An EDHEC-Risk Institute Working Paper

Climate Change and Credit Risk

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Abstract

We investigate the relationship between exposure to climate change and firm credit risk. We show that the distance-to-default, a widely used market-based measure of corporate default risk, is negatively associated with the amount of a firm's carbon emissions and carbon intensity. Therefore, companies with high carbon footprint are perceived by the market as more likely to default, ceteris paribus. The carbon footprint decreases the distance-to-default following shocks - such as the Paris Agreement - that reveal policymakers' intention to implement stricter climate policies. Overall, these results indicate that the exposure to climate risks affects the creditworthiness of loans and bonds issued by corporates. Financial regulators and policymakers should consider carefully the impact of climate change risks on the stability of both lending intermediaries and corporate bond markets.

ABOUT THE AUTHORS

Giusy Capasso is an Analyst at Rothschild & Co. Previously, she was with UBS Asset Management, a leading player in sustainable investing. At UBS, she worked on climate change finance helping distributing sustainable products in the Italian market. Giusy holds a MSc in Finance from Bocconi University.

Gianfranco Gianfrate is Professor of Finance at EDHEC Business School and Sustainable Finance Lead Expert at EDHEC-Risk Institute . He writes and researches on topics related to innovation financing, corporate valuation, and climate change finance. Prior to joining EDHEC Business School, he held teaching and research positions at Erasmus University (Netherlands), Harvard University (USA), and Bocconi University (Italy). Gianfranco also has extensive experience in the financial industry, having worked, among others, for Deloitte Corporate Finance (Italy), Hermes Investment Management (UK), and iStarter (UK). Gianfranco holds a BA and a PhD in Business Administration from Bocconi University and a Master in Public Administration from Harvard University.

Marco Spinelli is a graduate finance student at EDHEC Business School. He supports the EDHEC-Risk Institute research efforts in Sustainable Finance and Climate Finance. He holds a Bachelor Degree from the University of Bologna.

1. Introduction

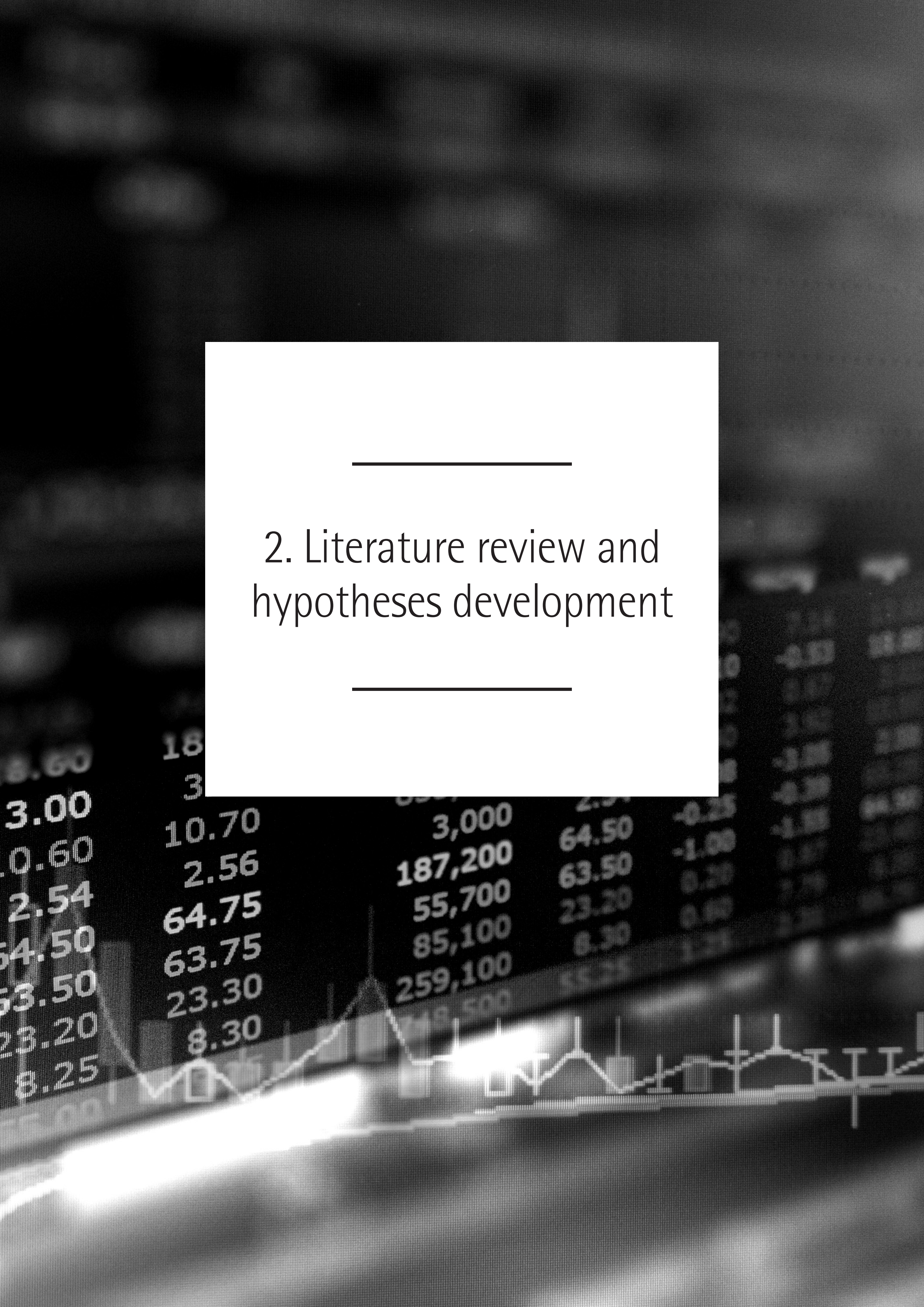
As climate change and global warming are addressed by tougher regulation by governments (especially in the form of carbon pricing mechanisms), new emerging technologies, and shifts in consumer behaviors, global investors are increasingly concerned with the implications of climate change on the pricing of financial assets and on the allocation of their investment portfolios (Krueger et al., 2019). Recent estimates are shedding light on the broader indirect impact of climate change on the value of assets held by banks and financial companies. Battiston et al. (2017) finds that while direct exposures to the fossil fuel sector are small, the combined exposures to climate-policy relevant sectors are large, heterogeneous, and amplified by large indirect exposures via financial counterparties. Thus, the exposure to climate risk could potentially pose systemic threats to global financial stability.

While the relationship between climate risks exposure and share prices is receiving growing attention by scholars and investors, the impact on corporate bonds and loans appears relatively underexplored. We contribute to this literature gap by investigating whether firm's exposure to climate risks, measured as level of CO2 emissions and carbon intensity, is associated to Merton's distance to default, a measure or creditworthiness widely used by rating agencies and investors. Several papers analyze the influence of sustainability factors either on the value of the company or on its cost of capital: we instead focus on the impact on the perceived default probability (measure as distance to default).

Using a panel least squares regression, we show that there is, ceteris paribus, a significant and negative relation between distance to default and both the level of CO2 emissions and the carbon intensity (namely, the ratio between carbon emissions and sales). Several robustness checks are performed and the results confirm a significant and negative relation between distance to default and CO2 footprint.

