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

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Motivation

- Climate change is having a significant economic and societal impact (Stern, 2007; IPCC, 2018; Hsiang et al, 2017)
- As climate change is mostly caused by **accumulations of greenhouse gases (GHG)** in earth's atmosphere, any regulation will have to target at significantly curbing firms' carbon emissions (e.g., carbon tax or cap-and-trade system)

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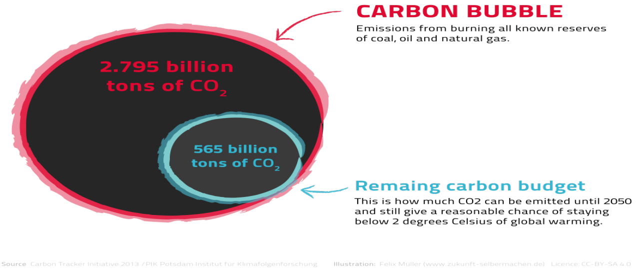

McGlade & Ekins Estimate:
"Our results suggest that, globally, **a third of oil reserves, half of gas reserves and over 80% of coal reserves** should remain unused [...] in order to meet the target of 2°C."
– EnergyPolicy vol 64, Oct 2014

IEA Estimate:
"No **more than one-third of proven reserves** can be consumed if the world is to achieve the 2°C gaol, unless carbon capture and storage technology is widely deployed."
– IEA Energy Outlook, Jan 2012

Motivation (cont'd)

- "The Carbon Bubble":
  - A hypothesized bubble in the valuation of companies dependent on fossil-fuel-based energy production
  - The true costs of carbon dioxide in intensifying global warming *are not yet taken into account* in a company's market valuation
- The effect of more stringent governmental regulations is likely to be heterogeneous and most relevant for carbon-intensive firms
  - Regulations can lead to stranded assets or a large increase in operating costs
  - Subject to higher financing costs due to climate-related capital requirements and trends towards sustainable investing

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  - Subject to higher financing costs due to climate-related capital requirements and trends towards sustainable investing
- More stringent climate policies are likely to be proposed and implemented when the global climate worsens unexpectedly
  - Leading to lower firm values when climate change matters most to investors' welfare
- The "Carbon Risk Premium" hypothesis:
  - Investors should demand **higher expected returns** for holding securities issued by carbon-intensive firms

Motivation (cont'd)

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- Climate policies mainly constitute as a downside risk to carbon intensive firms, thus should matter more for bond investors compared to equity investors
  - Ilhan, Sautner, and Vilkov (2020); Sautner, Starks, and Zhou (2020)
  - Bond is equivalent to short a put option on firm assets plus a riskfree bond (Merton, 1974)
- Different frictions between equity and bond markets:
  1. Equities and bonds attract **different clienteles**
  2. **Risk appetites and investment objectives (horizon)** of institutional and retail investors differ
  3. **Shorting costs** as well as **liquidity levels** are markedly different across the two asset classes, suggesting arbitrage frictions
  4. Equities and bonds are held by investors who are subject to different **regulatory, capital, and funding liquidity constraints**

Motivation (cont'd)

- Corporate bonds are mainly held by institutional investors, who are sophisticated and likely take carbon risks into account
  - Krueger, Sautner, and Starks (2020): 55% of institutional investors believe the regulatory risk of climate change is already materializing
- Heterogeneity in important bond characteristics (ratings and maturities) allows us to test the underlying channels of the (mis)pricing of carbon risks
- Goldstein, Jiang and Ng (2017) document **fragility** in the corporate bond funds, amplifying the stability concern of sudden shift in climate policies

Preview of Empirical Results

- We measure firm-level carbon emission intensity (CEI) as a firm's CO2 emissions (in units of tons) scaled by its total revenues
- We find evidence contrary to the "Carbon Risk Premium" hypothesis in US corporate bond market

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  - High-CEI bonds are **riskier** than low-CEI bonds, as reflected in higher bond market beta and downside risk, higher credit risk, and higher illiquidity
  - Yet high-CEI bonds **significantly underperform** by 1.7% (t=2.62) per annum relative to low-CEI bonds
  - The "low carbon premium" we find persists after adjusting systematic risk exposures and controlling for a comprehensive list of bond characteristics in the cross-sectional regression

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- **"Investor Preference" hypothesis** (Pastor, Stambaugh, and Taylor, 2020)
  - Green assets could perform better than brown assets if investors' ESG concerns strengthen unexpectedly
  - We test this explanation and find institutional investors indeed divest from bonds issued by carbon-intensive firms
  - However, the "low carbon premium" **cannot be fully explained** by shifts in institutional demand

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  - We test this explanation and find institutional investors indeed divest from bonds issued by carbon-intensive firms
  - However, the "low carbon premium" **cannot be fully explained** by shifts in institutional demand
- **"Investor Underreaction" hypothesis**: (Pedersen, Fitzgibbons, and Pomorski, 2020)
  - Green assets could earn higher returns if being carbon efficient indicates strong firm fundamentals, and the market underreacts to this predictability of fundamentals
  - We find supporting evidence as high CEI predicts lower future cash flow news, deteriorating bond creditworthiness, and more frequent environmental incidents

Contribution and Related Literature - Climate Finance

Physical Risks: direct costs results from the adverse effects of climate change on economic activity (extreme weather events, sea-level rises etc.)

