Is Carbon Risk Priced in the Cross-Section of Corporate Bond Returns?

Online Appendix

To save space in the paper, we present additional results in the Online Appendix. Section A.1 investigates the persistence of carbon emissions intensity. Section A.2 conducts additional robustness checks for the main results. Section A.3 investigates carbon emissions intensity and environmental incidents. Section A.4 examines the implications of carbon emissions intensity for a firm's left tail risk.

Variable Definitions

Variables	Description
Carbon Emission Variables	
Carbon emissions intensity (scope 1)	Scope 1 emissions divided by the firm's revenue (unit: tCO2e/$million). Scope 1 emissions are greenhouse gas emissions generated from burning fossil fuels and production processes which are owned or controlled by the company (unit: tCO2e).
Carbon emissions intensity (scope 2)	Scope 2 emissions divided by the firm's revenue (unit: tCO2e/$million). Scope 2 emissions are greenhouse gas emissions from consumption of purchased electricity, heat or steam by the company (unit: tCO2e).
Carbon emissions intensity (scope 3)	Scope 3 emissions dvided by the firm's revenue (unit: tCO2e/$million). Scope 3 emissions are other indirect emissions from the production of purchased materials, product use, waste disposal, outsourced activities, etc. (unit: tCO2e).
ln(CEI)	The natural logarithm of carbon emissions intensity (scope 1).
Corporate Bond Variables	
β^{Bond}	The bond market beta is estimated for each bond from the time-series regressions of individual bond excess returns on the bond market excess returns (MKT^{Bond}) using a 36-month rolling window. MKT^{Bond} is the aggregate bond market portfolio, proxied by the Merrill Lynch U.S. Aggregate Bond Index.
Downside risk	Downside risk is the 5% Value-at-Risk (VaR) of corporate bond return, defined as the second lowest monthly return observation over the past 36 months. The original VaR measure is multiplied by -1 so that a higher VaR indicates higher downside risk.
Illiq	Bond illiquidity is computed as the autocovariance of the daily bond price changes within each month, multiplied by -1 as defined in Bao, Pan, and Wang (2011).
Rating	Raings are in conventional numerical scores, where 1 refers to an AAA rating and 21 refers to a C rating. Higher numerical score means higher credit risk. Numerical ratings of 10 or below (BBB- or better) are considered investment grade, and ratings of 11 or higher (BB + or worse) are labeled high yield.
ΔRating	The bond credit rating in June of year $t+1$ minus the bond credit rating in June of year t.
Maturity	The time to maturity of the bond in years.
Size	The total amount outstanding for the bond (Size, $ billion).
Lag return	The holding period bond return in the previous month $t-1$.
Return$_{(t-7:t-2)}$	The cumulative holding period bond returns from month $t-7$ to month $t-2$.
β^{DEF}	The default risk beta is estimated for each bond from the time-series regressions of individual bond excess returns on the default factor (DEF) using a 36-month rolling window, after controlling for the bond market excess return (MKT^{Bond}) and the term factor (TERM).
β^{TERM}	The term risk beta is estimated for each bond from the time-series regressions of individual bond excess returns on the term factor (TERM) using a 36-month rolling window, after controlling for the bond market excess return (MKT^{Bond}) and the default factor (DEF).

Variables	Description
β^{UNC}	The macroeconomic uncertainty risk beta is estimated for each bond from the time-series regressions of individual bond excess returns on the macroeconomic uncertainty factor (UNC) using a 36-month rolling window, after controlling for the bond market excess return (MKT^{Bond}).
$\beta^{Climate}$	The climate change news beta is estimated for each bond from the time-series regressions of individual bond excess returns on the climate change news index (Climate) using a 36-month rolling window, after controlling for the bond market excess return (MKT^{Bond}).
ΔINST_Bond	The bond institutional ownership in June of year $t+1$ minus the bond institutional ownership in June of year t. The bond institutional ownership is the fraction of the outstanding amount held by institutions in percentage.
Firm Variables	
β^{Stock}	The bond market beta is estimated for each stock from the time-series regressions of individual stock excess returns on the CRSP value-weighted market index excess returns using a 36-month rolling window.
Firm size	The natural logarithm of market capitalization at the end of June.
BM	The book equity for the fiscal year ending in calendar year $t-1$ divided by the market equity at the end of December of year $t-1$. The book equity is the book value of stockholders' equity, plus balance sheet deferred taxes and investment tax credit if available, minus the book value of preferred stock.
MOM	The cumulative holding period stock returns from month $t-12$ to $t-2$ preceding the quarterly earnings announcement month.
Amihud	Amihud Illiquidity measure, calculated as the absolute price change scaled by the volume.
VOL	The stock return volatility based on the past 60 monthly returns.
IVOL	The idiosyncratic volatility based on the Fama-French 3 factor model using the past 60 monthly returns.
INST_Stock	The number of shares held by institutions from 13F filings divided by the total number of outstanding shares at the end of December.
Gross profit/Assets	Gorss profit divided by total assets.
ROA	Operating income before depreciation as a fraction of average total assets based on most recent two periods.
ROE	Income before extraordinary items divided by average book value of equity.
Operating profit/Assets	Operating profit divided by total assets.
Debt/Equity ratio	Total debt divided by the book value of equity.
Tobin's Q	The ratio of the market value of assets (market cap of equity plus book value of debt) divided by the book value of assets.
Cash/Assets	Cash holdings divided by total assets.
Age	The number of years since the IPO year.
SUE	The change in split-adjusted quarterly earnings per share from its value four quarters ago divided by the standard deviation of this change over the prior eight quarters (four quarters minimum).
SURGE	The change in revenue per share from its value four quarters ago divided by the standard deviation of this change over the prior eight quarters (four quarters minimum).

Variables	Description
CAR(−2,+1)	Four-day cumulative abnormal return from two days before to one day after the earning announcement day (day 0), where daily abnormal return is the difference between daily stock return and the CRSP value-weighted market index return.
R&D	R&D expenditures divided by sales.
Investment	The annual growth in total assets.
OCF	The operating cash flows divided by lagged total assets.
ΔO_Score	The one-year ahead change of O-Score relative to the most recent quarter before June of year t.
Incidents	The sum of all positive changes in the RepRisk Index for a firm from June of year t to June of year $t+1$. A higher index number indicates a higher ESG risk exposure and each positive change represents an ESG incident. To ensure we capture a firm's environmental incidents rather than the S and G aspects of the RepRisk Index, we require the percentage of environmental issues used to compute the RepRisk Index is greater than 50%.
NCSKEW	The negative of the third moment of firm-specific weekly returns for each firm sample year and divided by the standard deviation of firm-specific weekly returns raised to the third power.
DTURN	The average monthly share turnover form July of year $t-1$ to June of year t minus the average monthly share turnover from July of year $t-2$ to June of year $t-1$. The monthly share turnover is calculated as the monthly trading volume divided by the total number of shares outstanding during the month.
SIGMA	The standard deviation of firm-specific weekly returns from July of year $t-1$ to June of year t.
RET	The average firm-specific weekly returns from July of year $t-1$ to June of year t.

A.1. The persistence of carbon emissions intensity

To test whether investors ex-ante require higher expected returns for bonds more exposed to carbon risk, they first need to predict a firm's future carbon emissions reasonably well. Because we use past CEI in asset pricing tests, a natural question is whether historical CEI is a good proxy for the "expected" future carbon intensity. Table A.1 of the Online Appendix investigates this issue by presenting the average year-to-year transition matrix for portfolios sorted on past CEI. Specifically, Panel A of Table A.1 presents the average probability that a firm in decile i (defined by the rows) in one year will be in decile j (defined by the columns) in the subsequent year. If CEI is not persistent at all, then all the probabilities should be approximately 10%, since a high or a low CEI value in one year should say nothing about the CEI values in the following year. Instead, all the top-left to bottom-right diagonal elements of the transition matrix exceed 10%, illustrating that a firm's carbon emissions intensity is highly persistent. Of greater importance, this persistence is especially strong for the extreme portfolios. Panel A of Table A.1 shows that for the one-year-ahead persistence of CEI, firms in decile 1 (decile 10) have a 94.13% (80.30%) chance of appearing in the same decile next year. Similarly, Panel B shows that for the two-year-ahead persistence of CEI, firms in decile 1 (decile 10) have a 89.47% (81.41%) chance of appearing in the same decile the next two years. In Panels C to E, similar results are obtained using a three- to five-year gap between the lagged and lead carbon emissions intensity. Even after a five-year gap is established between the lagged and lead CEI, firms in decile 1 (decile 10) have a 79.52% (81.32%) chance of appearing in the same decile. Overall, Table A.1 indicates that a firm's past CEI is a very informative predictor for its expected carbon intensity in future.

A.2. Robustness checks

A. Usng model-implied returns and returns to maturity

In this section, we conduct two additional robustness checks for our main results by using (1) model-implied bond returns and (2) returns to maturity as proxies for expected bond returns.

To estimate the model-implied bond return, we impose the dependence between expected bond and stock returns via the Merton (1974) model. The steps involved are as follows:

First, we estimate the hedge ratio based on the following regression model following Choi and Kim (2018),

$$R^B_{is} = \alpha_i + h_{it} R^E_{is} + \epsilon_{is}, s = t - 36, ..., t \quad \text{(A.1)}$$

where R^B_{is} is the firm-level excess bond returns in month s, calculated as the value-weighted average returns of individual bonds issued by firm i; R^E_{is} is the excess equity return of the same firm i in month s. The regression is based on a 36-month rolling window and the coefficients of interest are $\hat{h}_{it}$ and $\hat{\alpha}_i$. The intercept α captures corporate bond return premia that cannot be explained by equity return. Thus, α measures the extent to which bond returns are consistent with the corresponding equity returns and hedge ratios.

Following Equation A.1, the expected bond return is calculated as,

$$E(R^B_{it+1}) = \hat{\alpha}_i + \hat{h}_{it} E(R^E_{it+1}). \tag{A.2}$$

where $E(R^E_{it+1})$ is the expected stock return, for which we use realized stock return at month $t+1$ as a proxy. In addition to the model-implied bond returns, we also calculate returns to maturity for each corporate bond using its prices at the date. Specifically, returns to maturity is calculated taking into account of bond prices in month t plus the accrued interest and the expected coupon payment, if any, as well as the bond prices at the maturity date.

We then repeat the univariate portfolio sorting and cross-sectional regression analyses in Tables II and III, using these two alternative measures of expected bond return. Table A.4 of the Online Appendix reports a significant low carbon alpha based on these two alternative measures of expected bond returns. The six-factor alphas of the high-minus-low CEI portfolio are -0.18% (t-stat. = -3.20) and -0.22% (t-stat. = -2.51) per month for the model-implied bond returns and returns to maturity, respectively. These estimates are even larger and more significant than the corresponding estimates based on realized bond returns, suggesting that our main finding of a negative CEI-bond return relationship is robust to using different proxies of expected bond returns. Similarly, Table A.5 of the Online Appendix reports the Fama-MacBeth regression results of bond expected return on the logarithm of carbon emissions intensity. The results show that ln(CEI) negatively predict both the model-implied bond returns (columns 1 and 2) and returns to maturity (columns 3 and 4) and are highly significant.

