Funding the Fittest?

Pricing of Climate Transition Risk in the Corporate Bond Market*

Martijn A. Boermans †, Maurice J. G. Bun ‡, Yasmine van der Straten §

Updated: August 21, 2024
First Version: January 11, 2024

Abstract

We study whether climate transition risk is priced in corporate bond markets and if investors value companies' green innovation efforts. Using confidential bond-level holdings data and global firm-level data on carbon emissions and green innovation, we find a positive transition risk premium. This premium is smaller for emission-intensive firms that engage in green innovation, suggesting that investors value companies' efforts to mitigate climate change. We show that European investors, in particular institutional investors, have a higher demand for bonds from emission-intensive firms that engage in green innovation and thus influence yield spreads related to climate transition risk.

Keywords — Climate Change, Climate Transition Risk, Carbon Premium, Greenium, Green Innovation, Bond Markets, Institutional Investors.

JEL codes — G12, G15, G23, Q51, Q54.

*DNB Working Paper No 797. The views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank nor the Eurosystem. Data have been cleared by the Eurosystem for non-disclosure of confidential data. Details are available at www.ecb.europa.eu/stats/financial_markets_and_interest_rates/securities_holdings/html/index.en.html. For helpful comments and suggestions we thank Aleksandar Andonov, Thibault Cezanne, Jeroen Derwal, Jens Dick-Nielsen, Tim Eisert, Eline Jacobs, Marcin Kacperczyk, Marleen de Jonge, Stefano Lugo, Christoph Meinerding, Benjamin Schneider, and Thomas Walther. This paper further benefited from discussions with participants of the ESCB Research Cluster Climate Change (2024), RCEA International Conference in Economics, Econometrics, and Finance (2024), IAAE conference (2024), IPDC conference (2024), and seminar participants at Robeco Asset Management (2024), Utrecht University (2024), De Nederlandsche Bank (2024), Imperial College Business School (2024) and University van Amsterdam (2024).

†De Nederlandsche Bank. E-mail: m.a.boermans@dnb.nl.
‡De Nederlandsche Bank and University of Amsterdam. E-mail: m.j.g.bun@dnb.nl.
§Corresponding Author. University of Amsterdam and Tinbergen Institute. E-mail: y.vanderstraten@uva.nl

I. Introduction

Achieving net-zero emissions by 2050 will pose a significant challenge for the global economy (IPCC, 2014). Current public policies and actions are inadequate in addressing climate change (UNEP, 2023), creating considerable uncertainty around the transition, and leaving firms exposed to climate transition risk. Forward-looking, financial investors may anticipate climate transition risks and price this accordingly in financial markets. As the price of capital serves as a signal of risk, and hence guides efforts to mitigate climate risk, investors may thus play a key role in promoting the green transition by redirecting capital towards green activities. We study whether investors in the corporate bond market take up this role in the period following the adoption of the Paris Agreement in December 2015.

In this study we assess whether corporate bond investors price climate transition risk. We focus specifically on corporate bond investors, as climate and environmental risks are downside risks, and thus have more fundamental implications for corporate bond investors (Seltzer et al., 2022; Hoepner et al., 2024). The corporate bond market is also the marginal source of finance for many firms (Gourio, 2013), and the polluting sectors particularly relies on bond financing (Papoutsi et al., 2022). While the green transition requires companies to reduce their future emissions, emission data is inherently backward looking. We therefore consider companies' efforts to mitigate climate change by innovating in the green space alongside their past and current carbon emissions in the bond pricing relationship. Specifically, we study (i) whether corporate bond investors demand a positive transition risk premium from companies with a high emission intensity and, (ii) whether the risk premium is smaller for emission-intensive companies that engage in green innovation.

To answer these questions we combine global firm-level data on greenhouse emissions from Trucost Environmental with confidential bond-level holdings data. Data on bond holdings are from the ECB Securities Holdings Statistics by Sector database. Our regression analysis, which considers the period from 2016-Q1 to 2021-Q4, provides evidence of a positive carbon premium that increases with the emission intensity of a company. Specifically, a one standard deviation increase in emission intensity raises the bond yield spread with 48.4 basis points - an economically sizable effect. Other factors, such as bond credit risk, bond liquidity, maturity and whether the bond has a green bond label, cannot explain the transition risk premium, emphasizing the pivotal role of carbon emissions in determining the cost of capital. We also verify that the results are not driven by a disproportionate expansion bond supply of emission-intensive companies (Ivanov et al., 2024).

To assess whether the transition risk premium is lower for emission-intensive companies that engage in green innovation, we augment our dataset with firm-level data on (green) patents from Orbis Intellectual Property. We obtain information on the total number of patents of each company as well as the number of 'green' patents they own. We consider all patents that are classified as patents in the Climate Change Mitigation and Adaptation class under the Cooperative Patent Classification (CPC) as green patents (Haščič and Migotto, 2015). To account for differences in the extent to which companies engage in patenting activities, we consider the amount of patents related to green technologies relative to the total amount of patents of a given company (Bolton et al., 2023). We find that the interaction between emission intensity and the green patent ratio significantly affects bond yield spreads. Specifically, a one standard deviation increase in the green patent ratio reduces the yield spread of a bond issued by a company with a mean emission intensity by 13.6 basis points. This indicates that investors reward emission-intensive companies that make efforts to become more green. We verify that this result continues to hold in various robustness tests. We show that our results become stronger once we adopt a stricter classification for green patents, focusing on green patents for technologies aimed at the reduction of greenhouse gasses related to energy generation, transmission or distribution (Acemoglu et al., 2023). Furthermore, we verify that our results are not driven by investments or patenting in general. Instead, we show that green innovation activities are particularly significant to investors, since it is not merely the overall involvement in green innovation that matters to investors, but also the incremental addition of new green patents. Since the Corporate Sector Purchase Programme (CSPP) of the ECB has led to a significant easing in financing conditions in the euro area corporate debt market, we also verify that our results are neither driven by eligibility of bonds in our sample for purchase under the CSPP, nor by the actual purchases made by the ECB. Specifically, while CSPP lowered yields for eligible bonds, we show that it did not asymmetrically favour emission intensive companies that also innovate in the green space. Our results are also robust against considering absolute Scope 1 and 2 emissions as explanatory variable, rather than emission intensity.

Overall, our results indicate that investors care about whether companies are 'fit' for the green transition. To address concerns that our results are driven by the joint determination of bond credit ratings and emission intensity or green innovation (Carbone et al., 2021), we interact our main variables of interest with bond credit ratings. The joint effect of emission intensity and green innovation remains statistically significant once we incorporate the interactions with bond credit ratings. The interaction with bond credit ratings is statistically insignificant, mitigating concerns of a joint-hypothesis problem. We also confirm the robustness of our results by interacting our main variables of interest with bond liquidity. We find that the residual maturity of a bond matters, as the joint effect of emission intensity and green innovation varies across maturity buckets. Specifically, the joint effect of emission intensity and the green patent ratio is stronger for bonds with shorter maturities. This suggests that the disciplining effect of corporate bond investors becomes stronger as the bond maturity shortens, since firms will face more urgent needs to refinance by rolling over their debt (De Haas and Popov, 2023).

In the final part of our analysis, we examine whether European investors are more inclined to incorporate climate transition risk into their investment decision compared to other investors. This is what we expect given the European Union's extensive efforts to promote green transition goals as well as the strong public concern about climate change within Europe.[1] First, we assess whether European investors directly affect corporate bond spreads in relation to companies' emission intensity and green

[1]See `https://www.eib.org/en/infographics/eu-climate-change-peer-us-china`.

innovation efforts. To this end, we interact the green patent ratio with various holder-shares, which are defined as the holdings of specific European investors of a given bond relative to the total amount outstanding (at market values) in a given period. To take into account the size of the investor sector, we scale this measure by the total holdings of the investor sector relative to the total holdings in that given period. We consider all European investors, and focus specifically on the subset of institutional investors and banks. We find that European investors are more likely to price the exposure of a company to climate transition risk, although when the effect size is small in economic terms. Specifically, a standard deviation increase in the share of holdings of European investors reduces the yield spread of company with a mean emission intensity and mean green patent ratio by approximately 2.6 basis points. The pricing of climate transition risk is predominantly driven by institutional investors. Holdership by banks does not significantly affect bond yield spreads.

Our findings indicate that the presence of European investors affects bond yield spreads in relation to companies' carbon emissions and green innovation efforts. We therefore examine whether European investors have a higher demand for these bonds. We analyze investors' demand for bonds issued by emission-intensive firms that engage in green innovation activities by interacting emission intensity and the green patent ratio with an indicator for each investor type. To elicit investor demand, we follow the methodology of Khwaja and Mian (2008) and Acharya et al. (2024). More precisely we compare whether different investor types have a differential demand for bonds of the same firm and whether this demand is related to the firm's exposure to climate transition risk. Our results demonstrate that European investors, and particularly institutional investors, have a higher demand for bonds issued by emission-intensive firms that engage in green innovation. This aligns with our previous finding that European institutional investors lower yields for bonds of emission-intensive firms that engage in green innovation. In conclusion, our findings highlights the growing importance of sustainability in investment decisions, with an emphasis on firms efforts to mitigate climate risk.

A. Related literature

This paper relates to two broad strands of literature. First, our paper contributes to the literature on the pricing of climate transition risk in financial markets, which has focused mainly on stock markets. Bolton and Kacperczyk (2021) find evidence of a positive carbon premium in the cross-section of U.S. stock returns and Bolton and Kacperczyk (2023) show that this premium is observed in global stock markets. Hsu et al. (2023) consider the asset pricing implications of industrial pollutants, rather than just CO2-related emissions, and show that environmental policy uncertainty helps price the cross-section of stocks returns. On the contrary, Loyson et al. (2023) do not find evidence that carbon risk is being priced in the European equity market. Aswani et al. (2024) suggest that the association between corporate emissions and stock returns disappears when using emission intensity rather than unscaled emission levels. Boermans and Galema (2023) affirm this result for European stock, but find a carbon premium for non-European stocks using emission intensity. Pástor et al. (2022) and Ardia et al. (2023) empirically test whether green firms outperform brown firms when concerns about climate change increase unexpectedly (Pástor et al., 2021). Bauer et al. (2022) find more generally and for a range of methodologies that green stocks provide higher returns than brown stocks for much of the past decade.

A more recent literature studies whether this risk is accounted for in bank lending decisions (e.g., Sastry et al., 2024; Ivanov et al., 2024; Altavilla et al., 2023; Kacperczyk and Peydró, 2022; Delis et al., 2024). Using syndicated loan data, D'Arcangelo et al. (2023) show that that the costs of debt are lower for firms with lower emission intensity, especially in countries where climate-change mitigation policies become more stringent (e.g., Ali et al., 2023; Heinkel et al., 2001). Using administrative credit registry data from Europe, Altavilla et al. (2023) provide evidence that loan spreads are higher for emission-intensive firms. This effect is particularly driven by banks that publicly commit to environmentally responsible lending practices. Sastry et al. (2024), however, highlight the limits of voluntary commitments for decarbonization, finding that net zero banks neither reduce credit supply to sectors targeted for decarbonization, nor reduce financed emissions through engagement. Also Giannetti et al. (2023) show that banks that emphasize the environment in their disclosures do not adhere to more environmentally friendly lending practices, as they hesitate to sever ties with existing brown borrowers, especially if they exhibit financial underperformance.

Less research has been conducted on the pricing of climate transition risk in the corporate bond market. Seltzer et al. (2022) provide evidence that climate regulatory risks affect bond yield spreads. Broeders et al. (2024) also find evidence of a carbon premium that investors demand for bonds issued by firms with high emissions in the euro area. Duan et al. (2023), who focus on bonds issued by U.S. companies and traded on the U.S. public market, find that bonds of more carbon-intensive firms earn significantly lower returns due to investor underreaction to the predictability of emission intensity for firm's financial performance. We contribute to the literature by considering companies' green innovation efforts alongside their past and current carbon emissions in the bond pricing relationship. Our findings indicate that the 'carbon premium is smaller for emission-intensive companies that engage in green innovation, indicating that investors take into consideration firm's efforts to mitigate climate risk.[2]

Second, this paper also relates to the literature on green innovation and financial performance.[3] Leippold and Yu (2023); Battiston et al. (2023) focus on the association between green innovation and stock returns. Leippold and Yu (2023) show that stocks of firms with higher green innovation measures have lower expected returns and Battiston et al. (2023) find that the adoption of sustainable technologies is associated with better future financial and operating performance. Accetturo et al. (2022) consider credit supply, showing for Italian SMEs that there is a large positive elasticity of green investments to credit supply. . We contribute to this literature by showing that investors asymmetrically reward green innovation efforts. Specifically, investor particularly value green innovation efforts of companies which are currently emission-intensive.

[2]While we focus on the corporate bond market as a whole and do not focus on corporate green bonds exclusively, our paper also relates to studies in this literature (e.g., Flammer, 2021; Pietsch and Salakhova, 2022; Zerbib, 2019; ElBannan and Löffler, 2024)) as we find evidence of a substantive 'greenium'.

[3]Our paper somewhat relates to the literature on the effect of green innovation on environmental performance (see e.g., Leippold and Yu, 2023; Hartzmark and Shue, 2023; Dugoua and Gerarden, 2023; ElBannan and Löffler, 2024; Bolton et al., 2023; Cohen et al., 2023).

Table 1: Summary statistics

	Mean	Median	SD	P10	P90
Environmental Variables					
(Scope1 + Scope2) Emission Intensity	2.805	0.509	4.908	0.191	8.958
(Scope1 + Scope2) Absolute Emissions (in log)	14.670	14.242	2.101	12.297	17.448
Green Patent Ratio	0.006	0.001	0.018	0.001	0.013
Bond Characteristics					
Yield to Maturity (%)	2.131	1.809	2.256	0	4.368
Spread (%)	1.516	1.020	1.993	0.253	3.168
Bond Holding Value (in m EUR)	201.837	55.825	304.245	2.990	630.378
Amount Outstanding (in m EUR)	663.315	504.572	541.098	109.731	1300
Fixed Coupon	0.902	1	0.298	1	1
EUR	0.346	0	0.476	0	1
USD	0.509	1	0.500	0	1
Green bond	0.012	0	0.111	0	0
Corporate Fundamentals					
Revenue (in bn EUR)	57.994	30.138	84.247	4.903	152
Total Assets (in bn EUR)	92.182	54.122	94.005	8.922	277
Total Debt (in bn EUR)	29.229	17.057	32.151	2.389	67.499
Profitability-Ratio (%)	5.061	4.042	5.819	-0.217	11.992
Leverage-Ratio (%)	32.393	30.480	12.994	17.910	50.748
Cash-Ratio (%)	5.536	3.320	8.224	0.323	9.557
Investment-Ratio (%)	12.593	7.444	14.586	1.160	34.271

Note: Based on 38,374 observations, reported at quarterly frequency and the security-by-security level. Absolute emissions levels are measured in CO2e and are reported in natural logarithms. Emission intensity, measured in CO2e/USDm, is scaled by a factor 1/100 and winsorized at the 2.5% level. Yield to maturity is winsorized at the 1% level. Fixed coupon is a dummy which is equal to 1 if a bond has a fixed coupon. EUR respectively USD are dummy variables, which are equal to 1 if a bond is denominated in euros respectively dollars. Green bond is a dummy which is equal to 1 if a bond has a green bond label. The profitability-ratio is defined as net income dividend by total assets (ROA). Leverage is defined as total debt divided by total assets. The cash- and investment ratio are defined as cash and capital expenditures divided by total assets, respectively. All ratio's are reported in percentages.

