market value of equity for each trading day in the past 12 months, we compute V. Using these V's, we calculate asset returns and their resulting standard deviation, which becomes the value of σ for the next iteration. We repeat this process until the values of σ from two iterations converge, and then calculate V.

We compute these V's and σ's as of November 2015 (i.e. the month before the Paris Agreement) and refer to them as V^{pre}, σ^{pre}. We then employ these values in Equation 15 to calculate the model-implied change in bond yield spreads, conditional on pre-Paris asset values and volatilities. A comparison between the change in model-implied bond yield spreads and the change in actual bond yield spreads (Figure A.3) shows that model-implied changes in bond yield spreads are statistically significantly smaller than observed changes in bond yield spreads. We conclude from this analysis that the underlying parameters of the credit model must have changed after the Paris Agreement. To better understand what drives this change in yield spreads, we next employ the structural model to examine how the firms' asset values and volatilities change after the Paris Agreement.

5.3. Estimating the changes in asset values and volatilities

From the Merton model, a firm's equity value and credit spread can be written as follows:

$$E(V,\sigma) = VN(d_1(V,\sigma)) - Ke^{-\tau r}N(d_2(V,\sigma)), \tag{16}$$

$$CS(V,\sigma) = -\frac{ln[VN(-d_1(V,\sigma))e^{\tau r}/K + N(d_2(V,\sigma)]}{\tau}. \tag{17}$$

Given our estimated pre-Paris structural parameters V^{pre} and σ^{pre} for each firm using the iterative method, we can calculate the firm's equity value $E(V^{pre}, \sigma^{pre})$ and bond credit spread $CS(V^{pre}, \sigma^{pre})$ just before the Paris Agreement. We define a firm's target post-Paris equity value

[30] In this procedure, we use the total debt for an issuer from Compustat as K, the sum of Compustat interest, dividends and repurchases scaled by total assets as δ, the one-year Treasury bond rate as r, and the bond time to maturity from Mergent as τ. If the total debt is missing or equal to zero in Compustat, we use the issuer's total bonds principal outstanding from Mergent.

as its pre-Paris equity value multiplied by the observed equity return between the Paris Agreement announcement and t month(s) afterwards:

$$E^{post}(V^t, \sigma^t) := E(V^{pre}, \sigma^{pre})(1 + r_t^e), \tag{18}$$

and a firm's target post-Paris credit spread as its pre-Paris credit spread plus the observed credit spread change arising from the Agreement:

$$CS^{post}(V^t, \sigma^t) := CS(V^{pre}, \sigma^{pre}) + \Delta CS^t. \tag{19}$$

The remaining question is then what new values of V^t and σ^t are compatible with the post-Paris Agreement equity value $E^{post}(V^t, \sigma^t)$ and credit spread $CS^{post}(V^t, \sigma^t)$? Using Equation 16 and Equation 17 we derive the following equations:

$$E^{post}(V^t, \sigma^t) = V^t N(d_1(V^t, \sigma^t)) - Ke^{-\tau r} N(d_2(V^t, \sigma^t)), \tag{20}$$

$$CS^{post}(V^t, \sigma^t) = -\frac{ln[V^t N(-d_1(V^t, \sigma^t))e^{\tau r}/K + N(d_2(V^t, \sigma^t)]}{\tau}. \tag{21}$$

We solve this nonlinear system of equations for each of the six months after the Paris Agreement ($t = 1, 2, 3, ..., 6$) to find V^t, σ^t.[31] Note that as described in Schaefer and Strebulaev (2008), credit yield spreads contain both a credit and non-credit component, whereas Merton (1974) models the credit component. To address this point, we solve this system of equations using the credit-component of the change in credit spreads calculated with the methodology in Longstaff et al. (2005).

After solving for V^t and σ^t for each issuer, we calculate the changes in asset values and volatilities

[31] This system of nonlinear equations is solved in MATLAB, which requires an initial value for the asset value and volatility. Firms' pre-Paris Agreement model asset values are the initial values for the firms' asset values. The initial values for the firms' volatilities are computed based on the methodology in Feldhütter and Schaefer (2018). Specifically, we estimate $(1 - L_t)\sigma_{E,t}$, where L_t is market leverage and $\sigma_{E,t}$ is volatility of equity returns, and multiply this by 1 if $L_t \leq 0.25$, 1.05 if $0.25 < L_t \leq 0.35$, 1.10 if $0.35 < L_t \leq 0.45$, 1.20 if $0.45 < L_t \leq 0.55$, 1.40 if $0.55 < L_t \leq 0.75$ and 1.80 if $L_t > 0.75$, and use the final product as our initial value.

for each of the six months after the Paris Agreement ($t = 1, 2, 3, ..., 6$) for every bond in the sample:

$$\Delta V^t = \frac{V^t - V^{pre}}{V^{pre}} \tag{22}$$

$$\Delta \sigma^t = \sigma^t - \sigma^{pre} \tag{23}$$

Then, for each given time horizon t, we examine treated firms' differential changes in asset value and asset volatility relative to control firms by running the following regressions:

$$\Delta V_i^t = \beta EnvProf_j + \kappa_p + \epsilon_i, \tag{24}$$

$$\Delta \sigma_i^t = \beta EnvProf_j + \kappa_p + \epsilon_i, \tag{25}$$

where κ_p are matched-pair fixed effects. Just as in the difference-in-differences analysis, $EnvProf_i$ is an indicator equal to one if an issuer is in the top-quartile of carbon emissions, in the top-quartile of carbon intensities, in a top 15 carbon emitting industry, or has a below median environmental score, and otherwise, zero. Since these tests are based on the model-implied asset values and volatilities, they can be interpreted as describing how much of a change in asset value and volatility would have been needed to jointly explain the observed changes in bond yield spreads and equity values.

Results from these regressions on changes in asset values are plotted in Figure 5. Panel (a) displays results using top-quartile carbon emission firms as the treated group. For bonds issued by these companies, we estimate that their asset values drop by about five percent in the first three months after the Paris Agreement, before eventually reverting back. Panels (b), (c), and (d) focus on bonds issued by firms with top-quartile carbon intensity, firms in the top 15 emitting industries, and firms whose environmental scores fall below median, respectively. We find broadly consistent evidence that the asset values of these firms drop after the Paris Agreement, although the magnitude of the asset value drops is not as large under some specifications.

The first four columns of Table 7 provides the corresponding regression results at the 1, 3 and 6 month time horizons after the Paris Agreement. Panel A shows that at the 1-month horizon, there is a statistically significant drop in asset values for bonds issued by treated firms. At three months after the Paris Agreement (Panel B), the drop in asset value steepens for every profile definition, and the magnitude is about 2.7 to 6.1 percentage points (relative to pre-Paris value). Interestingly at the six-month horizon, the point estimate completely reverts back to zero. These results show that the model-implied declines in asset values following the Paris Agreement were significant but also modest and short-lived.

Figure 6 illustrates the plots for changes in asset volatilities. Panels (a) and (b) show that the asset volatility of firms with top-quartile emissions or carbon intensity increases by almost 20 percent following the Paris Agreement. The increase in asset volatility only partially reverses and stays elevated at about 8 or 9 percent six months after the Agreement. Panels (c), and (d) show similar patterns although not as high, using membership in the top 15 emitting industries or below median environmental score as the definition for treated issuers. Columns (5) through (8) of Table 7 reports the corresponding regression results for asset volatilities at the 1, 3 and 6 month time horizons. We observe a significant 10-20 percentage point increase in asset volatilities of high carbon emitting firms at the 3-month horizon. In contrast to the complete reversal of asset value changes, the changes in asset volatilities following the Paris Agreement are relatively persistent and remain statistically and economically significant at the 6-month horizon.

These results provide evidence that asset values and volatilities change differentially for affected bonds relative to others after the Paris Agreement. The relative weakness and eventual reversal in the changes in asset values juxtaposed with the persistence of the changes in asset volatilities suggests that the changes in bond yield spreads after the Paris Agreement arise primarily from the changes in asset volatilities. These effects could be due to the fact that the Clean Power Plan, the primary initial tool for the US to enact the Paris Agreement goals, was put on hold in February 2016, which created uncertainty over whether regulation to implement the Paris Agreement goals would continue to exist if a Republican was elected as President. Thus, the uncertainty would remain until the November 2016 election. This interpretation is consistent with previous literature showing that political uncertainty affects asset prices (Pastor and Veronesi, 2013). Specifically, these results imply that even in the absence of implementation of climate policies, uncertainty over those policies can affect corporate bond markets.

5.4. Probabilities of default

In this section we estimate changes in probabilities of default to consider the financial stability implications of the change in credit spreads after the Paris Agreement. This test will also allow us to consider whether the changes in asset values or changes in asset volatilities had more of an impact on issuers' default risks. To do this, we calculate a model-implied probability of default using the estimated values of V^t and σ^t:

$$DD = \frac{ln(V/K) + (\mu - \sigma^2/2)T}{\sigma\sqrt{T}}, \tag{26}$$

$$P(default) = 1 - N(DD), \tag{27}$$

where DD is the model-implied distance to default, μ is the expected growth rate of assets, which is calculated using maximum-likelihood estimation on the bond issuer's historical equity return. In addition to the model-implied probability of default, we calculate two counterfactual probabilities of default. In the first counterfactual calculation, we use the model-implied asset value while holding the asset volatility constant at its pre-Paris estimate. In the second counterfactual calculation, we use the model-implied asset volatility while holding the asset value constant at its pre-Paris estimate. This approach allows us to study how much changes in probabilities of default are driven by asset values or asset volatilities.

We tabulate the change in probability of default for bonds issued by firms in the top-quartile of emissions and matched control bonds in Table 8. Panel A displays all bonds, regardless of their rating. Prior to the Paris Agreement, there was no substantial difference in the probability of default for treated and matched control bonds. However, after the Paris Agreement, there was an increase of 2.05% in the probability of default for bonds issued by firms with high emissions relative to others. This result shows that the changes in bonds issued by high-emitting firms following the Paris Agreement translated into increases in the probability of default. Moreover, Panels B and C divide the sample into investment grade bonds and noninvestment grade bonds, and show that the majority of the effect is from bonds rated below investment grade. This difference in changes between the investment grade and noninvestment grade bonds highlights the potential challenges to financial stability, as these bonds are the ones that are more likely exposed to risk of financial distress ex-ante.

Figure 7 shows the plots (in blue) for the estimated probabilities of default for bonds issued by firms with high emissions. The default probability of treated bonds sharply increases after the Paris Agreement, reaching a peak of about 3%, before starting to decrease in February, 2016. Furthermore, the default probability does not completely decrease to its original value, but instead remains elevated for at least six months. This increase in the probability of default is economically meaningful as corporate bond prices are strongly correlated with firm investment (Philippon, 2009). For this reason, market distress can feed back into the real economy and can lead to reduced investment by firms (Gilchrist and Zakrajšek, 2012; Gilchrist et al., 2014).[32]

Counterfactual probabilities of default holding either the asset value or volatility constant at pre-Paris estimates are displayed in the same plot. When we shut down the asset value channel by holding it constant, the hypothetical default probability (shown in green) is only slightly lower than the observed one. However, there is almost zero change in the probability of default when holding volatilities constant (shown in red). These estimates provide evidence that the change in default probabilities following the Paris Agreement was primarily driven by the change in asset volatilities.