B. Different scopes of carbon emissions

Our results so far use a firm's scope 1 carbon emissions scaled by total revenue as the main measure of carbon emissions intensity. As is shown by Bolton and Kacperczyk (2021), the data on scope 1 and scope 2 emissions are widely reported. Scope 3 emissions, on the other hand, are estimated using an input-output matrix and have only been widely reported by companies as of recently. As a result, in this section, we examine whether our main results hold using a different category of carbon emissions based on scope 2 emissions scaled by total revenue as the main measure of carbon emissions intensity. In addition, we combine scope 1 and scope 2 emissions to generate a broader category measure of carbon emissions intensity, $Total\ Scope$, defined as below:

$$Total\ Scope = \frac{Scope\ 1(tCO2e) + Scope\ 2(tCO2e)}{revenue(\$mil)}. \tag{A.3}$$

Panel A of Table A.6 shows that our main findings remain similar when we use different scopes of carbon emissions. The average return and six-factor alpha spreads between low- and high-CEI bonds are -0.12% (t-stat. = -1.90) and -0.16% (t-stat. = -2.46), respectively, when we use a firm's scope 2 carbon emissions as the main measure of carbon emissions intensity. Moreover, panel A shows economically and statistically significant returns and alpha spreads when we combine both scope 1 and scope 2 carbon emissions ($Total\ Scope$), indicating a significant relation between the broader measure of carbon emissions intensity and future bond returns.

C. Excluding the most carbon-intensive industries

Carbon emissions intrinsically vary across industries, and we control for industry effects when forming portfolios in Section A and in the cross-sectional regression analyses in Section B. In this section, we further investigate whether our results remain intact when we exclude the most carbon-intensive industries that could drive the main results. For instance, firms in the energy, chemical, or utility industry are highly likely to be carbon-intensive compared to firms in other industries. To investigate whether the low carbon alpha exists across a broader category of industries, not just the most carbon-intensive industries, we exclude the most carbon-intensive industries one by one and then all together.[39]

Panel B of Table A.6 shows that the most carbon-intensive industries do not drive our main results, rather the effect exists among a broader category of industries. Specifically, the six-factor alpha spreads between low- and high-CEI bonds remain economically and statistically significant and are -0.07% (t-stat. = -1.87), -0.11% (t-stat. = -2.87), and -0.11% (t-stat. = -2.77), respectively, when we exclude the energy, chemical, or utilities industry one by one. Moreover, when we exclude all three carbon-intensive industries, the average return and six-factor alpha spreads between low- and high-CEI bonds are -0.11% (t-stat. = -2.39) and -0.09% (t-stat. = -2.21), respectively, indicating the presence of a pervasive low carbon alpha in other industries.

D. Orthogonalized carbon emissions intensity

As discussed earlier, carbon emission intensity and firm-level characteristics are correlated. To investigate the concern about what unique information carbon emission intensity carries, we construct orthogonalized carbon emission intensity. Specifically, we run contemporaneous cross-sectional regressions of carbon emission intensity (in logarithm) with respect to firm-level characteristics to investigate the unique information in CEI, above and beyond these firm-level characteristics, including return-on-assets (ROA), debt-to-assets ratio (Debt/Assets), Tobin's Q, cash-to-assets ratio (Cash/Assets), and firm age (Age):

$$\begin{aligned} ln(CEI_{i,t}) &= \lambda_{0,t} + \lambda_{1,t}ROA_{i,t} + \lambda_{2,t}(Debt/Assets)_{i,t} + \lambda_{3,t}(Tobin's\ Q)_{i,t} \\ &\quad + \lambda_{4,t}(Cash/Assets)_{i,t} + \lambda_{5,t}Age_{i,t} + \epsilon_{i,t}^{CEI}. \end{aligned} \tag{A.4}$$

Once we generate the residuals from the above regression, we label them as orthogonalized carbon emission intensity ($\text{CEI}^{\perp}$). We then repeat the Fama-MacBeth regressions of Table III using $\text{CEI}^{\perp}$ as the main independent variable and report the results in Table A.8 of the Online Appendix. The results show that the orthogonalized carbon emission intensity remains as a significant predictor for future bond returns and are robust to controlling for the other bond-level risk characteristics.

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[39] We also perform an additional test to ascertain the predictive power of carbon emissions intensity of corporate bond returns at the industry level in Table A.7 of the Online Appendix. We form quintile portfolios of corporate bonds based on the average industry-level CEI using the Fama-French 30 industry classifications. Consistent with the earlier findings in Table II, Table A.7 of the Online Appendix shows the average return and six-factor alpha spreads of corporate bonds between low- and high-CEI industry are -0.15% (t-stat. = -2.62) and -0.10% (t-stat. = -1.92), respectively, indicating the presence of a pervasive low carbon alpha at the industry-level.

E. Firm-level evidence

Our empirical analyses thus far have been based on bond-level data since we test whether the carbon emissions intensity of a firm predicts the firm's future bond returns. One concern is that firms with large numbers of distinct bond issues can have a material impact on the cross-sectional relations that we are testing. In this section, we use three different approaches to control for the effect of multiple bonds issued by the same firm by (1) forming value-weighted average bond returns across the same firm and (2) picking the largest bond or the most-liquid bond as representative of the firm to replicate our portfolio-level analysis using this firm-level data set. Panel C of Table A.6 presents the value-weighted quintile portfolios, which indicate significant differences in the cross-section of firm-level bond returns. Specifically, the value-weighted average return and six-factor alpha spreads between low-CEI and high-CEI firms are -0.10% (t-stat. = -2.78) and -0.09% (t-statistic = -2.23), respectively. In panel C when the largest or the most-liquid bond is chosen as the representative of the firm, the return effect remains highly significant.

F. Subperiod analyses

We examine whether our finding is robust across different subperiods. First, we estimate the carbon premium after excluding the period of the financial crisis, which we define as September 2008 to December 2009. Lins, Servaes, and Tamayo (2017) find that high-corporate-social-responsibility (CSR) firms reported significantly better stock and operating performance than do low-CSR firms during the 2008–2009 financial crisis. Carbon emissions is an important component of firms' ESG rating, so the outperformance of low-CEI bonds could be concentrated in the crisis period. Panel D of Table A.6 shows that the average return and alpha spreads between the low- and high-CEI portfolios are, respectively, -0.14% per month (t-stat. = -2.21) and -0.12% per month (t-stat. = -2.18), indicating that excluding the crisis period does not affect our results.

Second, we investigate the carbon premium for the two subperiods based on a six-year interval: (a) the first precrisis subperiod from July 2006 to June 2013 and (b) the most recent subperiod from July 2013 to June 2019. Panel D of Table A.6 shows the effect is stronger for the first subperiod; the average return and alpha spreads between the low- and high-CEI portfolios are, respectively, -0.18% per month (t-stat. = -2.06) and -0.14% per month (t-stat. = -2.02). The carbon premium has a weaker economic significance for the second subperiod but remains statistically significant; the average return and alpha spreads between the low- and high-CEI portfolios are, respectively, -0.11% per month (t-stat. = -1.96) and -0.11% per month (t-stat. = -2.00).

A.3. Carbon emissions intensity and environmental incidents

Our results so far suggest that firms with higher carbon emissions intensity have more negative cash flow news and deteriorating creditworthiness in the future. In this section, we explore one specific channel through which higher CEI translates into lower future firm fundamentals. Our conjecture is that a firm's environmental risk is persistent and carbon-intensive firms are more likely to face negative environment incidents in the future than carbon efficient firms. If investors are unaware of these firms' persistently high environmental risks, carbon-intensive firms could experience negative cash flow news and lower realized bond returns.

To analyze the persistency in a firm's environment risks, we obtain the data on ESG incidents from RepRisk. RepRisk uses a rigorous process to identify and rate *negative* ESG incidents, using information from over 80,000 sources on firm incidents that are related to one of the 28 predefined ESG incidents.[40] The incident is quantified by the RepRisk Index, a proprietary algorithm, with a higher index value indicating higher ESG-related risk exposure of a firm.[41] One important advantage of the RepRisk index is that it is constructed using realized ESG incidents that are identified by systematically searching through the news, and hence is less prone to manipulation by firms (Derrien et al., 2021).

We test our prediction by examining whether carbon-intensive firms experience more environmental incidents subsequently. As every positive change in the RepRisk index indicates an ESG incident, we measure the overall amount of ESG incidents in a year using the annual sum of the positive changes in the RepRisk Index. To ensure that we capture a firm's environmental incidents rather than the "Social" and "Governance" aspects of the RepRisk Index, we require the percentage of environmental issues used to compute the RepRisk Index is greater than 50%.[42] Our regression specification is

$$ln(1 + Incidents_{i,t+1}) = \lambda_{0,t} + \lambda_{1,t} \cdot ln(CEI_{i,t}) + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1}, \quad \text{(A.5)}$$

where $Incidents_{i,t+1}$ is the sum of all positive changes in the RepRisk Index of firm i from July of year t to June of year $t+1$. We take the natural log of the variable $Incidents_{i,t+1}$ because it is highly skewed to the right. Note that the variable $ln(1 + Incidents_{i,t+1})$ has a value of zero when firm i has no ESG incidents over a period. The key independent variable is $ln(CEI_{i,t})$, the natural log of firm-level carbon emissions intensity in June of each year t, for firms with a fiscal year ending in year $t-1$. $Control_{k,t}$ denotes the same set of control variables as in Equation 7, except that we replace lagged measures of firm creditworthness with lagged environmental incidents.

Table A.18 of the Online Appendix shows the regression results. Column (1) shows that the coefficient on $ln(CEI)$ is 0.099 with a highly significant t-statistic of 14.73, indicating that high-CEI firms experience more environmental incidents in the next year than low-CEI firms do. Multiplying the coefficient on $ln(CEI)$ with the spread in the average $ln(CEI)$ between quintiles 5 and 1 in Table II yields an estimated difference of 0.30 (=0.099 $\times$ 3.07). As a result, the economic significance shows that high-CEI firms (quintile 5) experiences 30% more environmental incidents than low-CEI firms (quintile 1) over the following year. In column 2, we control for industry fixed effects and find similar results. Overall, the results support our conjecture that carbon-intensive firms have persistently high environment risk exposures, which are subsequently manifested in more environmental incidents, poorer fundamentals, and deteriorating creditworthiness.

[40]The RepRisk website and Derrien, Krueger, Landier, and Yao (2021) provide great details on its data sources and methodology.

[41]The RepRisk index ranges from 0 to 100, with a higher number indicating a higher ESG risk exposure. The RepRisk index of a firm increases whenever the firm is associated with an ESG incident, and the relative increase depends on the severity, the reach, and the novelty of the incident and on the intensity of the news about the incident.

[42]Our results are similar if we use alternative threshold of 60% and 80% as cutoff.

A.4. Carbon emissions intensity and downside risk

Finally, we investigate the implication of carbon emissions intensity for a firm's left tail risk, as bond values are particularly sensitive to downside risk (Hong and Sraer, 2013). This test is partly motivated by practitioners' argument that a major driver of integrating ESG scores into the investment process is to reduce downside risk exposures, as negative ESG exposures could imply substantial legal, reputational, operational, and financial risks (BlackRock, 2015). Following the literature (Chen, Hong, and Stein, 2001; Kim, Li, and Zhang, 2011), we use stock price crash risk proxies to measure the downside risk of a firm. To calculate firm-specific crash risk measures, we first estimate firm-specific weekly returns for each firm and year.[43] Specifically, the firm-specific weekly return, denoted by W, is defined as the natural log of one plus the residual return from the expanded market model regression,

$$r_{i,t} = \beta_{0,t} + \beta_{1,t} r_{m,t-2} + \beta_{2,t} r_{m,t-1} + \beta_{3,t} r_{m,t} + \beta_{4,t} r_{m,t+1} + \beta_{5,t} r_{m,t+2} + \epsilon_{i,t}, \tag{A.6}$$

where $r_{i,t}$ is the return on stock i in week t and $r_{m,t}$ is the return on the CRSP value-weighted market index in week t. We include the pre- and post-two weeks for the market index return to allow for nonsynchronous trading. The firm-specific return for firm i in week t, $W_{i,t}$, is measured by the natural log of one plus the residual return from Equation A.6, $W_{i,t} = ln(1 + \epsilon_{i,t})$.

