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Firm biodiversity risk, climate vulnerabilities, and bankruptcy risk

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ABSTRACT

This study examines the relationship between firms' biodiversity risk, climate susceptibility, and bankruptcy risk. The findings indicate that firm exposure to biodiversity risk increases the likelihood of financial distress. Furthermore, we document that firms' susceptibility to climate risk increases the likelihood of bankruptcy risk. We also demonstrate that financial constraints, growth opportunities, and membership in carbon-intensive industries can worsen or alleviate the bankruptcy implications of climate-related risk. Firms' continent of operation is also an important consideration. The findings imply that severe climate-related vulnerabilities and firm biodiversity risk have profound consequences for corporate outcomes. This study sheds more light on how corporate financial outlook is impacted by ecological degradation and climate-related vulnerabilities.

1. Introduction

Ecological degradation and climate-related challenges in the form of desertification, cyclones, hurricanes, typhoons, droughts, rising ocean levels, ocean warming, ocean acidification, water shortages, coastal flooding, forest fires, dissipating species, and displacement pose significant economic risks to the world economy. For instance, because of climate-related risk, it is estimated that a decline of about 10 % in the United States (US) GDP will probably occur by the end of the century (Jay et al., 2018). Furthermore, worldwide estimates of financial losses due to adverse climate events between 1996 and 2015 have been set at over $3.08 trillion (Kreft et al., 2017). Similarly, conservative estimates of economic losses attributable to ecological losses or other damage to the ecosystem currently sit at between $4trn to $20trn annually (Kapnick, 2022). Some proponents argue that firms contribute disproportionately to these events. Corroborating this view, Riley (2017) demonstrates that 100 multinational companies emit 71 % of world carbon emissions.

In recognition of the salient role of firms in combatting severe climate events and ecological degradation, corporate stakeholders are beginning to pay attention to firm environmental practices (Ali et al., 2024; Azar et al., 2021). Firm climate vulnerabilities are beginning to feature in the cost structure of corporate services. For example, auditors account for firms' climate risk when estimating fees. Audit offices charge a premium when firms have low climate risk-adaptive capabilities (Yu et al., 2023). Other stakeholders, such as banks, are also beginning to pay attention to corporate green credentials for decision-making. In this regard, high-emitting firms encounter difficulties in accessing the debt market (Kacperczyk and Peydro, 2021). Consequently, banks favour loan applications from firms with very good environmental practices. In effect, firms with poor environmental credentials are likely to face unfavourable debt financing contracts, which could worsen their financial health.

Adverse loan criteria, such as high interest rates, severe covenant constraints, and collateralized loan agreements, have become prevalent among firms with significant climate risk (Huang et al., 2022). Similarly, firms with acute exposure to climate risk face

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increased costs of capital (Agoraki et al., 2024). We contend that this pressure in debt and capital markets would ultimately exacerbate financial distress and increase the likelihood of bankruptcy. Albeit the burgeoning academic conversation on firms' environmental practices and corporate outcomes acknowledges a myriad of implications for corporate climate action or inaction (Adamolekun et al., 2022; Adamolekun and Kyiu, 2023; Alam et al., 2022; Huang et al., 2022; Kacperczyk and Peydro, 2021; Li et al., 2024), the literature on the implications of firm environmental practices for corporate financial health is scant. We contribute to this conversation by examining whether firms' climate vulnerabilities and corporate biodiversity risks have important implications for corporate financial distress.

Furthermore, this study advances current conversations that have sought to distinguish between the implications of biodiversity and climate risk (Carvalho et al., 2023; Giglio et al., 2023; Kapnick, 2022). Conceptually, biodiversity risks differ from climate-related vulnerabilities. Firms with high climate vulnerability refer to companies that are negatively affected by adverse climate events(Sautner et al., 2023; Wang et al., 2022). However, the literature identifies various facets of firms' climate risk. The first dimension is the physical risks, which stem from extreme weather events and consistent changes in climate patterns (Krueger et al., 2020; Sautner et al., 2023; Wang et al., 2022). The occurrence of these events can significantly disrupt operations by damaging key infrastructures and ultimately translate to higher-cost operations (Wang et al., 2022). Firm climate change risk also manifests in terms of costs associated with transitioning to the low-carbon economy (Krueger et al., 2020; Sautner et al., 2023). This typically takes the form of compliance costs, the cost of investing in carbon–neutral technologies, and loss in market share as a result of reduced competitive capacity or reputational damage (Wang et al., 2022).