In order to investigate causality between climate risk exposure and creditworthiness we investigate the impact of the 2015 Paris Agreement as an exogenous policy shock. After the Paris agreement, high emitting companies significantly shorten their distance to default in comparison to low emitters. This finding supports the view that financial markets are increasingly pricing climate change exposure of listed companies, and such exposure affects the overall creditworthiness of companies. This result contributes to the academic and policymaking discourse about the potential financial consequences of climate change risks that could amount to a new form of systemic risk with extensive implications for financial stability.

The paper is structured as follows. Section 2 discusses the main contributions on the relationship between environmental and financial performance of corporates, and introduces the hypotheses to be tested. In Section 3, the methodology is presented discussing the distance to default models, the data and the main models used. Section 4 shows the findings about the relation between distance to default and emission levels. Section 5 presents some additional robustness tests. Finally, Section 6 discusses the main findings and policy implications.



2. Literature review and hypotheses development

A growing body of research and studies by academics and policymakers focus on climate-related risks. Economic agents are increasingly aware that the consequences of climate change they thought lay in the distant future are now much closer, thus posing a relevant and present danger to the global economy and financial sector. The "tragedy of the horizon" of the climate change challenge is raising the possibility of "Minsky moment" of financial fragility caused by climate-related shocks.

Following a distinction introduced by Mark Carney, climate change risk can impact financial stability through three channels. First, physical risks such as extreme meteorological, hydrological and other climatological events are affecting the value of financial assets worldwide. Second, liability risks stemming from the increased compensation paid to economic agents affected by climate change. Finally, transition risks may result from the adjustment of asset prices towards a low-carbon economy. Transition risks are specifically materializing where greater disclosure of carbon footprint is required and new regulation creates obligations to move towards a lower-carbon economy. In particular, by putting a price on greenhouse gas emissions a growing number of countries is bringing down emissions and driving private investments into cleaner options (World Bank, 2019). Therefore, all the CO2-emitting assets could be subject to penalizing regulation thus changing investors' perception of future profitability, business sustainability, and creditworthiness. If the regulatory changes are unexpected and abrupt, a fire sale might result, potentially triggering a financial crisis (Battiston et al., 2017).

Financial literature has explored the links between environmental footprint and corporate debt. For example, Oikonomou et al. (2014) study the impact of various dimensions of sustainability performance on the pricing of corporate debt and credit quality of specific bond issues. Their analysis suggests that each CSR factor substantially lessen the risk premia, reducing the cost of corporate debt; the correlation with credit spreads is less significant from an economic viewpoint.

Hoepner et al. (2017) show that bonds issued by companies with no concerns and no controversies significantly outperform the market benchmark. These findings are particularly strong in times of market turmoil and are also valid for different remaining maturities; bonds are priced on the perception of riskiness and no news are perceived by investors as less risky.

Bauer and Hann (2010) demonstrate that poor environmental performances are associated with worse credit ratings and higher spreads for corporate bonds. Similarly, Chava (2014) shows that firms with multiple environmental concerns must pay higher costs on their bank loans. They conclude that socially responsible lending has the potential to have an impact on the environmental policies of the firm through the cost of capital channels.

Literature that further focuses on carbon emissions is growing. Delis et al. (2018) demonstrate that climate-policy risk is priced in syndicated loans, especially in sectors related to fossil-fuel. Kleimeier and Viehs (2015) also show a significant and negative relation between CO2 emission levels and the cost of bank loans. Jung et al. (2016) provide evidence of the existence of a positive association between cost of debt and carbon-related risks for firms that failed to respond to the Carbon Disclosure Project (CDP) survey. They add that the debt market seems to incorporate historical carbon emissions and forward-looking indicators of carbon performance. Ilhan et al. (2019) estimate the effects of carbon emissions on downside risk as the tail loss reflected in out-of-the-money put options for firms in the S&P 500. They find that higher carbon emissions increase downside risk, especially for firms in high-emission industries.

All in all, the literature not only underlines the importance of carbon awareness as business strategy for polluting firms, but also show the key role it plays with respect to those lenders that are exposed to their clients' default and reputational risk. However, whether investors consider the level of CO_2 emissions footprint in assessing creditworthiness is an empirical question that deserves further investigation also for the implications for financial stability.

2.1 Hypotheses development

This paper contributes to the literature on the impact of climate risks on credit risks. Our focus is specifically on the relationship between the exposure to climate transition risks and firm creditworthiness. Because the companies with larger carbon footprint are relatively more exposed to progressively stricter climate-related regulations (eg higher carbon taxes or more expensive carbon allowances in emissions trading schemes), their future cash flows are likely to be affected to a larger extent than those of companies with lesser carbon footprint. Lower expected cash-flows imply lower firm assets' values, which in turn determine a lower perceived ability to repay debt and thus a reduced creditworthiness.

Carbon footprint can be measured at absolute level but also in terms of carbon intensity. The latter measure, obtained by scaling the total emissions by the firm revenues captures the operational configuration of companies and therefore their ability to switch to less polluting technology. We therefore state the two following hypotheses:

H1a: The higher the firm's carbon footprint the higher its credit risk.
H1b: The higher the firm's carbon intensity the higher its credit risk.

In order to establish a causal relationship between exposure to carbon footprint and credit risk, we test whether following the Paris Agreement that involved an abrupt tightening of global climate policies, credit risk increases for companies that emit relatively more CO2. The choice of December 2015' Paris Agreement as an unexpected turning point in global climate regulation is consistent with various literature contributions. Delis, De Greif and Ongena (2018) use syndicated loan data and find that, before 2015, banks did not price climate policy risk; on the contrary, following the Paris Agreement the risk is priced: banks appeared to be more aware of the climate regulation issue and started pricing such risk after 2015. Ginglinger and Quentin (2019) find that greater climate risk leads to lower leverage in the post-2015 period. Similarly, Ilhan et al. (2019) show that the tail risk of polluting firms significantly increased after 2015, and Monasterolo and De Angelis (2018) indicate that investors require higher risk premia for carbon-intensive industries' equity. Along the same line, our further hypothesis is:

H2: Following the Paris Agreement, companies with larger carbon footprint increase their credit risk more than companies with lesser carbon footprint.

3. Methodology

3.1 Distance to default

Credit risk is defined as the risk that a borrower is not able to meet its financial obligations on time. The Basel Committee defines credit risk as "the risk that a borrower will default on any type of debt by failing to make required payments[1]". Among the approaches used in practice to estimate the probability of corporate default, the structural one – that calculates the default probability on the basis of the capital structure of the firm – is likely to be the most popular. In particular, the Merton distance to default (DD) which is based on Merton's (1974) bond pricing model that is widely used in practice for example in the form of Moody's KMV (Bharat and Shumway, 2008). The innovation of this model lies in applying the option pricing theory developed by Black and Scholes to the risk of insolvency, considering that the firm's equity is like a call option on the firm's assets.

The model assumptions appear particularly restrictive:

1 - "Perfect" and frictionless markets: there are no transaction costs, taxes or bankruptcy costs, no problems with indivisibility of goods, complete information, unrestricted borrowing and lending at a constant interest risk-free rate, short-selling is allowed;

2 - Debt structure: companies have only one form of liability that is a zero-coupon bond with maturity in T; the company cannot issue additional debt, enter into repurchase agreement or pay dividends;

3 - Modigliani-Miller theorem is respected: the value of the company does not depend on its financial structure;

4 - Dynamic of A_t: the value of the company A_t is defined as:

Value of the company A_t = Value of Equity (E_t) + Value of Liabilities (K_t)

A_t follows a stochastic process and it is lognormally distributed with constant volatility. This process is "autoregressive": all the past information are essential elements for predicting the future dynamics of A_t.