Following Chen, Hong, and Stein (2001), our first measure of crash risk is the negative conditional return skewness (NCSKEW). NCSKEW for a firm-year is calculated by taking the negative of the third moment of firm-specific weekly returns for each sample year and dividing it by the standard deviation of firm-specific weekly returns raised to the third power, as shown in Equation A.7,

$$NCSKEW_{i,t} = \frac{n\,(n-1)^3 \sum W_{i,t}^3}{(n-1)\,(n-2)\left(\sum W_{i,t}^2\right)^{3/2}} \tag{A.7}$$

Our second measure of crash risk is the "down-to-up volatility" (DUVOL), which captures asymmetric volatilities between negative and positive firm-specific weekly returns. DUVOL for a firm-year is calculated by first separating all weeks with returns below the sample mean ("down" weeks), from those with returns above the sample mean ("up" weeks), and then taking the standard deviation for each of these subsamples separately. We then take the natural log of the ratio of the standard deviation on the down weeks to the standard deviation on the up weeks, as shown in Equation A.8,

$$DUVOL_{i,t} = log\left\{\frac{(n_u - 1)\sum_{Down} W_{i,t}^2}{(n_d - 1)\sum_{Up} W_{i,t}^2}\right\} \tag{A.8}$$

[43] The crash risk measures are constructed using weekly stock return data from July 2006 to June 2019. Specifically, we first calculate the weekly return by compounding daily returns from Monday to Friday, and then assign weekly returns to the 12-month period over July of year t to June of year $t + 1$ for each firm-year. We require at least 26 weeks of data available in a firm-year.

In our setting, we examine the predictability of carbon emissions intensity for the future stock price crash risk using the specification below,

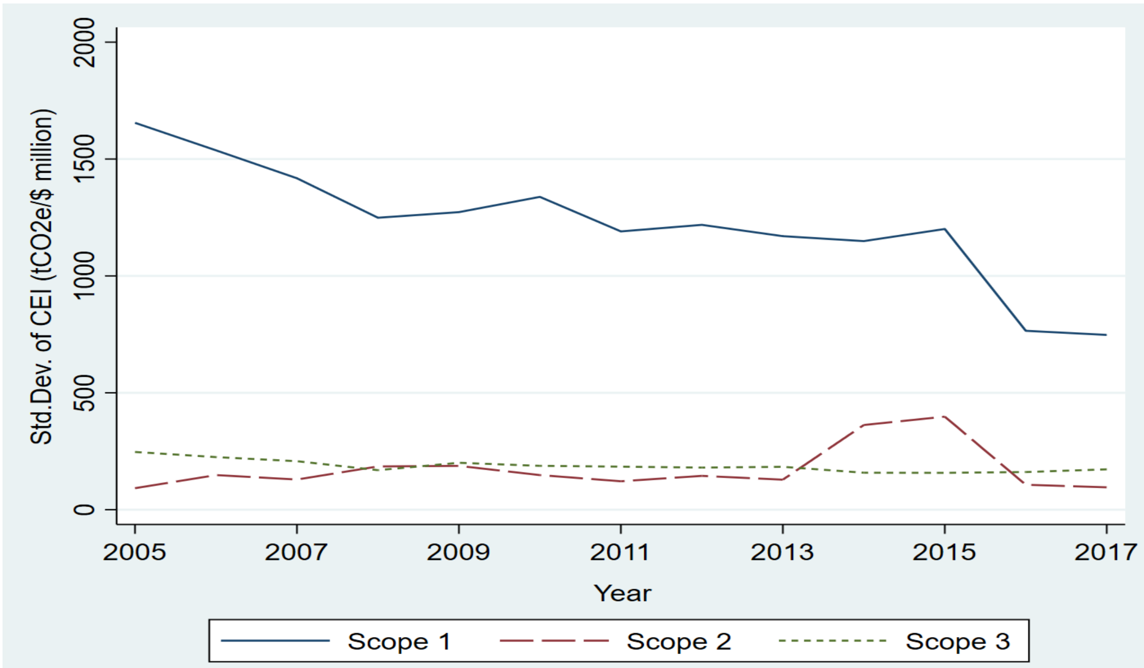
$$(\text{A.9}) \qquad NCSKEW(DUVOL)_{i,t+1} = \lambda_{o,t} + \lambda_{1,t} \cdot ln(CEI_{i,t}) + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1},$$

where $NCSKEW_{i,t+1}$ is the negative conditional return skewness of firm i over the period from July of year t to June of year $t+1$. $DUVOL_{i,t+1}$ is the "down-to-up volatility" of firm i over the period from July of year t to June of year $t+1$. The key independent variable is $ln(CEI_{i,t})$, the natural log of firm-level carbon emissions intensity in June of each year t, for firms with a fiscal year ending in year $t-1$. $Control_{k,t}$ denotes control variables, including the one-year-lagged dependent variable, DTURN, SIGMA, RET, firm size, the book-to-market ratio, return-on-assets, and leverage, specified in the Appendix. We also include industry and year fixed effects in the regression and cluster standard errors at the firm level. Table A.19 of the Online Appendix reports the regression results and shows that the coefficients of $ln(CEI_{i,t})$ are significantly positive, 0.0170 (t-stat. = 2.25) and 0.0096 (t-stat. = 2.08), respectively, for NCSKEW and DUVOL, indicating that firms with high carbon emissions intensity experience elevated future stock price crash risk. Our result is consistent with Kim, Li, and Li (2014) who document that socially responsible firms experience lower future stock price crash risk.

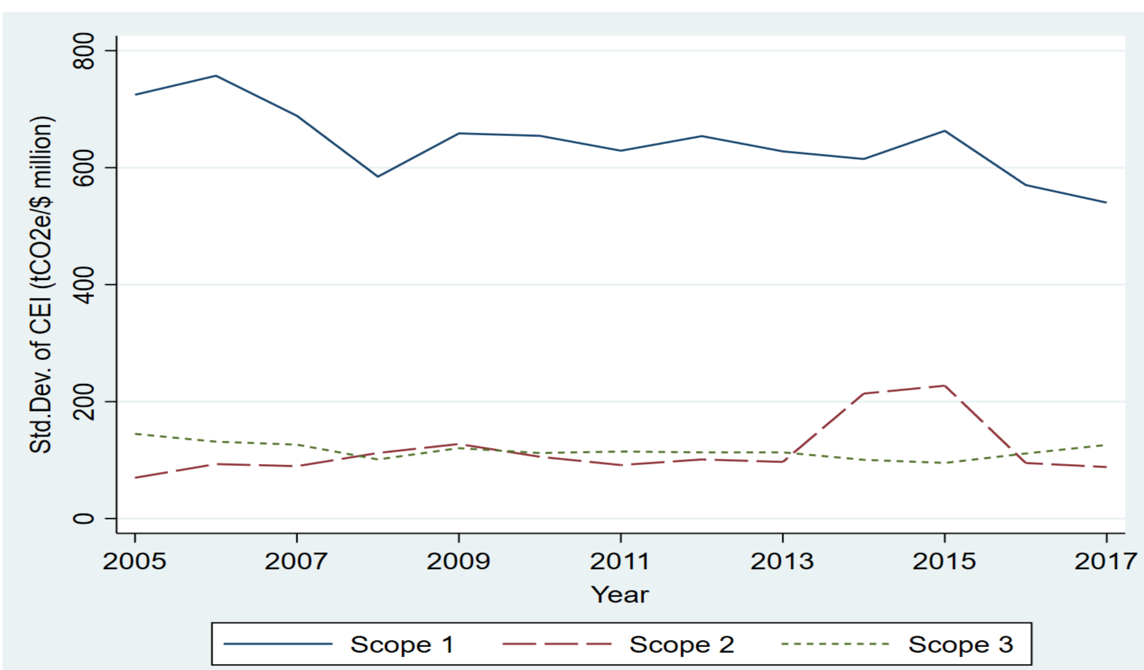
FIGURE A.1

Cross and Within-Industry Variation in Carbon Emissions Intensity

Panel A: Cross-industry standard deviation in carbon emissions intensity



Panel B: Within-industry standard deviation in carbon emissions intensity

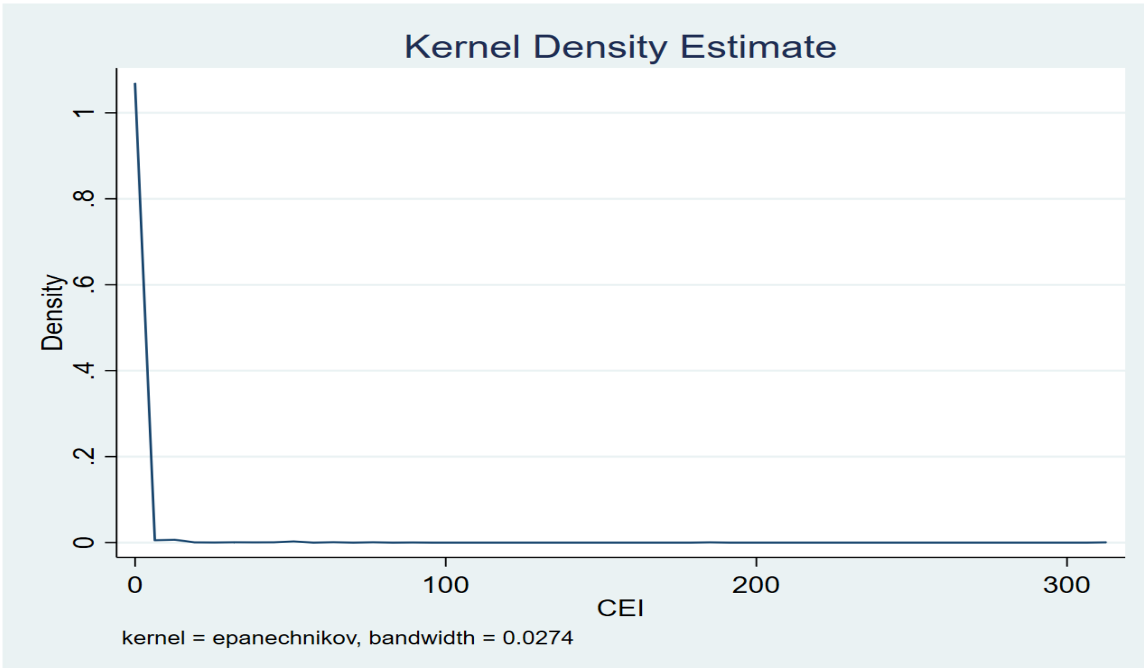


Panel A (Panel B) of the figure depicts the cross-industry (within-industry) standard deviations in carbon emissions intensity over time based on the Trucost dataset. The sample period is from 2005 to 2017.