On the other hand, firm biodiversity risk captures firms' susceptibility to the adverse consequences of damage to ecosystems or other forms of ecological degradation. For example, companies in the fishery and construction industries may face shortages in raw materials because of disruption in ecosystems (Kedward et al., 2023). The scarcity of such key resources may translate into disruptions in the supply chains of firms in the retail industry (Kedward et al., 2023). Admittedly, a growing body of literature has sought to address the impact of biodiversity risks on various corporate economic outcomes (e.g. Bassen et al., 2024; Carvalho et al., 2023). However, no prior studies have addressed how exposure to biodiversity risk affects firms' financial health. This study deepens our understanding of the implications of firms' exposure to biodiversity.

While there is a global focus on climate change risks, little emphasis has been placed on biodiversity risk because of its localized nature. For example, in the regulatory landscape, there has been a concerted effort to establish and implement climate change regulations (Wang et al., 2022). As a result, initiatives like carbon taxes, carbon trading, carbon offsetting schemes, and other emission trading schemes have been established (Adamolekun et al., 2024; Ramadorai and Zeni, 2024). Consequently, there is a marked difference in how firms manage biodiversity risk when compared with climate change risk (Carvalho et al., 2023; Wang et al., 2022) However, despite the potentially severe implications of biodiversity risk being as detrimental as climate change risk, stakeholders have paid less attention to this phenomenon. This study addresses this lacuna by demonstrating its bankruptcy implications.

We also advance the literature that addresses the implications of firm exposure to physical and transition risks associated with climate change. In this regard, we contribute to the literature on corporate climate risk (see, for instance, Huang et al., 2022; Yu et al., 2023), by demonstrating the connection between various categories of climate risk and firms' risk of financial distress. This study also expands the debate on carbon risk (see, for example, Bolton and Kacperczyk, 2021; Hossain et al., 2023; Jung et al., 2018) by showing that it influences corporate financial health. Furthermore, the study complements the body of literature that discusses how green credential affects corporate outcomes (Adamolekun et al., 2022; Adamolekun and Kyiu, 2023; Alam et al., 2022). We demonstrate that corporate environmental practices have profound implications for corporate survival. Finally, we extend the extensive debate on firm bankruptcy risk (see, for example, Becchetti and Sierra, 2003; Biddle et al., 2022; Darrat et al., 2016; Dichev, 1998; Habermann and Fischer, 2023; Singh et al., 2022; Verwijmeren and Derwall, 2010). We represent the first attempt in this subset of the literature to identify the implications of different indicators of corporate greenness and biodiversity risk on corporate survival.

Our study is closely related to the work of Feng et al. (2024) who evaluate the relationship between climate change exposure and bankruptcy risk. However, our study differs from theirs in several ways. Firstly, whilst they limit the scope of their study to climate exposure, our study addresses how biodiversity risk affects corporate financial health, among other things. Notably, the climate change exposure measure they adopted captures both risks and opportunities. However, decoupling firm climate exposure into subcomponents and categories is valuable for understanding its financial distress implications. Therefore, rather than examining the relationship between managers' attention to climate-related issues and firm bankruptcy risk, we adopt a different approach by evaluating the role of various categories of climate vulnerability (i.e., carbon dependency, climate change risk, and climate change exposure) in the context of firms' financial health.

The findings indicate that corporate exposure to biodiversity risk and biodiversity regulatory risk exacerbates the risk of financial distress. Using various proxies to quantify corporate climate vulnerabilities (i.e., firm carbon dependency levels, climate change exposure and climate change risks), we find that corporate susceptibility to adverse climate events increases the likelihood of bankruptcy. In examining how the combination of biodiversity risk exposure and climate risk vulnerability affects firm bankruptcy risk, we observe that the likelihood of bankruptcy increases among firms that are jointly exposed to biodiversity and climate risks. We document that financial constraints could moderate the adverse impact of climate risk on financial distress. However, we demonstrate that financial constraints worsen bankruptcy risk for firms with high carbon emissions. In addition, we find evidence that growth opportunities mitigate the adverse impact of carbon emission levels and the effect of climate-related vulnerabilities on bankruptcy risk. Contrastingly, the results indicate that for firms in carbon-intensive industries, the association between corporate climate susceptibilities and bankruptcy likelihood is less pronounced. Furthermore, the results also reveal that the firm's continent of operation is an important consideration in understanding the dynamics of the relationship between firm climate vulnerabilities and bankruptcy likelihood.