Finally, we consider the cross-sectional variation in the changes of asset values and volatilities and whether they are related to regulatory risk. To examine this, we run the following regressions:

$$\begin{aligned}\Delta V_i^1 &= \beta_1 EnvProf_j + \beta_2 HighRegStringency_j + \beta_3 EnvProf_J \times HighRegStringency_j \\ &\quad + \kappa_p + \epsilon_i, \qquad (28)\\ \Delta \sigma_i^1 &= \beta_1 EnvProf_j + \beta_2 HighRegStringency_j + \beta_3 EnvProf_J \times HighRegStringency_j \\ &\quad + \kappa_p + \epsilon_i, \qquad (29)\end{aligned}$$

where $\Delta V_t^1, \Delta \sigma_t^1$ are one-month changes in asset values and volatilities, and $HighRegStringency_j$ are high regulatory enforcement firms. In this regression, the main parameter of interest is β_3, which is informative of how asset values and volatilities change in the month after the Paris Agreement for firms with poor environmental profiles operating in strict regulatory environments. If the change in

[32]The importance of these relationships is reflected in the fact that policymakers are now monitoring corporate bond markets to safeguard financial stability. (Boyarchenko et al., 2021).

asset values and volatilities after the Paris Agreement is primarily driven by a change in regulatory risk, we expect that this coefficient should be negative in the asset value regressions and positive in the asset volatility regressions.

Columns (1) to (4) of Table 9 show the results for changes in asset value. The estimates for β_3 are broadly negative, and statistically significant when we define treated issuers as those operating in high-emission industries and those having a low environmental score. When we examine the changes in asset volatilities for environmentally problematic firms in columns (5) through (8), we find that regulatory enforcement stringency is an important factor. For example, when we define environmentally problematic firms as those with top-quartile carbon intensity (column 6), we find that when these firms are located in low regulatory enforcement environments, they experience a 4.7 percentage point increase in asset volatilities, while the firms located in high regulatory enforcement states experience a 23.4 (18.7 + 4.7) percentage point increase in asset volatilities. Although the asset values are only moderately affected by the interaction between an issuer's environmental profile and regulatory exposure, the change in asset volatilities following the Paris Agreement seems to be driven primarily by regulatory risk. The findings on the interaction between a bond's environmental profile and its regulatory exposure imply that firms may be primarily affected by this interaction through the channel of asset volatility.

5.5. Policy implications from the structural model

The structural model results provide important implications for climate policy. In particular, although the model-implied default probabilities eventually revert back, temporary dislocation of the bond market can have economically material effects on firm investments and ultimately, financial stability and the real economy. For companies whose bonds are affected by uncertainty arising from prospective changes in climate regulations, there exists a concern that the increasing credit spreads could lead to reduced investment, resulting in negative consequences for the real economy (Gilchrist et al., 2014).

At the same time, given the relative illiquidity in the corporate bond market, especially in the high-yield segment, there exists a concern that disruption in the credit conditions of various industries would transmit to other parts of the market and generate credit risk contagion. When credit spreads widen abruptly, they can trigger a sell-off as investors seek to offload perceived risky assets. In an illiquid market, this sell-off can exacerbate price declines, leading to a cascading effect that even impacts securities of companies not directly related to high-carbon emissions. Policymakers may need to consider mechanisms to enhance liquidity or provide temporary support in times of stress to prevent systemic risks, as evidenced in the recent Covid-19 corporate bond market stress research (O'Hara and Zhou, 2021; Boyarchenko et al., 2021). The possibility that regulators need to provide liquidity in the event of increased regulatory uncertainty highlights the policy importance of these results.

Another possible source of broader financial stability concern is that in recent years, corporate bonds are largely held by certain types of institutional investors, such as insurers (Koijen and Yogo, 2023). Insurers, banks and other financial institutions that hold corporate bonds of high-carbon-emission companies are directly exposed to any declining value of these assets. Thus, a significant drop in bond values can erode the balance sheets of these institutions, thereby impairing their abilities to underwrite insurance, extend credit, and invest in the capital markets. There have been recent proposals for regulators to conduct "climate stress tests" of the financial sector (e.g., Acharya et al., 2023; Jung et al., 2023) and ensure that systemically important institutions have adequate capital buffers and appropriate disclosure about their exposures to high-carbon-emitting sectors. Financial institutions themselves may also mitigate their exposure to high-emitting firms in response to changes in climate policies (e.g., Ivanov et al., 2024).

6. Institutional bond ownership changes around the Paris Agreement

The implications of the structural model for financial institutions suggest that after the Paris Agreement, institutional investors would have reevaluated their corporate bond holdings more exposed to climate risk. In addition, numerous theoretical and empirical works imply differences across investor perspectives towards firms more exposed to climate risks (e.g., Heinkel, Kraus, and Zechner, 2001; Pastor, Stambaugh, and Taylor, 2021; Oehmke and Opp, 2024; Pedersen, Fitzgibbons, and Pomorski, 2021; Goldstein, Kopytov, Lin, and Xiang, 2024; Dyck, Lins, Roth, and Wagner, 2019; Ilhan, Krueger, Sautner, and Starks, 2023; Starks, Venkat, and Zhu, 2024). Thus, investors with varying time horizons could treat the uncertainty arising from the Paris Agreement shock quite differently. That is, investors with longer time horizons may be more concerned with the future changes in regulatory events, than those with shorter horizons. Accordingly, we distinguish two classes of major investors in the corporate bond market that have been argued to have different investment horizons due to the differences in their investment strategies: insurance companies and mutual funds. In particular, insurance companies tend to hold their bonds to maturity, while mutual funds tend to trade more frequently and hence have a much shorter horizon (Massa, Yasuda, and Zhang, 2013). As long-term investors have been shown to care more about firms' environmental profiles (Starks, Venkat, and Zhu, 2024), we posit that insurance companies are more likely to reduce their holdings of corporate bonds issued by firms with poor environmental profiles after the Paris Agreement. Further, these changes should be relevant to the bond pricing changes we find because insurance companies collectively hold around 25-30% of corporate bonds and mutual funds hold around 15% of outstanding bonds.

We conduct difference-in-differences analyses using eight quarterly snapshots of institutional portfolio holdings around the Paris Agreement (from the fourth quarter of 2014 to the fourth quarter of 2016). The data consists of institutional investor holdings obtained from Refinitiv eMAXX (formerly Lipper eMAXX). Each quarter, we sum up individual bond holdings of (1) all institutional investors included in the eMAXX reporting entities, (2) all mutual funds, and (3) all insurance companies, where we scale each of the investor's bond holdings by the outstanding amount of the particular bond issue. Each treated bond is matched to a control bond using bond characteristics: issue principal size, credit rating, time to maturity and the oil beta of the firm's equity. We then regress the particular institutional ownership variable (all institutional investors, mutual funds or insurance companies) on an indicator variable indicating quarters after the Paris Agreement, an indicator variable indicating issuers with low environmental profiles and the interaction between the two variables:

$$Ownership_{it} = \beta_1 Treated_i \times AfterParis_t + \beta_2 Treated_i + BondControl + \kappa_t + \epsilon_{it}. \qquad (30)$$

We define $Treated_i$ bonds in the same four ways by assigning an indicator variable equal to one if the issuing firm (i) is in the top-quartile in terms of firm-level total carbon emissions in 2014,

(ii) is in the top-quartile in terms of firm-level carbon intensity, (iii) is in a top carbon emissions industry, or (iv) has a below-median environmental score in December 2014. The bond-level control variables ($BondControl$) include issuance amount, years to maturity, and bond credit rating.

Table 10 shows the results of the difference-in-differences analyses for the changes in total institutional investor ownership, mutual fund ownership, and insurance company ownership around the Paris Agreement for the treated bonds. When we define the treated bonds as bonds issued by firms whose carbon emission amount is in the top-quartile, we find that the total institutional ownership of the treated bonds stay relatively unchanged after the Paris Agreement, but the composition of bond owners shifts significantly. Specifically, we find that insurance companies significantly reduce their holdings of high-emission companies' bonds by 1.022 percentage points, relative to their holdings of matched issuers' bonds. In contrast, the ownership of high-emission issuers' bonds by mutual funds, which typically have a relatively shorter investment horizon, increases by 0.741 percentage point around the Paris Agreement.

The other regression results reported in Table 10 are based on alternative definitions of the treated bonds. A consistent pattern emerges: the total institutional ownership either declines (in the case of high-emission industries) or does not change (in the case of top-quartile carbon intensity and low-median environmental score). However, the ownership held by insurance companies consistently decreases by around one percentage point, while the ownership held by mutual funds consistently increases. These analyses suggest that the Paris Agreement resulted in a transfer of ownership from relatively long-term bond investors (insurance companies) to investors with typically shorter horizons (mutual funds), which is consistent with the argument that environmental and climate risks are likely to materialize in the future and investors have different considerations based on their investment horizon.[33]

7. Conclusions

Environmental risks, particularly climate risks, have been receiving more focused attention from both financial market participants and policy makers. In this study, we provide empirical evidence

[33] The reduction of insurance company bond ownership of high-emission firms is not driven by the occurrence of bond credit rating downgrades after the Paris Agreement. In untabulated tests, we drop all bonds that experienced a credit rating downgrade during the 12 months following the Paris Agreement. The results for the remaining bonds in the sample remain robust with a significant reduction of insurance company ownership.

that suggests uncertainty about future regulatory actions can induce financial market participants to respond to firms' environmental performance, and particularly, changes in firms' exposures to climate risks.

We present empirical results suggesting that for corporations with poor environmental performance, including a more significant carbon footprint, is associated in general with lower credit ratings and higher bond yield spreads, particularly for firms located in states with stricter environmental regulations. We also provide evidence of a causal component to these results by examining bond credit ratings and yield spreads after a shock to their regulatory risk. We find that the December 2015 Paris Agreement appears to have increased the regulatory risk for high emissions firms or firms that have poor environmental performance in general, as these firms' bonds experience reduced credit ratings and increased yield spreads. Importantly, we observe these effects to be stronger in states that enforce environmenal regulations more strictly, highlighting the channel for regulatory risks. By examining the results through a structural lens, we demonstrate that consistent with regulatory uncertainty affecting bond pricing, the change in bond yield spreads can be attributed primarily to changes in asset volatility rather than changes in asset values, which helps explain why the effects in the bond market are stronger than those previously found in the stock market.

Our findings carry significant implications for the relationship between firms' environmental profiles and market participants' assessments of their corporate bonds risks and values. The results suggest that credit rating analysts and bond investors are concerned with issuers' environmental performance, primarily due to the uncertainty surrounding potential regulatory costs. Additionally, given that our structural demonstrates that the change in bond pricing can be associated with a quantitatively meaningful increase in issuers' probabilities of default, climate risks and associated regulatory uncertainties may undermine the financing capacity of high carbon issuers.

The heightened uncertainty within the regulatory landscape has consequences for corporations and their investors. While recent U.S. political developments might suggest a reduction in climate risk volatility for high emission firms' bond returns, this perspective does not consider the global climate policy framework. It is especially important to consider global climate policy given that the bond market serves as the primary source of marginal financing for many of the large firms in our sample. The oscillating stances of U.S. presidential administrations and legislative bodies, coupled with the ongoing regulatory changes in Europe, indicate that high carbon-emitting firms, as well as their downstream supply chain partners, continue to face significant climate policy uncertainty. That is, this uncertainty extends beyond national borders, as many U.S. firms with multinational operations in Europe are likely to be affected by European climate policies.

Our results on the effects of climate risk in the corporate bond market suggest that future research could consider measures of policy-induced volatility and examine its effects in various asset classes along with its transmission mechanisms within and across various asset classes. Further, our findings demonstrating the corporate bond market's sensitivity to environmental profiles and regulatory risks emphasizes the need for policymakers to consider the broad impacts of regulatory uncertainty on financial markets and the broader economy.