- Hong, Li, and Xu (2019): food stocks underreact to drought risks
- Giglio et al. (2018), Bernstein et al. (2020), Baldauf et al. (2020), and Murfin and Spiegel (2020) examine whether SLR risks are priced in real estate markets
- Painter (2020): long-maturity municipal bonds impacted by SLR risk of issuing counties
- Barnett and Yannelis (2021): projected climate change damage affects yields for sovereign bonds with long maturities

Regulatory/Transition Risks: costs imposed on firms from policies and regulations implemented to combat climate change and transit towards a low-carbon economy

- Ilhan, Sautner and Vilkov (2020): Climate policy uncertainty is priced in out-of-money put options
- Bolton and Kacperczyk (2020, 2021): carbon emissions (level and growth) affect the cross-section of stock returns in US and globally
- Hsu, Li, and Tsou (2020): firms with more intense toxic emissions earn higher stock returns

Contribution and Related Literature (cont'd)

- **Firms' ESG characteristics and stock performance:**
  - Investors demand higher expected returns for holding stocks with poor ESG scores in various contexts (Hong and Kacperczyk, 2009; Chava, 2014)
  - Firms' stocks perform better if they are better-governed (Gompers, Ishii, and Metrick, 2003), have higher employee satisfaction (Edmans, 2011), or are more carbon efficient (In, Park, and Monk, 2019)

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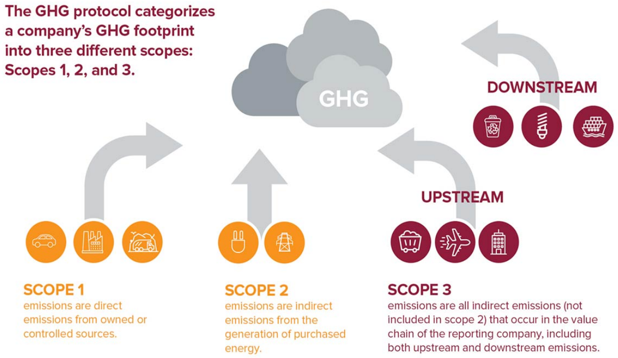
- **Cross-sectional determinants of corporate bond returns:**
  - Bond characteristics such as illiquidity, past returns and BM ratio (Gebhardt, Hvidkjaer, and Swaminathan, 2005; Bali, Subrahmanyam, and Wen, 2020; Bartram, Grinblatt and Nozawa, 2020)
  - Systematic risk (Gebhardt, Hvidkjaer, and Swaminathan, 2005), liquidity risk (Lin, Wang, and Wu, 2011), downside risk (Bai, Bali, and Wen, 2019), and macroeconomic uncertainty risk (Bali, Subrahmanyam, and Wen, 2020)

Data on Carbon Emissions

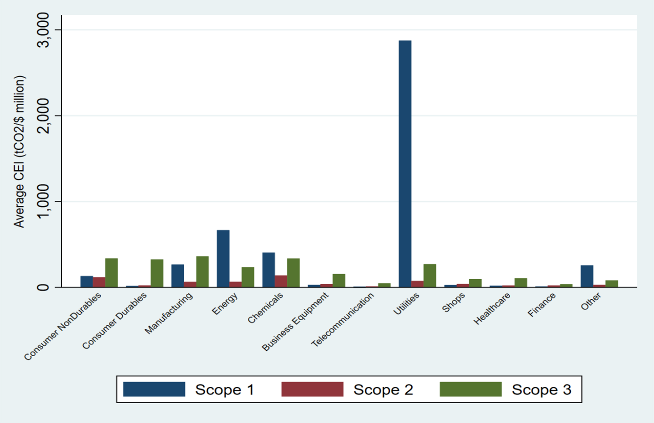
- Firm-level carbon emissions data from S&P Trucost
- We begin with the universe of all firms in Trucost with a fiscal year ending between calendar years 2005 and 2017
- Sample coverage improves over time (here)
- 3 scopes of carbon emissions set by the Greenhouse Gas Protocol



Average Carbon Emission Intensity Over Time

- Carbon emission intensity (CEI) is measured as $CEI = \frac{tCO2e}{revenue(\$mil)}$
- CEI is a standard metric of measuring carbon footprint used by both practitioners (e.g., MSCI low carbon index) and academia
- We perform this scaling because the impacts of climate regulation should be evaluated relative to firm size

Carbon Emission Intensity by FF12 Industry



- The top-three most carbon-intensive industries are Utilities, Energy, and Chemicals

Cross-sectional Variation of Carbon Intensity Across Industry

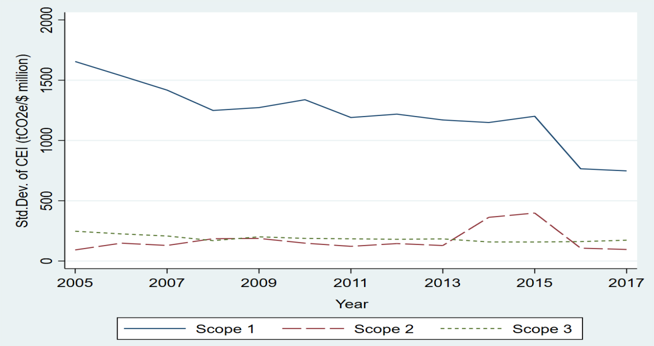


Figure: Cross-industry Standard Deviation of CEI

- There is substantial cross-sectional variation in CEI across industries
- We control for the industry effect in our empirical analyses

Cross-sectional Variation of Carbon Intensity Within Industry

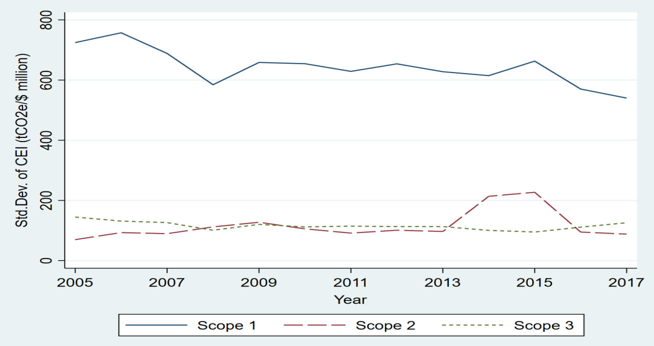


Figure: Within-industry Standard Deviation of CEI

- CEI measure exhibits significant cross-sectional variation even within the same industry

Corporate Bond Data

- Pricing data based on Enhanced TRACE (2002–2019)
  - TRACE dataset offers the best quality of corporate bond transactions with intraday observations on price, trading volume, buy and sell indicators: Bessembinder, Maxwell, and Venkataraman (2006)
- Data filtering rules:
  - Remove bonds that are not traded in the U.S. public market;
  - Remove bonds that are structured, mortgage backed or asset backed
  - Remove bonds with private placement, or under Rule 144A
  - Remove bonds under convertible contract
  - Remove bonds with floating coupon payment
  - Remove bonds if price$<$ \$5 or time-to-maturity $<$ 1yr
- Bond characteristics are from Mergent Fixed Income Securities Database (FISD), including rating, coupon, bond type, option features, etc.