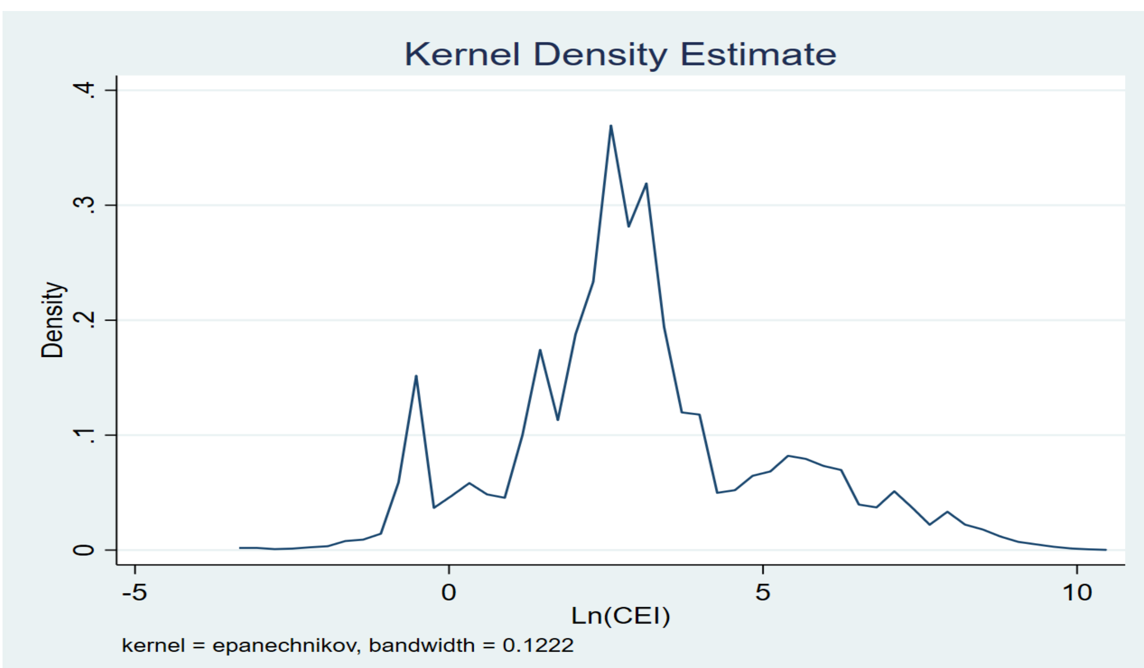
FIGURE A.2

Kernel Density Estimates of Carbon Emissions Intensity

Panel A: Kernel Density Estimates of CEI



Panel B: Kernel Density Estimates of ln(CEI)



Panel A (Panel B) of this figure depicts the kernel density estimates of carbon emissions intensity (the natural logarithm of carbon emissions intensity), defined as firm-level carbon emissions divided by the total revenue of the firm in millions of US dollars.

TABLE A.1

Transition Matrix of Carbon Emissions Intensity

This table reports the year-to-year transition matrix for portfolios of firms sorted on the carbon emissions intensity from one- to five-year-ahead. Each year from 2005 to 2017, we form decile portfolios of firms based on their scope 1 carbon emissions intensity (CEI), defined as the firm-level greenhouse gas emission in CO2 equivalents divided by the total revenue of the firm in millions of dollars. The table presents the average probability that a firm in decile i (defined by the rows) in one year will be in decile j (defined by the columns) in the subsequent year. If carbon emissions intensity were completely random, then all the probabilities should be approximately 10%, since a high or low CEI in one year should say nothing about the carbon emissions intensity in the following year. Instead, all the diagonal elements of the transition matrix exceed 10%, illustrating that CEI is highly persistent.

Panel A: One-year-ahead

Decile	Low CEI	2	3	4	5	6	7	8	9	High CEI
Low CEI	**94.13%**	3.47%	0.68%	0.85%	0.21%	0.38%	0.08%	0.17%	0.00%	0.04%
2	9.43%	**58.03%**	3.21%	1.44%	0.46%	0.38%	0.17%	0.13%	0.04%	0.00%
3	0.38%	6.68%	**73.42%**	3.30%	1.10%	0.46%	0.25%	0.34%	0.00%	0.04%
4	0.30%	0.51%	6.93%	**72.61%**	4.31%	2.07%	0.51%	0.42%	0.08%	0.00%
5	0.08%	0.21%	0.51%	8.79%	**74.26%**	4.31%	0.59%	0.21%	0.04%	0.00%
6	0.04%	0.04%	0.38%	0.80%	7.48%	**68.09%**	5.92%	0.97%	0.17%	0.00%
7	0.00%	0.04%	0.21%	0.34%	1.06%	7.44%	**68.98%**	6.47%	0.30%	0.17%
8	0.00%	0.13%	0.17%	0.21%	0.93%	0.97%	7.95%	**69.86%**	4.95%	0.34%
9	0.04%	0.00%	0.08%	0.00%	0.04%	0.13%	0.17%	5.62%	**74.85%**	5.16%
High CEI	0.00%	0.00%	0.00%	0.00%	0.04%	0.00%	0.04%	0.38%	5.28%	**80.30%**

Panel B: Two-year-ahead

Decile	Low CEI	2	3	4	5	6	7	8	9	High CEI
Low CEI	**89.47%**	5.48%	1.04%	2.03%	0.44%	0.93%	0.16%	0.38%	0.00%	0.05%
2	12.34%	**59.70%**	4.99%	2.96%	1.04%	0.88%	0.38%	0.22%	0.11%	0.05%
3	1.15%	11.84%	**68.20%**	4.88%	2.36%	1.37%	0.55%	0.49%	0.00%	0.05%
4	0.55%	1.81%	13.27%	**65.02%**	6.25%	3.40%	1.15%	1.04%	0.11%	0.00%
5	0.22%	0.38%	1.15%	14.97%	**67.43%**	6.74%	1.37%	0.33%	0.22%	0.00%
6	0.05%	0.05%	0.88%	1.86%	11.84%	**64.80%**	7.89%	1.97%	0.27%	0.00%
7	0.05%	0.11%	0.22%	0.71%	2.19%	11.73%	**66.23%**	7.46%	0.38%	0.33%
8	0.00%	0.27%	0.44%	0.49%	1.04%	1.32%	9.92%	**69.08%**	7.51%	0.82%
9	0.05%	0.00%	0.22%	0.00%	0.05%	0.27%	0.49%	8.22%	**73.68%**	8.06%
High CEI	0.00%	0.00%	0.00%	0.00%	0.05%	0.00%	0.11%	0.66%	8.55%	**81.41%**

Panel C: Three-year-ahead

Decile	Low CEI	2	3	4	5	6	7	8	9	High CEI
Low CEI	**84.05%**	7.83%	1.73%	3.16%	0.60%	1.43%	0.60%	0.60%	0.00%	0.00%
2	12.49%	**70.13%**	6.47%	4.89%	1.81%	1.66%	0.75%	0.15%	0.23%	0.08%
3	1.50%	18.13%	**65.46%**	6.02%	3.46%	2.41%	1.13%	0.68%	0.08%	0.08%
4	1.05%	2.78%	19.71%	**60.12%**	8.20%	4.89%	1.66%	1.73%	0.15%	0.00%
5	0.45%	0.68%	1.88%	23.02%	**62.45%**	9.48%	2.48%	0.60%	0.08%	0.00%
6	0.00%	0.23%	1.13%	3.01%	14.75%	**66.29%**	10.31%	2.71%	0.45%	0.00%
7	0.08%	0.15%	0.38%	1.05%	3.46%	16.10%	**64.79%**	9.26%	0.15%	0.53%
8	0.00%	0.38%	0.68%	0.83%	0.90%	1.81%	12.94%	**69.22%**	11.21%	1.35%
9	0.08%	0.00%	0.23%	0.00%	0.00%	0.45%	0.98%	11.51%	**73.89%**	11.66%
High CEI	0.00%	0.00%	0.00%	0.08%	0.00%	0.00%	0.15%	1.05%	12.42%	**84.95%**

Table A.1: **(Continued)**

Panel D: Four-year-ahead

Decile	Low CEI	2	3	4	5	6	7	8	9	High CEI
Low CEI	**81.39%**	8.31%	2.16%	3.90%	0.78%	1.65%	1.13%	0.69%	0.00%	0.00%
2	13.94%	**67.53%**	6.15%	5.89%	2.51%	1.73%	0.87%	0.17%	0.35%	0.00%
3	2.42%	19.65%	**60.52%**	7.53%	3.98%	3.38%	1.39%	0.87%	0.17%	0.09%
4	1.47%	3.98%	23.81%	**49.70%**	8.48%	6.75%	2.42%	2.42%	0.17%	0.00%
5	0.52%	0.69%	2.42%	29.18%	**57.14%**	11.43%	2.60%	0.87%	0.09%	0.00%
6	0.09%	0.26%	1.56%	3.72%	17.32%	**57.14%**	10.74%	3.72%	0.43%	0.00%
7	0.00%	0.17%	0.35%	1.39%	4.94%	18.53%	**62.86%**	9.18%	0.26%	0.61%
8	0.00%	0.35%	1.04%	1.04%	0.78%	2.16%	14.37%	**66.15%**	11.95%	1.90%
9	0.09%	0.00%	0.35%	0.00%	0.00%	0.69%	1.13%	12.64%	**70.82%**	13.33%
High CEI	0.00%	0.00%	0.00%	0.00%	0.09%	0.00%	0.17%	1.30%	14.37%	**83.03%**

Panel E: Five-year-ahead

Decile	Low	2	3	4	5	6	7	8	9	High
Low CEI	**79.52%**	8.39%	3.00%	3.80%	0.80%	2.10%	1.30%	1.10%	0.00%	0.00%
2	14.49%	**64.84%**	6.09%	7.19%	2.70%	1.90%	1.10%	0.20%	0.20%	0.00%
3	3.10%	21.28%	**55.84%**	8.29%	4.70%	3.90%	1.90%	0.80%	0.30%	0.10%
4	1.80%	4.60%	26.37%	**42.46%**	8.09%	8.39%	3.20%	3.10%	0.20%	0.00%
5	0.60%	0.70%	2.50%	33.37%	**50.65%**	13.29%	2.30%	1.40%	0.10%	0.00%
6	0.20%	0.20%	2.00%	4.50%	22.48%	**48.95%**	11.09%	4.00%	0.50%	0.00%
7	0.00%	0.20%	0.70%	1.50%	4.90%	21.78%	**59.54%**	8.79%	0.60%	0.60%
8	0.00%	0.30%	1.30%	1.00%	1.00%	2.50%	15.68%	**62.44%**	12.59%	2.60%
9	0.10%	0.00%	0.50%	0.00%	0.00%	0.80%	1.10%	13.59%	**68.63%**	14.19%
High CEI	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%	0.20%	1.50%	15.68%	**81.32%**

TABLE A.2

Firm Characteristics of Corporate Bond Portfolios Sorted by Carbon Intensity

Panel A of this table reports the average firm-level characteristics of Table II including stock market beta (β^{Stock}), Firm size (natural log of market equity), BM (book-to-market), MOM (Return$_{t-12:t-2}$), Amihud measure of illiquidity, VOL (stock return volatility based on the past 60 monthly returns), IVOL (idiosyncratic volatility based on the Fama-French 3 factor model using the past 60 monthly returns), and institutional ownership (INST_Stock, %). Panel B reports the average firm-level fundamental characteristics including Gross profit/Assets, ROA (return-on-assets), ROE (return-on-equity), Operating profit/Assets, Debt/Equity ratio, Debt/Assets ratio, Tobin's Q, Cash/Assets ratio, and firm age. Newey-West adjusted t-statistics are given in parentheses. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

Panel A: Average firm characteristics

	β^{Stock}	Firm size	BM	MOM	Amihud	VOL (%)	IVOL (%)	INST_Stock (%)
Low	1.11	23.95	0.54	0.10	0.16	8.22	6.35	70.42%
2	1.10	23.77	0.57	0.11	0.16	8.58	6.76	70.72%
3	1.09	23.94	0.53	0.11	0.15	8.09	6.19	70.54%
4	1.09	23.99	0.58	0.11	0.16	8.18	6.28	70.47%
High	1.19	23.38	0.62	0.11	0.21	9.09	7.07	74.78%
High − Low	0.09***	-0.56***	0.08***	0.01	0.05***	0.88***	0.72***	4.36***
	(3.29)	(-9.34)	(4.93)	(0.60)	(3.48)	(5.95)	(5.83)	(7.55)

Panel B: Average firm characteristics (accounting fundamentals)