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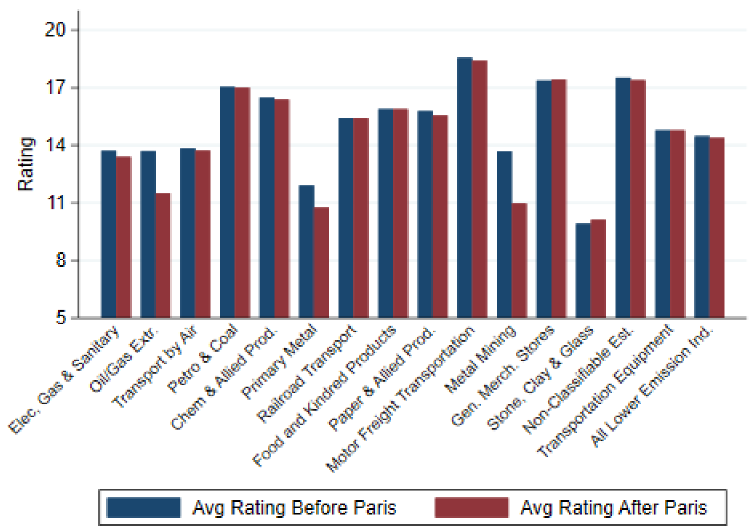
Fig. 1. Credit ratings and yield spreads of high carbon emissions industries' bonds before and after the Paris Agreement.

This figure displays equal-weighted average ratings and spreads for each of the top 15 carbon-emitting industries, before and after the Paris Agreement, where the pre-period runs from December 2014 through November 2015 and the post-period runs from December 2015 through November 2016. A numerical rating of 1 corresponds to a D rating, a rating of 5 to a Caa2 rating, a rating of 10 to a Ba3 rating, a rating of 15 to a Baa1 rating a rating of 20 to a Aa2 rating and a rating of 22 to a Aaa rating.

(a) Ratings



(b) Spreads

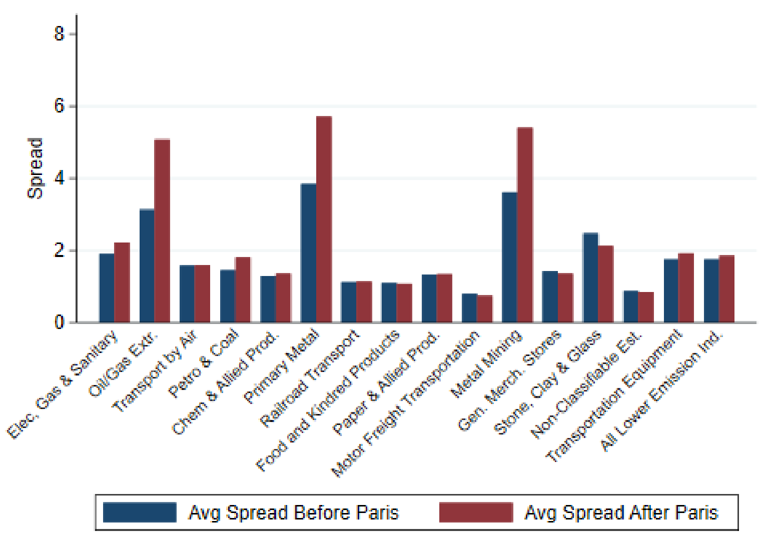
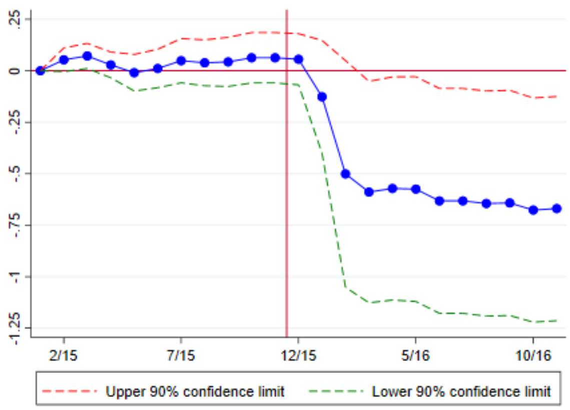
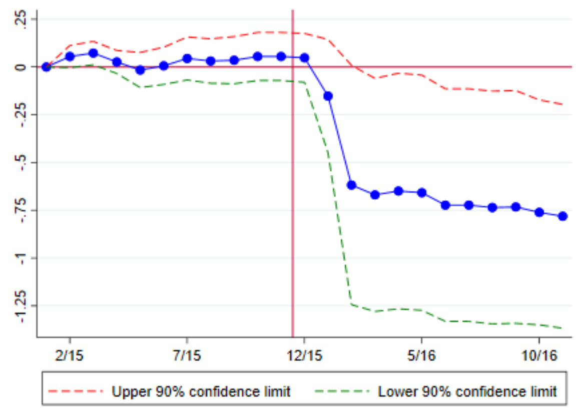


Fig. 2. Bond credit ratings around the Paris Agreement announcement.
This figure plots the coefficients from the following regression equation:
$Rating_{it} = \sum_{k=-11}^{11} \beta_k [\mathbb{1}(t = k) \times EnvProf_j] + \gamma_i + \kappa_t + \epsilon_{it}$.
$EnvProf_j$ is equal to one for treated observations, where the treatment is defined alternatively as a below-median environmental score, being in the top 15 carbon-emitting industries, being in the top-quartile of CDP emissions, or being in the top-quartile of CDP carbon intensity (tons of emissions divided by revenue in \$1,000). Control observations are all other securities. γ_i, κ_{tp} are security and time fixed effects. Pre-period runs from December 2014 through November 2015 and post-period runs December 2015 through November 2016. The chart includes all interaction terms except for December 2014, which serves as the benchmark period. Higher numerical scores indicate better credit ratings. We show 90% confidence intervals, where standard errors are double-clustered at the 3-digit SIC industry and month levels.

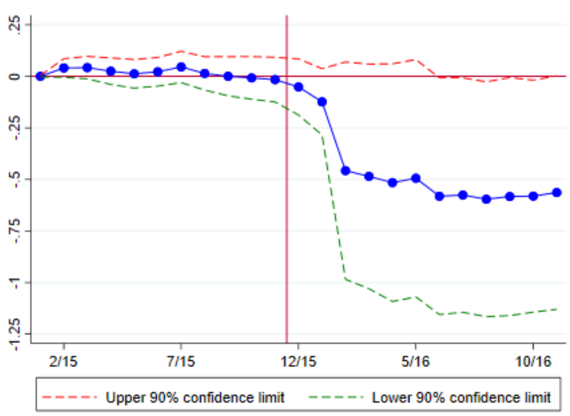
(a) Top-Quartile Emissions



(b) Top-Quartile Carbon Intensity



(c) Top 15 Emitting Industry



(d) Below Median Environmental Score

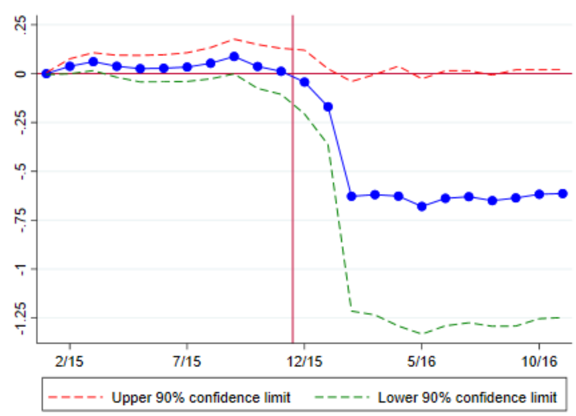


Fig. 3. Yield spreads around the Paris Agreement announcement.
This figure plots the coefficients from the following regression equation:
$Spread_{it} = \sum_{k=-11}^{11} \beta_k[\mathbb{1}(t = k) * EnvProf_j] + \gamma_i + \kappa_{tp} + \epsilon_{it}$.
$EnvProf_j$ is equal to one for treated observations, where the treatment is defined alternatively as a below-median environmental score, being in the top 15 carbon-emitting industries, being in the top-quartile of CDP emissions, or being in the top-quartile of CDP carbon intensity (tons of emissions divided by revenues in $1,000). Control observations are selected using a one-to-one nearest neighbor Mahalanobis matching with replacement procedure on rating, time to maturity, issue principal outstanding and oil beta as of year-end 2014. γ_i, κ_{tp} are security and matched-pair-by-time fixed effects. Pre-period runs from December 2014 through November 2015 and post-period runs December 2015 through November 2016. The chart includes all interaction terms except for December 2014, which serves as the benchmark period. We show 90% confidence intervals, where standard errors are double-clustered at the 3-digit SIC industry and month levels.

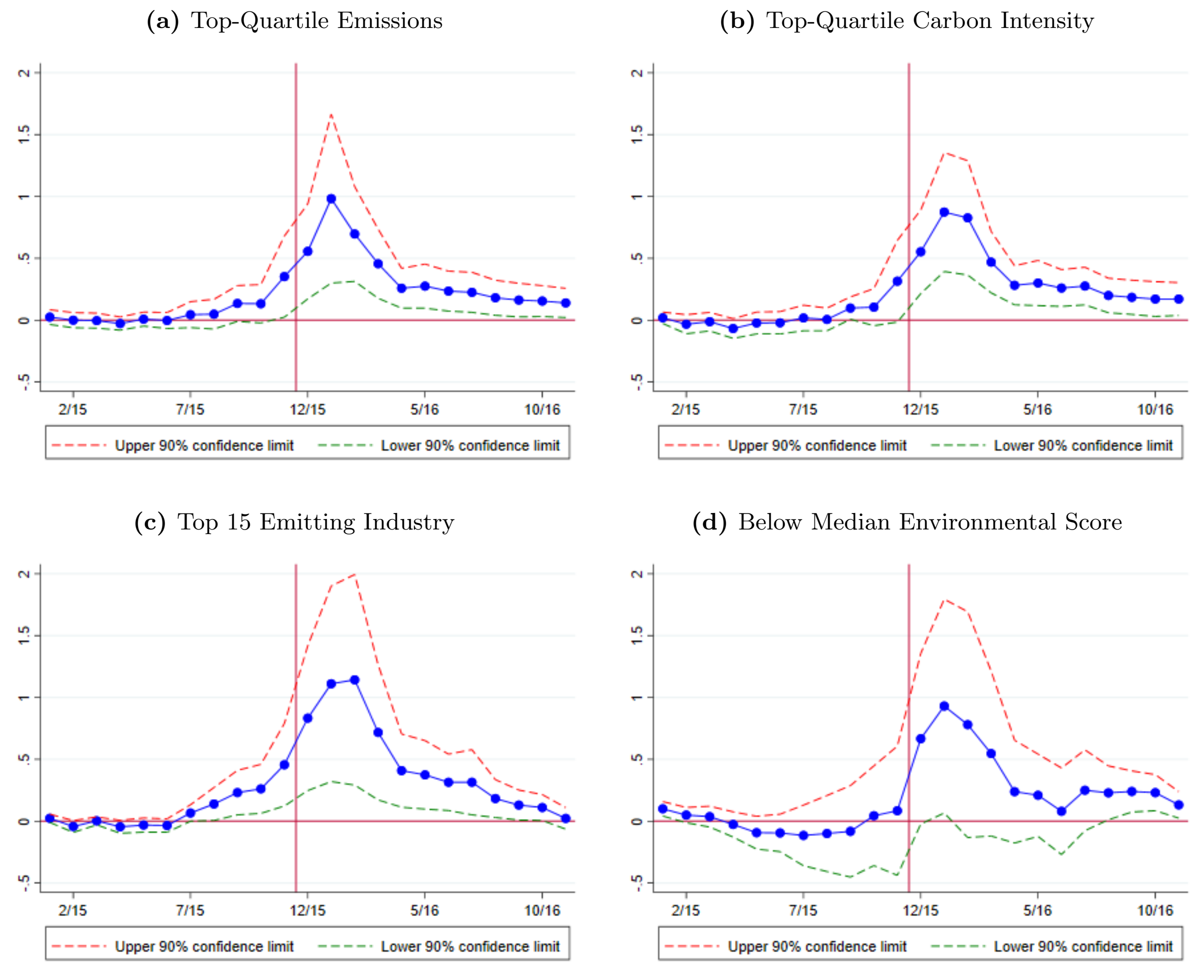
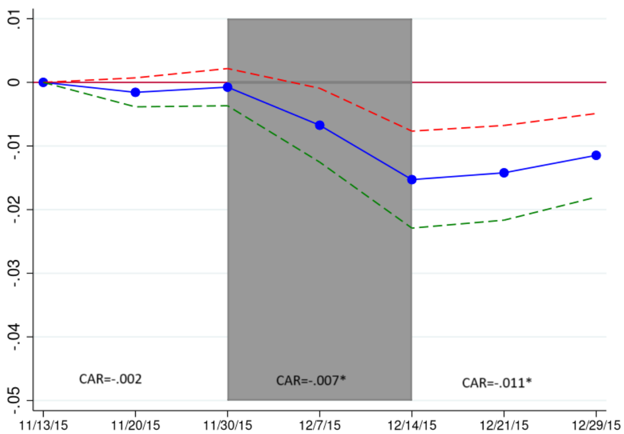
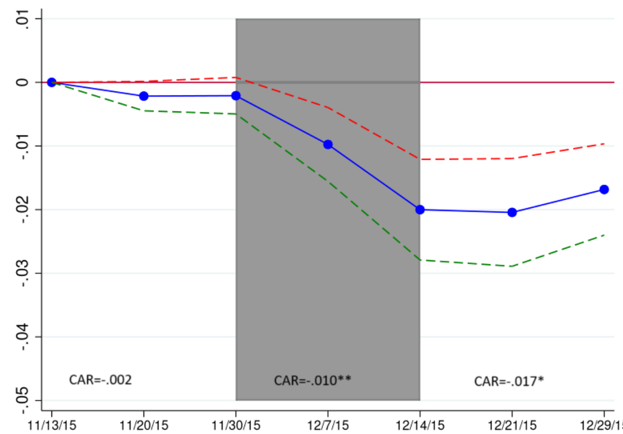