Measuring Corporate Bond Returns

- Excess return on corporate bond i at month t,

$$R_{i,t}^{excess} = \left(\frac{P_{i,t} + AI_{i,t} + Coupon_{i,t}}{P_{i,t-1} + AI_{i,t-1}} - 1 \right) - R_{f,t}$$

  - Final sample includes includes 20,668 bonds issued by 1,178 unique firms, covering the sample period from July 2006 to June 2019
  - About 75% are investment-grade and the remaining 25% are high-yield bonds.

Risk Factors

We use several factor models to calculate risk-adjusted returns of CEI-sorted bond portfolios

1. *5-factor model with stock market factors*
    - the excess return on the market portfolio (MKT^{Stock}), a size factor (SMB), a book-to-market factor (HML), a momentum factor (MOM^{Stock}), and a liquidity risk factor (Fama and French, 1993; Carhart, 1997; Pastor and Stambaugh, 2003)
2. *4-factor model with bond market factors*
    - the aggregate corporate bond market factor (MKT^{Bond}), the downside risk factor (DRF), the credit risk factor (CRF), and the liquidity risk factor (LRF) (Bai, Bali, and Wen, 2019)
3. *9-factor model* that combines the five stock market factors with the four bond market factors

Univariate Portfolio Analysis

- At June of each year t, we form quintile portfolios of corporate bonds **within each of the FF12 industries**, based on firm-level CEI in fiscal year $t-1$
- Calculate value-weighted portfolio returns from July of year t to June of year $t+1$, and average across industries

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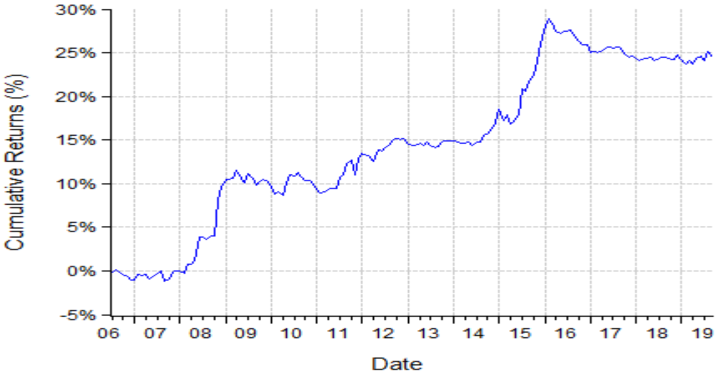
Quintiles	Average CEI	Average return	5-factor stock alpha	4-factor bond alpha	9-factor alpha
Low	36.75	0.37	0.26	0.11	0.11
		(3.66)	(2.42)	(2.38)	(2.62)
2	153.18	0.35	0.24	0.03	0.04
		(3.42)	(2.31)	(0.77)	(1.00)
3	333.77	0.33	0.22	0.05	0.06
		(3.42)	(2.29)	(1.08)	(1.55)
4	518.59	0.31	0.21	0.03	0.03
		(3.28)	(2.14)	(0.65)	(0.68)
High	1127.34	0.23	0.13	-0.05	-0.04
		(2.51)	(1.30)	(-0.69)	(-0.84)
High − Low		–0.14***	–0.13***	–0.16***	–0.15***
		(–2.62)	(–3.13)	(–2.98)	(–3.47)

Characteristics of Bond Portfolios Sorted on CEI

- High-CEI bonds are **riskier** than low-CEI bonds, as indicated by:
  - Higher bond market beta and downside risk
  - Higher illiquidity
  - Higher credit risk
- High-CEI firms are also **less** profitable than low-CEI firms

	β_{Bond}	Downside Risk (5\% VaR)	ILLIQ	Rating
Low	0.98	4.77	0.90	7.61
2	1.06	5.03	0.89	8.27
3	1.01	4.48	0.91	8.02
4	0.86	4.38	0.91	7.69
High	1.14	5.20	1.17	9.01
High − Low	0.15**	0.42***	0.27***	1.41***
	(2.14)	(3.56)	(4.14)	(13.15)

Cumulative Return for the L/S Bond Portfolio Sorted on CEI



- Bonds issued by firms with **low carbon intensity** consistently outperform those with high carbon intensity
- The low carbon premium declined since 2016, which corresponds to the post Paris agreement signed in December 2015

Bond-level Fama-MacBeth Regressions

- FM regression of future bond returns on firm-level CEI

$$R_{i,t+1} = \lambda_{0,t} + \lambda_{1,t} \cdot Ln(CEI_{i,t}) + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1}, \tag{1}$$

- $R_{i,t+1}$ is the excess return on bond i from July of year t to June of year $t+1$
- $Ln(CEI_{i,t})$ is the log of firm-level CEI in June of year t

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- $Ln(CEI_{i,t})$ is the log of firm-level CEI in June of year t
- $Controls_{k,t}$ denotes a set of control variables, including
    1. **Bond characteristics** such as bond market beta ($\beta_{i,t}^{MKT}$), downside risk proxied by the 5% Value-at-Risk ($VaR_{i,t}$), bond-level illiquidity, credit rating, time-to-maturity, bond amount outstanding (size) etc.
    2. **Systematic risk proxies** such as the default beta ($\beta_{i,t}^{DEF}$), the term beta ($\beta_{i,t}^{TERM}$), and the macroeconomic uncertainty beta ($\beta_{i,t}^{UNC}$)
    3. **Bond climate news risk beta** ($\beta_{i,t}^{Climate}$) which measures bond exposure to unexpected changes in climate news index (Huynh and Xia, 2020)
- Controlling for industry fixed effects in FM regressions