	Gross profit/Assets	ROA	ROE	Operating profit/Assets	Debt/Equity ratio	Debt/Assets	Tobin's Q	Cash/Assets	Age (yr)
Low	0.30	0.14	0.18	0.13	3.04	0.68	1.90	0.14	37.68
2	0.25	0.13	0.14	0.11	3.09	0.69	1.62	0.12	40.31
3	0.26	0.13	0.16	0.12	3.40	0.71	1.67	0.09	45.16
4	0.23	0.13	0.15	0.12	3.16	0.67	1.64	0.09	45.06
High	0.22	0.13	0.12	0.11	2.39	0.66	1.64	0.09	39.48
High − Low	-0.07***	-0.02***	-0.06***	-0.02***	-0.65***	-0.02***	-0.26***	-0.05***	1.80***
	(-16.70)	(-3.84)	(-7.76)	(-4.66)	(-4.06)	(-3.45)	(-8.65)	(-8.99)	(3.66)

TABLE A.3

Alternative Factor Models for Corporate Bond Portfolios Sorted by CEI

This table replicates the results in Table II for quintile portfolios of corporate bonds sorted by the firm-level carbon emissions intensity (CEI). The table reports, for each quintile portfolio, the average CEI, the next-month average excess return, the 5-factor alpha estimated from the Fama and French (2015) model, the Q4-factor alpha from the Hou, Xue, and Zhang (2015) model, and the 6-factor and 5-factor alphas from combining these models with the 1-factor bond CAPM model. The 1-factor bond CAPM model includes the excess bond market return. The last row reports the differences in monthly average returns and alphas for the quintile 5 and quintile 1 portfolios. Newey-West adjusted t-statistics are given in parentheses. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

Quintiles	Average CEI	Average return	FF 5-factor alpha	Q4-factor alpha	(FF5 + bond CAPM) 6-factor alpha	(Q4 + bond CAPM) 5-factor alpha
Low	36.75	0.37	0.24	0.34	0.05	0.07
		(3.66)	(2.16)	(3.22)	(1.29)	(1.46)
2	153.18	0.35	0.22	0.33	0.04	0.08
		(3.42)	(2.03)	(3.33)	(0.99)	(1.74)
3	333.77	0.33	0.22	0.31	0.05	0.06
		(3.42)	(2.21)	(3.23)	(1.45)	(1.56)
4	518.59	0.31	0.19	0.28	0.02	0.02
		(3.28)	(1.88)	(2.80)	(0.39)	(0.44)
High	1127.34	0.23	0.11	0.18	-0.02	-0.01
		(2.51)	(1.29)	(2.26)	(-0.43)	(-0.06)
High - Low		-0.14***	-0.13***	-0.16***	-0.07*	-0.08*
		(-2.62)	(-2.68)	(-2.81)	(-1.89)	(-1.81)

TABLE A.4

Portfolio Sorting with Alternative Proxies for Expected Bond Returns

This table replicates the results in Table II with two alternative proxies for expected bond returns. Columns 1 and 2 (columns 3 and 4) report returns and alphas of quintile portfolios using model-implied bond returns (returns to maturity). We form quintile portfolios of corporate bonds based on the firm-level carbon emissions intensity (CEI) in June of each year t for firms with fiscal year ending in year $t-1$. The portfolio returns are calculated for July of year t to June of year $t+1$ and then rebalanced. The last row reports the differences in monthly average returns and alphas for the quintile 5 and quintile 1 portfolios. CEI is defined as the firm-level greenhouse gas emission in CO2 equivalents divided by the total revenue of the firm in millions of dollars. Newey-West adjusted t-statistics are given in parentheses. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

	Using Model-Implied Returns		Using Returns to Maturity	
	Average return	6-factor alpha	Average return	6-factor alpha
Low	0.18	0.10	0.37	0.12
	(1.95)	(1.46)	(1.96)	(1.46)
2	0.13	0.07	0.4	0.12
	(1.49)	(0.86)	(2.43)	(1.44)
3	0.12	0.03	0.11	0.04
	(1.40)	(0.40)	(0.55)	(0.51)
4	0.13	-0.04	0.16	-0.07
	(1.51)	(-0.52)	(0.83)	(-0.76)
High	0.00	-0.08	0.08	-0.10
	(0.01)	(-1.40)	(0.44)	(-1.17)
High - Low	-0.17***	-0.18***	-0.29**	-0.22**
	(-3.18)	(-3.20)	(-2.42)	(-2.51)

TABLE A.5

Fama-MacBeth Regressions with Alternative Proxies for Expected Bond Returns

This table reports the average intercept and slope coefficients from the Fama and MacBeth (1973) cross-sectional regressions of proxies for expected bond returns on the logarithm of carbon emissions intensity (CEI), with and without controls. In columns 1 and 2 (columns 3 and 4), the dependent variable is the model-implied bond returns (returns to maturity) from July of year t to June of year $t+1$ and the key independent variable independent variable ln(CEI) is based on the firm-level carbon emissions intensity in June of each year t for firms with fiscal year ending in year $t-1$. Control variables include bond market beta (β^{Bond}), bond characteristics (ratings, maturity, size), downside risk, bond-level illiquidity, and one-month lagged returns. Ratings are in conventional numerical scores, where 1 refers to an AAA rating and 21 refers to a C rating. A higher numerical score implies higher credit risk. Time-to-maturity is defined in terms of years and Size is defined in terms of $billion. Illiq is the bond-level illiquidity computed as the autocovariance of the daily price changes within each month. We also control for systematic risk betas such as the default beta (β^{DEF}), term beta (β^{TERM}), macroeconomic uncertainty beta (β^{UNC}), and climate change news beta ($\beta^{Climate}$). Newey-West (1987) t-statistics are reported in parentheses to determine the statistical significance of the average intercept and slope coefficients. The last row reports the average adjusted R^2 values and we control for the Fama-French 12 industry fixed effects in all specifications. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively.

	Using Model-implied Returns		Using Returns to Maturity	
	(1) Univariate	(2) Controlling for all variables	(3) Univariate	(4) Controlling for all variables
ln(CEI)	-0.023**	-0.028***	-0.018***	-0.016**
	(-2.65)	(-2.85)	(-3.73)	(-2.71)
β^{Bond}		0.265***		0.239***
		(3.94)		(3.83)
Downside risk (5% VaR)		0.087***		0.101***
		(3.57)		(4.26)
ILLIQ		-0.003		-0.006
		(-0.25)		(-0.60)
Rating		0.009		0.005
		(0.87)		(0.51)
Maturity		0.007		0.004
		(1.84)		(1.15)
Size		0.002		0.002
		(0.09)		(0.06)
Lag Return		-0.131***		-0.111***
		(-5.68)		(-4.67)
β^{DEF}		-0.052		-0.049
		(-0.73)		(-0.69)
β^{TERM}		0.127		0.127
		(1.26)		(1.30)
β^{UNC}		0.109		0.124
		(0.81)		(0.92)
$\beta^{Climate}$		0.219		0.102
		(0.25)		(0.12)
Intercept	0.287*	0.260**	0.149	0.214
	(1.97)	(2.13)	(1.13)	(1.80)
Industry Fixed Effects	YES	YES	YES	YES
Adj. R^2	0.048	0.247	0.043	0.264

TABLE A.6

Robustness Checks

This table conducts a battery of robustness checks. Panel A reports results using different categories of a firm's carbon emissions based on the scope 2 emissions scaled by total revenue, as well as scope 1 and scope 2 emissions combined, as the main measure of CEI. Panel B investigates whether the main results remain intact when excluding the most carbon-intensive industries such as the energy, chemicals, and utilities industries. Panel C conducts firm-level analyses and uses three different approaches to control for the effect of multiple bonds issued by the same firm by (1) forming the value-weighted average of the bond returns across the same firm, (2) picking one bond of the largest size, and (3) picking the most liquid bond as representative of the firm and replicate the portfolio-level analysis using this firm-level data set. Panel D conducts subperiod analyses for the two subperiods based on a six-year interval.

Panel A: Quintile portfolios of corporate bonds sorted by firm-level Scope 2 carbon emission and Scope 1 and 2 combined

	Scope 2 carbon emissions only					Scope 1 and 2 carbon emissions combined (Total Scope)			
	Average return	5-factor stock alpha	1-factor bond alpha	6-factor alpha		Average return	5-factor stock alpha	1-factor bond alpha	6-factor alpha
Low	0.36	0.26	0.08	0.06	Low	0.36	0.26	0.08	0.06
	(3.77)	(2.49)	(1.77)	(1.52)		(3.77)	(2.51)	(1.73)	(1.50)
2	0.37	0.26	0.07	0.06	2	0.36	0.26	0.07	0.06
	(3.81)	(2.58)	(2.28)	(2.02)		(3.65)	(2.51)	(1.89)	(1.82)
3	0.34	0.24	0.07	0.06	3	0.31	0.19	0.02	0.00
	(3.68)	(2.59)	(2.11)	(1.75)		(3.09)	(1.88)	(0.56)	(0.07)
4	0.34	0.23	0.04	0.02	4	0.36	0.26	0.09	0.08
	(3.30)	(2.29)	(0.90)	(0.64)		(3.96)	(2.96)	(2.39)	(2.10)
High	0.23	0.08	-0.06	-0.10	High	0.25	0.11	-0.04	-0.08
	(1.94)	(0.67)	(-0.71)	(-1.45)		(2.23)	(0.98)	(-0.64)	(-1.43)
High - Low	-0.12*	-0.18***	-0.13**	-0.16**	High - Low	-0.11**	-0.15***	-0.12**	-0.14***
	(-1.90)	(-2.87)	(-2.31)	(-2.46)		(-2.17)	(-3.15)	(-2.30)	(-3.02)

Panel B: Excluding the most carbon-intensive industries

	Excluding energy industry only		Excluding chemicals industry only		Excluding utilities industry only		Excluding all three industries	
	Average return	6-factor alpha	Average return	6-factor alpha	Average return	6-factor alpha	Average return	6-factor alpha
Low	0.37	0.05	0.37	0.04	0.37	0.05	0.36	0.03
	(3.63)	(1.31)	(3.56)	(1.07)	(3.63)	(1.25)	(3.44)	(0.80)
2	0.37	0.08	0.34	0.03	0.34	0.03	0.36	0.06
	(3.86)	(2.26)	(3.27)	(0.63)	(3.36)	(0.84)	(3.65)	(1.63)
3	0.35	0.05	0.32	0.02	0.32	0.03	0.32	0.03
	(3.59)	(1.47)	(3.24)	(0.49)	(3.35)	(0.83)	(3.29)	(0.71)
4	0.31	0.02	0.30	0.01	0.31	0.01	0.29	0.01
	(3.29)	(0.47)	(3.21)	(0.20)	(3.22)	(0.32)	(3.14)	(0.17)
High	0.28	-0.02	0.25	-0.07	0.25	-0.06	0.25	-0.06
	(2.79)	(-0.34)	(2.33)	(-1.36)	(2.32)	(-1.27)	(2.38)	(-1.09)
High - Low	-0.09**	-0.07*	-0.12***	-0.11***	-0.12**	-0.11***	-0.11**	-0.09**
	(-2.17)	(-1.87)	(-2.87)	(-2.87)	(-2.58)	(-2.77)	(-2.39)	(-2.21)

Table A.6 (Continued)