According to Merton, A_t, the value of a firm's assets, follows a geometric Brownian motion, hence the dynamics of assets is governed by the following differential equations:

$$A_t,\ dA_t = \mu A_t dt + \sigma A_t\, dz_t, \qquad A_0>0 \qquad (1)$$

Where

A_t, dA_t are the firm's asset value and the change in asset value

μ is the firm's value drift rate (which is the expected annual rate of return on the firm's assets)

σ is the firm's annualized assets volatility t represents today's date dz is a Wiener process.

It follows that the logarithm of the asset value is normally distributed. For example, the value of the logarithm of assets at time T is:

$$\ln A_T \sim N\left(\ln A_t + \left(\mu - \frac{\sigma^2}{2}\right)(T-t),\ \sigma^2\,(T-t)\right) \quad (2)$$

With T and t expressed in years.

In addition, the assumptions state that the company's debt consists of a single bond with maturity T and face value K. At time T, the shareholders' payoff is the residual value of the firm's asset once the debt is repaid:

Cash-flow for shareholder at time T: $(A_T - K)^+$.

The probability of default evaluated at time t, which is the probability that the market value of the firm's assets (A_T) will be less or equal to the book value of the firm's liabilities (K) at the time of maturity (T):

$$P_t = \Pr(A_T \leq K)$$

Knowing that the log asset value in T follows a normal distribution such as:

$$\ln A_T \sim N\left(\ln A_t + \left(\mu - \frac{\sigma^2}{2}\right)(T-t),\ \sigma^2\,(T-t)\right) \quad (3)$$

Considering the logarithm of the variables, the probability can be written as:

$$P_t = \Pr(\ln(A_T) - \ln(K) \leq 0)$$

1 - Principles for the Management of Credit Risk, Final document, Basel Committee on Banking 2 Supervision, BIS Sep.2000, Retrieved 13 September 2013.

$$P_t = \Phi\left(-\frac{\ln(A_t) + \left(\mu - \frac{\sigma^2}{2}\right)(T - t) - \ln(K)}{\sigma\sqrt{T-t}}\right)$$

$$P_t = \Phi\left(-\frac{\ln\left(\frac{A_t}{K}\right) + \left(\mu - \frac{\sigma^2}{2}\right)(T - t)}{\sigma\sqrt{T-t}}\right)$$

Where:
P_t is the probability of default at time T, measured at time t
A_t is the market value of firm's assets at time t
K is the book value of the firm's liabilities to be paid by time T
σ^2 is the annual variance of the logarithm of assets' return
μ is the annual expected rate of return on asset
Φ is the cumulative distribution function of the standardised normal variable $Z \sim N(0,1)$.

The distance to default is the number of standard deviations that the firm's asset value is away from the default and can be defined as:

$$DD = \frac{\ln\left(\frac{A_t}{K}\right) + \left(\mu - \frac{\sigma^2}{2}\right)(T - t)}{\sigma\sqrt{T-t}} \qquad (5)$$

3.2 Calculation of Assets' Market Value and Volatility and Limitations

The only limit in applying formula (5) is that market value of assets and volatility of assets are not observable. However, thanks to the Merton Model's assumption we can use the standard Black-Scholes call option formula:

$$E_t = A_t\,\Phi(d_1) - K\,e^{-r(T-t)}\,\Phi(d_2) \qquad (6)$$

Where:
E_t is the market value of firm's equity

$$d_1 = \frac{\ln\left(\frac{A_t}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)(T - t)}{\sigma\sqrt{T}}$$

$$d_2 = d1 - \sigma\sqrt{T-t}$$

r is the risk-free rate interest;
we have omitted time subscripts for the d_1s and d_2s for brevity.

The intuitive idea is that the value of equity will be equal to the difference between the future value of the assets at time T, given that the option will be in the money, and the discounted value of the liabilities adjusted by the probability that the option will not be exercised.

(4)

To find the two unknowns, A_t and σ^2, we use an iterative procedure: starting with an approximation of the asset value, we apply the Black and Scholes to obtain subsequent estimations of A_t and σ, until they converge (Bharat and Shumway, 2008).

Several empirical studies have demonstrated that this approach tends to underestimate defaults because of restrictive assumptions. One of the main limitations of the approach, is in fact the underlying assumption that asset returns empirically are not normally distributed. The other limitation is that default occurs only at maturity T, in realty default can happen every time. For this reason, modern applications of the Merton model use a barrier option instead of a European option for the calculation of asset value (Brockman and Turtle, 2003; Wong, 2008). In this work we consider only 1-year default to address this limitation of the model. Another problem of Merton's DD model is that it implies that the value of the risk-free and volatility are constant over time. In this study, time-varying interest rates and liabilities are used.

3.3 Application of the Merton Model distance to default with Iterative Procedure

For the purpose of this study we estimate 1-year probabilities of default for a sample of companies from 2007 to 2017 (as discussed in next paragraph). The starting point is the inversion of the equation (6):

$$A_t = \frac{E_t - Ke^{-r(T-t)}\Phi(d_2)}{\Phi(d_1)} \qquad (7)$$

Typically, firms have different types of liabilities with different maturities. Usually in literature it is assumed that the firm has only one type of liabilities maturing in one year (Wong, 2008).

To calculate each 1-year probability of default, formula (7) is applied to calculate the market value of assets for each of the 260 trading days:

$$A_t = \frac{E_t - K_t e^{-r_t(T-t)}\Phi(d_2)}{\Phi(d_1)}$$

$$A_{t-1} = \frac{E_{t-1} - K_{t-1} e^{-r_{t-1}(T-(t-1))}\Phi(d_2)}{\Phi(d_1)}$$

……………

$$A_{t-260} = \frac{E_{t-260} - K_{t-260} e^{-r_{t-260}(T-(t-260))}\Phi(d_2)}{\Phi(d_1)}$$

This system of 260 equations is solved through an iterative process, as follows: the value of asset is calculated for each trading day, approximating it as sum of the market value of equity and book value of liabilities for the same date. Using the obtained series of estimation for asset values, log asset returns are calculated and then their volatility is computed.

The newly calculated volatility of asset value σ is introduced in the inverted S formula (6) to obtain a new series of market value of assets and then a new value for σ is computed and the basis of these new asset values. This process is iterated until the difference between two adjacent estimates of asset values (calculated as the sum of squared differences) is lower than an arbitrary quantity determined as 10^{-5}. Once the assets' market value estimates are obtained, the next step is the calculation of distance to default and corresponding probability of default applying formula (5).

3.4 Data

Our sample consists of the companies included in the *Bloomberg Barclays Agg Corporate Index*. Out of the index constituents, only companies that issued investment grade fixed-rate corporate bonds: the final sample comprise 458 companies observed between from December 2007 to December 2017.

For the calculation of annual distance to default, daily data for market value of equity, index returns and risk-free returns are employed. For liabilities, their book values are used, hence, only annual observations were usually available. Brent oil price (in US dollar) is from Federal Reserve Economic Data. All data are collected from Thomson Reuters DataStream, and expressed in US dollars. All data on emissions are from Thomson Reuters's Asset4.