Fig. 4. Characteristic-adjusted Weekly Cumulative Abnormal Returns for the Treated Firms Around the Announcement of the Paris Agreement.
This figure shows the average cumulative bond returns, adjusted for bond time to maturity, principal outstanding, rating bins, issuer market to book, market value of assets and equity returns, as well as the 90% confidence intervals from the two weeks before the UN Climate Change Conference (COP21) to three weeks after the announcement of the Paris Agreement. The shaded region marks the Paris Climate Talks from November 30, 2015 until December 12, 2015 (two trading weeks). We winsorize returns at the 1% and 99% levels and aggregate abnormal returns at the issuer-level as the average abnormal return for all of the issuer's bonds, weighted by the bond principal outstanding. The date on the x-axis is the first date of the week. Cumulative Abnormal Returns, along with their statistical significance levels, for the period before, during and after the Paris Climate Talks are displayed in the figures.

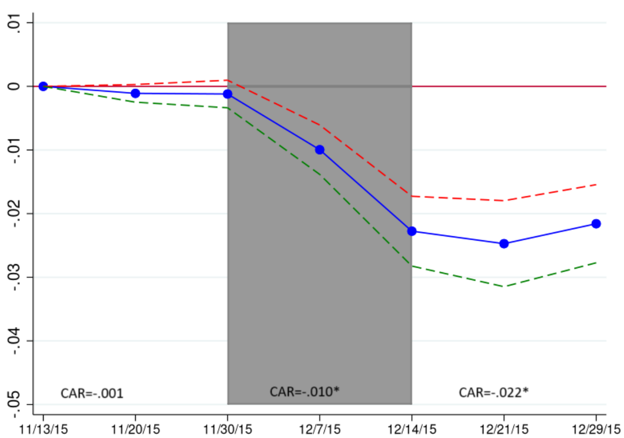
(a) Top-Quartile Emissions



(b) Top-Quartile Carbon Intensity



(c) Top 15 Emitting Industry



(d) Below Median Environmental Score

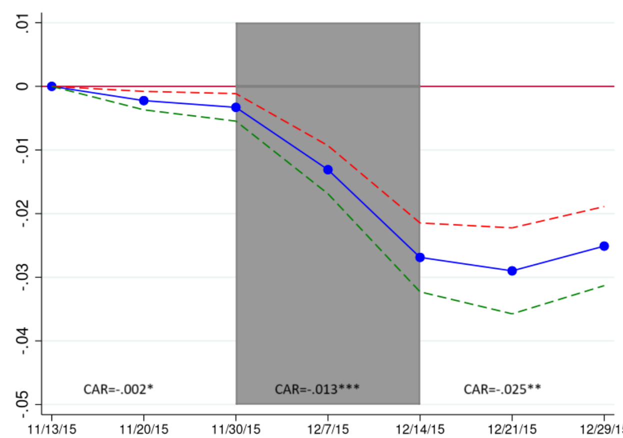
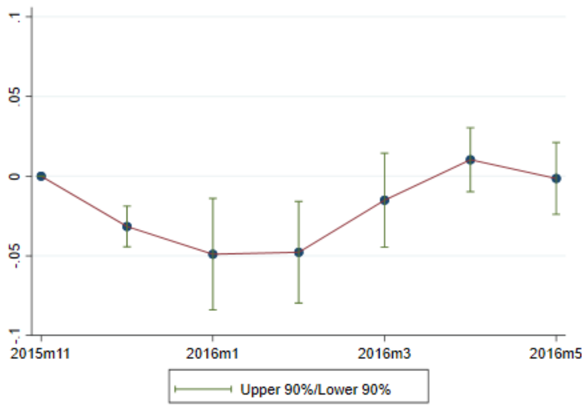
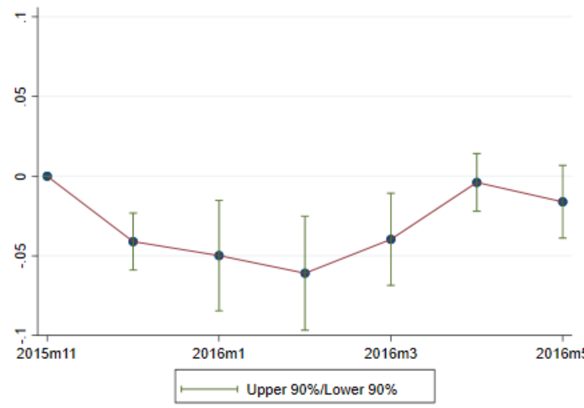


Fig. 5. Change in asset values around the Paris Agreement announcement
This figure plots period-by-period regressions of the percent change in asset values on an environmentally problematic firm indicator from the month before the Paris Agreement was announced (2015m11) and the next six months. The indicator is one if an issuer is in the top-quartile of emissions (Panel a), in the top-quartile of carbon intensity (Panel b), in the top 15 carbon-emitting industries (Panel c), or has a below-median environmental score (Panel d). Control observations are selected using a one-to-one nearest neighbor Mahalanobis matching with replacement procedure on rating, time to maturity, issue principal outstanding and oil beta as of year-end 2014. Standard errors are clustered at the 3-digit SIC industry level.

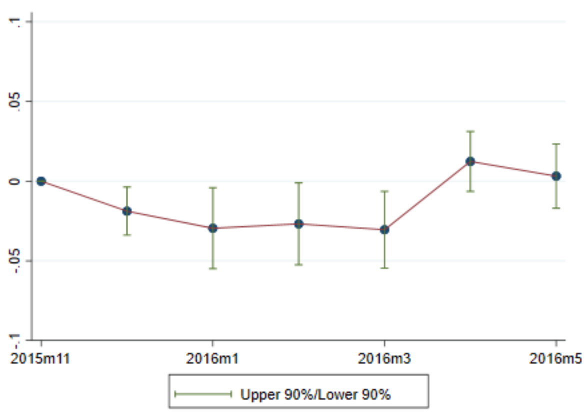
(a) Top-Quartile Emissions



(b) Top-Quartile Carbon Intensity



(c) Top 15 Emitting Industry



(d) Below Median Environmental Score

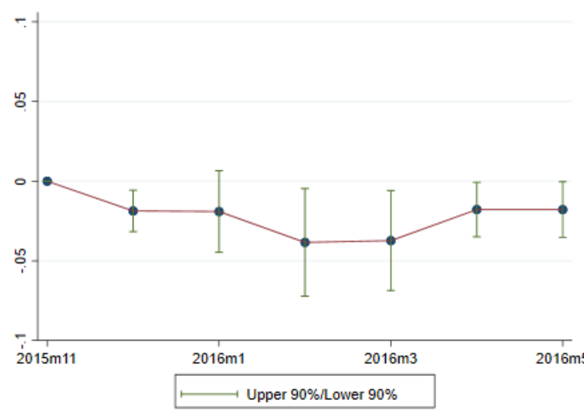
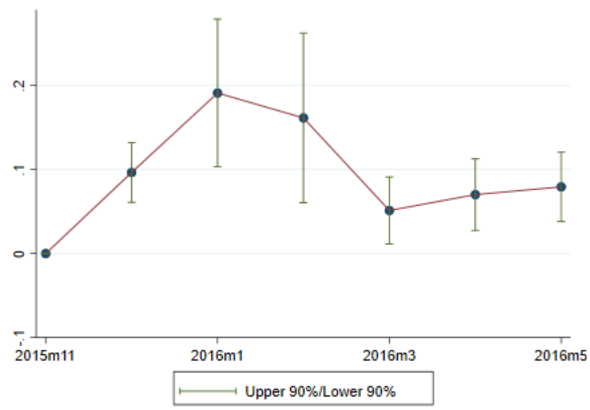
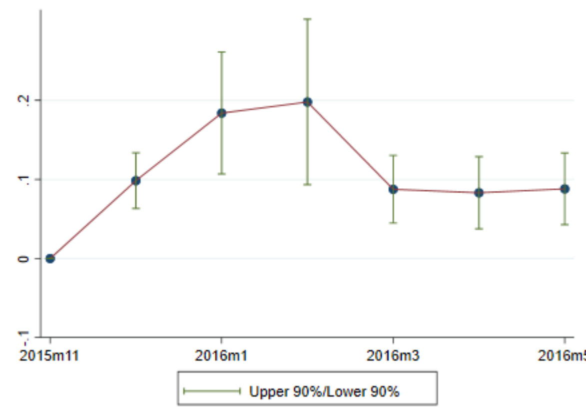


Fig. 6. Changes in asset volatilities around the Paris Agreement announcement
This figure plots period-by-period regressions of the change in asset volatilities on an environmentally problematic firm indicator from the month before the Paris Agreement was announced (2015m11) and the next six months. The indicator is one if an issuer is in the top-quartile of emissions (Panel a), in the top-quartile of carbon intensity (Panel b), in the top 15 carbon-emitting industries (Panel c), or has a below-median environmental score (Panel d). Control observations are selected using a one-to-one nearest neighbor Mahalanobis matching with replacement procedure on rating, time to maturity, issue principal outstanding and oil beta as of year-end 2014. Standard errors are clustered at the 3-digit SIC industry level.

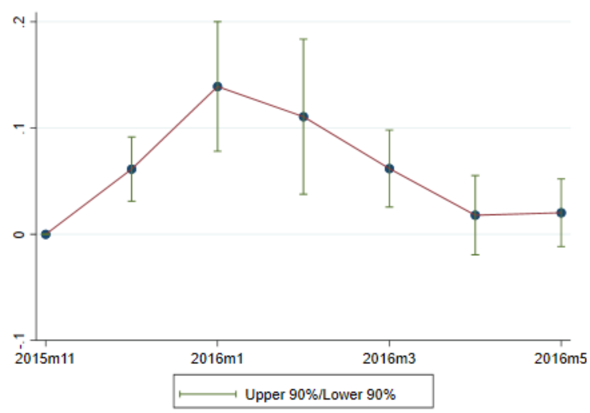
(a) Top-Quartile Emissions



(b) Top-Quartile Carbon Intensity



(c) Top 15 Emitting Industry



(d) Below Median Environmental Score

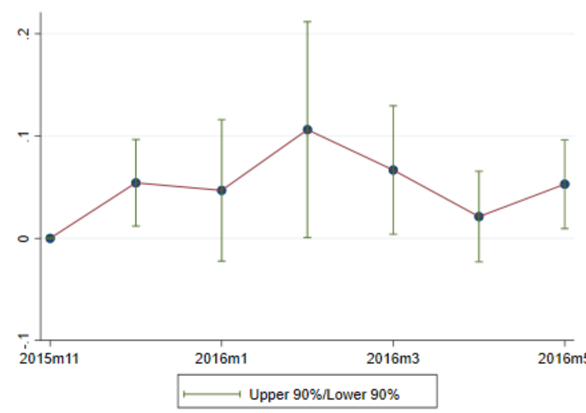


Fig. 7. Changes in high emissions issuers' default probabilities relative to counterfactuals
The blue line plots the changes in the probabilities of default for high emissions issuers estimated using a Merton model based on the estimated asset values and volatilities solved from observed credit spread changes and equity returns. The red line and the green line plot the counterfactual probability of default where the high emissions issuers' asset values or asset volatilities are held constant at their pre-Paris level, respectively. High emissions firms are defined as firms in the top-quartile of carbon emissions. The calculations are based on a one-year time horizon.