II. Data

We construct a comprehensive dataset by compiling data from various sources. Our sample covers the period 2016-Q1 up until 2021-Q4. Data is reported at quarterly frequency at the security-by-security level for bonds issued worldwide. We use confidential data on security-level portfolio holdings from the ECB Securities Holdings Statistics Sectoral (SHS-S, hereafter referred to as SHS). This data is complemented with the ECB Centralised Securities Database (CSDB), which provides various issuer- and bond characteristics at the security level.[4] We use Trucost Environmental for data on corporate carbon emissions and collect (green) patent information from Orbis Intellectual Property (IP). Corporate fundamentals and bond characteristics are obtained from Refinitiv. Table 1 provides summary statistics.

[4]Both SHS and CSDB are collected and operated by the European System of Central Banks (ESCB).

A. *Security-level portfolio holdings*

The Securities Holdings Statistics provides detailed information on aggregate security-level portfolio holdings by financial and non-financial holders from all 20 euro area countries (denoted by c), as well as six other European Union countries not part of the euro area. Data is reported quarterly at the security-by-security level for bonds issued globally.[5] In each period, we observe the bond holdings value held by a specific holder (j), which is identified at the country-sector level for each period t. Investors are classified into 8 distinct investor sectors (denoted by s), i.e. insurance companies, pension funds, mutual funds, banks, other financial institutions (including securitizations vehicles), non-financial corporations, governments and households (including non-profit institutions serving households). The magnitude of holdings (as measured by total bond holdings at market value) within our sample encompasses 1.05 trillion euro in 2016-Q1 and rises to 1.46 trillion euro (in 2021-Q4), which covers approximately 58% of all security holdings reported for euro area investors for non-financial corporate issuers.[6]

The CSDB complements the European holdings data with various issuer - and bond characteristics at the security level, such as issuer name and country, the outstanding amount, the coupon rate, the currency in which the bond is denominated, the residual maturity of the bond and the yield to maturity. To reduce the impact of outliers, we winsorize the yield to maturity at the 1%.[7]Since we are interested in estimating risk premia, we determine the return in excess of the risk free rate. To this end we subtract from the yield to maturity the maturity-matched Eurozone Central Government Bond Par Yield Curve Spot Rate.[8] The CSDB also provides us with data on bond credit ratings. Rating data is directly reported by ratings agencies Fitch, Moody's, S&P and DBRS to the ECB.[9] Bond credit ratings range from 1 to 22 within our 'carbon premium' sample. A bond rating of 1 indicates that the bond is of the highest quality and has an AAA-rating. A bond rating of 22 indicates that the bond is near-default, with a CC-rating. Within our main sample, the average credit rating is 7.350 (standard deviation of 2.539), which corresponds to an upper medium-grade (A-) bond.[10] We obtain information on the residual maturity of the bond from the CSDB. To control for the maturity of a bond in our regressions, we construct a dummy variable which indicates whether the residual maturity of the bond is longer than 10 years. Within our sample, approximately 24 percent of bonds have a residual maturity longer than 10 years. The CSDB also contains information on green bond labels. From the 3,313 bonds within our sample, 69 bonds have a green bond label (2% of all bonds) and these are issued by 34 distinct companies (9% of all companies).

[5]Data is reported at market value. Nominal values are also available, which are given the aggregated nominal amount of the security, excluding accrued interest.

[6]Short-positions, non-active securities, and investments in tax havens are excluded and small positions, highly implausible prices, and debt types as warrants and equity like debt are dropped.

[7]Since bonds are frequently observed for multiple periods, we assess the time series properties of bond yields by estimating an autoregressive model in Appendix A, which confirms that bond yields are stationary. We also plot the evolution of the mean and median bond yields over time in Figure A1 in Appendix A.

[8]The percentage of bonds within our sample which are denominated in euros is 31.57%. Since a large amount of bonds within our sample is denominated in US dollars (52.16%), we use Treasury Rates when determining the spread for these bonds. Bonds denominated in other currencies are benchmarked against the euro area rates.

[9]Ratings data is only available for 16,889 observations, which is 44% of our main sample.

[10]For our 'carbon premium' sample, ratings data is only available for 37,998 observations. The average credit rating over this sample is 8.102 (s.d. of 2.584). This corresponds to a lower medium-grade ($BBB+$) bond. The highest bond rating within this sample is equal to 1 (highest quality, AAA), and the lowest is 22 (near-default, CC).

B. Corporate environmental performance

We collect information on corporate carbon emissions from Trucost Environmental, which provides firm-level data on carbon and other greenhouse gas emissions annually. Trucost's global coverage significantly expands after 2016, coinciding with the Paris Agreement, which heightened climate change awareness and emphasized the importance of measuring and reporting environmental data (Bolton and Kacperczyk, 2021).[11] As the data is published with a considerable publication lag, our analysis focuses on the period from 2016-Q1 until 2021-Q4. Trucost provides data on absolute carbon emissions (measured in tons of CO2e) and emission intensities, which are given a company's emissions relative to its revenue, measured in tons of CO2 emissions per million dollars of revenue (CO2e/USDm). A distinction is made between three sources of emissions. Scope 1 emissions cover emissions from the use of fossil fuels in the companies' production (direct emissions). Scope 2 emissions cover indirect emissions, which stem from the purchase and consumption of heat, steam and electricity by a company. Scope 3 emissions cover indirect emissions, which are are the result of activities from assets not owned or controlled by the company, but that arise along its value chain. These emissions are more challenging to measure and are less frequently reported, often requiring estimates from data providers. Due to the lack of methodological clarity in estimating Scope 3 emissions, the data are often noisy and inconsistent compared to Scope 1 and 2 emissions (Klaaßen and Stoll, 2021). Therefore, we exclude Scope 3 emissions from our analysis.

We construct a measure of a company's environmental performance by jointly considering Scope 1 and Scope 2 emissions. Companies with higher emissions face higher regulatory and operational costs as they adapt to stricter environmental policies. Emission intensity, which measures these costs relative to a company's revenue, gives insight into the potential impact of environmental regulation on the firm's financial health and the risk of default, which is particularly relevant for corporate bond investors. Therefore, our focus is on emission intensity and we measure a companies' emissions relative to its size, determined by its revenue for the same year:

$$\text{Emission Intensity}_{f,t} = \frac{\text{Scope } 1_{f,t} + \text{Scope } 2_{f,t}}{Revenue_{f,t}}$$

where emission intensity is reported in tons of CO2e/USDm. We scale 'Emission Intensity' by a factor 1/100 and winsorize it at the 2.5% level (Bolton and Kacperczyk, 2021).[12] We plot the evolution of mean (median) emission intensity at the firm-year level in Figure A2 in Appendix A, which shows that, on average, emission intensity falls by 5 percent annually over our sample period.[13] In our analysis below, we study whether this decline is partly explained by green innovation by emission-intensive firms.

[11] Although Trucost primarily reports emissions data for private companies, our study is limited to public companies for which we have bond data available.

[12] Our measure is similar to the ECB Climate Indicators for the financial sector's carbon intensity and the financed emissions when measuring carbon emissions in absolute terms, (see European Central Bank, 2024) and used in others studies (e.g., Andersson et al., 2016; Boermans and Galema, 2023; Aswani et al., 2024). We do not correct revenue for inflation rates as inflation was very low in our sample period 2016-2021

[13] We also assess the time series properties of our emission intensity variable (see Appendix A). Our estimates show considerable persistence. Once controlling for time- and firm specific effects, however, there is no evidence of a unit root.

C. (Green) patent information

We obtain information on (green) patents from Orbis IP, which provides global data of patent of public and private companies filed at the European Patent Office (EUPO), the US Patent Office (USPO) and the Japanese Patent Office (JPO). We match the security identifiers in our primary sample with their corresponding identifiers in Orbis (Bureau Van Dijk-ID numbers) to identify all patents registered by a given company within our sample. We identify 19,399,500 patents associated with 1,241 unique companies, which is approximately 83% of all firms on which we obtain information in SHS and Trucost. We gather information on the total number of patent publications of a given firm, as well as the number of patent publications and explorations in each year. We use this information to determine the total amount of active patents in a specific year.

Since we are interested in green innovation, we utilize Cooperative Patent Classification (CPC) codes to identify companies' green patents. We follow Haščič and Migotto (2015) and consider the entire class on Climate Change Mitigation and Adaptation (with CPC-code Y02).[14,15] We obtain information on the publication number, the current owners, the description of the patent, the priority - and application date, as well as the classification of each green patent according to its CPC-code. We identify green patents for a specific company and year based on the application date and the identifier of current owners. This process results in 221,930 green patents, held by 383 unique companies. Hence, green patents represent only 1.1% of the total number of patents within our dataset and among the companies in our sample engaged in patenting, only 31% also hold green patents. However, these companies collectively hold 89.7% of all patents, amounting to 17,396,360 patents out of the total 19,399,500. This suggests a strong correlation between a company's involvement in green patenting and patenting in general.

To address this correlation, we construct a relative measure of green innovation, the green patent ratio. This measure calculates the number of patents related to green technologies relative to the total number of patents held by a specific company (Bolton et al., 2023):

$$\text{Green Patent Ratio}_{f,t} = \frac{\#\text{Green Patents}_{f,t}}{\#\text{Patents}_{f,t}}$$

We focus on companies that have at least one green patent in our main sample. The resulting sample consists of 3,313 unique bonds (i), issued by 383 unique companies (f) from 37 countries worldwide,

[14]The Y02 consists of 8 subclasses, i.e. technologies for adaptation to climate change (Y02A); climate change mitigation technologies related to buildings (Y02B); capture, storage, sequestration or disposal of greenhouse gases (Y02C); climate change mitigation technologies in ICT (Y02D); reduction of greenhouse gasses related to energy generation, transmission or distribution (Y02E); climate change mitigation technologies in the production or processing of goods (Y02P); climate change mitigation technologies related to transportation (Y02T); climate change mitigation technologies related to wastewater treatment or waste management (Y02W).

[15]Bolton et al. (2023) argue that this classification does not always distinguish between patents on renewable energy technologies ("green") and brown efficiency improvement patents. Therefore, the authors classify patents into 3 categories: i) "green" patents for environmental technologies; ii) "general efficiency improvement" patents that deal with technologies that improve process efficiency and therefore could reduce emission intensity; iii) "brown" patents that deal with technological innovation for fossil fuel-based technologies. This classification relies on four technology classification sources on patents relating to the environmental impact of technologies, in particular: the International Patent Classification (IPC) Green Inventory (for green patents), the efficiency-improving fossil fuel-technology categories of Lanzi et al. (2011), as well as a self-identified classification based on patents from the Corporate Knights Clean 200. The OECD classification is used for robustness (Bolton et al., 2023).

Table 2: Number of Patents and Green Patents Filed over the Sample Period

Variable	2016	2017	2018	2019	2020	2021
Patents (All companies)	641,047	650,080	648,820	627,067	565,062	476,300
Patents (Companies with green patents)	556,190	566,459	564,623	546,625	491,318	413,546
Green Patents	7,001	6,827	7,201	7,435	5,649	7,317

which gives us 38,374 observations (N). We verify the robustness of our results when including all companies for which patent information is available. This sample consists of 8,321 unique bonds, issued by 1,239 unique firms from 52 countries worldwide, resulting in 90,953 observations.

D. *Corporate Fundamentals and Bond Characteristics*

We collect information on corporate fundamentals via Refinitiv, which is also available at a quarterly frequency.[16] The data includes details on companies' total assets, revenue, equity, long-term debt, capital expenditures, cash-holdings, as well as sector - and industry classification based on the Global Industry Classification Standard (GICS). We exclude all financial corporations from our analysis. Table 3 summarizes the mean emission intensity, mean green patent ratio and mean amount of green patents across sectors. A more detailed classification based on GIC Industries is provided in Appendix B, with 53 distinct industries. There is large variation in the green patent ratio across industries.The green patent ratio is highest in the utilities sector, which also has the highest emission intensity on average. The green patent ratio is lowest in the health care sector, which has the lowest emission intensity on average. Table 3 underscores the importance of considering the number of green patents relative to the overall number of patents, as e.g. the utilities industry has the highest green patent ratio, but the number of green patents is amongst the lowest. We also provide an overview of the issuer-countries within our sample in in Appendix B. Approximately 23% of the distinct firms in our sample are established in the United States, and 38% in the European Union.[17]

We also obtain data on daily bid- and ask prices via Refinitiv. The bid-ask spread for bond i is calculated as:

$$\text{Bid-ask spread}_{i,t} = \frac{(\text{Ask Price}_{i,t} - \text{Bid Price}_{i,t})}{\text{Ask Price}_{i,t}}$$

and is expressed in percentages. The daily bid-ask spreads are averaged to determine the bid-ask spread at a quarterly frequency. We obtain the bid-ask spread for approximately 93 percent of the bonds within our sample. The mean bid-ask spread is 0.404, with a standard deviation of 0.442.[18]

[16]There are a few companies for which data is missing in a given quarter quarters. These are filled with the most recent observation of the specific variable of the firm.

[17]In our 'carbon premium sample', approximately 24% of the distinct firms in our sample are established in the United States, and 39% in the European Union.

[18]Within our 'carbon premium' sample, the mean bid-ask spread is 0.479 (s.d. of 0.507).

Table 3: Distribution of observations across sectors

GIC Sector	Observations	Emission Intensity	Green Patent Ratio	#Green Patents
Basic Materials	879	7.195	0.109	40.850
Consumer Cyclicals	614	0.669	0.010	2167.720
Consumer Non-Cyclicals	411	1.626	0.009	344.202
Energy	444	4.684	0.025	43.788
Healthcare	494	0.324	0.002	85.747
Industrials	1,080	1.026	0.011	198.309
Real Estate	45	1.039	0.010	3.333
Technology	924	0.478	0.005	875.560
Utilities	542	10.219	0.033	181.220

Note: Distribution of observations across GIC Sectors. Observations are reported at the quarterly frequency and firm-level. We report the mean of emission intensity, the green patent ratio and the number of green patents.

III. Empirical Analysis

A. Primer: The Carbon Premium

We observe each bond i, issued by a company f, held by holder j (located in country c and sector s) in period t. Observations are reported quarterly. We start with estimating the 'carbon premium', i.e. whether bond yield spreads are larger for bonds issued by companies with a higher emission intensity.[19] To this end, we estimate the following regression for the bond yield spread, measured in percentage points, at the bond-period level:

$$\text{Spread}_{i,t} = \beta \text{ Emission Intensity}_{f,t-1} + \delta' X_{f,t-1} + \gamma' Z_{i,t-1} + \eta_f + \lambda_t + \epsilon_{i,t} \quad (1)$$

where emission intensity is measured at the firm level in tons of CO2 emissions per million dollars of revenue (CO2e/USDm). We include the lagged value of emission intensity because emission data becomes available to investors with a lag (Zhang, 2024). The vector of one-period lagged corporate (f) fundamentals ($X_{f,t-1}$) includes the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio. We also include a vector of lagged bond (i) characteristics, $Z_{i,t-1}$, which includes the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro and a dummy which indicates whether the bond has a green bond label. We further verify the robustness of the results against controlling for the bond rating, liquidity (measured by the bid-ask spread) and the bonds' maturity.[20] We estimate Equation (1) using three different sets of fixed effects. We use (i) time fixed effects (λ_t) only, and (ii) time fixed effects and firm fixed effects

[19]The sample for our 'carbon premium' regressions consists of 9,310 unique bonds, issued by 1,495 unique companies from 57 countries worldwide, resulting in 99,869 observations.

[20]Since we take a corporate perspective, we do not incorporate bond factors. For related approaches in the literature that analyze determinants of corporate bond spreads, see e.g., Dick-Nielsen et al. (2012); Helwege et al. (2014); Huang and Petkevich (2016); Bauer et al. (2021). Note that for yield spread regressions, bond factors are absent as control variables.

(η_f). We use firm fixed effects rather than industry fixed effects since this controls for all unobserved firm-characteristics including and beyond those related to the industry the firm operates in (note that firm fixed effect include, amongst others, industry fixed effects). Additionally, to assess whether there is a relationship between emission intensity and bond yield spreads at the within bond-level, we estimate Equation (1) using (iii) time fixed effects and bond fixed effects (θ_i). In this specification, the bond fixed effects replace the firm fixed effects.[21] We also include analytical weights based on the total number of bonds outstanding of each firm in a given period.[22] We cluster standard errors at the more detailed GICS industry level (see Table B3 in Appendix B), allowing the idiosyncratic error term $\epsilon_{i,t}$ to be correlated both within firm clusters and over time.