3.5 Variables

To test the relationship between distance to default and climate change exposure, we quantify the carbon footprint measured - as the amount of CO2 emitted - and the carbon intensity measured as the ratio of CO_2 emissions and firm's revenues. The emissions data considered in the analysis are only the direct (Scope 1) emissions as reported by Asset4. The literature highlighted several limitations of most used reported emissions data and ESG rating scores at firm level (Busch et al., 2018; Berg et al., 2019). Moreover, the coverage of carbon emissions is partial with many public (and private) companies not covered by the main available databases (Battiston and Monasterolo, 2019). While the limitation of the coverage can determine a potential bias, our sample of listed companies is fairly representative of across countries and industries. When assessing the reliability of Asset4's Scope 1 data against alternative sources (Bloomberg, CDP, MSCI, Sustainalytics, Trucost), the quantification "appears to be rather consistent" (Busch et al., 2018).

The control variables are identified in the existing literature about corporate characteristics found to influence the distance to default. In particular, the control variables are:

- The firm size measured as the natural logarithm of total assets. Larger firms are expected to have lower probability of default compared to smaller firms;
- The firm profitability provides important information on the probability for a firm to go bankrupt (Tudela and Young, 2004). Less profitable firms are assumed to be more likely to be acquired or to go bankrupt. We use the operating margin as the metric to account for profitability;
- The financial leverage is associated with the probability for a firm to go bankrupt (Zmijewski, 1984). Firms with lower equity would face more difficulties during periods of liquidity shortage, when it becomes

tougher to renew debt;
- The volatility of asset value has been included: firms for which the volatility of assets is higher are expected to be more vulnerable than others;
- A measure of short-term liquidity needs is included, namely the ratio between working capital and total assets (Zeitun et al., 2007);
- The retained earnings as an equity buffer to deal with potential unexpected growth opportunities and shocks. The ratio between retained earnings and total assets is used (Zeitun et al., 2007);
- Finally, industry and country effects are accounted for. Each sector and country has different structural characteristics and cyclical sensitivities that could impact firms' creditworthiness (Longstaff and Schwartz, 1995; (Nelles and Menz, 2007).

3.6 Models

Our baseline tests examine the relation between carbon footprint ownership and firms' distance to default using the following specification:

$$DD_{it} = \alpha + \beta X_{it} + \gamma' Y_{it} + \varepsilon_{it} \tag{8}$$

where the dependent variable is the distance to default of firm *i* in year *t*, X_{it} is the carbon footprint measured alternatively as amount of CO_2 emissions or as carbon intensity obtained as CO_2 emissions scaled by firm revenues, Y_{it} are a set of firm-level, industry and country controls in year *t*.

As a further test of the hypothesis that carbon footprint cause changes in firm's distance to default, we use the 2015 Paris Agreement as a quasi-natural experiment. This unexpected event – the actual passing of the most ambitious climate deal ever struck - serves as an exogenous shock to the importance that financial markets assign to firms' exposure to climate risks. If carbon footprint drives firms' creditworthiness, we expect that firms with greater carbon footprint at the time of the Paris Agreement will subsequently display lower distance to default, as the financial markets are concerned with exposure to tougher climate policies.

For this test, we follow a difference-in-differences approach by estimating:

$$\begin{aligned} DD_{it} = {} & \alpha + \beta_1 Carbon\ Intensity_i + \beta_2 Post\ Event + \\ & \beta_3 Carbon\ Intensity \times Post\ Event + \gamma' Y_{it} + \varepsilon_{it} \end{aligned} \tag{9}$$

where the dependent variable is the distance to default, Post Event equals one for the years 2016 or after, and zero otherwise. All the other variables are as in Eq. (4). The main coefficient of interest is β_3 for the interaction term *Carbon Intensity × Post Event*.


3.00
2.54
10.70
2.56
64.75
63.75
23.30
8.30
3,000
187,200
55,700
85,100
259,100
64.50
63.50
23.20
8.30
-0.25
-1.00

4. Results

An initial investigation of the data is obtained by partitioning the sample by level of CO2 emissions. The pooled data are divided into quintiles: in each quintile there are about 453 observations. Quintile 1 contains the top 20% companies with the lowest level of carbon emissions, and the 5th quintile contains the bottom 20%.

The mean and the median distance to default are respectively 9.118 and 9.138 for companies in the first quintile. On the contrary, firms in the fifth quintile have a lower distance to default: the mean and median are 7.422 and 7.069. In addition, a paired sample t-test is run. The value of the t-test is 4.866, the rejection value is 1.96, hence the null hypothesis of no difference between the means is rejected with 5% confidence level. Similar results are obtained by partitioning the sample in deciles.

We have tested our dataset to check for the presence of heteroskedasticity and serial correlation. The results of the Wooldridge test confirmed the presence of serial correlation for observations of the same firm. Evidently, distance to default, as most other financial variables, present a strong autocorrelation with prior values. In addittion, we have also run different heteroskedasticity tests (White, Breusch-Pagan) all signaling that the Homoskedasticity hypothesis does not hold.

In light of the results, we decided to apply cluster-robust standard errors, also called Rogers Robust standard errors, to make our estimates robust to disturbances being heteroscedastic and autocorrelated. Then, a second regression is performed maintaining Merton distance to default as dependent variable and natural logarithm of total emissions as independent variable, but including also all the control variables described in the section before. From Table 1, it can be observed that all the specifications have a good explanatory power with R^2 ranging from 48% to 50%. In models 1 and 2, the natural logarithm of carbon emissions has a significant (at 5% level) negative relation with distance to default. Companies that generate more CO2 emissions are more exposed to potential costs related to regulation (eg carbon pricing mechanisms) thus showing a shorter distance to default. Emissions level is part of non financial data that are evidently considered by investors when making decisions. In terms of economic significance, an increase by one percent in carbon emissions reduces the firm's distance to default by about 0.002 on average, all the other variables remaining constant.

All the control variables which are used are indicators of an high probability of bunkruptcy for a company from a financial point of view. The relation between the distance to default and the debt ratio is negative

Figure 1. Distance to default by levels of emissions' quintiles.

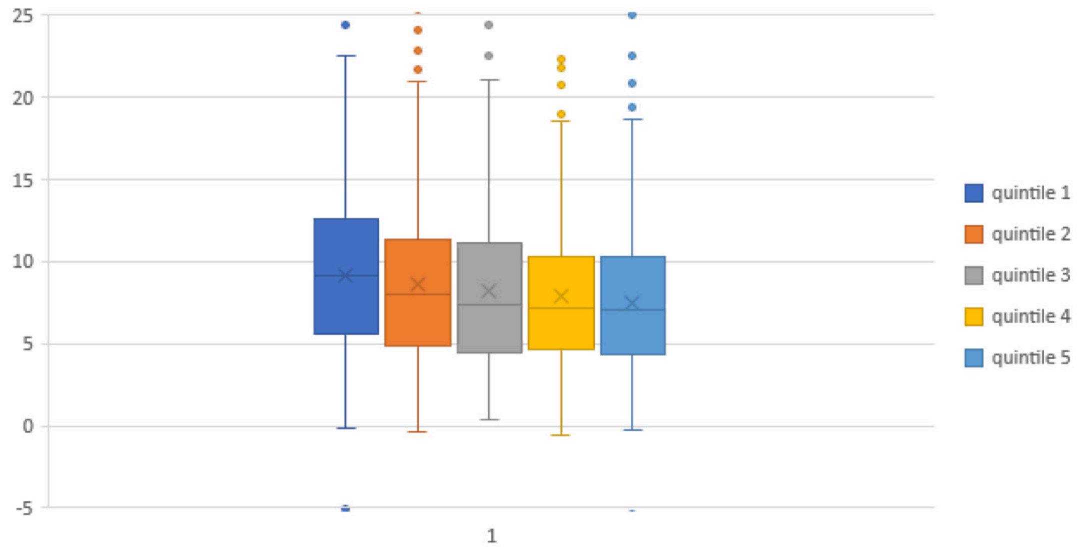


Table 1 – Results of the multivariate analysis with pooled cross sections OLS of the calculated Merton distance to default (2007-2017).