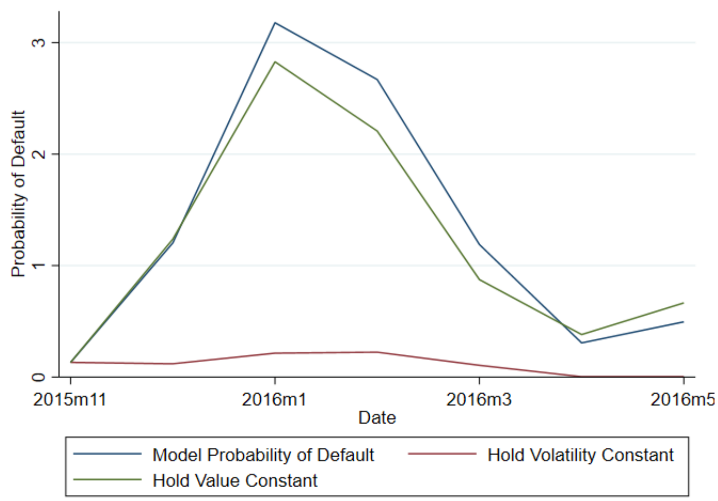


Table 1: Summary statistics.

This table reports the summary statistics for the at-issue bond sample with a sample period of 2009 through 2017. Offering yield spreads, profitability, leverage, annual returns, ln(total assets), and cash/assets are winsorized at the 1% and 99% levels. The ratings variable is assigned such that a higher number indicates a better rating. A numerical rating of 1 corresponds to a D rating, a rating of 5 to a Caa2 rating, a rating of 10 to a Ba3 rating, a rating of 15 to a Baa1 rating a rating of 20 to a Aa2 rating and a rating of 22 to a Aaa rating. Reg stringency is measured as the firm's regulatory stringency determined as the revenue-weighted average number of EPA penalties issued in a given year divided by the number of facilities (in thousands) in that state for the states the firm operates in. When information on a firm's facility locations is not available, we use the number of EPA penalties in the state the firm's headquarters are located in divided by the number of plants regulated by the EPA in that state (in thousands). Top 15 emissions industries are defined as the top 15 carbon emissions industries based on carbon emissions using the CDP data.

Variable	Observations	Mean	Median	Std. Dev.
Credit rating	1,940	15.312	15.000	2.828
Offering spread	1,940	1.835	1.481	1.273
Firm-weighted average maturity	1,940	9.414	9.274	3.336
Environmental score	1,940	59.960	60.000	14.050
Reg Stringency	1,940	0.714	0.446	0.950
Top 15 emissions industry	1,940	0.487	0.000	0.500
Emissions (millions of ton)	1,312	6.680	0.438	19.665
Carbon intensity (ton per $1,000 revenue)	1,312	0.319	0.014	0.997
Ln(1 + Principal)	1,940	13.384	13.305	0.602
Time to maturity	1,940	9.969	10.000	7.289
Callable	1,940	0.970	1.000	0.170
Leverage	1,940	0.287	0.274	0.147
Pre-tax interest coverage	1,940	19.303	11.760	23.433
Ln(Total assets)	1,940	10.197	10.234	1.259
Cash/assets	1,940	0.118	0.072	0.131
Profitability	1,940	0.222	0.168	0.185
Tangibility	1,940	0.302	0.188	0.256
Annual stock returns	1,940	15.599	13.648	24.203
Ln(Standard deviation of returns)	1,940	2.939	2.902	0.415

Table 2: Credit ratings and regulatory stringency

This table displays results from the following panel regression:

$$Rating_{ijt} = \beta_1 EnvProf_{jt-1} + \beta_2 RegStringency_{jt-1} + \beta_3 EnvProf_{jt-1} \times RegStringencyjt - 1 + \beta_4 X_{jt-1} + FE + \epsilon_{it}.$$

All observations are at-issue bonds. Environmental scores, leverage, ln(total assets), profitability, annual stock returns, and the standard deviation of stock returns are winsorized at the 1% and 99% levels. Environmental scores, lagged by one month, regulatory stringency lagged by one year and other firm characteristics lagged by one quarter are used in regressions. Reg stringency, defined as the revenue-weighted average number of EPA penalties in a given year divided by the number of facilities in that state (for the states in which the firm operates), is also standardized by mean and scaled by standard deviation. *, ** and *** indicate 10%, 5% and 1% significance, respectively. Fixed effects are indicated in each column. Standard errors, which are double-clustered at the 3-digit SIC industry and month levels, are shown in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)
Environmental Score × Reg Stringency	0.020***			0.019***		
	(0.007)			(0.005)		
Emissions × Reg Stringency		-0.021**			-0.021***	
		(0.009)			(0.008)	
Carbon Intensity × Reg Stringency			-0.283**			-0.328***
			(0.112)			(0.099)
Environmental Score	0.027***			0.014**		
	(0.009)			(0.007)		
Emissions		-0.013			-0.014**	
		(0.010)			(0.006)	
Carbon Intensity			-0.514***			-0.231***
			(0.138)			(0.070)
Reg Stringency	-1.031***	0.180*	0.140	-0.983***	0.127	0.114
	(0.336)	(0.102)	(0.101)	(0.271)	(0.087)	(0.087)
Firm Weighted Average Maturity	0.016	-0.026	-0.035	0.041	-0.004	-0.003
	(0.032)	(0.034)	(0.037)	(0.027)	(0.031)	(0.032)
Leverage	-1.978*	-0.394	-0.221	-2.146**	-1.312	-1.299
	(1.093)	(1.299)	(1.250)	(1.074)	(1.280)	(1.295)
Pre-tax interest coverage	0.029***	0.037***	0.035***	0.021***	0.017***	0.016***
	(0.006)	(0.007)	(0.006)	(0.004)	(0.004)	(0.004)
Ln(Total Assets)	0.946***	1.085***	1.033***	1.059***	1.201***	1.191***
	(0.157)	(0.171)	(0.169)	(0.152)	(0.150)	(0.148)
Cash/Assets	3.904***	5.178***	5.324***	2.501**	3.099***	3.163***
	(1.069)	(1.181)	(1.195)	(1.099)	(0.946)	(0.946)
Profitability	0.776	1.187	0.688	0.442	3.716**	3.647**
	(0.826)	(0.958)	(0.905)	(1.054)	(1.438)	(1.416)
Tangibility	-0.258	0.496	1.100*	1.679*	1.991	2.006
	(0.500)	(0.543)	(0.608)	(1.000)	(1.346)	(1.351)
Annual Stock Returns	-0.006**	-0.005	-0.004	-0.005**	-0.001	-0.001
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
Ln(Standard Deviation Returns)	-1.785***	-1.957***	-2.100***	-1.665***	-1.533***	-1.533***
	(0.267)	(0.339)	(0.318)	(0.231)	(0.245)	(0.244)
Time Fixed Effects	Y	Y	Y	Y	Y	Y
Industry Fixed Effects	N	N	N	Y	Y	Y
Within R2	0.587	0.555	0.574	0.546	0.526	0.527
Observations	1,940	1,312	1,312	1,938	1,309	1,309

Table 3: Offering spreads and regulatory stringency.

This table displays results from the following panel regression:

$$Spread_{ijt} = \beta_1 EnvProf_{jt-1} + \beta_2 RegStringency_{jt-1} + \beta_3 EnvProf_{jt-1} \times RegStringency_{jt-1} + \beta_4 X_{jt-1} + \beta_5 Z_{it} + FE + \epsilon_{it}.$$

All observations are at-issue bonds. Environmental scores, coupon rate, leverage, ln(total assets), profitability, annual stock returns, and the standard deviation of stock returns are winsorized at the 1% and 99% levels. Environmental scores, lagged by one month, regulatory stringency lagged by one year and other firm characteristics lagged by one quarter are used in regressions. Reg stringency, defined as the revenue-weighted average number of EPA penalties in a given year divided by the number of facilities in that state (for the states in which the firm has facilities), is also standardized by mean and scaled by standard deviation. *, ** and *** indicate 10%, 5% and 1% significance, respectively. Fixed effects are indicated in each column. Standard errors, which are double-clustered at the 3-digit SIC industry and month levels, are shown in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)
Environmental Score × Reg Stringency	-0.005**			-0.006***		
	(0.002)			(0.002)		
Emissions × Reg Stringency		0.007**			0.009***	
		(0.004)			(0.003)	
Carbon Intensity × Reg Stringency			0.073			0.101
			(0.068)			(0.063)
Environmental Score	-0.009***			-0.004		
	(0.003)			(0.003)		
Emissions		0.007***			0.003	
		(0.002)			(0.002)	
Carbon Intensity			0.162***			0.088**
			(0.053)			(0.044)
Reg Stringency	0.225**	-0.078**	-0.065*	0.333***	-0.062**	-0.054**
	(0.112)	(0.037)	(0.035)	(0.101)	(0.027)	(0.026)
Ln(1 + Principal)	0.254***	0.189***	0.216***	0.217***	0.179***	0.184***
	(0.069)	(0.062)	(0.062)	(0.050)	(0.049)	(0.049)
Time to Maturity	0.090***	0.093***	0.093***	0.091***	0.094***	0.094***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Callable	0.391**	0.296**	0.275**	0.058	0.033	0.022
	(0.190)	(0.129)	(0.128)	(0.112)	(0.123)	(0.127)
Leverage	1.193**	0.520	0.435	1.004**	0.582	0.586
	(0.458)	(0.438)	(0.424)	(0.411)	(0.411)	(0.415)
Pre-tax interest coverage	-0.007***	-0.007***	-0.006***	-0.006***	-0.005***	-0.005***
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Ln(Total Assets)	-0.250***	-0.190***	-0.177***	-0.297***	-0.236***	-0.237***
	(0.047)	(0.038)	(0.037)	(0.060)	(0.050)	(0.050)
Cash/Assets	-0.473	-0.564**	-0.635**	-0.184	-0.361	-0.368
	(0.305)	(0.266)	(0.260)	(0.257)	(0.285)	(0.295)
Profitability	-0.246	-0.211	-0.081	-0.322	-0.715	-0.685
	(0.250)	(0.181)	(0.175)	(0.444)	(0.564)	(0.563)
Tangibility	0.157	-0.291*	-0.366**	0.197	-0.530	-0.561*
	(0.156)	(0.167)	(0.153)	(0.348)	(0.330)	(0.331)
Annual Stock Returns	-0.003**	-0.003**	-0.003**	-0.003**	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Ln(Standard Deviation Returns)	1.045***	0.850***	0.878***	0.927***	0.675***	0.677***
	(0.113)	(0.125)	(0.123)	(0.115)	(0.125)	(0.124)
Time Fixed Effects	Y	Y	Y	Y	Y	Y
Industry Fixed Effects	N	N	N	Y	Y	Y
Within R2	0.596	0.672	0.678	0.601	0.715	0.715
Observations	1,940	1,312	1,312	1,938	1,309	1,309

Table 4: Effects of the Paris Agreement on credit ratings.