The estimation results of Equation (1) are displayed in Table 4. For each of the three fixed effects specifications, the first column reports the results for the regression in which only our main explanatory variable of interest, i.e. the emission intensity, is incorporated. The second column reports the results once we include our control variables. We find evidence of a carbon premium in the specification with time fixed effects (column 1-3), as corporate bonds of companies with a higher emission intensity face a larger bond yield spread. In this specification, the effect of emission intensity on the bond spreads is positive and statistically significant at the 5 percent significance level. An increase in emission intensity by one standard deviation[23] raises the yield spread with 48.4 basis points, which is an economically sizable effect. The magnitude of the coefficient declines slightly once we add our control variables, as the results in column 2 show. Nevertheless, the magnitude remains comparable across all specifications. To disentangle the carbon premium (i.e. the positive risk premium for exposure to carbon risk) from the 'greenium' (i.e. the yield discount associated with green bonds), and thus prevent that the results are driven by the green bonds within our sample, we additionally control for whether a bond has a green bond label. The results in column 3 indicate that bonds that qualify as green bond are associated with a large and highly significant yield discount.[24] While this coefficient cannot be interpreted as estimate of the greenium within our sample, as the greenium is usually estimated by determining the average difference in yield spreads between green bonds and the most similar conventional bonds, (e.g., Zerbib, 2019), controlling for whether a bond has a green bond label does not change the effect of emission intensity on yield spreads. The effect stays in similar in size and remains statistically significant at the 5 percent significance level.

In column 4-6 of Table 4, we estimate the relationship with firm- and time fixed effects, which enlarges the explanatory power of the regression considerably. The effect of emission intensity on bond spreads remains statistically significant and is comparable in terms of magnitude. Specifically, a one standard deviation increase in emission intensity increases bond yield spreads by 47.9 basis points.[25] The similarity in effect size suggests that there are no unobserved firm characteristics driving the positive

[21] Note that the firm dimension, f, is nested in the bond dimension, i.

[22] Companies have on average 17.4 bonds outstanding in a given time period, and the highest number of bonds outstanding for a given company in a given period is equal to 103.

[23] For the 'carbon premium' sample this is 4.654, see Table B1 in Appendix B.

[24] The emission intensity of green bond issuers is on average 2.547 (s.d. of 3.720) compared to an average of 2.539 (s.d. of 4.671) for non-green bond issuers.

[25] The within-firm standard deviation is 1.244. Using this estimate, the effect of a one standard deviation increase in emission intensity increases bond yield spreads by 12.8 basis points.

Table 4: The Effect of Emission Intensity on Yield Spreads

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Emission Intensity$_{f,t-1}$	0.104**	0.077**	0.077**	0.111*	0.105*	0.103*	0.086	0.081
	(0.044)	(0.036)	(0.036)	(0.058)	(0.059)	(0.060)	(0.069)	(0.069)
Green Bond$_{i,t-1}$			-0.413***			-0.241**		
			(0.142)			(0.106)		
Corporate Fundamentals	No	Yes	Yes	No	Yes	Yes	No	Yes
Bond Characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-FEs	No	No	No	Yes	Yes	Yes	No	No
Bond-FEs	No	No	No	No	No	No	Yes	Yes
Observations	99,869	99,869	99,869	99,869	99,869	99,869	99,869	99,869
R-squared	0.080	0.190	0.191	0.538	0.546	0.546	0.797	0.798

Note: OLS estimation results for Equation (1). The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). We exploit three different sets of fixed effects, i.e. time fixed effects (column 1-3), firm fixed effects (which include, amongst others, industry fixed effects) and time fixed effect (column 4-6), and bond fixed effects and time fixed effects (column 7-8). For each set of fixed effects, the first column reports the results of a simple regression using emission intensity as explanatory variable, which is measured in CO2e/USDm. The second column reports the results when including control variables. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. The third column additionally controls for whether a bond has a green bond label. Standard errors are reported in parentheses and are clustered at the industry level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

association between emission intensity and bond yield spreads.

We also estimate Equation (1) using bond - and time fixed effects, see column 7-8.[26] This is an additional test to assess whether the positive relationship between emission intensity and bond yield spreads is observed within the individual bond's time series.[27] We no longer find significant evidence that emission intensity positively affects bond yield spreads. Hence, the results indicate that the effect we find is largely identified within firms.

We conduct several tests to assess the robustness of our results, for which we use the specification with firm- and time fixed effects. The results are reported in Table C1 in Appendix C. We first assess the sensitivity of our results against the inclusion of bond credit ratings, liquidity and bond maturity, which constitute important determinants of the yield spread. The results are reported in column 1-3 of Table C1. All these sensitivity checks show that the main effect of emission intensity of yield spreads remains significant and stable in effect size. We also provide evidence of the pricing of climate transition risk by European investors for companies based in the United States. The results, which are reported in column 4, show particularly strong effects for companies located in the United States. The coefficient doubles in magnitude and is statistical significance at the 1 percent level. This result may suggest that European investors are more concerned about the green transition of firms in the United States, possibly due to perceived differences in regulatory stringency. We also verify the robustness of our results against the exclusion of analytical weights in column 5.

Since there is some evidence that banks have started to incorporate the exposure to climate transition risk in their lending decisions and are reducing lending to emission-intensive firms (e.g., Ivanov et al., 2024; Altavilla et al., 2023), we examine whether our results are driven by the substitution from bank to bond financing by emission-intensive firms. We find that the results from Table 4 are not driven by a disproportionate expansion bond supply of emission-intensive companies. We do so by plotting the evolution of the total amount outstanding in million euros in Figure 1. We split the sample based on the emission intensity of the issuing company and plot the total amount outstanding for each emission intensity quartile. Figure 1 shows that the trends are comparable for firms in the second, third and fourth emission intensity quartile. In contrast, firms with the lowest emission intensity nearly doubled their total bond amount outstanding over the sample period. This can partially be explained by the increase in coverage in Trucost of low-emission-intensive firms after the Paris Agreement (2016), which also increases the number of bonds of low-emission-intensive firms in our sample. This observation is in line with previous literature (e.g., Bolton and Kacperczyk, 2021).

[26]Note that the green bond status is subsumed in the bond fixed effects.

[27]Seltzer et al. (2022) do not include bond fixed effects in their main specification either.

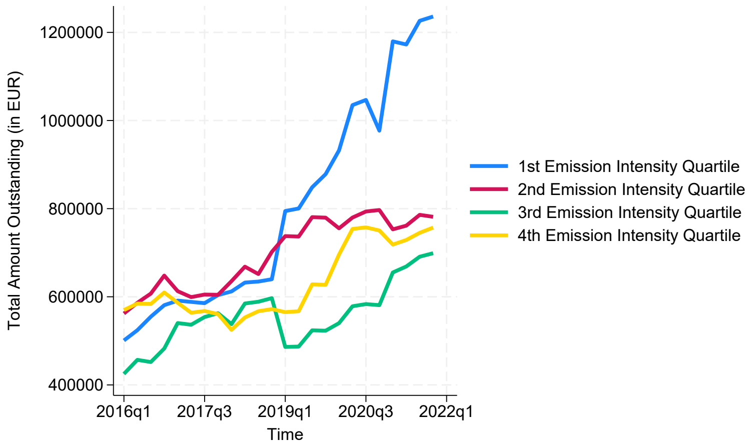

FIGURE 1: THE EVOLUTION OF TOTAL AMOUNT OUTSTANDING (IN M EUR) BY EMISSION QUARTILE OVER THE SAMPLE PERIOD.

B. *Main Results: Emission Intensity and Green Innovation*

In this section, we test whether corporate bond investors reward emission-intensive companies that make an effort to become more green, as measured by their relative engagement in green innovation. We interact emission intensity with our relative measure of green innovation. Thus, we estimate the following regression at the bond-period level:

$$\begin{aligned} \text{Spread}_{i,t} = {} & \beta_1 \text{Emission Intensity}_{f,t-1} + \beta_2 \text{Green Patent Ratio}_{f,t-1} + \beta_3 \text{Emission Intensity}_{f,t-1} \\ & \cdot \text{Green Patent Ratio}_{f,t-1} + \delta' X_{f,t-1} + \gamma' Z_{i,t-1} + \eta_f + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{2}$$

where we take the lagged value of emission intensity, the green patent ratio and the interaction between the two. We include a similar vector of corporate fundamentals, $X_{f,t-1}$, bond characteristics, $Z_{i,t-1}$. For brevity, we only show estimation results including firm- (η_f) and time fixed effects (λ_t). Again, we use firm fixed effects rather than industry fixed effects since this controls for all unobserved firm-characteristics including and beyond those related to the industry the firm operates in. However, we still show the robustness of our results against using industry and issuer-country fixed effects, rather than firm fixed effects. We cluster standard errors at the industry-level (see Table B5 in Appendix B for a list of industries). Only a subset of companies in our sample have green patents and we focus on these firms for the subsequent results, which gives us a sample of 38,374 observations.

Table 5 reports the estimation results of Equation (2). For each specification, the first column reports the results when emission intensity is included as explanatory variable, whereas the second column reports the results when the green patent ratio is included as explanatory variable. Column 3 shows the results when we include both variables and column 4 adds the interaction between the green patent ratio and emission intensity, which is our main explanatory variable of interest (β_3). Finally, in column 5 we add

Table 5: Effect of Emission Intensity and Green Patenting on Yield Spreads

	(1)	(2)	(3)	(4)	(5)
Emission Intensity$_{f,t-1}$	0.128**		0.128**	0.145***	0.145***
	(0.056)		(0.056)	(0.053)	(0.053)
Green Patent Ratio$_{f,t-1}$		14.017	14.012	55.971***	55.642***
		(12.520)	(13.217)	(16.045)	(16.367)
EI$_{f,t-1}\times$ GPR$_{f,t-1}$				-2.724***	-2.701***
				(0.813)	(0.821)
Green Bond$_{i,t-1}$					-0.485**
					(0.207)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes
Observations	38,374	38,374	38,374	38,374	38,374
R-squared	0.443	0.439	0.444	0.445	0.446

Note: OLS estimation results of Equation (2) with firm fixed effects (which include, amongst others, industry fixed effects) and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Emission intensity is measured in CO2e/USDm. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. "$EI \times GPR$" is the interaction between emission intensity and the green patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.

the green bond indicator as well.

Table 5 reveals that emission intensity affects bond yield spreads, with a coefficient which is statistically significant at the 5 percent significance level. As a result, the climate transition risk premium becomes somewhat larger: a one standard deviation increase in emission intensity raises yield spreads by 62.8 basis points.[28] Table 5 shows that the interaction between the green patent ratio and emission intensity (labeled '$EI \times GPR$') is significantly negative at the 1 percent level. A one-standard deviation increase in the green patent ratio reduces bond yield spreads by 13.6 basis points for a company with a mean emission intensity. This constitutes a reduction in the carbon premium of approximately 22 percent (i.e., 13.6/62.8), indicating that investors reward emission-intensive companies that make efforts to become more green.[29] The reduction in the risk premium for emission-intensive companies that engage in green innovation cannot be explained by firm-specific characteristics, as we incorporate both firm controls and firm fixed effects. Finally, columns 2 and 3 show that the green patent ratio does not have a statistically significant effect on bond yield spreads, as the coefficient only turns statistically significant once we add the interaction term. The effect is positive, indicating that investors view high green innovation levels on their own as risky.

[28] The within-firm standard deviation is 1.258. Using this estimate, the effect of a one standard deviation increase in emission intensity increases bond yield spreads by 16.1 basis points.

[29] The within-firm standard deviation of the green patent ratio is 0.003. Using this estimate, the effect of a one standard deviation increase in the green patent ratio increases bond yield spreads by 2.3 basis points for a company with a mean emission intensity. Based on within-firm standard deviations, this is a reduction in the carbon premium of approximately 14 percent (i.e., 2.3/16.1).

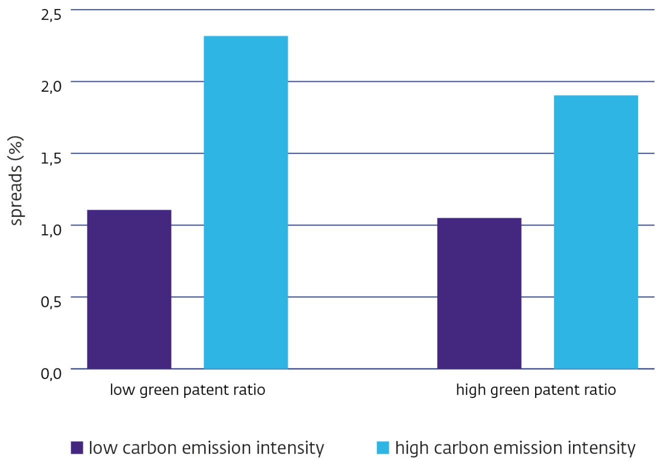

FIGURE 2: THE MEAN PREDICTED SPREAD (IN PERCENTAGES) FOR BONDS ISSUED BY FIRMS WITH A LOW/HIGH GREEN PATENT RATIO AND EMISSION INTENSITY

To further illustrate the magnitude of this result, we calculate the mean predicted yield spread for bonds issued by firms with a below-median green patent ratio and an above-median patent ratio. We then plot these against the emission intensity of the issuing firm in Figure 2. We calculate the mean predicted spread separately for firms with an emission intensity in the lowest and highest quartiles of the emission intensity distribution. Figure 2 highlights statistically and economically significant differences in yield spreads between the various firm categories.

Our results focus on the intensive margin of green innovation, as we only consider firms with at least one green patent within our sample. However, these results continue to hold when we include all companies for which patent information is available but do not have any green patents (that is, we include all companies with a green patent ratio of 0 in our sample). This expands our sample to 1,239 unique firms and 90,953 observations, which represents more than 90 percent of our 'carbon premium' sample. The results are reported in Table D1 in Appendix D. The joint effect of emission intensity and green patenting remains significant at the 5 percent significance level in this sample.[30]. In Appendix D, we also provide the results of the estimation of Equation (2) with industry- and time fixed effects, as well as issuer-country and time fixed effects in Table D2 and Table D3 respectively. In both cases, the interaction between emission intensity and the green patent ratio remains highly significant.

B.1 Alternative mechanisms

Our estimation results indicate that investors reward emission-intensive companies that make efforts to become more green, as measured by their relative engagement in green innovation. We examine whether our main results continues to hold against several alternative explanations. First, our green patent definition may be too broad, such that we contaminate our effect with general innovation. To exclude that we capture general innovation, we verify the robustness of our results against the adoption of a

[30]In the specification with bond- and time fixed effects, the joint effect of emission intensity and green patenting is significant at the 5 percent significance level as well.