Panel C: Firm-level analysis

	Firm-level bond returns		Largest bond		Most liquid bond	
	Average return	6-factor alpha	Average return	6-factor alpha	Average return	6-factor alpha
Low	0.39	0.09	0.38	0.06	0.38	0.12
	(4.03)	(2.16)	(3.80)	(1.73)	(4.05)	(2.16)
2	0.37	0.08	0.33	-0.01	0.33	0.02
	(3.77)	(1.50)	(2.92)	(-0.14)	(3.05)	(0.29)
3	0.28	-0.01	0.35	0.05	0.25	-0.06
	(2.90)	(-0.12)	(3.55)	(1.35)	(2.39)	(-1.08)
4	0.33	0.03	0.31	0.00	0.32	0.08
	(3.46)	(0.78)	(3.05)	(-0.05)	(3.32)	(1.84)
High	0.29	0.01	0.24	-0.06	0.25	-0.02
	(2.92)	(0.09)	(2.20)	(-1.06)	(2.32)	(-0.82)
High - Low	-0.10***	-0.09**	-0.15**	-0.13**	-0.13**	-0.14**
	(-2.78)	(-2.23)	(-2.44)	(-2.33)	(-2.50)	(-2.88)

Panel D: Subperiod analysis

	Excluding GFC (2008 - 2009)		1st Subperiod: July 2006 to June 2013		2nd Subperiod: July 2013 to June 2019	
	Average return	6-factor alpha	Average return	6-factor alpha	Average return	6-factor alpha
Low	0.35	0.03	0.40	0.09	0.34	0.07
	(4.48)	(0.82)	(2.42)	(2.96)	(3.09)	(1.37)
2	0.31	0.02	0.42	-0.06	0.26	0.09
	(3.97)	(0.37)	(2.65)	(-1.03)	(2.20)	(1.95)
3	0.32	0.02	0.40	-0.01	0.26	0.08
	(4.23)	(0.45)	(2.50)	(-0.15)	(2.52)	(1.66)
4	0.33	0.02	0.32	0.02	0.31	0.04
	(4.36)	(0.46)	(2.02)	(0.52)	(2.98)	(0.77)
High	0.21	-0.09	0.22	-0.04	0.23	-0.04
	(3.24)	(-1.71)	(1.59)	(-0.67)	(2.22)	(-0.63)
High - Low	-0.14**	-0.12**	-0.18**	-0.14*	-0.11*	-0.11**
	(-2.21)	(-2.18)	(-2.06)	(-2.02)	(-1.96)	(-2.00)

TABLE A.7

Additional Robustness (1): Portfolios Sorted by the Industry-Level Carbon Intensity

This table replicates the results in Table II based on the industry-level carbon emissions intensity (CEI), where industry is based on the Fama-French 30 industry classifications. We form quintile portfolios of corporate bonds based on the average carbon emissions intensity (CEI) at the industry level in June of each year t for firms with fiscal year ending in year $t-1$. The portfolio returns are calculated from July of year t to June of year $t+1$ and then rebalanced. The last row reports the differences in monthly average returns and alphas for the quintile 5 and quintile 1 portfolios. CEI is defined as the firm-level greenhouse gas emission in CO2 equivalents divided by the total revenue of the firm in millions of dollars. Newey-West adjusted t-statistics are given in parentheses. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

Quintiles	Average industry-level CEI	Average return	5-factor stock alpha	1-factor bond alpha	6-factor alpha
Low	6.38	0.41	0.27	0.07	0.03
		(3.38)	(2.29)	(1.30)	(0.61)
2	10.21	0.34	0.23	-0.05	-0.05
		(2.63)	(1.92)	(-0.46)	(-0.42)
3	11.21	0.32	0.22	-0.04	-0.05
		(2.84)	(1.71)	(-0.28)	(-0.38)
4	15.47	0.33	0.26	-0.03	0.02
		(3.43)	(2.56)	(-0.68)	(0.32)
High	948.16	0.25	0.11	-0.04	-0.07
		(2.67)	(1.66)	(-0.37)	(-0.56)
High - Low		-0.15**	-0.16**	-0.11**	-0.10*
		(-2.62)	(-2.45)	(-2.37)	(-1.92)

TABLE A.8

Additional Robustness (2): Orthogonalized Carbon Intensity and Bond Returns

This table replicates the results in Table III by using the orthogonalized carbon emission intensity (ln(CEI$^{\perp}$)) as the main independent variable. Specifically, we run contemporaneous cross-sectional regressions of carbon emission intensity (in logarithm) on a set of firm-level characteristics to isolate the unique information in CEI, above and beyond these firm-level characteristics, including return-on-assets (ROA), debt-to-assets ratio (Debt/Assets), Tobin's Q, cash-to-assets ratio (Cash/Assets), and firm age (Age):

$$ln(CEI_{i,t}) = \lambda_{0,t}+\lambda_{1,t}ROA_{i,t}+\lambda_{2,t}(Debt/Assets)_{i,t}+\lambda_{3,t}(Tobin's\,Q)_{i,t}+\lambda_{4,t}(Cash/Assets)_{i,t}+\lambda_{5,t}Age_{i,t}+\epsilon^{CEI}_{i,t},$$

Once we generate the residuals from the above regression, we label them as orthogonalized carbon emission intensity (ln(CEI$^{\perp}$)). We repeat the Fama and MacBeth (1973) regressions of Table III using ln(CEI$^{\perp}$) as the main independent variable. The dependent variable is the corporate bond excess return from July of year t to June of year $t+1$. Newey-West (1987) t-statistics are reported in parentheses to determine the statistical significance of the average intercept and slope coefficients. The last row reports the average adjusted R^2 values and we control for the Fama-French 12 industry fixed effects in all specifications. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively.

Dep.var = Return$_{t+1:t+12}$	(1) Univariate	(2) Controlling for bond characteristics	(3) Controlling for systematic and eclimate risk beta	(4) Controlling for all variables
ln(CEI$^{\perp}$)	-0.128***	-0.116**	-0.120**	-0.136**
	(-2.85)	(-2.46)	(-2.69)	(-2.50)
β^{Bond}		0.135***		0.134**
		(2.86)		(2.06)
Downside risk (5% VaR)		0.086***		0.062***
		(3.04)		(2.84)
ILLIQ		0.001		0.003
		(0.18)		(0.14)
Rating		0.012		0.024
		(0.35)		(0.50)
Maturity		0.103		0.106
		(1.03)		(1.08)
Size		0.004		0.005
		(0.12)		(0.17)
Lag Return		-0.034***		-0.046***
		(-4.28)		(-4.73)
β^{DEF}			-0.136	-0.106
			(-1.04)	(-0.64)
β^{TERM}			0.301	0.602
			(1.06)	(1.04)
β^{UNC}			-0.124**	-0.321
			(-2.18)	(-1.63)
$\beta^{Climate}$			-0.650	0.064
			(-0.49)	(0.03)
Intercept	0.302	0.164	0.160	0.107**
	(1.04)	(1.28)	(1.06)	(2.12)
Industry Fixed Effects	YES	YES	YES	YES
Adj. R^2	0.040	0.251	0.162	0.290

TABLE A.9

Carbon Emissions Intensity, Changes in Ownership by Different Types of Institutions, and Corporate Bond Returns

This table replicates the results in Panel B of Table IV by separately including changes in ownership by three main categories of institutional investors including: (1) mutual funds, (2) insurance companies, and (3) pension funds. The dependent variable is the corporate bond excess return from July of year t to June of year $t+1$. Newey-West (1987) t-statistics are reported in parentheses to determine the statistical significance of the average intercept and slope coefficients. The last row reports the average adjusted R^2 values and we control for the Fama-French 12 industry fixed effects in all specifications. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively.

	Mutual funds		Insurance companies		Pension funds	
Dep.var = $\text{Return}_{t+1:t+12}$	(1) Univariate	(2) Controlling for all variables	(3) Univariate	(4) Controlling for all variables	(5) Univariate	(6) Controlling for all variables
ln(CEI)	-0.018**	-0.016**	-0.029**	-0.024**	-0.025**	-0.022**
	(-2.45)	(-2.22)	(-2.58)	(-2.50)	(-2.35)	(-2.30)
ΔINST_Bond	-0.202	-0.210	-0.344	-0.295	-0.208	-0.195
	(-1.08)	(-1.06)	(-1.23)	(-1.16)	(-0.85)	(-0.99)
1-year lagged ΔINST_Bond	-0.238	-0.542	1.041	0.396	0.867	0.477
	(-0.55)	(-1.40)	(1.62)	(1.15)	(1.57)	(1.82)
β^{Bond}		0.008		0.075		0.052
		(0.14)		(0.62)		(0.60)
Downside risk (5% VaR)		0.026		-0.028		-0.038
		(0.75)		(-1.14)		(-1.67)
ILLIQ		0.009		0.021**		0.021**
		(1.28)		(2.22)		(2.47)
Rating		0.004		0.012		0.005
		(0.10)		(0.21)		(0.10)
Maturity		0.009		0.004		0.003
		(1.33)		(0.54)		(0.36)
Size		0.083		0.066		0.029
		(1.13)		(1.00)		(0.61)
Lag Return		-0.257***		-0.273***		-0.272***
		(-6.44)		(-6.82)		(-6.78)
β^{DEF}		-0.012		-0.020		-0.012
		(-0.10)		(-0.27)		(-0.02)
β^{TERM}		-0.030		-0.046		-0.010
		(-0.12)		(-0.40)		(-0.04)
β^{UNC}		0.106		0.107		0.210
		(0.71)		(0.23)		(0.83)
$\beta^{Climate}$		1.064		1.074		1.107
		(0.32)		(0.58)		(0.80)
Intercept	0.341	0.453	0.661	0.130	0.624	0.313
	(1.03)	(1.51)	(1.80)	(0.36)	(1.67)	(0.96)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Adj. R^2	0.068	0.263	0.072	0.290	0.070	0.290

TABLE A.10

Subsample Analysis Based on the Stock-Bond Momentum Spillover Effect

This table replicates the results in Table II for the subsamples of bonds based on the stock-bond momentum spillover effect. We first run cross-sectional regressions of future bond returns on stock return momentum (e.g., cumulative stock returns from month $t-7$ to $t-2$) at the firm-level and denote the estimated coefficients (γ) on the stock momentum variable as the stock-bond momentum spillover effect. We then divide the sample into two groups based on the median value of γ. Finally, we report the returns and alphas of quintile portfolios sorted by CEI within each subsample. The portfolio returns are calculated for July of year t to June of year $t+1$ and then rebalanced. The last row reports the differences in monthly average returns and alphas for the quintile 5 and quintile 1 portfolios. CEI is defined as the firm-level greenhouse gas emission in CO2 equivalents divided by the total revenue of the firm in millions of dollars. Newey-West adjusted t-statistics are given in parentheses. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

	$\gamma \leq \gamma^{Median}$		$\gamma > \gamma^{Median}$	
	Average return	6-factor alpha	Average return	6-factor alpha
Low	0.39	0.03	0.37	0.00
	(3.86)	(0.21)	(1.96)	(0.01)
2	0.34	0.05	0.40	0.07
	(3.08)	(0.40)	(2.43)	(0.60)
3	0.39	-0.08	0.11	-0.33
	(3.90)	(-0.65)	(0.55)	(-2.12)
4	0.24	-0.09	0.16	-0.29
	(2.51)	(-0.85)	(0.83)	(-1.77)
High	0.10	-0.08	0.08	-0.31
	(1.62)	(-0.75)	(0.44)	(-2.14)
High - Low	-0.18*	-0.11*	-0.29**	-0.31***
	(-2.02)	(-1.96)	(-2.42)	(-2.62)

TABLE A.11

Corporate Bond Portfolios Sorted by Changes in Firm-Level Carbon Intensity

This table replicates the results in Table II for corporate bonds sorted by changes in firm-level carbon emissions intensity (CEI), calculated as the difference in a firm's CEI reported in year t and year $t-1$. The table reports, for each quintile portfolio, the next-month average excess return, the 5-factor alpha estimated from the Fama and French (2015) model, the one-factor alpha estimated from the one-factor bond factor model, and the 6-factor alpha estimated from the five stock market factors combined with the bond market factor. The last row reports the differences in monthly average returns and alphas for the quintile 5 and quintile 1 portfolios. The one-factor bond factor model includes the excess bond market return. Newey-West adjusted t-statistics are given in parentheses. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