This table displays changes in credit ratings around the signing of the Paris Agreement. Treatment bonds are defined in four ways: (1) an indicator variable equal to one if the firm is in the top-quartile of carbon emissions in 2014 (*Top-Quartile Emissions*), (2) an indicator variable equal to one if the firm is in the top-quartile of carbon intensity (defined as tons of emissions per $1,000 in revenue) in 2014 (*Top-Quartile Carbon Intensity*), (3) an indicator variable equal to one if the firm is in one of the top 15 carbon-emitting industries (*High Emission Industry*), (4) or an indicator variable equal to one if the firm has a below median environmental score in December 2014 (*Low Environmental Score*). $AfterParis_t$ is an indicator variable equal to one if the observation occurs in December 2015 or later. $HighRegStringency_j$ is equal to one if the firm is in the top-quartile of exposure to EPA penalties from 2012 through 2015. Security and time fixed effects are included in all regressionse. Sample runs from December 2014 through November 2016. *, ** and *** indicate 10%, 5% and 1% significance, respectively. Standard errors, which are double-clustered at the 3-digit SIC industry and month levels, are shown in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
After Paris × Top-Quartile Emissions	-0.551*				-0.153			
	(0.272)				(0.098)			
After Paris × Top-Quartile Carbon Intensity		-0.627*				-0.157		
		(0.304)				(0.100)		
After Paris × High Emissions Industry			-0.482				-0.111	
			(0.285)				(0.091)	
After Paris × Low Environmental Score				-0.580*				-0.100
				(0.321)				(0.114)
After Paris × Top-Quartile Emissions × High Reg Stringency					-1.371***			
					(0.414)			
After Paris × Top-Quartile Carbon Intensity × High Reg Stringency						-1.385***		
						(0.383)		
After Paris × High Emissions Industry × High Reg Stringency							-1.094**	
							(0.462)	
After Paris × Low Environmental Score × High Reg Stringency								-0.990**
								(0.449)
After Paris × High Reg Stringency					0.037	0.112	-0.009	-0.121
					(0.133)	(0.115)	(0.145)	(0.146)
Time Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Security Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Within R2	0.068	0.083	0.040	0.052	0.182	0.189	0.134	0.126
Observations	23,184	23,184	33,336	33,336	23,184	23,184	33,336	33,336

Table 5: Effects of the Paris Agreement on yield spreads.

This table displays changes in bond yield spreads around the signing of the Paris Agreement. Treated bonds are defined in four ways: (1) an indicator variable equal to one if the firm is in the top-quartile of carbon emissions in 2014 (*Top-Quartile Emissions*), (2) an indicator variable equal to one if the firm is in the top-quartile of carbon intensity (defined as tons of emissions per $1,000 in revenue) in 2014 (*Top-Quartile Carbon Intensity*), (3) an indicator variable equal to one if the firm is in one of the top 15 carbon-emitting industries (*High Emission Industry*), (4) or an indicator variable equal to one if the firm has a below median environmental score in December 2014 (*Low Environmental Score*). $AfterParis_t$ is an indicator variable equal to one if the observation occurs in December 2015 or later. $HighRegStringency_j$ is equal to one if the firm is in the top-quartile of exposure to EPA penalties from 2012 through 2015. Security and matched-pair-by-time fixed effects are included in all regressions. The sample is formed by using one-to-one nearest neighbor Mahalanobis matching of treated bond issues to control bond issues by oil beta, issue principal outstanding, time to maturity and credit rating as of year-end 2014. The sample period includes observations from December 2014 through November 2016. *, ** and *** indicate 10%, 5% and 1% significance, respectively. Standard errors, which are double-clustered at the 3-digit SIC industry and month levels, are shown in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
After Paris × Top-Quartile Emissions	0.301***				0.181**			
	(0.105)				(0.081)			
After Paris × Top-Quartile Carbon Intensity		0.347***				0.227**		
		(0.107)				(0.096)		
After Paris × High Emissions Industry			0.386**				0.146**	
			(0.167)				(0.068)	
After Paris × Low Environmental Score				0.394***				0.033
				(0.140)				(0.078)
After Paris × Top-Quartile Emissions × High Reg Stringency					0.199			
					(0.225)			
After Paris × Top-Quartile Carbon Intensity × High Reg Stringency						0.264		
						(0.176)		
After Paris × High Emissions Industry × High Reg Stringency							0.700*	
							(0.356)	
After Paris × Low Environmental Score × High Reg Stringency								0.911**
								(0.386)
After Paris × High Reg					0.340*	0.125	0.083	-0.169
					(0.185)	(0.106)	(0.115)	(0.179)
Pair-Time Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Security Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Within R2	0.029	0.051	0.023	0.015	0.050	0.066	0.044	0.029
Observations	12,096	10,416	31,008	21,504	12,096	10,416	31,008	21,504

Table 6: Effects of the Paris Agreement on yield spreads – Full panel with fixed effects.

This table displays changes in bond yield spreads around the signing of the Paris Agreement. Treated bonds are defined in four ways: (1) an indicator variable equal to one if the firm is in the top-quartile of carbon emissions in 2014 (*Top-Quartile Emissions*), (2) an indicator variable equal to one if the firm is in the top-quartile of carbon intensity (defined as tons of emissions per $1,000 in revenue) in 2014 (*Top-Quartile Carbon Intensity*), (3) an indicator variable equal to one if the firm is in one of the top 15 carbon-emitting industries (*High Emission Industry*), or (4) an indicator variable equal to one if the firm has a below median environmental score in December 2014 (*Low Environmental Score*). $AfterParis_t$ is an indicator variable equal to one if the observation occurs in December 2015 or later. $HighRegStringency_j$ is equal to one if the firm is in the top-quartile of exposure to EPA penalties from 2012 through 2015. Security and size-by-value-by-cash-by-IG-by-time fixed effects are used in all regressions. Size, value and cash are split into two bins each based on whether an issuer is above or below the median in the cross section. Size is defined as market value of equity plus book value of debt. Value is defined as the issuer's equity market-to-book ratio. Cash is defined as the issuer's cash and short-term investments scaled by total assets. The sample period includes observations from December 2014 through November 2016. *, ** and *** indicate 10%, 5% and 1% significance, respectively. Standard errors are double-clustered at the 3-digit SIC industry and month levels and are shown in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
After Paris × Top-Quartile Emissions	0.262**				0.103			
	(0.126)				(0.072)			
After Paris × Top-Quartile Carbon Intensity		0.364**				0.166*		
		(0.166)				(0.087)		
After Paris × High Emissions Industry			0.394*				0.161**	
			(0.203)				(0.078)	
After Paris × Low Environmental Score				0.439*				0.024
				(0.222)				(0.087)
After Paris × Top-Quartile Emissions × High Reg Stringency					0.616**			
					(0.293)			
After Paris × Top-Quartile Carbon Intensity × High Reg Stringency						0.619**		
						(0.273)		
After Paris × High Emissions Industry × High Reg Stringency							0.716*	
							(0.363)	
After Paris × Low Environmental Score × High Reg Stringency								0.849**
								(0.381)
After Paris × High Reg Stringency					0.087	0.047	0.142	0.131
					(0.057)	(0.040)	(0.091)	(0.077)
HD Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Security Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Within R2	0.007	0.014	0.011	0.011	0.028	0.032	0.036	0.036
Observations	23,184	23,184	33,336	33,336	23,184	23,184	33,336	33,336

Table 7: Effects of the Paris Agreement on asset value and volatilities

This table displays results of a regression of the percent change in asset values and volatilities observed over different time horizons on a poor environmental indicator. The indicator equals one if an issuer is in the top-quartile of emissions, in the top-quartile of emission-intensity, in the top 15 carbon emission industries, or has a below-median environmental score. Control observations are selected using a one-to-one nearest neighbor Mahalanobis matching with replacement procedure on rating, time to maturity, issue principal outstanding, and oil beta as of year-end 2014. *, ** and *** indicate 10%, 5% and 1% significance, respectively. Standard errors, which are clustered at the 3-digit SIC industry level, are shown in parentheses.

Dependent Variable	Asset Value				Asset Volatilities			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A – 1 month								
Top-Quartile Emissions	-0.032***				0.097***			
	(0.008)				(0.022)			
Top-Quartile Carbon Intensity		-0.041***				0.098***		
		(0.011)				(0.021)		
High Emissions Industry			-0.019**				0.061***	
			(0.009)				(0.018)	
Low Environmental Score				-0.019**				0.054**
				(0.008)				(0.026)
Pair Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Panel B – 3 months								
Top-Quartile Emissions	-0.048**				0.161**			
	(0.019)				(0.062)			
Top-Quartile Carbon Intensity		-0.061***				0.198***		
		(0.022)				(0.064)		
High Emissions Industry			-0.027*				0.111**	
			(0.016)				(0.044)	
Low Environmental Score				-0.038*				0.106
				(0.021)				(0.064)
Pair Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Panel C – 6 months								
Top-Quartile Emissions	-0.001				0.079***			
	(0.014)				(0.025)			
Top-Quartile Carbon Intensity		-0.016				0.088***		
		(0.014)				(0.028)		
High Emissions Industry			0.003				0.020	
			(0.012)				(0.019)	
Low Environmental Score				-0.018*				0.053**
				(0.011)				(0.026)
Pair Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y

Table 8: Change in high emissions firms' probabilities of default

These figures show how probabilities of default (estimated from a Merton model) changed for bonds issued by firms in the top-quartile of carbon emissions relative to matched control issuers in the three months after the Paris Agreement. Probabilities of default are estimated using a one year horizon. Matched controls are chosen in the same way as in the difference-in-differences analysis on bond yield spreads. Probabilities of default are winsorized at the 5% and 95% levels.

	Pre-Paris	3 Months After Paris	Difference
Panel A – All Bonds			
Matched Control	.05	.35	.3
Top-Quartile Emissions	.09	2.44	2.35*
Difference	.04	2.08*	2.05*
Panel B – Investment Grade Bonds			
Matched Control	.04	.34	.3
Top-Quartile Emissions	.07	1.32	1.26**
Difference	.02	.98**	.96**
Panel C – Noninvestment Grade Bonds			
Matched Control	.23	.51	.28
Top-Quartile Emissions	.53	9.18	8.65**
Difference	.3	8.67**	8.37**

Table 9: Regulatory stringency and the changes in asset value and volatilities after Paris

This table displays results of a regression of the percent change in asset values and volatilities observed in the month after the Paris Agreement on poor environmental indicators interacted with a regulatory stringency indicator. The poor environmental indicator equals one if an issuer is in the top-quartile of emissions, in the top-quartile of emission-intensity, in the top 15 carbon emission industries, or has a below-median environmental score. Bonds are identified as operating in high regulatory stringency environments if the issuing firm has top-quartile exposure to EPA penalties from 2012 through 2015. Control observations are selected using a one-to-one nearest neighbor Mahalanobis matching with replacement procedure on rating, time to maturity, issue principal outstanding and oil beta as of year-end 2014. *, ** and *** indicate 10%, 5% and 1% significance, respectively. Standard errors, which are clustered at the 3-digit SIC industry level, are shown in parentheses.

Dependent Variable	ΔAsset Value				ΔAsset Volatility			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Top-Quartile Emissions × High Reg Stringency	-0.012				0.108*			
	(0.027)				(0.059)			
Top-Quartile Carbon Intensity × High Reg Stringency		-0.026				0.187***		
		(0.027)				(0.056)		
High Emissions Industry × High Reg Stringency			-0.039***				0.136***	
			(0.013)				(0.035)	
Low Environmental Score × High Reg Stringency				-0.029**				0.031
				(0.014)				(0.048)
Top-Quartile Emissions	-0.026***				0.065***			
	(0.009)				(0.017)			
Top-Quartile Carbon Intensity		-0.029***				0.047**		
		(0.010)				(0.022)		
High Emissions Industry			-0.005				0.020	
			(0.006)				(0.015)	
Low Environmental Score				-0.004				0.029
				(0.006)				(0.021)
High Reg Stringency	-0.010	-0.009	-0.001	-0.012	-0.015	-0.061	-0.041	0.057
	(0.023)	(0.023)	(0.010)	(0.009)	(0.045)	(0.040)	(0.026)	(0.044)
Pair Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y

Table 10: Changes in institutional investor bond ownership around the Paris Agreement.