Table 6: Robustness: Joint Effect of Emission Intensity and Green Patenting on Bond Yield Spreads

	(1) Classification	(2) ΔGPR	(3) Ratings	(4) Liquidity	(5) Maturity	(6) Eligiblity	(7) Purchases	(8) Patents	(9) Investments	(10) No weights
Emission Intensity$_{f,t-1}$	0.184***	0.115***	0.212*	0.165**	0.151***	0.143**	0.149***	0.151***	0.176*	0.112**
	(0.064)	(0.039)	(0.123)	(0.062)	(0.050)	(0.058)	(0.052)	(0.055)	(0.089)	(0.057)
Green Patent Ratio$_{f,t-1}$	89.267***	-6.827	78.422**	57.652***	57.058***	53.504***	56.270***	56.263***	52.955***	42.544**
	(17.429)	(10.030)	(35.211)	(19.278)	(15.878)	(17.296)	(15.777)	(15.663)	(15.145)	(18.100)
EI$_{f,t-1}$ xGPR$_{f,t-1}$	-3.428**		-4.077**	-2.882***	-2.874***	-2.586***	-2.737***	-2.714***	-2.477***	-2.206***
	(1.283)		(1.840)	(0.976)	(0.795)	(0.874)	(0.800)	(0.790)	(0.649)	(0.849)
ΔGreen Patent Ratio$_{f,t-1}$		1.303								
		(6.398)								
EI$_{f,t-1}\times\Delta$ GPR$_{f,t-1}$		-0.843**								
		(0.399)								
Green Bond$_{i,t-1}$	-0.556**	-0.385*	-0.723***	-0.347**	-0.178***	-0.477**	-0.480**	-0.485**	-0.486**	-0.366***
	(0.209)	(0.208)	(0.216)	(0.148)	(0.056)	(0.191)	(0.194)	(0.207)	(0.208)	(0.117)
Bond Rating$_{i,t-1}$			0.524**							
			(0.242)							
Liquidity$_{i,t-1}$				1.028***						
				(0.130)						
Maturity$_{i,t-1}$					0.967***					
					(0.073)					
CSPP$_{i,t-1}$						-0.389***	-0.423***			
						(0.140)	(0.122)			
EI$_{f,t-1}$ xGPR$_{f,t-1}\times$CSPP$_{i,t-1}$						-0.104	-6.343			
						(4.337)	(10.888)			
Patents$_{f,t-1}$								-0.465		
								(0.382)		
EI$_{f,t-1}\times$Invest$_{f,t-1}$									-0.346	
									(0.444)	
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Double interactions CSPP	-	-	-	-	-	Yes	Yes	-	-	-
Time-FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	18,513	32,710	16,889	35,683	38,374	38,374	38,374	38,374	38,374	38,374
R-squared	0.430	0.248	0.476	0.496	0.511	0.453	0.454	0.446	0.446	0.562

Note: Robustness tests for Equation (2), estimated by OLS with firm and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Emission intensity is measured in CO2e/USDm. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. '$'EI \times GPR'$' is the interaction between emission intensity and the green patent ratio. Δgreen patent ratio is defined as the change in the number of green patents relative to the change in the number of total patents owned by the firm on an annual basis. 'EIxΔGPR' is the interaction between emission intensity and Δgreen patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. The bond rating is continuous variable which increases with the credit risk associated with the bond. Liquidity is measured using the bid-ask spread. Maturity is a dummy variable equal to 1 if the residual maturity of the bond is longer than 10 years. CSPP indicates whether a bond is eligible for purchase under CSPP (column 6) or whether the bond has been purchased under the CSPP (column 7). '$'EI \times GPR'$ xCSPP' is the interaction between emission intensity, the green patent ratio and CSPP. While not shown, we include all pairwise interactions as controls. Patents is the natural logarithm of the total number of patents owned by a firm. 'Invest' is the interaction between emission intensity and the investment ratio, which is one of our control variables. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses and are clustered at the industry-level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

more stringent classification of green patents in a subsample. We follow Acemoglu et al. (2023) who only consider a subset of innovations in the technological subclass Y02E of the CPC as green innovations.[31] This subclass, Y02 of the CPC, consists of green patents aimed to reduce carbon emissions related to energy generation, transmission or distribution. This classification reduces the amount of green patents on which we obtain information to 32,174 patents, which are held by 177 unique companies.[32] The results are reported in column 1 of Table 6. The results show that the joint effect of emission intensity and green patenting remains statistically significant, at the 5 percent significance level. This suggests that green innovations specifically aimed at the reduction of carbon emissions are effective in lowering their corporate bond spreads for emission-intensive firms.

Second, we verify the robustness of our results by examining the annual change in green patents relative to the change in total patents (ΔGPR).[33] The results, which are reported in column 2 of Table 6, show that the combined effect of emission intensity and the change in green patents relative to the change in total patents is statistically significant at the 5 percent level and is negative. This suggests that green innovation activities are particularly significant to investors, since it is not merely the overall involvement in green innovation that matters to investors, but also the incremental addition of a green patent.

Third, we include as control variables bond credit ratings, liquidity and maturity, see column 3-5 of Table 6. In line with the results in Table C1, the effects of these additional control variables are positive and highly statistically significant. The interaction between emission intensity and the green patent ratio remains highly statistically significant once we control for credit risk, liquidity and maturity, respectively.

Fourth, we rule out that our results are driven by differential trends in the credit risk, liquidity or maturity for bonds of emission-intensive firms that engage in green innovation. To this end, we include the interactions between our main variables of interest with each relevant bond characteristic. The results are reported in Table D4 in Appendix D. Summarizing the results, the joint effect of emission intensity and green innovation remains statistically significant at the 5 percent significance level once we incorporate the additional interactions with bond credit ratings. The interaction effect remains statistically significant at the 1 percent significance level once we incorporate the additional interactions with bond liquidity and maturity, respectively. Importantly, all interactions with bond credit ratings are insignificant, suggesting that traditional credit risk models do not (yet) appropriately account for climate risk. This alleviates concerns that our results are driven by the joint determination of bond credit ratings and environmental performance. Regarding maturity, the results in column 9 of Table D4 indicate that the yield discount due to green innovation is smaller for bonds with a residual maturity longer than ten years. This suggests that the disciplining effect of corporate bond investors becomes stronger as the bond maturity shortens, since firms need to roll over their debt more frequently. This aligns with the findings of De Haas and Popov (2023). We further analyze the variation in the interaction effect between emission intensity and

[31] Following Acemoglu et al. (2023), we only consider patents which are in the Y02E10 (renewable electricity), Y02E30 (nuclear energy) or Y02E50 (biofuels and fuel from waste) subclass as green patents.

[32] Under the stricter classification, the green patent ratio has a mean of 0.003 (s.d. of 0.012). Companies with green patents under the stricter classification have higher emissions on average. Specifically, the mean of emission intensity is 3.799 CO_2 (s.d. of 5.575 CO_2e).

[33] We observe the change in the green patent ratio for 32,710 observations. ΔGPR has a mean of 0.007 (s.d. of 0.022).

green patenting across various maturity buckets. The results are reported in Table D5 in Appendix D. Consistent with the understanding that climate risk is a long-term risk, the effect of emission intensity on bond yield spreads becomes more pronounced as the bond's residual maturity increases. Again, the interaction effect is notably stronger for bonds with shorter maturities.

Fifth, in column 6 and column 7 of Table 6 we rule out that the Corporate Sector Purchase Programme (CSPP) of the ECB, which commenced in 2016, explains our results. We generate a dummy which indicates whether a given bond in our sample is eligible for purchase under the CSPP.[34] Within our sample, 10.3% of the bonds are eligible for purchase under CSPP. We interact emission intensity and the green patent ratio (both separately and jointly) with the eligibility-dummy. The results reported in column 6 indicate that eligibility for purchase under CSPP significantly reduces bond yield spreads. Eligibility under CSPP is not driving our main results, as the interaction of emission intensity, the green patent ratio and the CSPP dummy is insignificant. We run a similar test using data of the euro system on the actual purchases made under CSPP in column 7. Again, the key interaction between emission intensity and green patent ratio for the yield spread regression remains significant, while the interaction with CSPP is not.[35] This indicates the CSPP is not a mechanism driving our main findings.

Sixth, we test the robustness of our results against the inclusion of the total number of patents (in log) in column 8 of Table 6. The results show that the effect of our interaction between emission intensity and the green patent ratio remains roughly equal in size and statistically significant at the 1 percent significance level. In column 9 of Table 6, we also include an interaction of emission intensity and the investment ratio as control variable, which is statistically insignificant. Both findings underscore the significance of green innovation activities by emission-intensive companies, as neither innovation nor investments in general explain our results.

Finally, we verify that the results are robust against the exclusion of sampling weights in column 10.[36] We also test the robustness of our results against considering absolute emissions, rather than emission intensity. The results, which are reported Table D6 in Appendix D, show that the joint effect of absolute emissions and green patenting remains statistically significant. The effect also becomes larger in magnitude once we consider absolute scope 1 and 2 emissions.

B.2 Linking Green Innovation and Corporate Environmental Performance

Our findings showed that investors 'reward' emission-intensive companies, measured by lower yield spreads, when they engage in green innovation. To better understand the implications of this finding we explore whether green innovation is associated with corporate environmental performance. In other words, we

[34] To be eligible for purchase under the CSPP, a bond should be (i) IG rated by S&P, Moody's, Fitch or DRBS, (ii) issued by a NFC in the eurozone, (iii) denominated in euros, (iv) have a residual maturity between 6 months and 31 years, and (v) have a yield to maturity that exceeds the ECB deposit facility rate. See `https://www.ecb.europa.eu/press/economic-bulletin/html/eb201803.en.html`.

[35] Focusing on the subset of bonds issued by firms located in the euro area results in similar outcomes.

[36] To further rule out that the results are driven by issuers of bonds with low values, we re-estimate Equation (2) for a sample which only includes bonds with an outstanding amount larger than 200 million euro. This reduces our sample by 15%, to 32,779 observations. In this specification, the interaction term remains significant at the one percent level, with a coefficient of -1.982.

investigate whether investors truly are 'funding the fittest'. Following Bolton et al. (2023), we assess whether green patenting is associated with a decline in future emissions. That is, we estimate the impact of green innovation on corporate environmental performance by linking a companies' contemporaneous green innovation activity to its future emission intensity, at the one-, two- and three-year horizon. The results are reported in Appendix E.

Overall, our results do not provide a clear answer to whether green innovation improves environmental performance. This is qualitatively in line with Bolton et al. (2023), who do not find that green innovation materializes into future emission reductions. This raises the question why investors take green innovation into account in the bond pricing relationship. One explanation is that investors anticipate emission reductions over a longer horizon. Another potential explanation is that owning green patents signals to investors that the company possesses advanced green technologies. This has a positive option value, especially if investors anticipate stricter climate policies in the future, since it positions the firm to respond more effectively to increased policy stringency. Our results may suggest that investors take this option value into consideration in their investment decisions.

C. Holdership Dynamics

In light of the European Union's broader efforts to promote green transition goals, we assess whether European investors directly affect corporate bond spreads in relation to companies' emission intensity and their green innovation efforts. Do these investors directly affect the pricing of corporate bonds? We asses whether the joint effect of emission intensity and green patent ratio depends on holder-area shares.[37]

We consider all European investors, and focus specifically on the subset of European institutional investors and European banks. To measure the holdings of each respective investor, we follow Crosignani et al. (2020) and construct the following variable:

$$\text{Holder Share}_{i,j,t} = \frac{\frac{\text{Bond Holdings}_{i,j,t}}{\text{Amount Outstanding}_{i,t}}}{\frac{\sum_i \text{Holdings}_{i,j,t}}{\sum_i \sum_j \text{Holdings}_{i,j,t}}}$$

The numerator measures the holdings of a specific European investor sector j of a given bond i relative to the total amount outstanding (at market values) in a given period t. To take into account the size of the investor sector, we divide the numerator by the total holdings of the investor sector relative to the total holdings in that given period.[38] For our worldwide sample of corporate bonds, the holder share of

[37] While some papers analyzing bond spreads use ownership data, these studies look at equity holdings of bond-issuing firms (e.g., Huang and Petkevich, 2016; Bauer et al., 2021) but not at the direct investors of the particular bond itself.

[38] Consider the following example. Bank A and Bank B buy €100 in corporate bonds of emission intensive firms that innovate in the green space and €100 in corporate bonds of low emission intensive firms. The total amount outstanding of bonds of emission intensive firms that innovate in the green space is €400 and €800 for bonds of low emission intensive firms. When focusing solely on the numerator of the holder share, the shares held by both bank A and B are 0.25 and 0.125 in the respective bonds. However, if Bank A is larger than Bank B, holdings should be weighted by the relative size of the bank's assets to take into account that Bank B has a stronger preferences for environmental performance relative to its size (i.e. Bank B relatively overweights bonds of firms with a better environmental performance in their portfolio relative to their size). By simply looking at holdings, even adjusted for the amount outstanding, the two banks do not seem to value environmental performance differentially (see Crosignani et al. (2020)).

European investors has a mean equal to 0.34 (s.d. of 0.374), signifying the large ownership of European investors in corporate bond markets globally. Most of the European investments in corporate bonds stem from institutional investors, which holder share is on average 0.32. The average holdings of banks relative to the total amount outstanding (i.e., the numerator of the holder share) in a given period is relatively small within our sample.[39] However, correcting for the relative size of the banking sector, the holder share of banks is on average 0.26.[40] We interact emission intensity and the green patent ratio with the holder share and estimate the following regression at the bond-period level:

$$\begin{aligned}\text{Spread}_{i,t} = {} & \beta_1\text{Emission Intensity}_{f,t-1} + \beta_2\text{Green Patent Ratio}_{f,t-1} + \beta_3\text{Holder Share}_{j,t-1} \\ & + \beta_4\text{Green Patent Ratio}_{f,t-1} \cdot \text{Emission Intensity}_{f,t-1} \cdot \text{Holder Share}_{j,t-1} \\ & + \delta' X_{f,t-1} + \gamma' Z_{i,t-1} + \lambda_t + \nu_{i,t} \end{aligned} \tag{3}$$

where we include all pairwise interactions between emission intensity, the green patent ratio, and the holder share as controls. The parameter of interest is β_4, which we expect to be negative. This parameter captures whether European investors ask a lower risk premium for emission-intensive firms that make an effort to become green by engaging in green innovation. We include a vector of corporate fundamentals, $X_{f,t-1}$, and bond characteristics, $Z_{i,t-1}$ as control variables.[41] Standard errors are clustered at the industry level.

Table 7 reports the results of Equation (3). The first column shows the effect of EU-holdership on bond yield spreads, and includes an interaction between the lagged emission intensity, green patent ratio and the share of EU-holder. The interaction effect is negative and statistically significant at the 1 percent significance level. A standard deviation increase in the share of EU-holders reduces the yield spread of a company with a mean emission intensity and mean green patent ratio by 2.6 basis points. Although the effect is marginal in economic terms, it indicates that European investors are more likely to price a company's exposure to climate transition risk, taking into consideration both the emission intensity of a company as well as its green patent ratio.

We analyze the effect of holdership by European institutional investors and banks on bond yield spreads in column 2 and 3, respectively. Column 2 of Table 7 shows that interaction between emission intensity, the green patent ratio, and the holder share of institutional investors is statistically significant at the 1 percent significance level. A standard deviation increase in the share of holdings of institutional investors reduces the yield spread of company with a mean emission intensity and mean green patent ratio by approximately 2.5 basis points. Column 3 reveals that the interaction of our main variables of

[39] Table F1 in Appendix F shows that the average holdings of each investor relative to the total amount outstanding steadily declines over our sample period.

[40] The standard deviation of the holder-share of institutional investors 0.362. For banks, the standard deviation is 0.372.

[41] There is limited within-firm variation in the holder shares, i.e. there is little change in the composition of the holder share for a given firm over time. Hence, once we include firm fixed effects in this specification, the double interaction of emission intensity and the green patent ratio absorbs all variation we are after, leaving little to be explained by the triple interaction with the holder share. Therefore, as the holder share is the explanatory variable of interest in this specification, we do not include firm-fixed effects in this specification, and identify the effect of specific holders on bond yield spreads in the cross-section.