	Dependent variable: Merton Distance to default			
	(1)	(2)	(3)	(4)
Carbon footprint				
Emissions (ln)	-0.180**	-0.181**		
	(0.084)	(0.083)		
Carbon Intensity			-0.179***	-0.176***
			(0.055)	(0.058)
Firm Characteristics				
Debt ratio	-2.141***	-2.156***	-2.152***	-2.166***
	(0.326)	(0.343)	(0.321)	(0.339)
Operating margin	0.331	0.401*	0.474**	0.541**
	(0.218)	(0.228)	(0.223)	(0.239)
Retained earnings ratio	-0.467***	-0.451***	-0.475***	-0.460***
	(0.093)	(0.093)	(0.089)	(0.090)
Size	-0.408**	-0.402**	-0.463***	-0.459***
	(0.162)	(0.162)	(0.157)	(0.157)
Volatility	-24.974***	-25.231***	-24.956***-25.212***	
	(1.748)	(1.747)	(1.747)	(1.745)
Working capital ratio	1.461***	1.462***	1.472***	1.473***
	(0.245)	(0.258)	(0.242)	(0.255)
Energy price				
Oil price		-0.034***		-0.034***
		(0.002)		(0.002)
Constant	23.741***	26.479***	22.063***	24.786***
	(2.923)	(2.890)	(2.816)	(2.781)
Industry Controls	Yes	Yes	Yes	Yes
Country Controls	Yes	Yes	Yes	Yes
Observations	2222	2222	2222	2222
R^2	.477	.504	.477	.501
F Statistic	2926.57***	2635.04***	2897.06***	2611.40***
	(df = 9; 201)	(df = 10; 201)	(df = 9; 201)	(df = 10; 201)

*The independent variable "Merton Distance to Default" is the distance to default calculated using Merton DD model. "Emissions" is the natural logarithm of "Total Emissions" from Asset4. "Carbon Intensity" is the ratio between "Total Emissions" from Asset4 and Sales from Datastream. "Debt Ratio" is a ratio between total liabilities from Datastream and Total Assets. "Operating margin" is the ratio of operating income and sales from Datastream. "Retained Earnings / Total Assets" is the ratio between retained earnings and total assets from Datastream. "Size " is the natural logarithm of Total Assets. "Working capital / Total Assets" is the ratio of working capital from Datastream and Total Assets. Cluster-Robust standard errors in parentheses. Notation of the significance levels: *p<0.1; **p<0.05; ***p<0.01.*

and significant. Indeed, the lower the debt ratio, the higher the likelihood that a firm will survive in the future; hence, an increase in that ratio tends to be associated with a decrease in the distance to default. The operating margin gives an indication of the profitability of the company and, therefore, it is appropriate to positively link it with distance to default, based on the following observation: the higher the profitability of a company, the lower the probability of default. Nontheless, for this particular regression, operating margin appears to not significantly affect distance to default. The ratio retained earnings to total assets helps to measure the extent to which a company relies on leverage. The higher this ratio, the higher the leverage of the company, which, again, increases the risk of bunkruptcy where the firm cannot timely fulfil its debt obligations. In fact, our regression shows a negative and significant relationship between this measure and distance to default. Volatility is another fundamental indicator of creditworthiness of a company. Merton's structural credit risk model (1974) was the first to indicate

Table 2 – Difference in Difference Model

	Dependent variable: Merton Distance to default
Carbon Intensity	-0.172***
	(0.054)
Post Event	0.110
	(0.095)
Carbon Intensity * Post Event	-0.129**
	(0.063)
Firm Characteristics	
Debt ratio	-2.152***
	(0.322)
Operating margin	0.467**
	(0.223)
Retained earnings ratio	-0.475***
	(0.090)
Size	-0.462***
	(0.157)
Volatility	-24.989***
	(1.743)
Working capital ratio	1.472***
	(0.242)
Constant	22.048***
	(2.820)
Industry Controls	Yes
Country Controls	Yes
Observations	2222
R^2	.477
F Statistic	2410.39***
	(df = 11; 202)

*The dependent variable "Merton Distance to Default" is the distance to default calculated using Merton DD model."Emissions" is the natural logarithm of "Total Emissions" from Asset4. "Post event" is a dummy that takes 1 for values post-2015; 0 for all the others. "Carbon Intensity*Post Event" is a variable created multipling year dummy with carbon intensity. "High Emitters" is a dummy which takes a value of 1 for all the observation related to the top 25% firms with highest carbon intensity. "High Emitter*Post Event" is a variable created multipling the High Emitters dummy with year dummy. "Debt Ratio" is a ratio between total liabilities from Datastream and Total Assets. "Operating margin" is the ratio of operating income and sales from Datastream. "Retained Earnings / Total Assets" is the ratio between retained earnings from Datastream and Total Assets. "Size" is the natural logarithm of Total Assets. "Working capital / Total Assets" is the ratio of working capital from Datastream and Total Assets. Cluster-Robust standard errors in parentheses. Notation of the significance levels: *p<0.1; **p<0.05; ***p<0.01.*

that a reduced volatility of the firm value also leads to lower risk premiums. Indeed, in the regression the relation is significant and negative. Lower volatility increases the value of the assets and leads to a rise of the distance to default. Finally, working capital to total assets represents the ability of a company to pay back creditors in the short term. Companies with healthy and positive working capital should not have problems in paying their bills, hence, they should have larger distance to default. Consistently, the association found is positive and significant.

In models 3 and 4, carbon intensity is employed as dependent variable. Carbon intensity is the ratio between the level of emissions and total sales and it is widely used in environmental economics literature as well by energy economics (typically, carbon emissions are dived by the megajoules of energy produced). The results are not different from the previous analysis. Carbon intensity is significantly (at 1% level) and negatively associated with Merton distance to default. The link between climate exposure and firms' creditworthiness could be attributed to the evolution of climate change regulation. We consider that Paris Agreement with its abrupt and (mostly) unexpected implied escalation of climate regulation as an exogenous shock that can shed light on the causality relationship between carbon footprint and distance to default. To capture the effects of this event we use a difference-in-difference regression model. Therefore, besides carbon intensity we introduce a dummy variable "Post Event" equal to one for the observations in the the years subsequent to 2015 (when the Paris Agreement was reached). The variable of interst is the interaction "Carbon Intensity*Post Event", which tries to capture the effect of the climate agreements on the distance to default of the relatively more polluting companies.

Table 2 shows the results of the regression model. The interaction variable has a negative coefficient staistically significant at 5% level. Such finding indicates that, after the strenghtening of climate policies of the Paris Agreeement, there has been a further shortening of distance to default for companies with relatively higher emission levels.

5. Robustness checks

A crucial problem in this analysis is the possible endogeneity bias, which limits drawing casual inferences. Firms with lesser carbon footprint enjoy larger distance to default because of the lower exposure to climate risks. Alternatively, financially healthier firms (more crediworthy) can afford to invest more in clenarer production facilities that reduce their level of carbon emissions. While the difference in difference analysis based on the Paris Agreement already sheds light on the likley direction of the relationship, we perform additional analyses to discard reverse causality issues.