This table reports changes in institutional investor ownership of corporate bonds around the signing of the Paris Agreement. Quarterly observations cover the fourth quarter of 2014 through the fourth quarter of 2016. The periods after the fourth quarter of 2015 constitute the *Post Paris Agreement* periods. Treated bonds are defined in four ways: (1) the issuer company has a top-quartile carbon emission level as of 2014 (per CDP disclosure), (2) the issuer company has a top-quartile carbon intensity (carbon emissions scaled by revenues) as of 2014, (3) the issuer company belongs to a high emissions industry (one of the top 15 most carbon-emitting industries), or (4) the issuer company has a below-median Sustainalytics environmental score as of December 2014, . Control bonds are one-to-one matched to treated bonds based on issue principal size, credit rating, bond time to maturity and the firm's equity oil beta. Standard errors are two-way clustered at the bond and quarter level and shown in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.

Treated bond defined by:	Top-quartile firm carbon emission			Top-quartile firm carbon intensity		
Ownership (%) by	All institutions	Mutual funds	Insurance firms	All institutions	Mutual funds	Insurance firms
	(1)	(2)	(3)	(4)	(5)	(6)
Treated bonds * Post Paris Agreement	-0.278	0.741***	-1.022***	-0.308	0.883***	-1.230**
	(0.221)	(0.163)	(0.233)	(0.378)	(0.165)	(0.398)
Treated bonds	2.218	0.137	2.060	1.618	0.431	1.192
	(1.584)	(1.110)	(1.849)	(1.477)	(1.232)	(1.861)
Ln(Issue amount)	-8.282***	0.813	-9.118***	-6.491***	0.535	-7.045***
	(1.369)	(0.869)	(1.579)	(1.740)	(0.990)	(1.995)
Years to maturity	-0.100	-0.204***	0.114	-0.0929	-0.187***	0.103
	(0.0903)	(0.0376)	(0.0968)	(0.0924)	(0.0365)	(0.101)
Credit rating (numerical)	0.131	-0.444**	0.571**	0.235	-0.549**	0.780**
	(0.218)	(0.139)	(0.240)	(0.190)	(0.201)	(0.258)
Observations	4375	4375	4375	3742	3742	3742
Adjusted R^2	0.110	0.113	0.105	0.088	0.110	0.093
Time FE	Y	Y	Y	Y	Y	Y

Treated bond defined by:	High emission industries			Below-median firm environmental score		
Ownership (%) by	All institutions	Mutual funds	Insurance firms	All institutions	Mutual funds	Insurance firms
	(1)	(2)	(3)	(4)	(5)	(6)
Treated bonds * Post Paris Agreement	-1.237***	-0.0333	-1.209***	-0.426	0.265***	-0.675**
	(0.182)	(0.0594)	(0.239)	(0.241)	(0.0635)	(0.234)
Treated bonds	0.297	0.780	-0.516	4.759***	2.921**	1.802
	(1.081)	(0.826)	(1.374)	(1.335)	(1.001)	(1.668)
Ln(Issue amount)	-7.633***	1.148	-8.812***	-3.633**	2.965**	-6.747***
	(1.007)	(0.687)	(1.241)	(1.210)	(0.983)	(1.475)
Years to maturity	-0.00141	-0.214***	0.222**	-0.107	-0.258***	0.160
	(0.0705)	(0.0288)	(0.0781)	(0.0882)	(0.0502)	(0.103)
Credit rating (numerical)	-0.554***	-1.110***	0.563**	0.195	-1.458***	1.667***
	(0.153)	(0.183)	(0.190)	(0.182)	(0.270)	(0.328)
Observations	11082	11082	11082	7640	7640	7640
Adjusted R^2	0.112	0.191	0.094	0.075	0.219	0.140
Time FE	Y	Y	Y	Y	Y	Y

Appendix

Estimation of weekly bond abnormal returns

To calculate weekly "abnormal" bond returns, we make adjustment to raw bond returns based on bond/firm characteristics, following the methodology of Bessembinder et al. (2019). We calculate weekly bond returns, by calculating the cumulative return over five business day bins. For each week t, we calculate the expected weekly return of bonds using the following cross-sectional regression run on the sample of weekly returns of all available bonds:

$$R_{i,t} = \beta_1 TMT_{i,t-4} + \beta_2 Principal_{i,t-4} + \beta_3 MTB_{i,t-4} + \beta_4 MVAssets_{i,t-4} + \beta_5 R^{Equity}_{i,t-4} + \sum_{r=B}^{AAA} \beta_r \mathbb{1}[Rating_{i,t-4} = r] + \epsilon_{i,t-4}, \tag{31}$$

where $R_{i,t}$ are trading bond returns for bond i at time t, $TMT_{i,t-4}$ are the bond time to maturity for bond i as of the month before time t, $Principal_{i,t-4}$ are the natural log of principal outstanding for bond i as of the month before time t, $MVA_{i,t-4}$ are the sum of debt and the market value of equity for the issuer of bond i as of one month before time t, $R^{Equity}_{i,t-4}$ is the rolling equity return based on trailing twelve month returns for the issuer of bond i as of one month before time t, and $\mathbb{1}[Rating_{i,t-4} = r]$ are rating indicators for the issuer of bond i. We use six rating indicators for AAA, AA, A, BBB, BB, or B or lower rating.

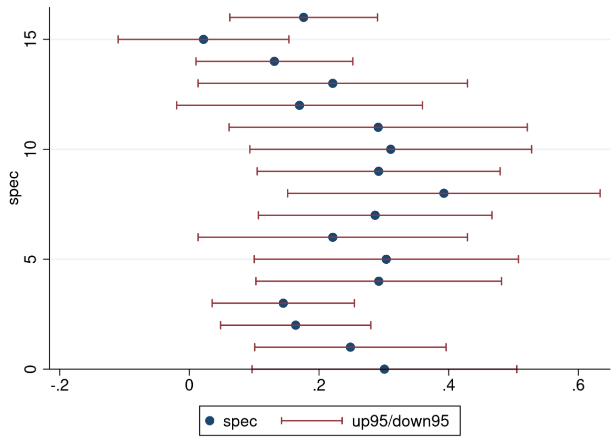
We use bond characteristics and the estimated coefficients from the regression to calculate expected return $E(R_{i,t+1})$, and then calculate the abnormal bond return $R^{Abnormal}_{i,t+1}$:

$$R^{Abnormal}_{i,t+1} = R_{i,t+1} - E(R_{i,t+1}). \tag{32}$$

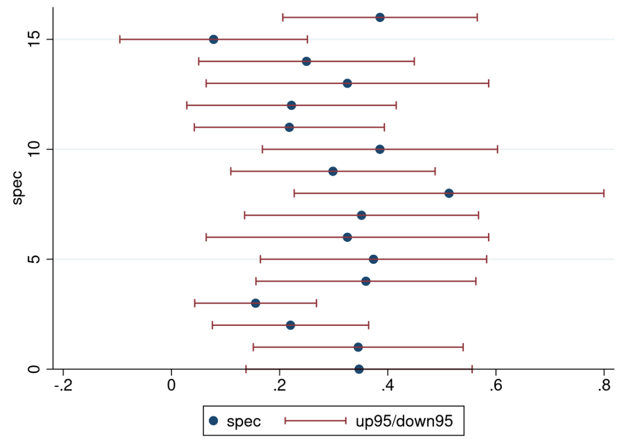
We then examine $R^{Abnormal}$ in the period surrounding the Paris Climate Talks, which were from November 30, 2015 until December 12, 2015. To ensure we estimate robust standard errors, we follow Bessembinder et al. (2008) and aggregate returns at the issuer-level by taking the average return weighted by bond issue size.

Fig. A.1. Sensitivity Analysis of Yield Spread Difference-in-differences analysis.
This figure displays displays results for different specifications of the difference-in-differences analysis. Specifications detailed in Table A.2. Note that Specification 16 is excluded for the high-emission industry because matching is conducted within industry for that specification.

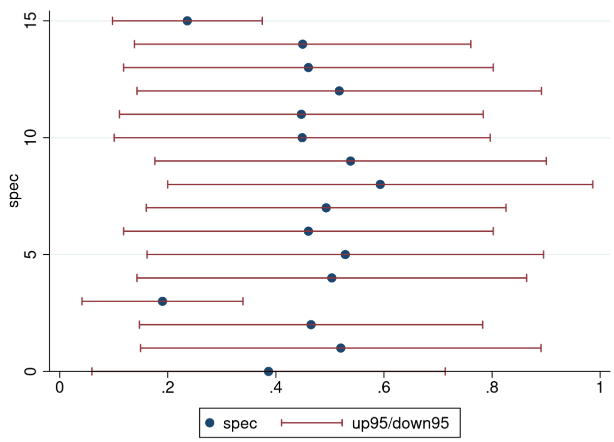
(a) Top-Quartile Emissions



(b) Top-Quartile Carbon Intensity



(c) Top 15 Emitting Industry



(d) Below Median Environmental Score

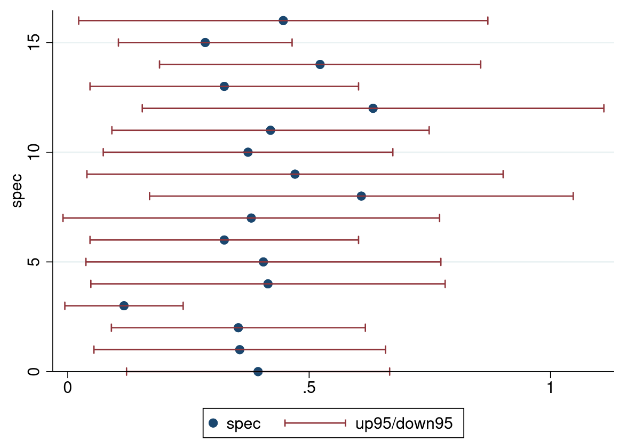
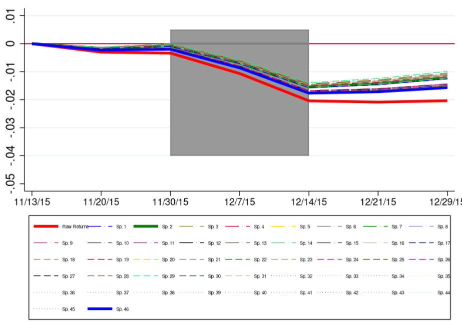
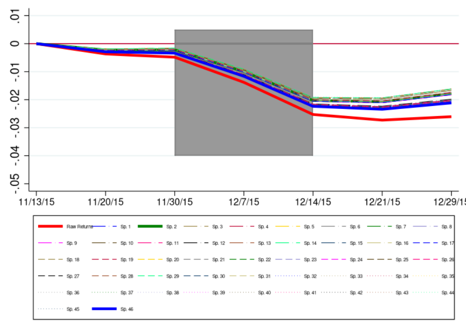


Fig. A.2. Sensitivity Analysis for Characteristic Adjusted Weekly Abnormal Returns for Cumulative Trading Bond Returns Around Paris.
Average cumulative bond returns, adjusted by the Bessembinder et al (RFS 2019) using 45 different combinations of covariates, calculated by five day bin. Raw cumulative bond returns, as well as those regressing bond returns on a constant and nothing else, are also included. The shaded region marks the Paris Climate Talks from November 30, 2015 until December 12, 2015. Returns are winsorized at the 1% and 99% levels. Excess returns are aggregated at the issuer-level, as the average of all excess returns for bonds from that issue, weighted by the bond principal outstanding.