Table 7: Bond Yield Spreads and Bond Holder Dynamics

	EU	Inst.	Bank
	(1)	(2)	(3)
$\text{EI}_{f,t-1}\times\text{GPR}_{f,t-1}$	-1.523	-1.428	-1.669
	(1.081)	(1.070)	(1.010)
$\text{EU-Share}_{i,t-1}$	-0.089		
	(0.261)		
$\text{EI}_{f,t-1}\times\text{GPR}_{f,t-1}\times\text{EU}_{i,t-1}$	-4.188***		
	(1.315)		
$\text{Inst.-Share}_{i,t-1}$		0.185	
		(0.249)	
$\text{EI}_{f,t-1}\times\text{GPR}_{f,t-1}\times\text{Inst.}_{i,t-1}$		-4.173***	
		(1.154)	
$\text{Bank-Share}_{i,t-1}$			-0.392**
			(0.185)
$\text{EI}_{f,t-1}\times\text{GPR}_{f,t-1}\times\text{Bank}_{i,t-1}$			0.598
			(1.736)
Corporate Fundamentals	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes
Double Interactions	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes
Observations	38,374	38,374	38,374
R-squared	0.232	0.230	0.255

*Note: Estimation results of Equation (3), estimated by OLS with time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). The first column reports the effect of EU-holdership, which is measured as the total bond value held by EU-investors as a fraction of the amount outstanding. $'EI \times GPR'$ is the interaction between emission intensity and the green patent ratio (which are both included as control variable). $'EI \times GPR \times EU'$ is the interaction between emission intensity, the green patent ratio and the EU-share. While not reported, we include all pairwise interactions as controls. We re-estimate Equation (3) using the share of institutional investors in column 2, and the share of holdings of banks in column 3. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.*

interest with the holder share of banks is statistically insignificant. Hence, our results indicate that the pricing of climate transition risk is predominantly driven by European institutional investors.

Our findings indicate that the presence of European investors marginally affects bond yield spreads in relation to companies' emission intensity and their green innovation efforts. Do European investors also have a higher demand for bonds of emission-intensive firms that engage in green innovation? We analyze investors' demand for bonds issued by emission-intensive firms that engage in green innovation. To this end, we collapse our sample to the firm-investor-time level and estimate the following bond demand regression (e.g., Khwaja and Mian, 2008; Boermans and Vermeulen, 2020; Acharya et al., 2024)):

$$\begin{aligned}\text{Holdings}_{j,f,t} = {} & \beta_1 \text{Emission Intensity}_{f,t-1} + \beta_2 \text{Green Patent Ratio}_{f,t-1} + \beta_3 \mathbb{1}_{\text{Investor Type}=j} \\ & + \beta_4 \text{Emission Intensity}_{f,t-1} \cdot \text{Green Patent Ratio}_{f,t-1} \cdot \mathbb{1}_{\text{Investor Type}=j} \\ & + \gamma' \text{Amount Outstanding}_{f,t-1} + \mu_{f,t} + \zeta_{c,s,t} + \nu_{j,f,t} \end{aligned} \tag{4}$$

where we include all pairwise interactions between emission intensity, the green patent ratio, and the investor-indicator as controls. The parameter of interest is β_4, which we expect to be positive. This parameter captures whether certain types of European investors have a higher demand for bonds of emission-intensive firms that make an effort to become green. In our most stringent specification, we estimate the regression with firm-time ($\mu_{f,t}$) and holder area-sector-time ($\zeta_{c,s,t}$) fixed effects.[42] Hence, we compare the demand of different investor types for bonds issued by firms with a similar exposure to climate transition risk. Our holder area-sector-time fixed effects control for potential differential portfolio choices of investors in different holder areas and sectors. Our firm-time fixed effects control for all other potential characteristics that might interact with the portfolio choice (Acharya et al., 2024).

The results are reported in Table 8. We first evaluate the joint effect of emission intensity and the green patent ratio on the demand of European investors generally. In column 1 we report the results with industry-country-time- and holder-area-sector fixed effects. The interaction effect is positive and statistically significant at the one percent significance level. This indicates that European investors have a higher demand for bonds of emission-intensive firms that engage in green innovation. The results remains qualitative similar when we incorporate industry-country-time- and holder-area-sector-time fixed effects, as shown in column 2.

In column 3-5 of Table 8, we assess whether institutional investors have a higher demand for bonds issued by emission-intensive firms that engage in green innovation. We interact emission intensity and the green patent ratio (both separately and jointly) with an dummy variable indicating whether the investor is an institutional investor. The results with industry-country-time- and holder-area-sector fixed effects are reported in column 3. Column 4 reports the results with industry-country-time- and holder-area-sector-time fixed effects. The results of our most stringent specification, with firm-time and holder-area-sector-time fixed effects, are reported in column 5. Our interaction effect is positive and statistically significant at the one percent significance level for institutional investors, across all specifications. This aligns with our previous finding that European institutional investors lower yields for bonds of emission-intensive firms that engage in green innovation, as the results demonstrate that institutional investors have a higher demand for bonds of these firms.

Finally, in column 6-8 of Table 8 we assess whether European banks have a differential demand for

[42] Note that all corporate fundamentals are absorbed in this specification. In our alternative specification, with industry-country-time fixed effects, we again include our vector of corporate fundamentals, $X_{f,t-1}$, as control variable.

Table 8: Bond Demand, Emission Intensity and Green Innovation

	EU		Inst.			Bank		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Emission Intensity$_{f,t-1}$	-0.081***	-0.081***	-0.029	-0.029		-0.038	-0.038	
	(0.022)	(0.023)	(0.025)	(0.026)		(0.024)	(0.025)	
Green Patent Ratio$_{f,t-1}$	-1.503	-1.367	4.211***	4.375***		1.014	1.079	
	(1.220)	(1.248)	(1.033)	(1.046)		(1.551)	(1.549)	
EI$_{f,t-1}$×GPR$_{f,t-1}$	1.082**	1.060**	-0.559	-0.579		0.285	0.264	
	(0.425)	(0.433)	(0.480)	(0.505)		(0.265)	(0.273)	
EI$_{f,t-1}$×GPR$_{f,t-1}$×Inst.$_{j,t-1}$			1.092***	1.085***	1.125***			
			(0.303)	(0.322)	(0.343)			
EI$_{f,t-1}$×GPR$_{f,t-1}$×Bank$_{j,t-1}$						0.702**	0.669**	0.809***
						(0.299)	(0.279)	(0.295)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Amount Outstanding	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Country-Time FEs	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Firm-Time FEs	No	No	No	No	Yes	No	No	Yes
Holder Area-Sector FEs	Yes	No	Yes	No	No	Yes	No	No
Holder Area-Sector-Time FEs	No	Yes	No	Yes	Yes	No	Yes	Yes
Observations	181,740	181,668	181,740	181,668	181,650	181,740	181,668	181,650
R-squared	0.632	0.640	0.645	0.653	0.659	0.644	0.652	0.659

*Note: Estimation of Equation (4), estimated by OLS and a varying set of fixed effects. The first and second column report the regressions of bond holding of all EU-investors on emission intensity, measured in CO2e/USDm, the green patent ratio, and their interaction. We estimate the regression with industry-country-time and holder area-holder sector respectively holder area-holder sector-time FEs. Column 3-5 report the regressions of bond holding of institutional investors on emission intensity, measured in CO2e/USDm, the green patent ratio, and an indicator variable indicating whether the holder is an institutional investor. We are interested in the effect of the interaction between these three variables. While not reported, we include all pairwise interactions as controls. Column 6-8 report the regressions of bond holding of banks on emission intensity, measured in CO2e/USDm, the green patent ratio, and an indicator variable indicating whether the holder is a bank. We are again interested in the effect of the interaction between these three variables, and include all pairwise interactions as controls. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as the total bond amount outstanding of the firm. Standard errors are reported in parentheses and are clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1.*

bonds issued by emission-intensive firms that engage in green innovation. Our interaction effect is again positive and statistically significant at the one percent significance level, across all specifications. This indicates that banks also have a higher demand for bonds of emission-intensive firms that engage in green innovation. While our previous findings suggested that banks do not influence bond yield spreads, our results show that banks have a higher demand for bonds from emission-intensive firms engaged in green innovation. This can be explained by the fact that, at a global level, banks' holdings are too small to significantly affect corporate bond yield spreads. In conclusion, our findings highlight the significant influence of emission intensity and green innovation on investor demand, particularly among European institutional investors, emphasizing the growing importance of sustainability in investment decisions.

IV. Conclusion

The urgency to meet the temperature targets set by the Paris Agreement necessitates a shift towards net-zero emissions by 2050. Financial investors can play a pivotal role in the green transition. We study whether financial investors take up this role in the period following the adoption of the Paris Agreement in December 2015.

Specifically, we aim to answer the question whether corporate bond investors value companies' efforts to mitigate climate change. Since emission data is inherently backward looking, our study also considers companies' green innovation efforts. We focus on the amount of green patents relative to the total amount of patents of a given company, and assess whether the interaction between emission intensity and the green patent ratio affects corporate bond yield spreads.

Our empirical results provide evidence that a firm's emission intensity positively affects the bond yield spread. At the same time, we find that investors reward those emission-intensive companies engaging in green innovation as yield spreads are reduced for those companies. These results are robust against controlling for factors such as bond credit ratings, liquidity and investments more generally. We find similar results when adopting a more stringent classification for green patents. Moreover, our results are unaffected by eligibility or purchases of corporate bonds under the Corporate Sector Purchase Program of the ECB.

Finally, our results reveal that European institutional investors have a higher demand for bonds from emission-intensive firms that engage in green innovation, thus influencing bond yield spreads related to climate transition risk. This regional focus on environmental policies aligns with the broader efforts within the European Union to promote sustainable finance. As investors increasingly recognize the importance of companies' alignment with climate goals, our findings provides valuable insights for policymakers, investors, and businesses.

References

Accetturo, A., G. Barboni, M. Cascarano, E. Garcia-Appendini, and M. Tomasi (2022): "Credit supply and green investments," *Mimeo*.

Acemoglu, D., P. Aghion, L. Barrage, and D. Hémous (2023): "Climate change, directed innovation, and energy transition: The long-run consequences of the shale gas revolution," *NBER Working Paper No. 31657*.

Acharya, V. V., R. Banerjee, M. Crosignani, T. Eisert, and R. Spigt (2024): "Exorbitant privilege? The bond market subsidy of prospective fallen angels," *Journal of Financial Economics*, Forthcoming.

Ali, K., M. Nadeem, R. Pandey, and G. S. Bhabra (2023): "Do capital markets reward corporate climate change actions? Evidence from the cost of debt," *Business Strategy and the Environment*, 32, 3417–3431.

Altavilla, C., M. Boucinha, M. Pagano, and A. Polo (2023): "Climate risk, bank lending and monetary policy," *CEPR Discussion Paper No. 18541*.

Andersson, M., P. Bolton, and F. Samama (2016): "Hedging climate risk," *Financial Analysts Journal*, 72, 13–32.

Ardia, D., K. Bluteau, K. Boudt, and K. Inghelbrecht (2023): "Climate change concerns and the performance of green vs. brown stocks," *Management Science*, 69, 7607–7632.

Arellano, M. and S. Bond (1991): "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations," *Review of Economic Studies*, 58, 277–297.

Aswani, J., A. Raghunandan, and S. Rajgopal (2024): "Are carbon emissions associated with stock returns?" *Review of Finance*, 28, 75–106.

Battiston, S., I. Monasterolo, and M. Montone (2023): "Technological greenness and long-run performance," *Mimeo*.

Bauer, M. D., D. Huber, G. D. Rudebusch, and O. Wilms (2022): "Where is the carbon premium? Global performance of green and brown stocks," *Journal of Climate Finance*, 1, 100006.

Bauer, R., J. Derwall, and N. Pankratz (2021): "Insider ownership, governance mechanisms, and corporate bond pricing around the world," *Journal of International Money and Finance*, 117, 102423.

Boermans, M. and R. Galema (2023): "Carbon home bias of European investors," *DNB Working Paper No. 786*.

Boermans, M. A. and R. Vermeulen (2020): "International investment positions revisited: Investor heterogeneity and individual security characteristics," *Review of International Economics*, 28, 466–496.

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

——— (2023): "Global pricing of carbon-transition risk," *Journal of Finance*, 78, 3677–3754.

Bolton, P., M. T. Kacperczyk, and M. Wiedemann (2023): "The CO2 question: Technical progress and the climate crisis," *Mimeo*.

Broeders, D., M. de Jonge, and D. Rijsbergen (2024): "The European Carbon Bond Premium," *DNB Working Paper No. 798*.

Carbone, S., M. Giuzio, S. Kapadia, J. S. Krämer, K. Nyholm, and K. Vozian (2021): "The low-carbon transition, climate commitments and firm credit risk," *ECB Working Paper No. 2631*.

Cohen, L., U. G. Gurun, and Q. H. Nguyen (2023): "The ESG-innovation disconnect: Evidence from green patenting," *NBER Working Paper No. 27990*.

Crosignani, M., M. Faria-e Castro, and L. Fonseca (2020): "The (unintended?) consequences of the largest liquidity injection ever," *Journal of Monetary Economics*, 112, 97–112.

De Haas, R. and A. Popov (2023): "Finance and green growth," *The Economic Journal*, 133, 637–668.

Delis, M. D., K. d. Greiff, M. Iosifidi, and S. Ongena (2024): "Being stranded with fossil fuel reserves? Climate policy risk and the pricing of bank loans," *Financial Markets, Institutions & Instruments*, 33, 239–265.

Dick-Nielsen, J., P. Feldhütter, and D. Lando (2012): "Corporate bond liquidity before and after the onset of the subprime crisis," *Journal of Financial Economics*, 103, 471–492.

Duan, T., F. W. Li, and Q. Wen (2023): "Is carbon risk priced in the cross section of corporate bond returns?" *Journal of Financial and Quantitative Analysis*, 1–35.

Dugoua, E. and T. D. Gerarden (2023): "Innovation, inventors and the energy transition," *NBER Working Paper No. 31714*.

D'Arcangelo, F. M., T. Kruse, M. Pisu, and M. Tomasi (2023): "Corporate cost of debt in the low-carbon transition: The effect of climate policies on firm financing and investment through the banking channel," *OECD Economics Department Working Paper No. 1761*.

ElBannan, M. A. and G. Löffler (2024): "How effectively do green bonds help the environment?" *Journal of Banking & Finance*, 158, 107051.

Flammer, C. (2021): "Corporate green bonds," *Journal of Financial Economics*, 142, 499–516.

Giannetti, M., M. Jasova, M. Loumioti, and C. Mendicino (2023): ""Glossy green" banks: the disconnect between environmental disclosures and lending activities," *ECB Working Paper*.

Gourio, F. (2013): "Credit risk and disaster risk," *American Economic Journal: Macroeconomics*, 5, 1–34.

Hartzmark, S. M. and K. Shue (2023): "Counterproductive sustainable investing: The impact elasticity of brown and green firms," *Mimeo*.

Haščič, I. and M. Migotto (2015): "Measuring environmental innovation using patent data," *OECD Environment Working Paper No. 89*.

Heinkel, R., A. Kraus, and J. Zechner (2001): "The effect of green investment on corporate behavior," *Journal of Financial and Quantitative Analysis*, 36, 431–449.

Helwege, J., J.-Z. Huang, and Y. Wang (2014): "Liquidity effects in corporate bond spreads," *Journal of Banking & Finance*, 45, 105–116.

Hoepner, A. G., I. Oikonomou, Z. Sautner, L. T. Starks, and X. Zhou (2024): "ESG shareholder engagement and downside risk," *Review of Finance*, 28, 483—-510.

Hsu, P.-h., K. Li, and C.-y. Tsou (2023): "The pollution premium," *Journal of Finance*, 78, 1343–1392.

Huang, K. and A. Petkevich (2016): "Corporate bond pricing and ownership heterogeneity," *Journal of Corporate Finance*, 36, 54–74.

IPCC (2014): *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ivanov, I., M. S. Kruttli, and S. W. Watugala (2024): "Banking on carbon: Corporate lending and cap-and-trade policy," *Review of Financial Studies*, 37, 1640—-1684.

Kacperczyk, M. T. and J.-L. Peydró (2022): "Carbon emissions and the bank-lending channel," *Mimeo*.

Khwaja, A. I. and A. Mian (2008): "Tracing the impact of bank liquidity shocks: Evidence from an emerging market," *American Economic Review*, 98, 1413–1442.