In order to discard the possibility that our results are driven by evolving regulation (beside the Paris Agreement) of high emitting industries, we exclude all the energy and extractive companies. As shown in Table 3, the OLS regression reveals that carbon intensity continues to be negatively related to distance to default with 1% significance level. Consistently with the results reported in Table 1, carbon footprint seems to affect distance to default also beyond fossil-fuel intensive industries.

Additionally, we test variable changes over time in a regression that should be less vulnerable to the endogeneity bias. The results (Table 4) confirm that changes in the distance to default between 2010 and 2017 are significantly and negatively related to changes in the level of carbon emissions.

Finally, we add a lags of the dependent variable into our regression to further address (ex-post) the issue of serial correlation. The models 1 and 3 in Table 5 show

Table 3 – OLS excluding firms operating in the energy and extractive industries

	Dependent variable: Merton Distance to Default
Emissions	
Carbon Intensity	-0.203***
	(0.057)
Firm Characteristics	
Debt ratio	-2.767***
	(0.763)
Operating margin	0.510*
	(0289)
Retained earnings/total assets	-0.621***
	(0.169)
Size	-0.365*
	(0.187)
Volatility	-26.830***
	(2.164)
Working capital/total assets	1.941***
	(0.570)
Constant	21.095***
	(3.371)
Industry Controls	Yes
Country Controls	Yes
Observations	1859
R^2	0.477
F Statistic	2662.65***
	(df = 9; 168)

*The independent variable "Merton Distance to Default" is the distance to default calculated using Merton DD model. "Emissions" is the natural logarithm of "Total Emissions" from Asset4. "Debt Ratio" is a ratio between total liabilities from Datastream and Total Assets as calculated with Merton model. "Operating margin" is the ratio of operating income and sales from Datastream. "Retained Earnings / Total Assets" is the ratio between retained earnings from Datastream and Total Assets. "Size" is the natural logarithm of Total Assets."Working capital / Total Assets" is the ratio of working capital from Datastream and Total Assets. Cluster-Robust standard errors in parentheses. Notation of the significance levels: *p<0.1; **p<0.05; ***p<0.01.*

Table 4 – Regression Based on Changes in the Variable

	Dependent variable: Δ Merton distance to default
Emissions	
Δ Emissions (ln)	-0.666**
	(0.334)
Firm Characteristics	
Δ Debt ratio	-2.288***
	(0.575)
Δ Operating margin	0.340
	(0.547)
Δ Retained earnings/total assets	1.605
	(1.078)
Δ Size	2.446***
	(0.466)
Δ Volatility	-33.718***
	(3.357)
Δ Working capital/total assets	1.065*
	(0.608)
Constant	5.642***
	(0.486)
Industry Controls	Yes
Country Controls	Yes
Observations	202
Adj. R²	.626
F Statistic	38.32***
	(df = 9; 192)

*The independent variable "Δ Merton Distance to Default" is the difference of distance to default calculated using Merton DD model between 2010 and 2017. "ΔEmission" is the difference of natural logarithm of "Total Emissions" from Asset4 between 2010 and 2017. "Δ Debt Ratio" is the difference between 2010 ratio of total liabilities from Datastream over Total Assets and the same ratio for 2017. "Δ Operating margin" is the difference of 2010 ratio of operating income and sales from Datastream and same ratio for 2017. "Δ Retained Earnings / Total Assets" is the difference between the 2010 ratio between retained earnings from Datastream and Total Assets and the same ratio for 2017. "Δ Size" is difference between the natural logarithm of 2010 Total Assets as calculated with the Merton model and natural logarithm of 2017 Total Assets. "Δ Volatility" is difference between volatility for 2010 and volatility for 2017 both as calculated in Merton model." Δ Working capital / Total Assets" is the difference between the ratio of working capital from Datastream and Total Assets and the same ratio for 2017. Standard errors in parentheses. Notation of the significance levels: *p<0.1; **p<0.05; ***p<0.01.*

that by adding the previous year distance to default as an explanatory variable the R2 of the regressions increases significantly to a level above 66%. This was expected because distance to default presents a positive serial correlation. The statitical significance of the coefficients for the log of emissions and carbon intensity remain intact. Similarly, models 2 and 4 that feature three lags of the distance to default variable show that both the natural logarithm of emission and carbon intensity remain significantly negatively associated with the dependent variable, respectively at a 5% and 1% level.

As a further investigation of possible reverse causality between carbon footprint and distance to default, we considered to instrument the carbon footprint. We employ the average carbon emissions of each industry as an instrument: such variable is highly correlated with the level of emissions of a given company in each period, but not with the error terms. Unreported results show that the coefficient of the instrumented carbon emissions is negative and highly significant. Thus, evidence corroborates that higher level of carbon emissions leads to a reduction of the distance to default.

Table 5 – Results of the multivariate analysis including first lag of the dependent variable (2008-2017)

	Dependent variable: Merton Distance to default			
	(1)	(2)	(3)	(4)
Lagged Dependent (previous year)				
Distance to Default (t-1)	0.473***	0.373***	0.473***	0.375***
	(0.022)	(0.033)	(0.022)	(0.033)
Distance to Default (t-2)		0.150***		0.150***
		(0.031)		(0.031)
Distance to Default (t-3)		0.243***		0.242***
		(0.025)		(0.025)
Emissions				
Emissions (ln)	-0.125**	-0.122**		
	(0.054)	(0.053)		
Carbon Intensity			-0.123***	-0.132***
			(0.031)	(0.038)
Firm Characteristics				
Debt ratio	-1.248***	-0.873***	-1.253***	-0.875***
	(0.197)	(0.144)	(0.196)	(0.140)
Operating margin	0.151	0.321**	0.247	0.448**
	(0.155)	(0.157)	(0.166)	(0.177)
Retained earnings ratio	-0.302***	-0.198***	-0.306***	-0.201***
	(0.050)	(0.032)	(0.048)	(0.031)
Size	-0.313***	-0.402***	-0.350***	-0.434***
	(0.091)	(0.071)	(0.088)	(0.069)
Volatility	-23.111***	-27.455***	-23.097***	-27.349***
	(1.716)	(1.533)	(1.715)	(1.529)
Working capital ratio	0.803***	0.506***	0.808***	0.509***
	(0.149)	(0.108)	(0.148)	(0.105)
Constant	16.811***	17.046***	15.609***	15.796***
	(1.800)	(1.620)	(1.677)	(1.431)
Industry Controls	Yes	Yes	Yes	Yes
Country Controls	Yes	Yes	Yes	Yes
Observations	2020	1616	2020	1616
R^2	.662	.764	.661	.764
F Statistic	6334.32***	5926.24***	6441.43***	5546.38***
	(df = 10; 201)	(df = 12; 201)	(df = 10; 201)	(df = 12; 201)