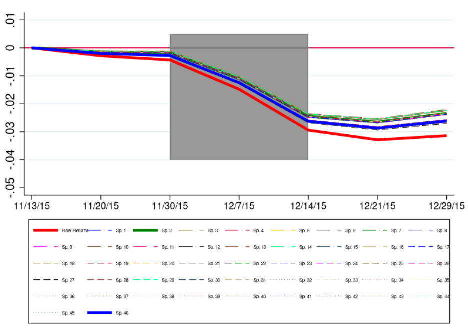
(a) Top-Quartile Emissions



(b) Top-Quartile Carbon Intensity



(c) Top 15 Emitting Industry



(d) Below Median Environmental Score

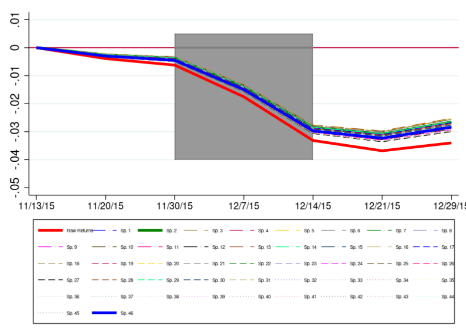
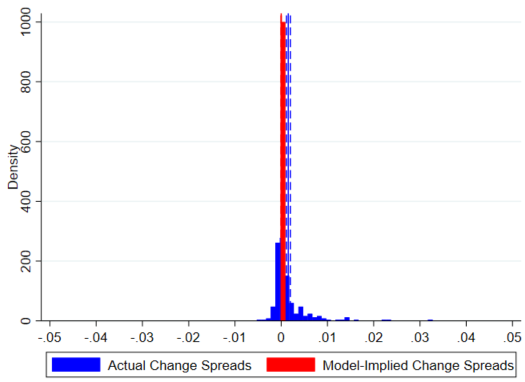
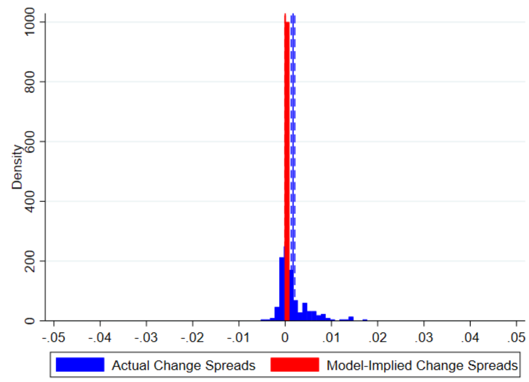


Fig. A.3. Changes in model-implied yield spreads around the Paris Agreement announcement
This figure plots the distribution of the observed change in the credit component of spreads relative to the change in the model-implied spread based on asset values and volatilities calculated from Vassalou and Xing (2004) for bonds issued by firms with poor environmental profiles in the month after the Paris Agreement. The model-implied change in spreads assumes a constant asset volatility before and after the Paris Agreement. A poor environmental profile is determined by whether an issuer is in the top-quartile of emissions (Panel a), in the top-quartile of emission-intensity (Panel b), in the top 15 carbon emission industries (Panel c), or has a below-median environmental score (Panel d). The blue-solid line shows the actual average change in yield spreads, while the red-solid line shows the model-implied change in yield spreads. The blue and red dashed lines show the 90% confidence intervals.

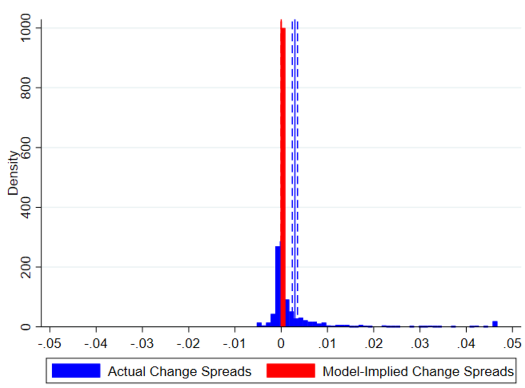
(a) Top-Quartile Emissions



(b) Top-Quartile Carbon Intensity



(c) Top 15 Emitting Industry



(d) Below Median Environmental Score

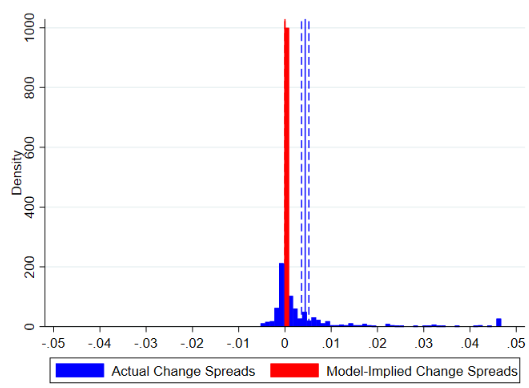


Table A.1: Summary statistics – matched sample for yield spreads around the Paris Agreement.

This table shows summary statistics as of December 2014 (one year before the Paris Agreement) for the sample matched on the alternative environment variables. The environment variables are defined alternatively as one of the following: the firm is in the top-quartile of carbon emissions in 2014 (Panel A) the firm is in the top-quartile of carbon intensity in 2014, measured as tons of emissions divided by firm revenue in thousands of dollars (Panel B), the firm is in a top 15 carbon emissions industry (Panel C), and the firm has a below median environmental score (Panel D). The matched sample is formed by using one-to-one nearest neighbor Mahalanobis matching of treated bond issues to control bond issues by oil beta, issue principal outstanding, time to maturity and credit rating as of year-end 2014. Spread, and profitability, are winsorized at the 1% and 99% levels. The ratings variable is assigned such that a higher number indicates a better rating. *, ** and *** indicate 10%, ** 5% and *** 1% significance respectively.

Group	**Sample**			**Control**			Diff Mean
Variable	Obs	Mean	St. Dev.	Obs	Mean	St. Dev.	
Panel A: Top-Quartile Carbon Emissions							
Security Level Variables							
Credit Rating	252	15.905	2.47	252	15.813	2.33	0.092
Spread	252	1.292	0.787	252	1.268	0.917	0.024
Time to Maturity	252	11.937	9.504	252	12.049	9.521	-0.112
Firm Level Variables							
Profitability	39	0.161	0.121	64	0.225	0.188	-0.064*
Oil Beta	39	0.004	0.032	64	-0.001	0.029	0.005
Panel B: Top-Quartile Carbon Intensity							
Security Level Variables							
Credit Rating	217	15.212	2.165	217	15.263	2.182	-0.051
Spread	217	1.413	0.83	217	1.311	0.907	0.102
Time to Maturity	217	11.791	9.412	217	11.818	9.493	-0.027
Firm Level Variables							
Profitability	38	0.134	0.09	64	0.228	0.165	-0.094***
Oil Beta	38	0.002	0.029	64	-0.004	0.025	0.006
Panel C: High Carbon Emissions Industry							
Security Level Variables							
Credit Rating	646	15.265	2.761	646	15.317	2.804	-0.052
Spread	646	1.565	1.244	646	1.38	0.927	0.185***
Time to Maturity	646	11.131	8.902	646	11.219	8.924	-0.088
Firm Level Variables							
Profitability	135	0.187	0.139	114	0.288	0.22	-0.101***
Oil Beta	135	0.006	0.033	114	0.003	0.031	0.003
Panel D: Below Median Environmental Score							
Security-Level Variables							
Credit Rating	448	13.493	2.47	448	13.714	2.331	-0.221
Spread	448	2.011	1.283	448	2.004	1.388	0.007
Time to Maturity	448	9.46	7.447	448	9.541	7.406	-0.081
Firm Level Variables							
Profitability	129	0.233	0.196	110	0.25	0.191	-0.017
Oil Beta	129	0.011	0.032	110	0.001	0.032	0.01**

Table A.2: Specifications in Sensitivity Analysis for Yield Spreads Difference-in-Differences Analysis

Specification #	**Caliper**	**Controls**
0 (i.e. main results)	1	Oil Beta, Ln(Principal Outstanding), Rating and Time to Maturity
1	0.75	Oil Beta, Ln(Principal Outstanding), Rating and Time to Maturity
2	0.5	Oil Beta, Ln(Principal Outstanding), Rating and Time to Maturity
3	0.25	Oil Beta, Ln(Principal Outstanding), Rating and Time to Maturity
4	1.25	Oil Beta, Ln(Principal Outstanding), Rating and Time to Maturity
5	1.5	Oil Beta, Ln(Principal Outstanding), Rating and Time to Maturity
6	1	Oil Beta, Ln(Total Assets), Rating and Time to Maturity
7	1	Oil Beta, Ln(MV Equity), Rating and Time to Maturity
8	1	Ln(Principal Outstanding), Rating and Time to Maturity
9	1	Oil Beta, Profitability, Ln(Principal Outstanding), Rating and Time to Maturity
10	1	Oil Beta, Ln(Principal Outstanding), and Rating
11	1	Oil Beta, Time to Maturity, and Rating
12	1	Oil Beta, Ln(Principal Outstanding, and Time to Maturity
13	1	Oil Beta, Ln(Principal Outstanding), Ln(Total Assets, Rating and Time to Maturity
14	1	Oil Beta, Ln(Principal Outstanding), Annual Stock Return, Rating and Time to Maturity
15	1	Oil Beta, Ln(Principal Outstanding), Annual Stock Return, Ln(Asset Size), Rating and Time to Maturity
16	1	Oil Beta, Ln(Principal Outstanding), Rating and Time to Maturity. Matched within industry.

Table A.3: Specifications in Sensitivity Analysis for Cumulative Abnormal Returns

Specification #	**Controls**
Raw Return	Raw bond returns
1	Regress bond returns on a constant
2	Control for Time to maturity, principal outstanding, market-to-book, market assets, equity return, rating indicators
3	Control for Principal outstanding, market-to-book, market assets, equity return, rating indicators
4	Control for Time to maturity, market-to-book, market assets, equity return, rating indicators
5	Control for Time to maturity, principal outstanding, market assets, equity return, rating indicators
6	Control for Time to maturity, principal outstanding, market-to-book, equity return, rating indicators
7	Control for Time to maturity, principal outstanding, market-to-book, market assets, rating indicators
8	Control for Time to maturity, principal outstanding, market-to-book, equity return
9	Control for market-to-book, market assets, equity return, rating indicator
10	Control for time to maturity, market assets, equity return, rating indicator
11	Control for time to maturity, principal outstanding, market-to-book, rating indicator
12	Control for time to maturity, principal outstanding, market-to-book, market assets
13	Control for principal outstanding, market assets, equity returns, rating indicator
14	Control for principal outstanding, market-to-book, equity returns, rating indicator
15	Control for principal outstanding, market-to-book, market assets, rating indicators
16	Control for principal outstanding, market-to-book, market assets, equity returns
17	Control for time to maturity, market-to-book, equity returns, rating indicator
18	Control for time to maturity, market-to-book, market assets, rating indicator
19	Control for principal outstanding, market-to-book, market assets, equity return
20	Control for market assets, equity return, rating indicator
21	Control for time to maturity, equity return, rating indicator
22	Control for time to maturity, principal outstanding, rating indicator
23	Control for time to maturity, market assets, rating indicator
24	Control for time to maturity, market-to-book, market assets
25	Control for time to maturity, principal outstanding, market assets
26	Control for time to maturity, principal outstanding
27	Control for time to maturity, market-to-book
28	Control for time to maturity, market assets
29	Control for time to maturity, equity return
30	Control for time to maturity, rating indicator
31	Control for principal outstanding, market-to-book
32	Control for principal outstanding, market assets
33	Control for principal outstanding, equity return
34	Control for principal outstanding, rating indicator
35	Control for market-to-book, market assets
36	Control for market-to-book, equity return
37	Control for market-to-book, rating indicator
38	Control for market assets, equity return
39	Control for market assets, rating indicator
40	Control for ime to maturity
41	Control for principal outstanding
42	Control for market-to-book
43	Control for market assets
44	Control for equity return
45	Control for rating indicator
46	Control for oil beta