Klaassen, L. and C. Stoll (2021): "Harmonizing corporate carbon footprints," *Nature Communications*, 12, 1–13.

Lanzi, E., E. Verdolini, and I. Haščič (2011): "Efficiency-improving fossil fuel technologies for electricity generation: Data selection and trends," *Energy Policy*, 39, 7000–7014.

Leippold, M. and T. Yu (2023): "The green innovation premium," *Swiss Finance Institute Research Paper No. 23-21.*

Loyson, P., R. Luijendijk, and S. v. Wijnbergen (2023): "The pricing of climate transition risk in Europe's equity market," *DNB Working Paper No. 778.*

Papoutsi, M., M. Piazzesi, and M. Schneider (2022): "How unconventional is green monetary policy," *Mimeo.*

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

——— (2022): "Dissecting green returns," *Journal of Financial Economics*, 146, 403–424.

Pietsch, A. and D. Salakhova (2022): "Pricing of green bonds: drivers and dynamics of the greenium," *ECB Working Paper No. 2728.*

Sastry, P., E. Verner, and D. Marques-Ibanez (2024): "Business as usual: Bank climate commitments, lending, and engagement," *ECB Working Paper No. 2921.*

Seltzer, L. H., L. Starks, and Q. Zhu (2022): "Climate regulatory risk and corporate bonds," *NBER Working Paper No. 29994.*

European Central Bank (2024): "Climate change-related indicators," *Access via: link.*

UNEP (2023): *Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again)*, Nairobi.

Zerbib, O. D. (2019): "The effect of pro-environmental preferences on bond prices: Evidence from green bonds," *Journal of Banking & Finance*, 98, 39–60.

Zhang, S. (2024): "Carbon returns across the globe," *Journal of Finance*, Forthcoming.

Appendix A. Time Series Properties

A1. Bond Yield

We estimate the following second-order autoregressive panel data model:

$$\text{Yield to Maturity}_{i,t} = \rho_1 \text{Yield to Maturity}_{i,t-1} + \rho_2 \text{Yield to Maturity}_{i,t-2} + \theta_i + \lambda_t + \epsilon_{i,t}$$

where θ_i are bond fixed effects, and λ_t are time fixed effects. We estimate the model by (i) pooled OLS, (ii) fixed effects OLS and (iii) first-differenced GMM. While pooled OLS only controls for time effects, fixed effects OLS and first-differenced GMM also control for the bond specific effects. Standard errors are clustered at the bond level.

Table A1: Autocorrelation in Bond Yields

	OLS	FE	GMM
Yield to Maturity$_{i,t-1}$	0.718**	0.534**	0.449**
	(0.031)	(0.006)	(0.051)
Yield to Maturity$_{i,t-2}$	0.204**	0.058**	0.156**
	(0.031)	(0.006)	(0.032)

*Note: Standard errors in parentheses, ** p<0.05, * p<0.1.*

Table A1 shows that there is significant autocorrelation in yields, even when including fixed effects as well as when estimating the relationship using GMM. The pooled OLS estimate, which only corrects for aggregate time effects, suggests that bond yields are highly persistent over time. The fixed effects OLS and GMM estimates, however, show that there is no reason to assume that bond yields are nonstationary. We therefore continue our estimation in levels, rather than in first-differences.

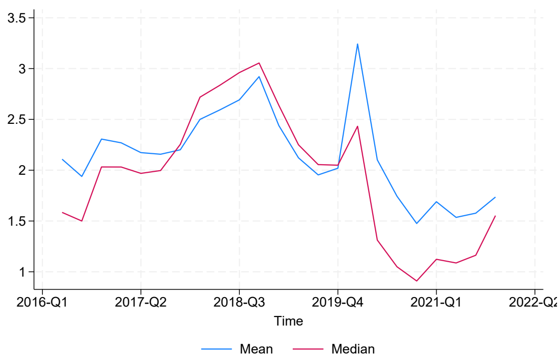

Figure A1: The evolution of the mean and median yield to maturity, reported at the quarterly-frequency and bond-level over the sample period.

A2. Emission Intensity

To assess the time series properties of emission intensity, we first collapse our sample to the firm-period level. We again use a second-order autoregressive model:

$$\text{Emission Intensity}_{f,t} = \rho_1 \text{Emission Intensity}_{f,t-1} + \rho_2 \text{Emission Intensity}_{f,t-2} + \eta_f + \lambda_t + \epsilon_{f,t}$$

where η_f are firm fixed effects and λ_t are time fixed effects. We estimate the model by the same three methods as before and standard errors are clustered at the firm-level.

Table A2: Autocorrelation in Emission Intensity

	OLS	FE	GMM
Emission Intensity$_{f,t-1}$	0.624**	0.006	0.142
	(0.140)	(0.026)	(0.297)
Emission Intensity$_{f,t-2}$	0.327**	0.181**	0.440**
	(0.135)	(0.029)	(0.091)

*Note: Standard errors in parentheses, ** p<0.05, * p<0.1.*

Table A2 displays the results. The pooled OLS estimate, which only corrects for aggregate time effects, suggests that emission intensity is persistent over time. However, the autocorrelation pattern weakens significantly when controlling for firm fixed effects as is apparent from the fixed effects OLS and GMM estimates. There is no sign that the emission intensity variable is nonstationary as the autoregressive estimates are far from the unit root.

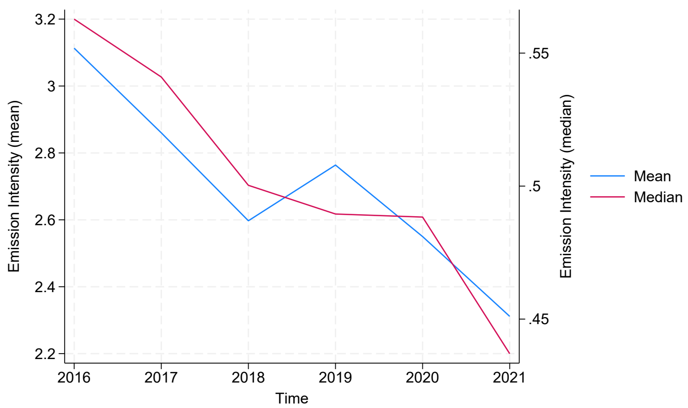

Figure A2: The evolution of the mean and median emission intensity, reported at the firm-year level over the sample period.

Appendix B. Additional Summary Statistics

B1. 'Carbon Premium' Sample

Table B1: Summary statistics

	Mean	Median	SD	P10	P90
Environmental Variables					
(Scope1 + Scope2) Emission Intensity	2.539	0.475	4.654	0.111	8.399
(Scope1 + Scope2) Absolute Emissions (in log)	13.592	13.676	2.421	10.396	16.862
Bond Characteristics					
Yield to Maturity (%)	2.638	2.256	2.782	0.31	5.352
Spread (%)	2.084	1.369	2.568	0.353	4.374
Bond Holding Value (in m EUR)	163.632	49.110	253.909	1.598	511.344
Amount Outstanding (in m EUR)	554.143	446.429	499.177	75	1096.491
Fixed Coupon	0.909	1	0.287	1	1
EUR	0.333	0	0.471	0	1
USD	0.485	0	0.500	0	1
Green bond	0.019	0	0.138	0	0
Corporate Fundamentals					
Revenue (in bn EUR)	34.304	12.126	61.864	0.851	76.642
Total Assets (in bn EUR)	57.614	24.718	78.079	3.129	162.75
Total Debt (in bn EUR)	19.5995	8.147	27.385	1.001	52.583
Profitability-Ratio (%)	4.636	4.147	6.170	-0.673	10.889
Leverage-Ratio (%)	36.485	35.936	14.529	19.362	54.604
Cash-Ratio (%)	6.326	2.944	10.158	0.354	13.641
Investment-Ratio (%)	15.122	6.912	21.082	9.109	41.255

Note: Based on 99,869 observations, reported at quarterly frequency and the security-by-security level. Absolute emissions levels are measured in CO2e and are reported in natural logarithms. Emission intensity, measured in CO2e/USDm, is scaled by a factor 1/100 and winsorized at the 2.5% level. Yield to maturity is winsorized at the 1% level. Fixed coupon is a dummy which is equal to 1 if a bond has a fixed coupon. EUR respectively USD are dummy variables, which are equal to 1 if a bond is denominated in euros respectively dollars. Green bond is a dummy which is equal to 1 if a bond has a green bond label. The profitability-ratio is defined as net income dividend by total assets (ROA). Leverage is defined as total debt divided by total assets. The cash- and investment ratio are defined as cash and capital expenditures divided by total assets, respectively. All ratio's are reported in percentages.

Table B2: Mean Emission Intensity by Simple Industry and Period

	Basic Mat.	Cons. Cyc.	Cons. N-Cyc.	Energy	Health.	Indus.	Real Estate	Tech.	Utilities
2016-Q2	7.755	0.830	1.460	5.026	0.464	2.311	0.692	0.491	11.657
2016-Q3	7.620	0.976	1.456	4.902	0.454	2.335	0.691	0.495	11.899
2016-Q4	7.404	0.829	1.465	4.967	0.453	2.243	0.701	0.438	12.054
2017-Q1	7.044	0.801	1.478	4.725	0.544	2.070	0.732	0.447	11.817
2017-Q2	7.175	0.793	1.475	5.060	0.440	2.040	0.766	0.405	11.439
2017-Q3	7.028	0.793	1.468	5.081	0.454	1.972	0.768	0.571	11.756
2017-Q4	7.240	0.815	1.391	4.764	0.452	1.919	0.753	0.551	11.554
2018-Q1	6.884	0.754	1.695	4.698	0.392	1.875	0.787	0.546	10.240
2018-Q2	6.580	0.579	1.732	4.806	0.345	1.940	0.881	0.543	10.348
2018-Q3	6.665	0.581	1.669	4.554	0.334	1.844	0.862	0.545	10.258
2018-Q4	6.577	0.562	1.388	4.509	0.337	1.832	0.871	0.531	10.289
2019-Q1	6.882	0.718	1.330	4.692	0.291	1.828	0.883	0.541	10.891
2019-Q2	7.176	0.720	1.584	5.210	0.318	1.866	0.859	0.538	10.950
2019-Q3	7.163	0.734	1.550	5.402	0.296	1.921	0.865	0.545	11.058
2019-Q4	7.153	0.741	1.566	5.637	0.296	1.927	0.861	0.538	11.026
2020-Q1	7.355	0.733	1.574	6.201	0.340	1.863	0.713	0.505	9.743
2020-Q2	7.180	0.722	1.562	5.904	0.355	1.798	0.696	0.508	9.736
2020-Q3	6.615	0.729	1.563	5.922	0.348	1.844	0.693	0.493	9.367
2020-Q4	6.798	0.716	1.455	5.883	0.347	1.799	0.696	0.419	9.300
2021-Q1	6.398	0.778	1.077	4.622	0.295	1.715	0.693	0.401	9.188
2021-Q2	6.407	0.718	1.028	4.669	0.348	1.813	0.749	0.402	8.502
2021-Q3	6.821	0.742	1.069	4.761	0.351	1.843	0.862	0.382	8.827
2021-Q4	6.606	0.729	1.011	4.845	0.338	1.822	0.861	0.342	8.933

Table B3: Distribution of observations and Emission Intensity across industries

	Emission Intensity	
GICS Industry Name	Mean	Median
Aerospace & Defense	0.353	0.234
Air Freight & Logistics	1.613	0.855
Automobile Components	1.129	0.627
Automobiles	0.251	0.239
Beverages	0.598	0.493
Biotechnology	0.323	0.352
Broadline Retail	0.440	0.262
Building Products	0.861	0.606
Capital Markets	0.046	0.049
Chemicals	5.470	4.397
Commercial Services & Supplies	1.023	0.435
Communications Equipment	0.188	0.162
Construction & Engineering	0.947	0.435
Construction Materials	15.990	19.940
Consumer Finance	0.350	0.352
Consumer Staples Distribution & Retail	0.496	0.447
Containers & Packaging	1.695	1.228
Distributors	0.386	0.379
Diversified Consumer Services	0.357	0.341
Diversified REITs	0.872	0.729
Diversified Telecommunication Services	0.534	0.385
Electric Utilities	11.330	11.669
Electrical Equipment	0.727	0.376
Electronic Equipment, Instruments & Components	0.654	0.429
Energy Equipment & Services	3.386	1.004
Entertainment	0.195	0.181
Financial Services	0.693	0.088
Food Products	1.519	0.740
Gas Utilities	2.761	2.100
Ground Transportation	1.937	1.512
Health Care Equipment & Supplies	0.267	0.198
Health Care Providers & Services	0.374	0.366
Health Care REITs	0.675	0.700
Health Care Technology	0.161	0.097
Hotels, Restaurants & Leisure	1.573	0.571

GICS Industry Name	Emission Intensity	
	Mean	Median
Household Durables	0.402	0.322
Household Products	1.612	1.235
IT Services	1.106	0.143
Independent Power and Renewable Electricity Producers	12.831	19.940
Industrial Conglomerates	4.783	1.797
Industrial REITs	0.550	0.701
Insurance	0.188	0.248
Interactive Media & Services	0.118	0.118
Leisure Products	0.544	0.604
Life Sciences Tools & Services	0.805	0.372
Machinery	0.387	0.366
Marine Transportation	11.084	11.756
Media	0.171	0.124
Metals & Mining	7.383	4.665
Mortgage Real Estate Investment Trusts (REITs)	0.110	0.071
Multi-Utilities	8.415	5.694
NULL	0.209	0.121
Office REITs	0.515	0.515
Oil, Gas & Consumable Fuels	5.988	4.700
Paper & Forest Products	6.584	5.078
Passenger Airlines	10.253	10.340
Personal Care Products	1.344	0.332
Pharmaceuticals	0.451	0.290
Professional Services	0.132	0.116
Real Estate Management & Development	0.829	0.681
Residential REITs	1.076	0.701
Retail REITs	0.692	0.707
Semiconductors & Semiconductor Equipment	1.633	0.740
Software	0.126	0.109
Specialized REITs	2.098	1.526
Specialty Retail	0.469	0.525
Technology Hardware, Storage & Peripherals	0.264	0.155
Textiles, Apparel & Luxury Goods	0.311	0.123
Tobacco	0.256	0.148
Trading Companies & Distributors	0.514	0.319
Transportation Infrastructure	0.855	0.522
Water Utilities	4.205	4.672
Wireless Telecommunication Services	0.445	0.328

Table B4: Distribution of observations across countries

Country	Freq.	%
Argentina	64	0.31%
Austria	326	1.56%
Australia	275	1.32%
Belgium	448	2.15%
Bulgaria	8	0.04%
Brazil	105	0.50%
Canada	1,069	5.12%
Chile	219	1.05%
China	421	2.02%
Colombia	59	0.28%
Cyprus	11	0.05%
Czech Republic	26	0.12%
Germany	1,085	5.20%
Denmark	135	0.65%
Estonia	8	0.04%
Finland	517	2.48%
Faroe Islands	6	0.03%
France	2,013	9.65%
Greece	61	0.29%
Hong Kong	107	0.51%
Hungary	23	0.11%
Indonesia	216	1.04%
Ireland	2	0.01%
Israel	34	0.16%
India	443	2.12%
Italy	586	2.81%
Japan	730	3.50%
Liberia	23	0.11%
Lithuania	4	0.02%
Luxembourg	261	1.25%

Country	Freq.	%
Malta	20	0.10%
Mauritius	1	0.00%
Mexico	361	1.73%
Malaysia	104	0.50%
Netherlands	494	2.37%
Norway	552	2.65%
New Zealand	100	0.48%
Panama	1	0.00%
Peru	92	0.44%
Philippines	113	0.54%
Poland	51	0.24%
Portugal	199	0.95%
Russia	168	0.81%
Saudi Arabia	7	0.03%
Singapore	267	1.28%
Slovenia	43	0.21%
South Africa	33	0.16%
South Korea	265	1.27%
Spain	497	2.38%
Sweden	879	4.21%
Switzerland	937	4.49%
Thailand	139	0.67%
Turkey	214	1.03%
Taiwan	46	0.22%
Ukraine	1	0.00%
United Arab Emirates	30	0.14%
United Kingdom	999	4.79%
United States	4,943	23.70%
Vietnam	20	0.10%