	Average return	5-factor stock alpha	1-factor bond alpha	6-factor alpha
Low	0.32	0.21	0.04	0.01
	(3.30)	(1.99)	(0.87)	(0.31)
2	0.25	0.12	-0.03	-0.06
	(2.38)	(1.19)	(-0.59)	(-1.15)
3	0.29	0.18	0.04	0.01
	(3.13)	(1.99)	(0.83)	(0.30)
4	0.24	0.13	-0.03	-0.06
	(2.44)	(1.27)	(-0.49)	(-1.14)
High	0.09	0.01	-0.10	-0.14
	(1.40)	(0.07)	(-1.34)	(-2.38)
High - Low	-0.23***	-0.20***	-0.14***	-0.16***
	(-3.25)	(-3.97)	(-2.68)	(-2.98)

TABLE A.12

Investor Attention and Low Carbon Alpha

This table reports the monthly return difference (Low − High) between the low-CEI portfolio (Quintile 1) and the high-CEI portfolio (Quintile 5), conditioning on measures of investor attention to climate change. In Panel A, we follow Choi et al. (2020) and measure investor attention to climate change using the Abnormal Google Search Volume Index (ASVI), calculated as the natural log of the ratio of SVI to the average SVI over the previous three month. ASVI_Climate Change is the ASVI corresponding to searches related to the topic "Climate Change", whereas ASVI_Global Warming is the ASVI corresponding to searches related to the topic "Global Warming". Positive (negative) ASVI is associated with an increase (decrease) in investor attention. In Panel B, we conduct subperiod analysis for the pre- and post-Paris agreement period. In Panel C, we conduct structural break test on the low-minus-high return with unknown break date. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

Panel A: Investor attention and the low carbon alpha

Variables	Low − High	t-stat	Variables	Low − High	t-stat
ASVI increases			ASVI decreases		
ASVI_Climate Change ≥ 0	0.05	0.84	ASVI_Climate Change < 0	0.26***	4.30
ASVI_Global Warming ≥ 0	0.07	1.25	ASVI_Global Warming < 0	0.23***	3.81

Panel B: Pre- and Post-Paris agreement and the low carbon alpha

Pre-Paris Agreement	0.19***	3.65	Post-Paris Agreement	0.02	0.45
			Difference in Mean (Post − Pre)	-0.16**	-2.38

Panel C: Tests for structural break for the low carbon alpha

Test for Unknown Structural Break Date	2016m3
p-value	0.022

TABLE A.13

Subsample Analysis Based on Firm Leverage Ratio

This table replicates the results in Table II for the subsamples of bonds issued by firms with high and low leverage ratio. Leverage ratio is defined as total debt (i.e., the sum of long term debt (DLTT) and debt in current liabilities (DLC)) as a percentage of total assets. Within each subsample, we form quintile portfolios of corporate bonds based on the firm-level carbon emissions intensity (CEI) in June of each year t for firms with fiscal year ending in year $t-1$. The portfolio returns are calculated for July of year t to June of year $t+1$ and then rebalanced. The last row reports the differences in monthly average returns and alphas for the quintile 5 and quintile 1 portfolios. CEI is defined as the firm-level greenhouse gas emission in CO2 equivalents divided by the total revenue of the firm in millions of dollars. Newey-West adjusted t-statistics are given in parentheses. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

	Leverage Ratio $<=$ Median				Leverage Ratio $>$ Median			
	Average return	5-factor Stock alpha	1-factor bond alpha	6-factor alpha	Average return	5-factor Stock alpha	1-factor bond alpha	6-factor alpha
Low	0.37	0.26	0.08	0.07	0.33	0.11	0.12	0.05
	(3.55)	(2.31)	(1.60)	(1.32)	(2.05)	(0.81)	(0.92)	(0.43)
2	0.35	0.24	0.15	0.14	0.12	-0.02	0.20	0.14
	(3.31)	(2.15)	(2.87)	(2.54)	(0.70)	(-0.15)	(1.66)	(1.45)
3	0.32	0.22	0.19	0.19	0.25	0.08	0.00	-0.10
	(3.43)	(2.18)	(4.06)	(3.87)	(1.78)	(0.56)	(0.02)	(-0.73)
4	0.33	0.24	0.12	0.13	0.45	0.29	0.05	-0.02
	(3.67)	(2.60)	(2.26)	(2.25)	(3.02)	(1.98)	(0.51)	(-0.29)
High	0.33	0.22	0.14	0.15	-0.25	-0.50	-0.23	-0.26
	(3.41)	(2.31)	(2.33)	(2.51)	(-1.12)	(-2.28)	(-1.16)	(-2.29)
High - Low	-0.03	-0.04	0.06	0.08	-0.58***	-0.60***	-0.35***	-0.31**
	(-0.95)	(-0.98)	(1.10)	(1.38)	(-3.15)	(-3.24)	(-2.74)	(-2.57)

TABLE A.14

Panel Regressions of Contemporaneous Stock Returns on Carbon Emissions

This table replicates the main findings of Bolton and Kacperczyk (2021) and reports the results from the panel regressions of contemporaneous stock returns on different measures of carbon emissions. The dependent variable is stock return of company i in month t. Measures of carbon emissions include (1) the logarithm of carbon emissions level (ln(CO2)), (2) the changes in the logarithm of carbon emissions level (Δln(CO2)), (3) carbon emissions intensity (CEI), and (4) the natural logarithm of carbon emissions intensity (ln(CEI)). Control variables include size, book-to-market, leverage, stock momentum, investment-to-assets (Invest/A), return on equity (ROE), HHI, ln(PPE), stock beta, volatility, sales growth rate, and EPS growth rate. t-statistics reported in parentheses are based on standard errors double clustered at firm and year level. The last row reports the average adjusted R^2 values and we control for the industry and year-month fixed effects in all specifications. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from January 2005 to December 2017.

	(1)	(2)	(3)	(4)
ln(CO2)	0.0793***			
	(3.87)			
Δln(CO2)		0.4402***		
		(4.21)		
CEI (scaled by 100)			0.0047	
			(0.72)	
ln(CEI)				-0.0823***
				(-4.47)
Size	-0.3134**	-0.2021*	-0.2909**	-0.3130**
	(-2.68)	(-2.14)	(-2.52)	(-2.69)
B/M	0.1888	0.2295	0.2108	0.2028
	(0.83)	(0.86)	(0.92)	(0.89)
Leverage	-0.0192	-0.0637	0.0133	0.0194
	(-0.06)	(-0.17)	(0.04)	(0.06)
MOM	0.1357	0.0964	0.1426	0.1445
	(0.44)	(0.37)	(0.47)	(0.47)
Invest/A	-0.7949	-1.9868	-1.1103	-1.0418
	(-0.43)	(-1.07)	(-0.59)	(-0.56)
ROE	0.1923	0.2100	0.2272	0.2223
	(1.05)	(1.44)	(1.20)	(1.19)
HHI	0.1068	0.0665	0.0886	0.0955
	(0.98)	(0.56)	(0.82)	(0.88)
Ln(PPE)	0.0624	0.0924**	0.1055	0.1222*
	(1.09)	(2.20)	(1.68)	(1.92)
Beta	-0.0331	0.1599	-0.0233	-0.0133
	(-0.24)	(1.27)	(-0.17)	(-0.10)
Volatility	0.6817	0.8475	0.5642	0.5133
	(0.26)	(0.26)	(0.21)	(0.19)
Sale growth rate	-0.1343	-0.0572	-0.1200	-0.1226
	(-0.44)	(-0.19)	(-0.39)	(-0.41)
EPS growth rate	-1.1257**	-1.0867*	-1.1461**	-1.1345**
	(-2.48)	(-2.08)	(-2.53)	(-2.48)
Constant	2.3491***	1.8458**	2.7537***	3.0871***
	(3.83)	(2.94)	(4.14)	(4.44)
Industry FEs	YES	YES	YES	YES
Year-Month FEs	YES	YES	YES	YES
Adj. R^2	0.188	0.206	0.188	0.188
Observations	176,898	145,536	176,898	176,898

TABLE A.15

Panel Regressions of Future Stock Returns on Carbon Emissions

This table reports the results from panel regressions of future stock returns on different measures of carbon emissions. The dependent variable is stock return of company i in month $t+1$. Measures of carbon emissions include (1) the logarithm of carbon emissions level (ln(CO2)), (2) the changes in carbon emissions level (Δln(CO2)), (3) carbon emissions intensity (CEI), and (4) the logarithm of carbon emissions intensity (ln(CEI)). Control variables include size, book-to-market, leverage, stock momentum, investment-to-assets (Invest/A), return on equity (ROE), HHI, ln(PPE), stock beta, volatility, sales growth rate, and EPS growth rate. t-statistics reported in parentheses are based on standard errors double clustered at firm and year level. The last row reports the average adjusted R^2 values and we control for the industry and year-month fixed effects in all specifications. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively. The sample period is from July 2006 to June 2019.

	(1)	(2)	(3)	(4)
ln(CO2)	-0.0237			
	(-1.09)			
Δln(CO2)		-0.0819		
		(-1.04)		
CEI (scaled by 100)			0.0073	
			(0.72)	
ln(CEI)				-0.0441*
				(-2.00)
Size	0.0280	0.1101	0.0249	0.0111
	(0.16)	(0.64)	(0.14)	(0.06)
B/M	-0.1313	-0.0287	-0.1377	-0.1445
	(-0.73)	(-0.14)	(-0.77)	(-0.82)
Leverage	-0.1960	0.0078	-0.2127	-0.2059
	(-0.47)	(0.02)	(-0.50)	(-0.49)
MOM	0.2163	0.1600	0.2150	0.2158
	(0.73)	(0.41)	(0.73)	(0.73)
Invest/A	-1.4736	-1.3131	-1.3330	-1.3197
	(-1.04)	(-0.72)	(-0.97)	(-0.98)
ROE	0.0247	0.0904	0.0122	0.0108
	(0.10)	(0.38)	(0.05)	(0.04)
HHI	0.0384	0.0620	0.0426	0.0487
	(0.29)	(0.43)	(0.31)	(0.35)
Ln(PPE)	0.0228	-0.0612	0.0065	0.0176
	(0.22)	(-0.63)	(0.06)	(0.17)
Beta	0.1096	0.1300	0.1038	0.1105
	(0.50)	(0.47)	(0.48)	(0.51)
Volatility	-1.1798	-1.8271	-1.1371	-1.1707
	(-0.78)	(-0.81)	(-0.75)	(-0.77)
Sale growth rate	-0.1676	-0.1511	-0.1716	-0.1723
	(-0.81)	(-0.62)	(-0.84)	(-0.84)
EPS growth rate	-0.6161	-0.6942	-0.6097	-0.6060
	(-0.84)	(-0.82)	(-0.83)	(-0.83)
Constant	0.8437	0.1835	0.7013	0.8905
	(1.15)	(0.26)	(1.00)	(1.26)
Industry FEs	YES	YES	YES	YES
Year-Month FEs	YES	YES	YES	YES
Adj. R^2	0.204	0.230	0.204	0.204
Observations	181,468	145,784	181,468	181,468