*The independent variable "Merton Distance to Default" is the distance to default calculated using Merton DD model. "Distance to Default (t-1) represent the previous year Distance to Default calculated with the Merton Model. "Distance to Default (t-2)" represent the Distance to Default of 2 years before calculated with the Merton Model. "Distance to Default (t-3)" represent the Distance to Default of 3 years before calculated with the Merton Model. "Emissions" is the natural logarithm of "Total Emissions" from Asset4. "Carbon Intensity" is the ratio between "Total Emissions" from Asset4 and sales from Datastream. "Debt Ratio" is a ratio between total liabilities from Datastream and Total Assets. "Operating margin" is the ratio of operating income and sales from Datastream. "Retained Earnings / Total Assets" is the ratio between retained earnings from Datastream and Total Assets. "Size " is the natural logarithm of Total Assets."Working capital / Total Assets" is the ratio of working capital from Datastream and Total Assets. Cluster-Robust standard errors in parentheses. Notation of the significance levels: *p<0.1; **p<0.05; ***p<0.01.*

6. Conclusions

Paris Agreement and the increased attention of policymakers on climate change issues imposes risks on companies with CO2 emissions. Rigorous enforcement of existing environmental laws and the introduction of stricter criminal and civil penalties for polluters are expected for the future. As outlined by ESRB (2016), this could result in a spike in costs and in impacts on issuers' creditworthiness. The central research question of this paper is whether CO2 emissions affect the firm's Merton distance to default. We contribute to this stream of literature by exploring whether the carbon footprint impacts, ceteris paribus, a firm's creditworthiness. Our results show that a higher level of emissions actually leads to lower distance to default.

Descriptive statistics already reveal the influence of CO2 emissions on the probability of default. The sample is divided in quintiles (and deciles) according to the firm level of emissions: we show that companies on the first decile or quintile (hence, less pollutant corporations) have higher distance to default compared to the most pollutant firms. We find strong evidence that emissions are negatively associated with distance to default. These findings are confirmed using both the natural logarithm of emissions and carbon intensity. Several robustness checks are run in order to detect the possible endogeneity issues and omitted variables. Our baseline results, hold even excluding energy and extractive industries. We additionally show that the carbon footprint decreases the distance-to-default following regulatory shocks, such as the Paris Agreement, that reveal policymakers' intention to implement stricter climate policies.

Given the outlook of increasing global temperature, it is important to assess the impact of rising temperatures on the macro-economy and financial markets. Potentially, rising temperatures may disrupt financial markets and the banking system. Our results show that firms' creditworthiness is already affected by exposure to climate risks. The policy implications are several.

First, credit rating agencies should embed even further climate risks exposure in their assessment of issuers' creditworthiness. In November 2019, Moody's announced it was considering stripping US oil major ExxonMobil of its triple A credit rating, flagging risks in its adjustment to a lower-carbon economy. Research shows that credit ratings do not reflect all the information related to climate risk (Ginglinger and Quentin, 2019). Credit rating agencies should develop better metrics of climate risk exposure and fully factor those in their operations. The recent acquisition of Trucost and Robeco SAM, two climate/sustainability analyses providers, by Standard & Poor's seems to indicate growing awareness of credit rating agencies for the sustainability profile of issuers.

Second, banks and lending institutions should consider the carbon footprint of borrowers to price efficiently the risks they are taking on. Regulatory and supervision initiatives that impose banks to fully embed the consideration of climate risks into governance frameworks including at board level, like the ones enacted by the Bank of England, are well placed.

Third, corporate bond investors should consider the exposure to climate risks of issuers. In a survey of institutional investors regarding their perceptions of climate risks, Krueger et al. (2019) find that climate risks difficult to price and hedge. More intellectual capital investments should be put to capture and price efficiently carbon risks associated with fixed-income investments.

Fourth, for all the actors in the economy the starting points for managing and pricing climate risks is transparency and full disclosure by (public and private) companies about carbon footprint. The Task Force on Climate-related Financial Disclosures (TCFD) has developed voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers, and other stakeholders. Our findings prove that the work and recommendations of the Task Force - and of similar initiatives (Campiglio et al. 2018) – are well placed as the amount of carbon emitted by companies provides investors with relevant information. However, given the relevance and nature of climate risks, voluntary disclosure initiative may fall short of the required effort. Governments and supervision authorities should consider enforcing mandatory disclosure on climate exposure data.

Fifth, the relationship we have identified between carbon footprint and creditworthiness has evident implications for financial stability. Since financial stability has been more or less explicitly incorporated in the mandate of many central banks, our results supports the view that central banks should be more concerned with climate risks (Campiglio et al. 2018).

Finally, one of the limitations of our analysis is the exclusive focus on Scope 1 emissions. Ideally, Scope 2 and 3 emissions should be considered as well. However, the measurement and estimation of those are methodologically challenging as of today. Academia, investors, and regulators should put a greater effort in the foreseeable future to introduce robust and standardized approaches to address the need to capture the comprehensive exposure to climate risks of industrial supply chains and interconnected investment actors.


3.00
10.70
2.56
64.75
63.75
23.30
8.30
2.54
8.25
3,000
187,200
55,700
85,100
259,100
64.50
63.50
23.20
-0.25
-1.00

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About EDHEC-Risk Institute

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Founded in 1906, EDHEC is one of the foremost international business schools. Operating from campuses in Lille, Nice, Paris, London and Singapore, EDHEC is one of the top 15 European business schools. Accredited by the three main international academic organisations, EQUIS, AACSB, and Association of MBAs, EDHEC has for a number of years been pursuing a strategy of international excellence that led it to set up EDHEC-Risk Institute in 2001. This Institute boasts a team of permanent professors, engineers and support staff, and counts a large number of affiliate professors and research associates from the financial industry among its ranks.

The Need for Investment Solutions and Risk Management

Investment management is justified as an industry only to the extent that it can demonstrate a capacity to add value through the design of dedicated and meaningful investor-centric investment solutions, as opposed to one-size-fits-all manager-centric investment products. After several decades of relative inertia, the much needed move towards investment solutions has been greatly facilitated by a true industrial revolution triggered by profound paradigm changes in terms of (1) mass production of cost- and risk-efficient smart factor indices; (2) mass customisation of liability-driven investing and goal-based investing strategies; and (3) mass distribution, with robo-advisor technologies. In parallel, the investment industry is strongly impacted by two other major external revolutions, namely the digital revolution and the environmental revolution.

In this fast-moving environment, EDHEC-Risk Institute positions itself as the leading academic think-tank in the area of investment solutions, which gives true significance to the investment management practice. Through our multi-faceted programme of research, outreach, education and industry partnership initiatives, our ambition is to support industry players, both asset owners and asset managers, in their efforts to transition towards a novel, welfare-improving, investment management paradigm.

EDHEC-Risk New Initiatives

In addition to the EDHEC Alternative Indexes, which are used as performance benchmarks for risk analysis by investors in hedge funds, and the EDHEC-IEIF Monthly Commercial Property index, which tracks the performance of the French commercial property market through SCPIs, EDHEC-Risk has recently launched a series of new initiatives.

• The EDHEC-Princeton Retirement Goal-Based Investing Index Series, launched in May 2018, which represent asset allocation benchmarks for innovative mass-customised target-date solutions for individuals preparing for retirement;

• The EDHEC Bond Risk Premium Monitor, the purpose of which is to offer to investment and academic communities a tool to quantify and analyse the risk premium associated with Government bonds;

• The EDHEC-Risk Investment Solutions (Serious) Game, which is meant to facilitate engagement with graduate students or investment professionals enrolled on one of EDHEC-Risk's various campus-based, blended or fully-digital educational programmes.