B2. Main Sample

TABLE B5: DISTRIBUTION OF OBSERVATIONS, EMISSION INTENSITY AND GREEN PATENTS ACROSS INDUSTRIES (MEAN)

GICS Industry Name	Emission Intensity	Green Patent Ratio	Green Patents
Aerospace & Defense	0.291	0.001	15.470
Air Freight & Logistics	1.466	0.001	3.500
Automobile Components	1.131	0.002	151.785
Automobiles	0.264	0.019	6056.737
Beverages	0.648	0.004	30.742
Biotechnology	0.286	0.002	15.227
Broadline Retail	0.322	0.009	6.537
Building Products	1.029	0.005	64.625
Chemicals	5.970	0.004	63.932
Commercial Services & Supplies	0.909	0.004	113.472
Communications Equipment	0.162	0.000	53.792
Construction & Engineering	0.488	0.013	10.114
Construction Materials	19.940	0.010	8.655
Consumer Staples Distribution & Retail	0.543	0.006	2.429
Containers & Packaging	1.687	0.002	4.511
Diversified Telecommunication Services	0.425	0.007	324.873
Electric Utilities	12.268	0.039	271.533
Electrical Equipment	0.789	0.025	221.485
Electronic Equipment, Instruments & Components	0.814	0.005	339.244
Energy Equipment & Services	0.773	0.010	1.519
Food Products	0.896	0.021	5.490
Gas Utilities	2.795	0.024	39.617
Ground Transportation	1.427	0.018	137.404
Health Care Equipment & Supplies	0.242	0.001	340.800
Health Care Providers & Services	0.026	0.000	0.000
Health Care Technology	0.415	0.000	20.000
Household Durables	0.624	0.011	8874.292
Household Products	0.307	0.001	67.619
IT Services	0.102	0.026	195.556
Independent Power and Renewable Electricity Producers	15.557	0.025	27.971
Industrial Conglomerates	5.693	0.007	1793.987
Leisure Products	0.462	0.010	370.913
Life Sciences Tools & Services	0.357	0.000	0.200

GICS Industry Name	Emission Intensity	Green Patent Ratio	Green Patents
Machinery	0.369	0.014	533.233
Marine Transportation	11.007	0.003	1.128
Media	0.120	0.002	3.000
Metals & Mining	9.291	0.027	26.631
Multi-Utilities	1.939	0.015	2.460
Oil, Gas & Consumable Fuels	5.455	0.011	22.342
Paper & Forest Products	3.327	0.003	22.421
Personal Care Products	0.342	0.000	8.000
Pharmaceuticals	0.362	0.002	60.865
Real Estate Management & Development	0.503	0.022	4.900
Semiconductors & Semiconductor Equipment	1.934	0.017	60.603
Software	0.120	0.001	3.261
Specialized REITs	1.565	0.000	2.000
Technology Hardware, Storage & Peripherals	0.182	0.001	561.889
Textiles, Apparel & Luxury Goods	0.906	0.001	17.167
Tobacco	0.386	0.003	88.409
Trading Companies & Distributors	1.026	0.009	95.479
Transportation Infrastructure	4.688	0.007	0.571
Water Utilities	0.830	0.008	2.667
Wireless Telecommunication Services	0.418	0.007	128.404

Table B6: Distribution of observations, Emission Intensity and Green Patents across industries (median)

GICS Industry Name	Emission Intensity	Green Patent Ratio	Green Patents
Aerospace & Defense	0.220	0.000	4.000
Air Freight & Logistics	1.352	0.001	3.500
Automobile Components	0.563	0.001	8.000
Automobiles	0.243	0.006	228.000
Beverages	0.477	0.002	14.000
Biotechnology	0.311	0.001	9.000
Broadline Retail	0.285	0.002	3.000
Building Products	0.777	0.001	54.000
Chemicals	4.101	0.001	10.000
Commercial Services & Supplies	0.339	0.000	1.000
Communications Equipment	0.177	0.000	67.000
Construction & Engineering	0.398	0.008	2.000
Construction Materials	19.940	0.001	3.000
Consumer Staples Distribution & Retail	0.515	0.005	2.000
Containers & Packaging	1.671	0.002	5.000
Diversified Telecommunication Services	0.422	0.009	7.000
Electric Utilities	13.815	0.045	16.000
Electrical Equipment	0.466	0.001	11.000
Electronic Equipment, Instruments & Components	0.295	0.003	15.000
Energy Equipment & Services	0.205	0.001	1.000
Food Products	0.630	0.000	3.000
Gas Utilities	3.667	0.002	1.000
Ground Transportation	1.350	0.011	101.000
Health Care Equipment & Supplies	0.133	0.001	7.000
Health Care Providers & Services	0.026	0.000	0.000
Health Care Technology	0.385	0.000	20.000
Household Durables	0.349	0.011	4590.000
Household Products	0.309	0.001	68.000
IT Services	0.125	0.001	292.000
Independent Power and Renewable Electricity Producers	19.940	0.015	11.000
Industrial Conglomerates	0.637	0.001	6.000
Leisure Products	0.365	0.005	201.000
Life Sciences Tools & Services	0.284	0.000	0.000

GICS Industry Name	Emission Intensity	Green Patent Ratio	Green Patents
Machinery	0.390	0.000	10.000
Marine Transportation	11.756	0.002	2.000
Media	0.130	0.002	3.000
Metals & Mining	7.456	0.003	8.000
Multi-Utilities	1.399	0.013	1.000
Oil, Gas & Consumable Fuels	4.884	0.003	10.000
Paper & Forest Products	3.074	0.002	11.000
Personal Care Products	0.332	0.000	8.000
Pharmaceuticals	0.242	0.000	21.000
Real Estate Management & Development	0.500	0.006	5.000
Semiconductors & Semiconductor Equipment	0.752	0.000	11.000
Software	0.099	0.000	3.000
Specialized REITs	1.526	0.000	2.000
Technology Hardware, Storage & Peripherals	0.110	0.000	3.000
Textiles, Apparel & Luxury Goods	0.083	0.000	17.000
Tobacco	0.391	0.004	94.000
Trading Companies & Distributors	0.735	0.009	112.000
Transportation Infrastructure	6.900	0.011	1.000
Water Utilities	0.818	0.010	3.000
Wireless Telecommunication Services	0.534	0.009	138.000

Table B7: Distribution of observations across countries

Country	Freq.	%
Austria	58	1.07%
Australia	22	0.40%
Belgium	106	1.95%
Brazil	72	1.32%
Canada	135	2.48%
Chile	23	0.42%
China	184	3.39%
Colombia	23	0.42%
Czech Republic	23	0.42%
Denmark	23	0.42%
Spain	125	2.30%
Finland	211	3.88%
France	383	7.05%
Germany	401	7.38%
Hong Kong	23	0.42%
Hungary	23	0.42%
India	136	2.50%
Italy	160	2.95%
Japan	648	11.93%
Luxembourg	54	0.99%
Malaysia	23	0.42%
Netherlands	162	2.98%
Norway	143	2.63%
New Zealand	23	0.42%
Philippines	6	0.11%
Poland	2	0.04%
Russia	94	1.73%
Saudi Arabia	7	0.13%
South Korea	222	4.09%
Sweden	195	3.59%
Switzerland	171	3.15%
Thailand	9	0.17%
Turkey	50	0.92%
Taiwan	40	0.74%
United Arab Emirates	23	0.42%
United Kingdom	185	3.41%
United States	1,245	22.91%

Appendix C. Robustness Tests for Equation (1)

Table C1: Robustness Tests: The Effect of Emission Intensity on Yield Spreads

	(1) Ratings	(2) Liquidity	(3) Maturity	(4) US	(5) No weights
Emission Intensity$_{f,t-1}$	0.139*	0.118*	0.104*	0.231***	0.069*
	(0.078)	(0.067)	(0.059)	(0.043)	(0.041)
Green Bond$_{i,t-1}$	-0.510***	-0.138	-0.036	-0.359***	-0.015
	(0.120)	(0.088)	(0.047)	(0.117)	(0.070)
Bond Rating$_{i,t-1}$	0.332*				
	(0.179)				
Liquidity$_{i,t-1}$		1.156***			
		(0.130)			
Maturity$_{i,t-1}$			1.021***		
			(0.039)		
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes
Bond-FEs	No	No	No	No	No
Observations	37,988	90,201	99,869	37,187	99,869
R-squared	0.507	0.599	0.598	0.451	0.650

Note: Robustness tests for Equation (1), estimated by OLS with firm- and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Emission intensity is measured in CO2e/USDm and green bond is a dummy variable indicating whether a bond has a green bond label. The bond rating is continuous variable which increases with the credit risk associated with the bond. Liquidity is measured using the bid-ask spread. Maturity is a dummy variable equal to 1 if the residual maturity of the bond is longer than 10 years. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses and are clustered at the industry-level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Appendix D. Robustness and Additional Tests for Equation (2)

D1. Full Sample of Patenting Firms

Table D1: Effect of Emission Intensity and Green Patenting on Yield Spreads

	(1)	(2)	(3)	(4)	(5)
Emission Intensity$_{f,t-1}$	0.105*		0.105*	0.113*	0.110*
	(0.059)		(0.059)	(0.060)	(0.061)
Green Patent Ratio$_{f,t-1}$		14.328	14.519	52.391***	51.811***
		(13.201)	(13.537)	(19.109)	(19.564)
EI$_{f,t-1}$×GPR$_{f,t-1}$				-2.465**	-2.427**
				(0.993)	(1.010)
Green Bond$_{i,t-1}$					-0.277***
					(0.097)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes
Observations	90,953	90,953	90,953	90,953	90,953
R-squared	0.539	0.536	0.539	0.539	0.539

Note: Estimation results for Equation (2), estimated by OLS with firm-fixed effects and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Emission intensity is measured in CO2e/USDm. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. $'EI \times GPR'$ is the interaction between emission intensity and the green patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.

D2. Industry Fixed Effects

Table D2: Effect of Emission Intensity and Green Patenting on Yield Spreads

	(1)	(2)	(3)	(4)	(5)
Emission Intensity$_{f,t-1}$	0.069		0.079	0.122*	0.121*
	(0.077)		(0.069)	(0.070)	(0.070)
Green Patent Ratio$_{f,t-1}$		-9.262	-13.141	8.447	8.443
		(9.617)	(11.328)	(7.045)	(7.070)
EI$_{f,t-1}$×GPR$_{f,t-1}$				-2.638***	-2.634***
				(0.884)	(0.887)
Green Bond$_{i,t-1}$					-0.460**
					(0.204)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes
Industry-FEs	Yes	Yes	Yes	Yes	Yes
Observations	38,374	38,374	38,374	38,374	38,374
R-squared	0.303	0.296	0.308	0.323	0.324

Note: Estimation results for Equation (2), estimated by OLS with firm-fixed effects and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Emission intensity is measured in CO2e/USDm. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. "$'EI \times GPR'$ ' is the interaction between emission intensity and the green patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.

D3. Issuer-Country Fixed Effects

TABLE D3: EFFECT OF EMISSION INTENSITY AND GREEN PATENTING ON YIELD SPREADS

	(1)	(2)	(3)	(4)	(5)
Emission Intensity$_{f,t-1}$	0.097*		0.123***	0.150***	0.150***
	(0.052)		(0.043)	(0.044)	(0.044)
Green Patent Ratio$_{f,t-1}$		-7.642*	-24.806**	-3.992	-3.733
		(4.210)	(9.934)	(7.241)	(7.300)
EI$_{f,t-1}$×GPR$_{f,t-1}$				-2.146***	-2.155***
				(0.730)	(0.731)
Green Bond$_{i,t-1}$					-0.392*
					(0.200)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes
Issuer-Country-FEs	Yes	Yes	Yes	Yes	Yes
Observations	38,374	38,374	38,374	38,374	38,374
R-squared	0.326	0.296	0.339	0.348	0.349

Note: Estimation results for Equation (2), estimated by OLS with firm-fixed effects and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Emission intensity is measured in CO2e/USDm. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. $''EI \times GPR'$ ' is the interaction between emission intensity and the green patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.

D4. Alternative Explanations

Table D4: Effect of Emission Intensity and Green Patenting on Yield Spreads

	(1) Ratings	(2) Ratings	(3) Ratings	(4) Liquidity	(5) Liquidity	(6) Liquidity	(7) Maturity	(8) Maturity	(9) Maturity
Emission Intensity$_{f,t-1}$	0.444*	0.444*	0.449*	0.193***	0.194***	0.203***	0.156***	0.157***	0.158***
	(0.249)	(0.249)	(0.249)	(0.065)	(0.066)	(0.064)	(0.051)	(0.050)	(0.050)
Green Patent Ratio$_{f,t-1}$	84.707**	87.167**	92.140**	58.948***	63.137***	66.268***	57.395***	56.180***	57.005***
	(35.800)	(36.737)	(34.982)	(19.226)	(17.988)	(16.813)	(15.883)	(16.485)	(15.853)
EI$_{f,t-1}\times$GPR$_{f,t-1}$	-4.438**	-4.397**	-7.393**	-2.847***	-2.753***	-3.794***	-2.867***	-2.912***	-3.048***
	(1.870)	(1.870)	(3.036)	(0.961)	(0.923)	(0.974)	(0.790)	(0.824)	(0.810)
Bond Rating$_{i,t-1}$	0.617*	0.617*	0.618*						
	(0.309)	(0.309)	(0.310)						
EI$_{f,t-1}$ xRating$_{i,t-1}$	-0.026	-0.026	-0.027						
	(0.020)	(0.020)	(0.021)						
GPR$_{f,t-1}\times$Rating$_{i,t-1}$		-0.427	-1.191						
		(1.249)	(1.043)						
EI$_{f,t-1}\times$GPR$_{f,t-1}\times$Rating$_{i,t-1}$			0.396						
			(0.290)						
Liquidity$_{i,t-1}$				1.272***	1.338***	1.442***			
				(0.146)	(0.121)	(0.141)			
EI$_{f,t-1}\times$Liquidity$_{i,t-1}$				-0.062***	-0.061***	-0.085***			
				(0.017)	(0.017)	(0.017)			
GPR$_{f,t-1}\times$Liquidity$_{i,t-1}$					-14.537	-28.637***			
					(10.222)	(3.549)			
EI$_{f,t-1}\times$GPR$_{f,t-1}\times$Liquidity$_{i,t-1}$						2.790***			
						(0.398)			
Maturity$_{i,t-1}$							1.005***	0.998***	1.019***
							(0.095)	(0.095)	(0.097)
EI$_{f,t-1}\times$Maturity$_{i,t-1}$							-0.016	-0.021	-0.026*
							(0.013)	(0.016)	(0.015)
GPR$_{f,t-1}\times$Maturity$_{i,t-1}$								8.328	-0.752
								(6.607)	(7.546)
EI$_{f,t-1}\times$GPR$_{f,t-1}\times$Maturity$_{i,t-1}$									0.816*
									(0.486)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15,496	15,496	15,496	35,683	35,683	35,683	38,374	38,374	38,374
R-squared	0.467	0.467	0.467	0.501	0.503	0.506	0.511	0.511	0.511

Note: Robustness tests for Equation (2), estimated by OLS with firm and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Emission intensity is measured in CO2e/USDm. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. $''EI \times GPR'$ ' is the interaction between emission intensity and the green patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. The bond rating is continuous variable which increases with the credit risk associated with the bond. Liquidity is measured using the bid-ask spread. Maturity is a dummy variable equal to 1 if the residual maturity of the bond is longer than 10 years. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.