The remainder of the paper is structured as follows. Section 2 discusses the related literature. Section 3 provides details of the empirical strategy. Section 4 presents the findings. Section 5 details the conclusion of the study.

2. Literature review and hypothesis development

2.1. Bankruptcy risk

The literature on financial distress identifies several categories of factors that contribute to the risk of corporate bankruptcy. These include firm-level fundamental indicators, corporate governance, and macroeconomic factors (Habib et al., 2020). In addition, a firm's accounting practices are valuable considerations for understanding the likelihood of firm bankruptcy. To this end, Biddle et al. (2022) opine that conditional and unconditional accounting conservatism reduces the incidence of bankruptcy. This practice enhances cash flow and mitigates earnings management, ultimately decreasing the likelihood of financial distress. Similarly, firms that boast robust employee satisfaction face a lower bankruptcy risk (Verwijmeren and Derwall, 2010). An explanation for this phenomenon is that such organisations operate with lower leverage (Verwijmeren and Derwall, 2010). Another proposition is that bankruptcy risk can be mitigated when firms have inside directors with significant specialist knowledge (Darrat et al., 2016). Similarly, well-diversified corporations are less exposed to the challenges of financial distress (Singhal and Zhu, 2011).

Cash flow pressure and the reputational standing of a firm are also important factors to consider. For example, due to the low likelihood of a payoff from R&D, firms that invest heavily in R&D are exposed to a high degree of bankruptcy risk (Zhang, 2014). Furthermore, committing cash to corporate socially responsible projects could exacerbate or mitigate a firm's cash flow risk and consequently heighten the risks of bankruptcy (Boubaker et al., 2020; Habermann and Fischer, 2023). Correspondingly, firms that issue more debts than equity, as well as those that pursue aggressive tax avoidance schemes, are exposed to high risks of financial distress (Dhawan et al., 2020). Equally, tax aggressiveness could increase firms' risk of financial distress, with this being more pronounced during periods of economic uncertainty(Richardson et al., 2015). Furthermore, improving corporate productivity could enhance financial health. To this end, Bryan et al. (2013), reveal that productivity reduces the risk of financial distress.

Despite the ample evidence on the core determinants of bankruptcy risk, the literature has so far provided limited evidence on how biodiversity risk and corporate climate vulnerabilities affect bankruptcy risk. This study addresses this gap in the literature by examining the linkages between both phenomena.

2.2. Biodiversity risk

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the extinction rate among species has accelerated to tens to hundreds of times higher than that obtained in the past 10 million years (IPBES, 2019). Consequently, over a million species face the risk of becoming extinct in the next decade (Bongaarts, 2019). According to remarks from central banks and supervisors Network for Greening the Financial System (NGFS), the consequences of accelerated ecological degradation pose profound risks to sustainable development and financial stability (NGFS and INSPIRE, 2022). Although financial economics research on biodiversity risk is scant, a few recent academic papers have evinced that biodiversity risk manifests at the firm level.

For example, in a recent study, Carvalho et al. (2023) opine that firms are beginning to take their exposure to biodiversity risks seriously. However, they document that, at large, exposure to biodiversity risk is still significant, with corporate exposure totalling about $7.2 trillion in enterprise value. Similarly, firms with high exposure to biodiversity risk build up their cash holdings level as a precaution (Ahmad and Karpuz, 2024). Turning to how biodiversity risk manifests in the stock market, Bassen et al. (2024) reveal that firms with robust biodiversity structures are less likely to face stock price crashes. They posit that having a biodiversity management apparatus enhances the information environment, which translates to a lower risk of stock price crashes.

Complementing this assertion, Ali et al. (2024) reveal that firms earn rewards when they disclose information on how they manage their biodiversity risk and how they value the ecosystem services within their operational structure. Firm exposure to biodiversity risk also manifests in the asset pricing literature. Accordingly, a risk premium is allocated to firms with high biodiversity risk (Coqueret and Giroux, 2023). This implies that the expected returns from firms with significant exposure to biodiversity risk are higher than those of firms with low exposure.