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Academic Excellence and Industry Relevance

In an attempt to ensure that the research it carries out is truly applicable, EDHEC has implemented a dual validation system for the work of EDHEC-Risk. All research work must be part of a research programme, the relevance and goals of which have been validated from both an academic and a business viewpoint by the Institute's advisory board. This board is made up of internationally recognised researchers, the Institute's business partners, and representatives of major international institutional investors. Management of the research programmes respects a rigorous validation process, which guarantees the scientific quality and the operational usefulness of the programmes.

Seven research programmes have been conducted by the centre to date:
• Investment Solutions in Institutional and Individual Money Management;
• Equity Risk Premia in Investment Solutions;
• Fixed-Income Risk Premia in Investment Solutions;
• Alternative Risk Premia in Investment Solutions;
• Multi-Asset Multi-Factor Investment Solutions;
• Reporting and Regulation for Investment Solutions;
• Technology, Big Data and Artificial Intelligence for Investment Solutions.

EDHEC-Risk Institute's seven research programmes explore interrelated aspects of investment solutions to advance the frontiers of knowledge and foster industry innovation. They receive the support of a large number of financial companies. The results of the research programmes are disseminated through the EDHEC-Risk locations in the City of London (United Kingdom) and Nice, (France).

EDHEC-Risk has developed a close partnership with a small number of sponsors within the framework of research chairs or major research projects:
• **Financial Risk Management as a Source of Performance**,
in partnership with the *French Asset Management Association (Association Française de la Gestion financière – AFG)*;
• **ETF, Indexing and Smart Beta Investment Strategies**,
in partnership with *Amundi*;
• **Regulation and Institutional Investment**,
in partnership with *AXA Investment Managers*;
• **Optimising Bond Portfolios**,
in partnership with *BDF Gestion*;
• **Asset-Liability Management and Institutional Investment Management**,
in partnership with *BNP Paribas Investment Partners*;
• **New Frontiers in Risk Assessment and Performance Reporting**,
in partnership with *CACEIS*;
• **Exploring the Commodity Futures Risk Premium: Implications for Asset Allocation and Regulation**,
in partnership with *CME Group*;
• **Asset-Liability Management Techniques for Sovereign Wealth Fund Management**,
in partnership with *Deutsche Bank*;

• **The Benefits of Volatility Derivatives in Equity Portfolio Management**,
in partnership with *Eurex*;
• **Innovations and Regulations in Investment Banking**,
in partnership with the *French Banking Federation (FBF)*;
• **Dynamic Allocation Models and New Forms of Target-Date Funds for Private and Institutional Clients**,
in partnership with *La Française AM*;
• **Risk Allocation Solutions**,
in partnership with *Lyxor Asset Management*;
• **Infrastructure Equity Investment Management and Benchmarking**,
in partnership with *Meridiam and Campbell Lutyens*;
• **Risk Allocation Framework for Goal-Driven Investing Strategies**,
in partnership with *Merrill Lynch Wealth Management*;
• **Financial Engineering and Global Alternative Portfolios for Institutional Investors**,
in partnership with *Morgan Stanley Investment Management*;
• **Investment and Governance Characteristics of Infrastructure Debt Investments**,
in partnership with *Natixis*;
• **Advanced Investment Solutions for Liability Hedging for Inflation Risk**,
in partnership with *Ontario Teachers*' Pension Plan;
• **Cross-Sectional and Time-Series Estimates of Risk Premia in Bond Markets**,
in partnership with *PIMCO*;
• **Active Allocation to Smart Factor Indices**,
in partnership with *Rothschild & Cie*;
• **Solvency II**,
in partnership with *Russell Investments*;
• **Advanced Modelling for Alternative Investments**,
in partnership with *Société Générale Prime Services (Newedge)*;
• **Structured Equity Investment Strategies for Long-Term Asian Investors**,
in partnership with *Société Générale Corporate & Investment Banking*.

The philosophy of the Institute is to validate its work by publication in international academic journals, as well as to make it available to the sector through its position papers, published studies and global conferences.

To ensure the distribution of its research to the industry, EDHEC-Risk also provides professionals with access to its website, https://risk.edhec.edu, which is devoted to international risk and investment management research for the industry. The website is aimed at professionals who wish to benefit from EDHEC-Risk's analysis and expertise in the area of investment solutions. Its quarterly newsletter is distributed to more than 150,000 readers.

Research for Business

EDHEC-Risk Institute also has highly significant executive education activities for professionals, in partnership with prestigious academic partners. EDHEC-Risk's executive education programmes help investment professionals upgrade their skills with advanced asset allocation and risk management training across traditional and alternative classes.

In 2012, EDHEC-Risk Institute signed two strategic partnership agreements. The first was with the Operations Research and Financial Engineering department of Princeton University to set up a joint research programme in the area of investment solutions for institutions and individuals. The second was with Yale School of Management to set up joint certified executive training courses in North America and Europe in the area of risk and investment management.

As part of its policy of transferring know-how to the industry, in 2013 EDHEC-Risk Institute also set up ERI Scientific Beta, which is an original initiative that aims to favour the adoption of the latest advances in smart beta design and implementation by the whole investment industry. Its academic origin provides the foundation for its strategy: offer, in the best economic conditions possible, the smart beta solutions that are most proven scientifically with full transparency in both the methods and the associated risks.

EDHEC-Risk Institute also contributed to the 2016 launch of EDHEC Infrastructure Institute (EDHEC*infra*), a spin-off dedicated to benchmarking private infrastructure investments. EDHEC*infra* was created to address the profound knowledge gap faced by infrastructure investors by collecting and standardising private investment and cash flow data and running state-of-the-art asset pricing and risk models to create the performance benchmarks that are needed for asset allocation, prudential regulation and the design of infrastructure investment solutions.

EDHEC-Risk Institute Publications and Position Papers (2018-2020)

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2020

• Capasso, G., G. Gianfranco and M. Spinelli. Climate Change and Credit Risk

2019

• Martellini, L. and V. Milhau. Factor Investing in Liability-Drivenand Goal-Based Investment Solutions (December).

• Martellini, L. and V. Le Sourd. The EDHEC European ETF, Smart Beta and Factor Investing Survey 2019 (September).

• Maeso, J.M., Martellini, L. and R. Rebonato. Cross-Sectional and Time-Series Momentum in US Sovereign Bond Markets (May).

• Maeso, J.M., Martellini, L. and R. Rebonato. Defining and Expoiting Value in Bond Market (May).

• Maeso, J.M., Martellini, L. and R. Rebonato. Factor Investing in Sovereign Bond Markets - Time-Series Perspective (May).

2018

• Goltz, F. and V. Le Sourd. The EDHEC European ETF and Smart Beta and Factor Investing Survey 2018 (August).

• Mantilla-Garcia, D. Maximising the Volatility Return: A Risk-Based Strategy for Homogeneous Groups of Assets (June).

• Giron, K., L. Martellini, V. Milhau, J. Mulvey and A. Suri. Applying Goal-Based Investing Principles to the Retirement Problem (May).

• Martellini, L. and V. Milhau. Smart Beta and Beyond: Maximising the Benefits of Factor Investing (February).

For more information, please contact:
Maud Gauchon on +33 (0)4 93 18 78 87
or by e-mail to: maud.gauchon@edhec-risk.com

EDHEC-Risk Institute
393 promenade des Anglais
BP 3116 - 06202 Nice Cedex 3
France
Tel. +33 (0)4 93 18 78 87

EDHEC Risk Institute—Europe
10 Fleet Place, Ludgate
London EC4M 7RB
United Kingdom
Tel: + 44 207 332 5600

risk.edhec.edu