D5. Variation Across Maturity Buckets

TABLE D5: THE JOINT EFFECT ACROSS MATURITY BUCKETS

	(1)	(2)	(3)	(4)	(5)
	<3 years	3-5 years	5-10 years	>10 years	>15 years
Emission Intensity$_{f,t-1}$	0.136***	0.184**	0.148**	0.139**	0.154**
	(0.037)	(0.071)	(0.071)	(0.063)	(0.060)
Green Patent Ratio$_{f,t-1}$	145.588*	66.552***	27.654	32.532*	37.756**
	(79.447)	(24.624)	(18.835)	(17.024)	(16.881)
EI$_{f,t-1}$×GPR$_{f,t-1}$	-6.696*	-3.327**	-2.086**	-1.320	-1.792*
	(3.474)	(1.321)	(0.964)	(0.855)	(0.894)
Green Bond$_{i,t-1}$	-0.144*	0.132	-0.140*	-0.363***	-0.191
	(0.073)	(0.109)	(0.073)	(0.090)	(0.219)
Time-FEs	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes
Observations	11,282	7,079	10,678	9,322	6,974
R-squared	0.489	0.586	0.610	0.480	0.496

*Note: Robustness tests for Equation (2), estimated by OLS with firm and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). We estimate Equation (2) for bonds with a residual maturity (i) of less than 3 years, (ii) between 3-5 years, (iii) between 5-10 years, (iv) of more than 10 years and (v) a residual maturity of more than 15 years. Emission intensity is measured in CO2e/USDm. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. ″$EI \times GPR'$ ' is the interaction between emission intensity and the green patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.*

D6. Absolute Scope 1 and 2 Emissions

Table D6: Joint Effect of Emissions and Green Patenting on Yield Spreads

	(1)	(2)	(3)	(4)	(5)
Scope 1+2 Emissions$_{f,t-1}$	0.137*		0.143**	0.235**	0.237**
	(0.075)		(0.071)	(0.091)	(0.091)
Green Patent Ratio$_{f,t-1}$		14.127	14.873	142.632***	143.262***
		(12.299)	(12.597)	(38.304)	(38.298)
Abs$_{f,t-1}$ xGPR$_{f,t-1}$				-7.177***	-7.212***
				(2.141)	(2.146)
Green Bond$_{i,t-1}$					-0.612***
					(0.220)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes
Bond Characteristics	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes
Observations	38,374	38,374	38,374	39,451	39,451
R-squared	0.439	0.439	0.440	0.496	0.498

*Note: Estimation results for Equation (2), estimated by OLS with firm-fixed effects and time fixed effects. The dependent variable in all regressions is the bond yield spread (YTM in excess of the risk free rate). Scope 1+2 emissions is the natural logarithm of scope 1 and 2 emissions measured in CO2e. The green patent is defined as the number of green patents owned by a given firm relative to the number of patents owned in total. 'AbsxGPR' is the interaction between absolute scope 1+2 emissions (in logs) and the green patent ratio. Green bond is a dummy variable indicating whether a bond has a green bond label. We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, investment-ratio and the natural logarithm of revenue, as well as bond characteristics, i.e. the outstanding amount, a dummy which indicates if the bond has a fixed coupon, a dummy which indicates whether the bond is denominated in euro. Standard errors are reported in parentheses errors and are clustered at the industry-level. Standard errors are clustered at the industry level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.*

Appendix E. Robustness Tests for Equation (3)

A recent, growing literature studies whether green innovation improves environmental performance. Cohen et al. (2023) find that firms with lower ESG-scores are key innovators in the United States' green patent landscape. Also Leippold and Yu (2023) show that firms that engage in green innovation reduce carbon emissions over time. ElBannan and Löffler (2024) document a significantly negative relationship between the volume of issued green bonds and future carbon intensity. This effect is concentrated among financially constrained firms, highlighting that the issuance of green bonds relaxes financial constraints, which enhances green innovations by issuing firms.

On the contrary, Bolton et al. (2023) find that there is path-dependency in innovation, as green innovation is predominantly undertaken by firms that are already green, while brown firms tend to innovate in brown technologies.Consequently,they find that green innovation does not reduce carbon emissions. This is confirmed by Dugoua and Gerarden (2023). Also Hartzmark and Shue (2023) demonstrate that brown firms face weak incentives to become more green, indicating that directing capital away from brown firms and toward green firms may be counterproductive as it makes brown firms more brown without making green firms more green.

Following Bolton et al. (2023), we estimate the impact of green innovation on corporate environmental performance by linking a companies' future emission intensity to its contemporaneous green innovation activity. That is, we estimate the following regression at the firm-year level:

$$\text{Environ. Performance}_{f,t} = \beta \text{Green Patent}_{f,t-h} + \delta' X_{f,t-1} + \eta_f + \lambda_t + \upsilon_{f,t} \quad \text{(E.1)}$$

where we use emission intensity as our main measure of environmental performance. We also verify the robustness of the results against using the absolute Scope 1 and 2 emissions (in log) as measure of environmental performance. We use either the green patent ratio as main explanatory variable in Equation (E.1) or the amount of green patents (in log). We include the vector of corporate fundamentals ($X_{f,t}$) and incorporate firm- (η_f) and time-fixed effects (λ_t).[43] For the regressions with absolute scope 1 and 2 emissions as dependent variable, we additionally include revenue (in log) as control variable. We estimate the effect over a horizon of one-, two- and three-years, i.e. $h \in \{1, 2, 3\}$. As before, standard errors are clustered at the industry-level.In each specification, Column 1-3 report the results when considering the green patent ratio as explanatory variable, and Column 4-6 report the results when using the (log) number of green patents as explanatory variable.

E.1 Emission Intensity

Following Bolton et al. (2023), we estimate the impact of green innovation on corporate environmental performance by linking a companies' future emission intensity to its contemporaneous green innovation

[43] Note that firm-fixed effects control for the average emission intensity of a given company over the sample period.

Table E1: Linking Green Innovation and Environmental Performance

	Emission Intensity$_{f,t}$					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Green Patent Ratio$_{f,t-1}$	14.632 (25.751)					
Green Patent Ratio$_{f,t-2}$		34.797 (31.313)				
Green Patent Ratio$_{f,t-3}$			53.721 (36.067)			
Green Patents$_{f,t-1}$				0.348 (0.234)		
Green Patents$_{f,t-2}$					0.348 (0.377)	
Green Patents$_{f,t-3}$						0.825** (0.363)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,363	1,009	709	1,262	923	643
R-squared	0.951	0.953	0.970	0.961	0.963	0.982

*Note: OLS estimation results of Equation E.1 with firm- and time fixed effects. We estimate the relationship between emission intensity, measured in CO2e/USDm, and the green patent ratio using a 1-, 2- and 3-year lag of the green patent ratio (column 1-3), and the amount of green patents measured in natural logarithms (column 4-6). We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.*

activity. We fail to find evidence that an increase in the amount of green patents leads to lower emission intensity. The estimates in Column 1-3 indicate that the green patent ratio is positively associated with a company's future emission intensity. However, the relationship is statistically insignificant at the one- and two- and three-year horizon for the green patent ratio. We find comparable results when considering the number of green patents as explanatory variable. In this case, we find a statistically significant, yet positive, relationship between emissions intensity and the green patent ratio at the three-year horizon.

E2. Absolute Scope 1 and 2 Emissions

We verify the robustness of our results using absolute scope 1 and 2 emission levels as outcome variable in Table E2. Again, we find no evidence that the green patent ratio or the number of green patents is associated with absolute scope 1 and 2 emissions, at the horizons we consider.

Table E2: Linking Green Patenting to Environmental Performance

	Absolute Scope 1 and 2 Emissions$_{f,t}$					
	(1)	(2)	(3)	(4)	(5)	(6)
Green Patent Ratio$_{f,t-1}$	-5.104					
	(4.925)					
Green Patent Ratio$_{f,t-2}$		-0.958				
		(4.406)				
Green Patent Ratio$_{f,t-3}$			8.074			
			(8.428)			
Green Patents$_{f,t-1}$				0.134		
				(0.104)		
Green Patents$_{f,t-2}$					0.164	
					(0.132)	
Green Patents$_{f,t-3}$						0.034
						(0.138)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes	Yes
Firm-FEs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,397	1,033	724	1,281	936	650
R-squared	0.962	0.960	0.961	0.967	0.968	0.970

*Note: Robustness tests for Equation (3), estimated by OLS including firm- and time fixed effects. We estimate the relationship between the natural logarithm of absolute scope 1 and 2 emissions, measured in CO2e, and the green patent ratio using a 1-, 2- and 3-year lag of the green patent ratio (column 1-3), and the amount of green patents measured in natural logarithms (column 4-6). We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, investment-ratio, and the natural logarithm of revenue. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.*

E3. GMM

Though we control for firm specific effects and exploit lagged green patent activity, there may still be reverse causality issues leading to bias in the fixed effects OLS estimator. This is because emission-intensive firms may have more incentives to innovate in the green space. We therefore also estimate the relationship using the Arellano and Bond (1991) two-step GMM estimator. The results using emission intensity as outcome variable are reported in Table E3 and the results using absolute scope 1 and 2 emissions are reported in Table E4. This procedure does not provide conclusive evidence either. We find a statistically significant and negative relationship between emission intensity and the number of green patents at the one- and two-year horizon. However, this association disappears when considering the absolute scope 1 and 2 emission levels. In this case, we find a statistically significant and positive relationship between absolute scope 1 and 2 emissions and the green patent ratio at the one-year horizon.

Table E3: Linking Green Patenting to Environmental Performance

	Emission Intensity$_{f,t}$					
	(1)	(2)	(3)	(4)	(5)	(6)
Green Patent Ratio$_{f,t-1}$	18.534					
	(18.197)					
Green Patent Ratio$_{f,t-2}$		30.180				
		(29.132)				
Green Patent Ratio$_{f,t-3}$			56.854			
			(87.770)			
Green Patents$_{f,t-1}$				-1.351**		
				(0.544)		
Green Patents$_{f,t-2}$					-1.071*	
					(0.586)	
Green Patents$_{f,t-3}$						-1.018
						(0.737)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes	Yes
Hansen p-value	0.566	0.409	0.478	0.809	0.816	0.462
AR(1) p-value	0.335	0.302	0.258	0.807	0.882	0.417
AR(2) p-value	0.031	0.630	-	0.061	0.260	-
Observations	1,363	1,009	709	1,262	923	643

*Note: Robustness tests for Equation (3), estimated by GMM with time fixed effects. We estimate the relationship between emission intensity, measured in CO2e/USDm, and the green patent ratio using a 1-, 2- and 3-year lag of the green patent ratio (column 1-3), and the amount of green patents measured in natural logarithms (column 4-6). We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, and investment-ratio. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.*

Table E4: Linking Green Patenting to Environmental Performance

	Absolute Scope 1 and 2 Emissions$_{f,t}$					
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Green Patent Ratio$_{f,t-1}$	7.806**					
	(3.976)					
Green Patent Ratio$_{f,t-2}$		4.504				
		(7.007)				
Green Patent Ratio$_{f,t-3}$			25.458			
			(17.346)			
Green Patents$_{f,t-1}$				-0.067		
				(0.306)		
Green Patents$_{f,t-2}$					0.211	
					(0.485)	
Green Patents$_{f,t-3}$						-0.156
						(0.634)
Corporate Fundamentals	Yes	Yes	Yes	Yes	Yes	Yes
Time-FEs	Yes	Yes	Yes	Yes	Yes	Yes
Hansen p-value	0.943	0.662	0.346	0.251	0.370	0.103
AR(1) p-value	0.096	0.122	0.147	0.177	0.177	0.222
AR(2) p-value	0.255	0.713	-	0.525	0.791	-
Observations	1,397	1,033	724	1,281	936	650

*Note: Robustness tests for Equation (3), estimated by GMM with time fixed effects. We estimate the relationship between the natural logarithm of the absolute scope 1 and 2 emissions, measured in CO2e, and the green patent ratio using a 1-, 2- and 3-year lag of the green patent ratio (column 1-3), and the amount of green patents measured in natural logarithms (column 4-6). We include a set of corporate fundamentals, i.e. the profitability-ratio, leverage-ratio, cash-ratio, investment-ratio, and the natural logarithm of revenue. Standard errors are reported in parentheses errors and are clustered at the industry-level. *** p<0.01, ** p<0.05, * p<0.1.*

Overall, our results do not provide a clear answer to whether green innovation improves environmental performance. This is qualitatively in line with Bolton et al. (2023), who do not find that green innovation materializes into future emission reductions. This raises the question why investors take green innovation into account in the bond pricing relationship. One explanation is that investors anticipate emission reductions over a longer horizon. While our data does not show that green innovation leads to emission reductions within one, two, or even three years, it is possible that implementing patented green technologies and achieving the associated emission reductions takes longer. However, extending the time frame makes it more challenging to clearly identify the effect of green innovation on corporate environmental performance. While we are not able to test this in our data, another potential explanation is that owning green patents signals to investors that the company possesses advanced green technologies. This has a positive option value, especially if investors anticipate stricter climate policies in the future, since it positions the firm to respond more effectively to increased policy stringency. Our results may suggest that investors take this option value into consideration in their investment decisions.

Appendix F. Holder-Shares

TABLE F1: EVOLUTION OF HOLDER-SHARES

	Unscaled			**Scaled**		
Period	**EU**	**Inst.**	**Banks**	**EU**	**Inst.**	**Banks**
2016-Q2	0.3693	0.3085	0.0345	0.3693	0.3417	0.2594
2016-Q3	0.3684	0.3098	0.0336	0.3684	0.3418	0.2625
2016-Q4	0.3635	0.3046	0.0338	0.3635	0.3360	0.2624
2017-Q1	0.3655	0.3113	0.0352	0.3655	0.3433	0.2600
2017-Q2	0.3586	0.3047	0.0353	0.3586	0.3366	0.2625
2017-Q3	0.3552	0.3023	0.0355	0.3552	0.3337	0.2624
2017-Q4	0.3510	0.3012	0.0333	0.3510	0.3319	0.2604
2018-Q1	0.3408	0.2924	0.0321	0.3408	0.3224	0.2574
2018-Q2	0.3354	0.2863	0.0322	0.3354	0.3170	0.2616
2018-Q3	0.3370	0.2899	0.0320	0.3370	0.3202	0.2592
2018-Q4	0.3287	0.2802	0.0335	0.3287	0.3102	0.2611
2019-Q1	0.3333	0.2856	0.0330	0.3333	0.3155	0.2584
2019-Q2	0.3449	0.2956	0.0351	0.3449	0.3264	0.2719
2019-Q3	0.3458	0.2965	0.0349	0.3458	0.3263	0.2745
2019-Q4	0.3369	0.2907	0.0349	0.3369	0.3187	0.2723
2020-Q1	0.3160	0.2721	0.0316	0.3160	0.3009	0.2543
2020-Q2	0.3247	0.2796	0.0316	0.3247	0.3079	0.2616
2020-Q3	0.3213	0.2799	0.0304	0.3213	0.3081	0.2651
2020-Q4	0.3216	0.2818	0.0335	0.3216	0.3097	0.2679
2021-Q1	0.3168	0.2757	0.0319	0.3168	0.3035	0.2591
2021-Q2	0.3098	0.2702	0.0321	0.3098	0.2975	0.2596
2021-Q3	0.3039	0.2640	0.0324	0.3039	0.2913	0.2604
2021-Q4	0.3014	0.2625	0.0320	0.3014	0.2894	0.2600
Total	0.3351	0.2877	0.0332	0.3351	0.3173	0.2624

Note: Based on a sample of 38,374 observations, reported at the quarterly frequency and bond level. We distinguish between EU-holders, institutional investors, and banks. The unscaled holder-share is defined as the holdings of a specific European investor sector of a given bond relative to the total amount outstanding (at market values) in a given period. The scaled holder-share is equal to the unscaled holder share scaled by the relative size of the investor sector.