Bond-level Fama-MacBeth Regressions

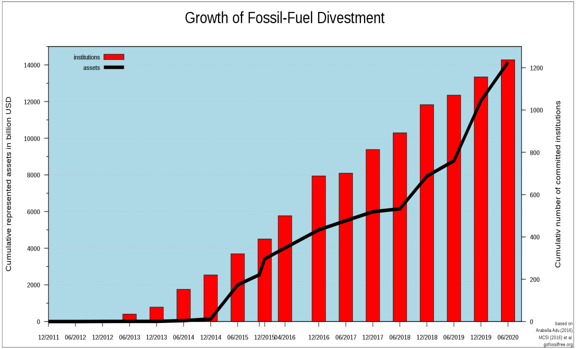
	(1)	(2)	(3)	(4)
	Univariate	Controlling for bond characteristics	Controlling for systematic/climate risk beta	Controlling for all variables
ln(CEI)	**–0.046**	**–0.042**	**–0.038**	**–0.036**
	(–2.76)	(–2.59)	(–2.51)	(–2.30)
β^{Bond}		**0.225**		**0.244**
		(3.17)		(3.77)
Downside risk (5% VaR)		**0.105**		**0.091**
		(3.18)		(3.54)
ILLIQ		0.002		0.003
		(0.20)		(0.34)
Rating		0.004		0.011
		(0.27)		(0.99)
Maturity		**0.011**		**0.008**
		(2.50)		(2.07)
Size		0.006		0.007
		(0.22)		(0.27)
Lag Return		**-0.117**		**-0.129**
		(-5.00)		(-5.57)
β^{DEF}			-0.259	-0.064
			(-1.80)	(-0.87)
β^{TERM}			**0.407**	0.151
			(2.29)	(1.41)
β^{UNC}			**-0.151**	**-0.159**
			(-2.37)	(-2.63)
$\beta^{Climate}$			-0.873	0.090
			(-0.89)	(0.11)
Intercept	0.251	0.276	0.260	0.208
	(1.86)	(1.94)	(2.13)	(2.09)
Industry Fixed Effects	YES	YES	YES	YES
Adj. R2	0.045	0.248	0.122	0.270

Robustness Checks

- We conduct a battery of robustness tests for the bond return predictability of carbon emission intensity including:
  1. Measuring CEI based on the scope 2 emissions, and scope 1 and scope 2 emissions combined (here)
  2. Excluding firms in the Energy, Chemicals or Utilities industries that are most carbon intensive (here)
  3. Conducting portfolio analysis at firm level to control for the impact of multiple bonds issued by the same firm (here)
  4. Excluding the period of global financial crisis (September 2008 to December 2009) and conducting subperiod analysis (here)
  5. Portfolio sorts based on industry-level CEI (here)
  6. Alternative factor models (here)
- We find similar "low carbon premium" in the stock market (here)

Testing "Investor Preference" Hypothesis

- Our evidence so far suggests the "Low Carbon Premium", opposite to the "Carbon Risk Premium" hypothesis
- **"Investor Preference" Hypothesis:** green assets could outperform brown assets if investors' preferences for green assets strengthen unexpectedly over the sample period (Pastor, Stambaugh, and Taylor, 2020)
- As of 2020, 1,200 institutions managing 14 trillion USD commit to divest the fossil fuel industry



Testing "Investor Preference" Hypothesis (cont'd)

- To test this explanation, we use institutional holdings of corporate bonds from Refinitiv eMAXX, which has a comprehensive coverage of fixed income holdings by U.S. institutional investors (e.g., insurance companies and mutual funds)

$$\Delta INST_{i,t+1} = \lambda_{0,t} + \lambda_{1,t} \cdot Ln(CEI_{i,t}) + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1}, \quad (2)$$

- $\Delta INST_{i,t+1}$ is defined as the institutional ownership in June of year $t+1$ minus the institutional ownership in June of year t
- To further examine whether changes in institutional ownership fully explain the low carbon premium, we include $\Delta INST_{i,t+1}$ in return predictability test

$$R_{i,t+1} = \lambda_{0,t} + \lambda_{1,t} \cdot Ln(CEI_{i,t}) + \lambda_{2,t} \cdot \Delta INST_{i,t+1} + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1}, \quad (3)$$

CEI and Changes in Bond Institutional Ownership

	Univariate	Controlling for bond characteristics	Controlling for systematic/climate risk beta	Controlling for all variables
ln(CEI)	**–0.471**	**–0.211**	**–0.489**	**–0.226**
	(–3.66)	(–2.65)	(–4.51)	(–2.42)
β^{Bond}		**0.312**		**0.276**
		(5.18)		(3.49)
Downside risk (5% VaR)		-0.018		-0.013
		(-0.19)		(-0.14)
ILLIQ		**0.402**		**0.355**
		(2.29)		(2.29)
Rating		**-0.725**		**-0.693**
		(-4.60)		(-4.75)
Maturity		**0.379**		**0.343**
		(3.95)		(3.76)
Size		-0.146		-0.119
		(-1.91)		(-1.70)
Return(t-7:t-2)		**4.744**		**4.738**
		(10.97)		(10.97)
β^{DEF}			-0.144	-0.089
			(-0.72)	(-0.55)
β^{TERM}			0.396	0.125
			(1.63)	(0.65)
β^{UNC}			**-0.328**	-0.189
			(-2.34)	(-1.61)
$\beta^{Climate}$			-0.126	-0.095
			(-1.37)	(-1.50)
Industry Fixed Effects	YES	YES	YES	YES
Adj. R2	0.016	0.277	0.033	0.280

- The coefficient of -0.226 on $Ln(CEI)$ in Column (4) represents an economic effect of 12.6% reduction relative to the mean $\Delta INST_{i,t+1}$

Do Changes in Institutional Ownership Fully Explain the Low Carbon Premium?