TABLE A.16

Regressions of Contemporaneous Bond Returns on Carbon Emissions

This table reports the average intercept and slope coefficients from the Fama and MacBeth (1973) cross-sectional regressions of contemporaneous corporate bond excess returns on different measures of carbon emissions, with and without controls. The dependent variable is the corporate bond excess return from July of year t to June of year $t+1$. Measures of carbon emissions include (1) the logarithm of carbon emissions level (ln(CO2)), (2) the changes in carbon emissions level (Δln(CO2)), (3) carbon emissions intensity (CEI), and (4) the logarithm of carbon emissions intensity (ln(CEI)). Control variables include bond market beta (β^{Bond}), bond characteristics (ratings, maturity, size), downside risk, bond-level illiquidity, and one-month lagged returns. Ratings are in conventional numerical scores, where 1 refers to an AAA rating and 21 refers to a C rating. A higher numerical score implies higher credit risk. Time-to-maturity is defined in terms of years and Size is defined in terms of $billion. Illiq is the bond-level illiquidity computed as the autocovariance of the daily price changes within each month. We also control for systematic risk betas such as the default beta (β^{DEF}), term beta (β^{TERM}), macroeconomic uncertainty beta (β^{UNC}), and climate change news beta ($\beta^{Climate}$). Newey-West (1987) t-statistics are reported in parentheses to determine the statistical significance of the average intercept and slope coefficients. The last row reports the average adjusted R^2 values and we control for the Fama-French 12 industry fixed effects in all specifications. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
ln(CO2)	-0.004			
	(-0.37)			
Δln(CO2)		0.038		
		(1.09)		
CEI (scaled by 100)			-0.001	
			(-1.08)	
ln(CEI)				-0.103**
				(-2.34)
β^{Bond}	0.202***	0.248***	0.202***	0.203***
	(3.11)	(2.91)	(3.07)	(3.09)
Downside risk (5% VaR)	0.071***	0.077***	0.071***	0.071***
	(3.07)	(3.79)	(3.04)	(3.08)
ILLIQ	-0.002	-0.001	-0.002	-0.002
	(-0.28)	(-0.02)	(-0.25)	(-0.29)
Rating	0.013	0.009	0.014	0.014
	(1.30)	(0.81)	(1.38)	(1.30)
Maturity	0.005	0.007	0.005	0.005
	(1.40)	(1.66)	(1.39)	(1.37)
Size	0.010	0.005	0.010	0.009
	(0.38)	(0.19)	(0.36)	(0.33)
Lag Return	-0.157***	-0.148***	-0.157***	-0.157***
	(-7.40)	(-6.59)	(-7.35)	(-7.36)
β^{DEF}	-0.078	-0.078	-0.076	-0.077
	(-1.27)	(-1.19)	(-1.24)	(-1.25)
β^{TERM}	0.142	0.144	0.138	0.141
	(1.51)	(1.45)	(1.47)	(1.48)
β^{UNC}	0.128	0.119	0.124	0.123
	(0.99)	(0.86)	(0.96)	(0.96)
$\beta^{Climate}$	0.116	0.287	0.107	0.087
	(0.14)	(0.33)	(0.13)	(0.10)
Intercept	0.209	0.207**	0.147	0.158
	(1.23)	(2.06)	(1.56)	(1.70)
Industry Fixed Effects	YES	YES	YES	YES
Adj. R^2	0.268	0.269	0.268	0.268

TABLE A.17

Regressions of Future Bond Returns on Carbon Emissions

This table reports the average intercept and slope coefficients from the Fama and MacBeth (1973) cross-sectional regressions of future corporate bond excess returns on different measures of carbon emissions, with and without controls. The dependent variable is the corporate bond excess return from July of year t to June of year $t+1$. Measures of carbon emissions include (1) the logarithm of carbon emissions level (ln(CO2)), (2) the changes in carbon emissions level (Δln(CO2)), (3) carbon emissions intensity (CEI), and (4) the logarithm of carbon emissions intensity (ln(CEI)). Control variables include bond market beta (β^{Bond}), bond characteristics (ratings, maturity, size), downside risk, bond-level illiquidity, and one-month lagged returns. Ratings are in conventional numerical scores, where 1 refers to an AAA rating and 21 refers to a C rating. A higher numerical score implies higher credit risk. Time-to-maturity is defined in terms of years and Size is defined in terms of $billion. Illiq is the bond-level illiquidity computed as the autocovariance of the daily price changes within each month. We also control for systematic risk betas such as the default beta (β^{DEF}), term beta (β^{TERM}), macroeconomic uncertainty beta (β^{UNC}), and climate change news beta ($\beta^{Climate}$). Newey-West (1987) t-statistics are reported in parentheses to determine the statistical significance of the average intercept and slope coefficients. The last row reports the average adjusted R^2 values and we control for the Fama-French 12 industry fixed effects in all specifications. *, **, and *** indicate the significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
ln(CO2)	-0.011			
	(-1.07)			
Δln(CO2)		0.052		
		(1.08)		
CEI (scaled by 100)			-0.002	
			(-1.27)	
ln(CEI)				-0.136**
				(-2.50)
β^{Bond}	0.265***	0.287***	0.264***	0.134**
	(3.95)	(4.10)	(3.91)	(2.06)
Downside risk (5% VaR)	0.086***	0.098***	0.086***	0.062***
	(3.56)	(3.83)	(3.55)	(2.84)
ILLIQ	-0.003	-0.003	-0.003	0.003
	(-0.25)	(-0.24)	(-0.25)	(0.14)
Rating	0.008	0.007	0.009	0.024
	(0.72)	(0.58)	(0.86)	(0.50)
Maturity	0.007	0.007	0.007	0.106
	(1.87)	(1.76)	(1.85)	(1.08)
Size	0.005	0.006	0.004	0.005
	(0.19)	(0.19)	(0.13)	(0.17)
Lag Return	-0.131***	-0.113***	-0.130	-0.046***
	(-5.71)	(-5.13)	(-5.65)	(-4.73)
β^{DEF}	-0.052	-0.059	-0.049	-0.106
	(-0.74)	(-0.77)	(-0.70)	(-0.64)
β^{TERM}	0.128	0.142	0.124	0.602
	(1.28)	(1.31)	(1.23)	(1.04)
β^{UNC}	0.110	0.107	0.108	-0.321
	(0.82)	(0.74)	(0.80)	(-1.63)
$\beta^{Climate}$	0.256	0.156	0.246	0.064
	(0.29)	(0.17)	(0.28)	(0.03)
Intercept	0.363	0.268**	0.212**	0.107**
	(1.88)	(2.58)	(2.06)	(2.12)
Industry Fixed Effects	YES	YES	YES	YES
Adj. R^2	0.270	0.268	0.269	0.290

TABLE A.18

Carbon Emissions Intensity and Environmental Incidents

This table reports the panel regression of the frequency of environmental incidents on firms' carbon emissions intensity. The dependent variable is $ln(1 + Incidents)$, defined as the nature logarithm of one plus the sum of all positive changes in the RepRisk Index from July of year t to June of year $t + 1$. To ensure we capture a firm's environmental incidents rather than the S and G aspects of the RepRisk Index, we require the percentage of environmental issues used to compute the RepRisk Index is greater than 50%. $Ln(1 + Incidents)$ has a value of zero when there is no ESG incidents in the year. The key independent variable is ln(CEI), defined as the natural logarithm of carbon emissions intensity (scope 1) in the fiscal year ending in calendar year $t - 1$. $ln(1 + Incidents)_{t-1}$ represents the one-year lagged value of $ln(1 + Incidents)$. Firm size is defined as the natural logarithm of market capitalization at the end of June in each year. BM is the book equity for the fiscal year ending in calendar year $t - 1$ divided by the market equity at the end of December of year $t - 1$. Book value of equity equals the value of stockholders' equity, plus deferred taxes and investment tax credits, and minus the book value of preferred stock. ROE is defined as income before extraordinary items in the fiscal year ending in calendar year $t - 1$ divided by average book value of equity in the fiscal year ending in calendar year $t - 1$. R&D is defined as R&D expenditures in the fiscal year ending in calendar year $t - 1$ divided by sales in calendar year $t - 1$. Investment is defined as the annual growth in total assets in fiscal year ending in calendar year $t - 1$. OCF is defined as operating cash flows in the fiscal year ending in calendar year $t - 1$ divided by lagged total assets. INST_Stock is defined as the sum of shares held by institutions from 13F filings at the end of December of year $t - 1$. The unit of analysis is at firm-year level. All variables are winsorized at 2.5% level, except for Firm size. Numbers in parentheses are t-statistics based on standard errors clustered by firm level. ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively. The sample period is from July 2007 to June 2019.

Variables	ln(1+Incidents)	
	(1)	(2)
ln(CEI)	0.0992***	0.0840***
	(14.73)	(9.50)
ln(1+Incidents)$_{t-1}$	0.4147***	0.3894***
	(22.56)	(20.87)
Firm size	0.0595***	0.0541***
	(5.65)	(5.45)
BM	0.1775***	0.1019***
	(5.21)	(2.80)
ROE	0.0057	0.0372
	(0.07)	(0.49)
R&D	-0.8148***	-0.6327**
	(-3.58)	(-2.31)
Investment	0.0436	0.0227
	(0.57)	(0.29)
OCF	0.3517	0.1429
	(1.47)	(0.61)
INST_Stock	-0.0505	-0.0175
	(-1.01)	(-0.36)
Constant	-1.5268***	-1.3082***
	(-5.94)	(-5.37)
Industry FEs	NO	YES
Year FEs	YES	YES
Adj. R^2	0.323	0.335
Observations	6,054	6,054

TABLE A.19

Carbon Emissions Intensity and Stock Price Crash Risk

This table reports the panel regression of stock price crash risk on firms' carbon emissions intensity. The dependent variables are $NCSKEW$ and $DUVOL$ from July of year t to June of year $t+1$. The key independent variable is ln(CEI), defined as the natural logarithm of carbon emissions intensity (scope 1) in the fiscal year ending in calendar year $t-1$. DTURN is the average monthly share turnover form July of year $t-1$ to June of year t minus the average monthly share turnover from July of year $t-2$ to June of year $t-1$, where the monthly share turnover is calculated as the monthly trading volume divided by the total number of shares outstanding during the month. SIGMA is the standard deviation of firm-specific weekly returns from July of year $t-1$ to June of year t. RET is the average firm-specific weekly returns from July of year $t-1$ to June of year t. Firm size is defined as the natural logarithm of market capitalization at the end of June in each year. BM is the book equity for the fiscal year ending in calendar year $t-1$ divided by the market equity at the end of December of year $t-1$. Book value of equity equals to the value of stockholders' equity, plus deferred taxes, and investment tax credits, and minus the book value of preferred stock. ROA is defined as operating income before depreciation in the fiscal year ending in calendar year $t-1$ as a fraction of average total assets based between the fiscal year ending in calendar year $t-1$ and the fiscal year ending in calendar year $t-2$. Leverage is the total debt as fraction of total assets in the fiscal year ending in calendar year $t-1$. Numbers in parentheses are t-statistics based on standard errors clustered by firm level. ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively.

Variables	NCSKEW (1)	DUVOL (2)
ln(CEI)	0.0170**	0.0096**
	(2.25)	(2.08)
Dependent variable$_{t-1}$	0.0542***	0.0740***
	(3.54)	(5.36)
DTURN	0.7836	1.7411
	(0.12)	(0.44)
SIGMA	-0.1628	-0.0132
	(-0.32)	(-0.04)
RET	4.1660**	4.4990***
	(2.17)	(3.87)
Firm size	0.0076	0.0030
	(0.96)	(0.60)
BM	-0.0370	-0.0253
	(-1.17)	(-1.27)
ROA	0.4108**	0.2857***
	(2.32)	(2.60)
Leverage	0.0447	0.0855**
	(0.63)	(2.03)
Constant	-0.1971	-0.1002
	(-0.99)	(-0.79)
Industry FEs	YES	YES
Year FEs	YES	YES
Adj. R^2	0.0143	0.0247
Observations	7,803	7,803