	Univariate	Controlling for bond characteristics	Controlling for systematic/climate risk beta	Controlling for all variables
ln(CEI)	**–0.039**	**–0.036**	**–0.031**	**–0.027**
	(–2.59)	(–2.03)	(–2.35)	(–2.15)
$\Delta INST$	0.125	0.134	0.042	0.122
	(0.60)	(0.79)	(0.21)	(0.73)
β^{Bond}		0.066		**0.148**
		(1.12)		(2.32)
Downside risk (5% VaR)		**0.046**		**0.040**
		(2.41)		(2.09)
ILLIQ		-0.001		-0.001
		(-0.13)		(-0.10)
Rating		0.005		0.004
		(0.23)		(0.24)
Maturity		0.003		0.002
		(0.72)		(0.51)
Size		0.032		0.026
		(0.79)		(0.64)
Lag Return		**-0.197**		**-0.206**
		(-6.34)		(-6.86)
β^{DEF}			-0.168	-0.012
			(-1.07)	(-0.23)
β^{TERM}			0.103	-0.017
			(0.66)	(-0.18)
β^{UNC}			**-0.258**	-0.217
			(-2.43)	(-1.45)
$\beta^{Climate}$			-0.035	0.537
			(-0.03)	(0.56)
Industry Fixed Effects	YES	YES	YES	YES

Testing the Investor Underreaction Hypothesis

- "Investor Underreaction" hypothesis: the "Low Carbon Premium" should be more pronounced among bonds with higher information asymmetry
  1. Non-investment-grade (here)
  2. Longer-maturity bonds (here)
  3. Less liquid bonds (here)

- Return predictability of CEI becomes weaker during periods when public attention to climate change issues is high
  - Abnormal Google Search Volume Index (ASVI) on the topics of **"climate change"** or **"global warming"**
  - Pre- and Post-Paris agreement period comparison (here)

Carbon Intensity and Cash Flow News

- "Investor Underreaction" hypothesis: investors underreact to the predictability of CEI for firm fundamentals (Pedersen, Fitzgibbons, and Pomorski, 2020)

Carbon Intensity and Cash Flow News

- "Investor Underreaction" hypothesis: investors underreact to the predictability of CEI for firm fundamentals (Pedersen, Fitzgibbons, and Pomorski, 2020)
- We use three proxies for firm cash flow news:
  1. standardized unexpected earnings SUE
  2. standardized unexpected revenue growth estimator SURGE (Jegadeesh and Livnat, 2006)
  3. cumulative abnormal return in a four-day window around earnings announcements (CAR(−2, +1))

$$SUE_{i,t+1} = \lambda_{0,t} + \lambda_{1,t} \cdot Ln(CEI_{i,t}) + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1}, \tag{4}$$

Carbon Intensity and Cash Flow News

Variables	SUE		SURGE		CAR $(-2, +1)$	
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(CEI)	−0.0177***	−0.0128**	−0.0446***	−0.0262***	−0.0004***	−0.0005**
	(−5.48)	(−2.19)	(−12.29)	(−4.20)	(−2.60)	(−1.99)
Dependent Variable$_{t-1}$	0.3259***	0.3237***	0.7441***	0.7394***	-0.0089	-0.0092
	(29.91)	(30.14)	(102.15)	(100.99)	(-1.14)	(-1.19)
Dependent Variable$_{t-4}$	-0.1881***	-0.1893***	-0.0398***	-0.0444***	-0.0043	-0.0046
	(-22.05)	(-22.43)	(-8.28)	(-9.13)	(-0.61)	(-0.65)
Ln (ME)	0.0402***	0.0410***	0.0411***	0.0382***	-0.0005	-0.0004
	(4.85)	(4.96)	(5.43)	(5.08)	(-1.61)	(-1.28)
Book-to-Market	-0.2813***	-0.2655***	-0.1855***	-0.1815***	-0.0013	-0.0009
	(-12.70)	(-11.38)	(-7.17)	(-6.62)	(-0.91)	(-0.62)
ROE	-0.3164***	-0.3568***	0.2154***	0.2580***	0.0027	0.0012
	(-5.39)	(-5.96)	(3.25)	(3.85)	(0.81)	(0.35)
R&D	-1.1300***	-0.9871***	-0.7490***	-0.7030*	0.0169	0.0289*
	(-4.49)	(-2.97)	(-2.74)	(-1.91)	(1.44)	(1.75)
Investment	-0.0065	0.0001	-0.1788***	-0.1644***	-0.0053**	-0.0053**
	(-0.14)	(0.00)	(-3.74)	(-3.35)	(-2.18)	(-2.15)
OCF	0.5771***	0.7639***	0.7893***	0.7867***	-0.0003	0.0040
	(3.08)	(3.90)	(4.32)	(3.95)	(-0.05)	(0.50)
Institutional Ownership	0.1320***	0.1333***	0.2007***	0.1745***	0.0050**	0.0053**
	(3.08)	(3.09)	(5.02)	(4.35)	(2.34)	(2.43)
Momentum	0.4454***	0.4397***	0.2733***	0.2757***	-0.0025*	-0.0026**
	(7.40)	(7.37)	(7.09)	(6.95)	(-1.94)	(-2.01)
Constant	-0.6590***	-0.7187***	-0.6860***	-0.6589***	0.0103	0.0077
	(-3.30)	(-3.55)	(-3.83)	(-3.63)	(1.29)	(0.94)
Industry FEs	NO	YES	NO	YES	NO	YES
Quarter FEs	YES	YES	YES	YES	YES	YES
Adjusted R-squared	0.1970	0.1990	0.6270	0.6290	0.0074	0.0075
Observations	28,691	28,691	28,654	28,654	28,666	28,666

- Firms with higher CEI have lower earnings (revenue) surprise as well as a more negative earnings announcement return

Carbon Intensity and Firm Creditworthiness

- The previous results suggest firms with lower (higher) CEI are associated with better (poorer) future fundamentals
- Better (poorer) fundamentals could lead to improving (deteriorating) firm creditworthiness, which then drive the higher (lower) realized returns of low (high) CEI bonds
- Two proxies for firm creditworthiness:
  - Change of bond-level credit ratings ($\Delta Rating$)
  - Change of Ohlson's O-Score ($\Delta O\_Score_{i,t+1}$). A higher O-score indicates a higher probability of financial distress

$$\Delta Rating_{i,t+1} = \lambda_{0,t} + \lambda_{1,t} \cdot Ln(CEI_{i,t}) + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1}, \quad (5)$$

Carbon Intensity and Firm Creditworthiness

Variables	$\Delta Rating$	ΔO_Score
	(1)	(2)
Ln(CEI)	0.0252***	0.0076**
	(3.02)	(2.01)
Ln(ME)	0.1515***	0.0069
	(12.96)	(1.24)
Book-to-Market	0.2827***	-0.0674**
	(14.62)	(-2.41)
ROE	-0.1396***	-0.1401**
	(-3.59)	(-2.30)
R&D	-2.1716**	0.6535***
	(-2.56)	(4.86)
Investment	-0.0528**	-0.0107
	(-2.07)	(-0.19)
OCF	0.6572***	-0.4574***
	(5.27)	(-2.87)
Institutional Ownership	-0.1526***	0.0080
	(-4.78)	(0.22)
Constant	-3.6909***	-0.1722
	(-12.76)	(-1.23)
Bond FEs	YES	-
Industry FEs	-	YES
Year FEs	YES	YES
Adjusted R-squared	0.2130	0.1120
Observations	43,485	4,500

- Carbon-intensive firms experience deteriorated creditworthiness subsequently

Carbon Intensity and Environmental Incidents

- What is the likely channel through which higher carbon intensity leads to poorer firm fundamentals?
  - Conjecture: **Environmental risks** are persistent and carbon-intensive firms are more likely to face negative environment incidents
- We use RepRisk data to capture ESG incidents:
  1. RepRisk uses a rigorous process to identify and rate *negative* ESG incidents, using information from over 80,000 sources
  2. ESG incident is quantified by the RepRisk Index, which takes into account the severity, the reach, and the novelty of the incident
  3. Compared to other ESG metrics, RepRisk is less subjective and less prone to firm manipulation
  4. Positive change in RepRisk Index indicates an ESG incident

$$Ln(1 + Incidents_{i,t+1}) = \lambda_{0,t} + \lambda_{1,t} \cdot Ln(CEI_{i,t}) + \sum_{k=1}^{K} \lambda_{k,t} Control_{k,t} + \epsilon_{i,t+1}, \quad (6)$$

Carbon Intensity and Environmental Incidents

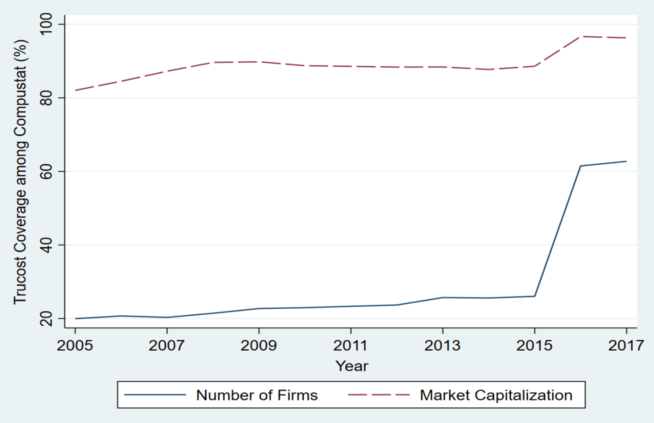
Variable	Ln(Incidents+1)	
ln(CEI)	0.1596***	0.1255***
	(15.90)	(9.79)
Firm size	0.0961***	0.0830***
	(6.06)	(5.96)
BM	0.2456***	0.1224**
	(5.13)	(2.58)
ROE	-0.0114	0.0580
	(-0.11)	(0.61)
R&D	-1.4576***	-0.9789***
	(-4.37)	(-2.60)
Investment	0.0504	0.0138
	(0.62)	(0.17)
OCF	0.2686	-0.0999
	(0.79)	(-0.33)
INST_Stock	-0.0959	-0.0457
	(-1.37)	(-0.69)
Constant	-2.3840***	-1.9198***
	(-6.23)	(-5.73)
Industry FEs	NO	YES
Time FEs	YES	YES
Adjusted R-squared	0.1790	0.2110
Observations	6,674	6,674

- High-CEI firms (quintile 5) experience 54.7% ($= 0.1596 \times 3.42$) more environmental incidents than low-CEI firms (quintile 1) over the following year

Conclusion

- Contrary to the “Carbon Risk Premium” hypothesis, we find that bonds issued by firms with higher carbon intensity earn significantly lower future returns
- Higher CEI predicts lower future cash flow news, deteriorating firm creditworthiness, and more environmental incidents
- Inefficient pricing of carbon risk in the corporate bond market has important implications for financial stability and climate mitigation policies

Trucost Sample Coverage



- Plots the sample coverage of Trucost as fraction of Compustat universe, both in terms of number of firms and Mktcap (back to main)

Subsample Analysis: Credit Rating

- the "low carbon premium" is more pronounced among non-investment-grade bonds (back to main)

	Investment-grade		Non-investment-grade	
	Average return	9-factor alpha	Average return	9-factor alpha
Low	0.37	0.08	0.41	0.25
	(3.63)	(1.99)	(2.58)	(2.19)
2	0.36	0.06	0.44	0.13
	(3.86)	(1.62)	(2.89)	(1.27)
3	0.35	0.09	0.30	-0.05
	(3.87)	(2.76)	(1.73)	(-0.44)
4	0.35	0.06	0.34	0.06
	(3.91)	(1.65)	(2.29)	(0.78)
High	0.25	-0.02	0.14	-0.11
	(1.98)	(-0.64)	(0.82)	(-1.04)
High - Low	-0.12**	-0.10**	-0.27***	-0.36***
	(-2.17)	(-2.01)	(-3.54)	(-4.08)

Subsample Analysis: Time-to-Maturity

- the "low carbon premium" is more pronounced in longer-maturity bonds (back to main)

	1yr < Maturity <= 6 yr		Maturity > 6 yr	
	Average return	9-factor alpha	Average return	9-factor alpha
Low	0.26	0.12	0.47	0.13
	(3.97)	(3.79)	(3.13)	(2.44)
2	0.25	0.09	0.47	0.02
	(3.75)	(2.23)	(3.16)	(0.32)
3	0.21	0.08	0.44	-0.00
	(3.31)	(2.25)	(2.99)	(-0.05)
4	0.20	0.08	0.40	-0.03
	(3.63)	(2.95)	(2.63)	(-0.46)
High	0.17	-0.01	0.31	-0.10
	(2.14)	(-0.28)	(2.08)	(-1.62)
High - Low	-0.10**	-0.13***	-0.15**	-0.23***
	(-2.34)	(-3.02)	(-2.56)	(-3.06)

Subsample Analysis: Illiquidity

- the "low carbon premium" is more pronounced in less liquid bonds (back to main)

	ILLIQ <= ILLIQMedian		ILLIQ > ILLIQMedian	
	Average return	9-factor alpha	Average return	9-factor alpha
Low	0.37	0.11	0.43	0.04
	(4.07)	(4.22)	(3.27)	(0.79)
2	0.29	0.03	0.48	0.09
	(3.14)	(0.65)	(3.89)	(1.89)
3	0.32	0.09	0.34	-0.04
	(3.60)	(2.58)	(2.75)	(-0.61)
4	0.33	0.09	0.34	-0.03
	(4.34)	(2.79)	(2.45)	(-0.56)
High	0.28	0.03	0.21	-0.15
	(3.42)	(0.83)	(1.65)	(-2.40)
High - Low	-0.09**	-0.08**	-0.22***	-0.20***
	(-2.06)	(-2.21)	(-3.28)	(-3.54)

Robustness 1: Scope 2 Emission

	Scope 2 only			
	Average return	5-factor stock alpha	4-factor bond alpha	9-factor alpha
Low	0.36	0.26	0.09	0.08
	(3.77)	(2.49)	(2.41)	(2.56)
2	0.37	0.26	0.08	0.08
	(3.81)	(2.58)	(2.65)	(3.09)
3	0.34	0.24	0.07	0.07
	(3.68)	(2.59)	(1.75)	(1.94)
4	0.34	0.23	0.00	0.01
	(3.30)	(2.29)	(0.05)	(0.32)
High	0.23	0.08	-0.07	-0.06
	(1.94)	(0.67)	(-0.94)	(-0.97)
High − Low	−0.12*	−0.18***	−0.15***	−0.15***
	(−1.90)	(−2.87)	(−2.93)	(−3.04)

- Go back to main

Robustness 2: Excluding Carbon-intensive Industries

	Excluding energy industry only		Excluding chemicals industry only		Excluding utilities industry only	
	Average return	9-factor alpha	Average return	9-factor alpha	Average return	9-factor alpha
Low	0.37	0.09	0.37	0.08	0.37	0.09
	(3.63)	(2.72)	(3.56)	(2.33)	(3.63)	(2.63)
2	0.37	0.09	0.34	0.03	0.34	0.03
	(3.86)	(2.89)	(3.27)	(0.73)	(3.36)	(0.88)
3	0.35	0.09	0.32	0.04	0.32	0.05
	(3.59)	(2.39)	(3.24)	(1.16)	(3.35)	(1.29)
4	0.31	0.03	0.30	0.03	0.31	0.02
	(3.29)	(0.87)	(3.21)	(0.72)	(3.22)	(0.52)
High	0.28	-0.00	0.25	-0.06	0.25	-0.06
	(2.79)	(-0.11)	(2.33)	(-1.21)	(2.32)	(-1.16)
High − Low	−0.09**	−0.09***	−0.12***	−0.14***	−0.12**	−0.14***
	(−2.17)	(−2.78)	(−2.87)	(−3.57)	(−2.58)	(−3.59)

▶ Go back to main

Robustness 3: Firm-level Analysis

	Firm-level bond returns		Largest bond		Most liquid bond	
	Average return	9-factor alpha	Average return	9-factor alpha	Average return	9-factor alpha
Low	0.39	0.13	0.38	0.10	0.38	0.11
	(4.03)	(2.89)	(3.80)	(3.02)	(4.05)	(3.00)
2	0.37	0.08	0.33	-0.00	0.33	0.03
	(3.77)	(1.82)	(2.92)	(-0.06)	(3.05)	(0.53)
3	0.28	0.02	0.35	0.06	0.25	-0.04
	(2.90)	(0.42)	(3.55)	(1.30)	(2.39)	(-0.71)
4	0.33	0.06	0.31	0.00	0.32	0.03
	(3.46)	(1.64)	(3.05)	(0.01)	(3.32)	(0.61)
High	0.29	0.01	0.24	-0.05	0.25	-0.01
	(2.92)	(0.11)	(2.20)	(-1.01)	(2.32)	(-0.24)
High – Low	–0.10***	–0.12***	–0.15**	–0.15***	–0.13**	–0.12**
	(–2.78)	(–2.93)	(–2.44)	(–3.43)	(–2.50)	(–2.42)

▶ Go back to main

Robustness 4: Subperiod analysis

	Excluding GFC (2008 - 2009)		1st Subperiod July 2006 to June 2013		2nd Subperiod July 2013 to June 2019	
	Average return	9-factor alpha	Average return	9-factor alpha	Average return	9-factor alpha
Low	0.35	0.06	0.40	0.17	0.34	0.10
	(4.48)	(2.21)	(2.42)	(2.11)	(3.09)	(1.87)
2	0.31	0.01	0.42	0.13	0.26	-0.08
	(3.97)	(0.24)	(2.65)	(2.33)	(2.20)	(-1.92)
3	0.32	0.03	0.40	0.15	0.26	-0.05
	(4.23)	(1.00)	(2.50)	(2.47)	(2.52)	(-1.67)
4	0.33	0.05	0.32	0.03	0.31	-0.00
	(4.36)	(1.62)	(2.02)	(0.61)	(2.98)	(-0.08)
High	0.21	-0.06	0.22	0.01	0.23	-0.01
	(3.24)	(-1.53)	(1.59)	(0.07)	(2.22)	(-1.87)
High – Low	–0.14**	–0.12***	–0.18**	–0.16**	–0.11*	–0.10**
	(–2.21)	(–3.17)	(–2.06)	(–2.46)	(–1.96)	(–2.48)

► Go back to main

Robustness 5: Sort on Industry-level CEI

	Average Intensity_rev_1	**Average return**	**5-factor stock alpha**	**BBW 4-factor bond alpha**	**9-factor alpha**
Low	6.38	0.41	0.27	0.03	0.02
		(3.38)	(2.29)	(0.68)	(0.35)
2	10.21	0.34	0.23	0.05	0.05
		(2.63)	(1.92)	(0.88)	(0.86)
3	11.21	0.32	0.22	0.12	0.07
		(2.84)	(1.71)	(3.71)	(2.47)
4	15.47	0.33	0.26	0.04	0.04
		(3.43)	(2.56)	(1.38)	(1.27)
High	948.16	0.25	0.11	-0.10	-0.10
		(2.67)	(1.66)	(-2.08)	(-1.75)
High − Low		−0.15**	−0.16**	−0.13**	−0.12**
		(−2.62)	(−2.45)	(−2.14)	(−2.38)

- Quintile portfolio sorts on industry-level CEI using the Fama-French 30 industry (back to main)

Robustness 6: Alternative Factor Models

	Average CEI	Average return	FF 5-factor alpha	Q-factor alpha	(FF 5 + BBW) 9-factor alpha	(Q4 + BBW) 8-factor alpha
Low	36.75	0.37	0.24	0.34	0.08	0.11
		(3.66)	(2.16)	(3.22)	(2.28)	(2.54)
2	153.18	0.35	0.22	0.33	0.03	0.08
		(3.42)	(2.03)	(3.33)	(0.59)	(1.66)
3	333.77	0.33	0.22	0.31	0.06	0.10
		(3.42)	(2.21)	(3.23)	(1.53)	(2.15)
4	518.59	0.31	0.19	0.28	0.03	0.04
		(3.28)	(1.88)	(2.80)	(0.99)	(0.98)
High	1127.34	0.23	0.11	0.18	-0.06	-0.02
		(2.51)	(1.29)	(2.26)	(-0.61)	(-0.41)
High − Low		−0.14***	−0.13***	−0.16***	−0.14***	−0.13**
		(−2.62)	(−2.68)	(−2.81)	(−2.69)	(−2.40)

- Back to main

CEI and Yield-to-Maturity

	Univariate	Controlling for bond characteristics	Controlling for systematic/climate risk beta	Controlling for all variables
ln(CEI)	**0.051**	**0.056**	**0.048**	**0.050**
	(6.18)	(4.17)	(3.84)	(4.03)
β^{Bond}		**-0.499**		**-0.703**
		(-2.70)		(-6.04)
Downside risk (5% VaR)		**0.669**		**0.505**
		(8.08)		(7.72)
ILLIQ		**0.091**		**0.086**
		(4.05)		(4.39)
Maturity		**0.030**		**0.054**
		(2.53)		(4.91)
Size		**-0.143**		**-0.176**
		(-4.58)		(-5.02)
β^{DEF}			**1.734**	**0.854**
			(6.65)	(4.30)
β^{TERM}			**-2.369**	**-1.584**
			(-6.07)	(-5.88)
β^{UNC}			**-1.469**	**-0.652**
			(-4.23)	(-2.52)
$\beta^{Climate}$			-6.625	2.216
			(-1.87)	(0.91)
Industry Fixed Effects	YES	YES	YES	YES
Adj. R2	0.064	0.468	0.279	0.514

- Carbon-intensive firms experience increase in YTM (back to main)

Univariate Portfolio Analysis for Stocks with Corporate Bonds

- We form quintile portfolios for stocks with corporate bonds, based on the firm-level CEI in June of each year t
- Form portfolios within each of the FF12 industries and then average across industries (back to main)

	Average CEI	Average return	FFCPS alpha	FF 5-factor alpha	Q-factor alpha
		Full sample July 2006 to June 2019			
Low	17.44	1.03	0.27	0.24	0.30
		(2.77)	(3.00)	(2.20)	(2.81)
2	64.27	0.96	0.22	0.16	0.30
		(2.06)	(1.44)	(0.87)	(1.70)
3	168.94	0.95	0.26	0.25	0.28
		(2.49)	(2.08)	(1.85)	(2.08)
4	453.75	0.90	0.13	0.10	0.25
		(1.93)	(0.81)	(0.59)	(1.27)
High	1218.84	0.69	-0.14	-0.28	-0.15
		(1.67)	(-0.90)	(-1.69)	(-0.84)
High − Low		−0.33**	−0.41***	−0.53***	−0.46***
		(−2.38)	(−2.79)	(−3.20)	(−2.81)

Univariate Portfolio Analysis for All Stocks

- We form quintile portfolios of all stocks based on the firm-level CEI in June of each year t
- Form portfolios within each of the FF12 industries and then average across industries

	Average CEI	Average return	FFCPS alpha	FF 5-factor alpha	Q-factor alpha
		Full sample July 2006 to June 2019			
Low	20.69	0.93	0.11	0.05	0.17
		(2.22)	(1.46)	(0.49)	(1.34)
2	57.52	0.83	0.08	0.03	0.11
		(2.11)	(1.13)	(0.35)	(1.35)
3	186.24	0.79	0.00	-0.03	0.03
		(1.92)	(0.02)	(-0.31)	(0.36)
4	417.12	0.84	0.07	0.02	0.12
		(2.05)	(0.95)	(0.26)	(1.18)
High	1149.57	0.71	-0.14	-0.16	-0.07
		(1.56)	(-0.85)	(-0.88)	(-0.41)
High − Low		−0.22*	−0.25*	−0.20	−0.24*
		(−1.74)	(−1.83)	(−1.39)	(−1.72)

Investor Attention and Return Predictability of CEI

Panel A: Investor attention and the low carbon premium

Variables	Low - High	t-stat	Variables	Low - High
Abnormal SVI increases			Abnormal SVI decreases	
DSVI_Climate Change $>= 0$	0.05	0.84	DSVI_Climate Change < 0	0.26***
DSVI_Global Warming $>= 0$	0.07	1.25	DSVI_Global Warming < 0	0.23***

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

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

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

Test for Unknown Structural Break Date	2016m3
P-value	0.022
Test for Known Structural Break Date	2016m1
P-value	0.025

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