Taken together, the literature implies that exposure to biodiversity risk poses future cash flow risk to firms (Ahmad and Karpuz, 2024; Carvalho et al., 2023). This can invariably exacerbate a firm's bankruptcy risk. Accordingly, building on the above conjecture, we hypothesise the following:

H1: Firm exposure to biodiversity risks increases bankruptcy likelihood

2.3. Firm climate risk

A myriad of studies in the corporate finance literature identify some linkages between firms' environmental practices and corporate outcomes. For instance, deep-pocketed firms (i.e., companies with high cash holdings) emit less carbon (Alam et al., 2022). The cash-holding effect is more pronounced among firms with low debt and low exposure to financing frictions. One explanation for this finding is that cash-rich firms are more agile in their carbon abatement efforts and as such, consume more renewable energy (Alam et al., 2022). Similarly, corporate ownership structure is also an important element to consider when modelling corporate emission levels. In support of this view, Safiullah et al. (2022) propose that institutional investors are valuable tools for corporate carbon abatement

efforts. Institutional investors can compel firms to transition to greener production processes.

Recent evidence suggests that carbon dependency and other climate-related risks are important considerations when decoupling firms' finances. For example, corporate carbon footprint has profound implications for accessing finance from the debt market. To this end, Kacperczyk and Peydro (2021) demonstrate that banks consider the greenness of a firm when considering credit applications. Consequently, firms with high emissions receive less credit from banks. Therefore, banks may be favourably disposed to financing green firms than brown firms. Such a limit on credit lines could harm firms' financial health. Confirming this assertion, Feng et al. (2024) reveal that firm climate change exposure increases the likelihood of bankruptcy.

Market participants also acknowledge a firm's climate risk when pricing corporate announcements. For example, high-emitting firms experience a discount in their share valuations during corporate restructuring announcements (Adamolekun and Kyiu, 2023). Analogously, investors demand a premium from firms with high carbon emissions levels (Bolton and Kacperczyk, 2021). Similarly, high emission levels at announcements reduce abnormal returns around the announcement of corporate acquisitions and other categories of corporate investments (Adamolekun et al., 2022). Corroborating this narrative, Pankratz et al. (2023) argue that exposure to excess heat reduces firms' sales and corporate earnings. Therefore, beyond the realms of carbon risk, other physical risk exposures pose significant operational risks to firms (Pankratz et al., 2023).

Typically, physical risks arise from extreme weather events and long-term changes in climate (Krueger et al., 2020; Sautner et al., 2023; Wang et al., 2022). Such events can significantly disrupt operations by damaging key infrastructures and ultimately translate to higher-cost operations (Wang et al., 2022). This would have wide-ranging implications on firm bankruptcy risk. Furthermore, firm climate change risk also manifests in terms of costs associated with transitioning to the low-carbon economy (Krueger et al., 2020; Sautner et al., 2023). The enactment of environmental legislation increases compliance costs (Wang et al., 2022). In addition, the cost of investing in carbon–neutral technologies and loss of market share as a result of reduced competitive capacity or reputational damage is an important element of transitioning costs (Wang et al., 2022). These additional costs can exacerbate the corporate risk of financial distress.

Building on the argument that exposure to various forms of climate risk inhibits access to finance in the debt market and adversely affects corporate earnings (Adamolekun et al., 2022; Bolton and Kacperczyk, 2021; Kacperczyk and Peydro, 2021; Pankratz et al., 2023; Wang et al., 2022), we conjecture that:

H2: Firm climate risk exacerbates bankruptcy risk

3. Data and empirical strategy

3.1. Data Source and Sampling

To test the hypotheses, we collect data from a variety of sources. We rely on various measures of firm climate vulnerabilities. First, we collect data on firms' carbon emissions from Refinitiv Eikon (LSEG Data and Analytics) to capture the degree of firms' carbon dependency. The carbon emissions measure accounts for both Scope 1 and Scope 2 emissions. To measure a firm's exposure to biodiversity risk, we turn to the measure suggested by Giglio et al. (2023). For climate change risk and climate change exposure, we rely on the proposition of (Sautner et al., 2020).One of the benefits of these proxies is that they are valuable in modelling firms' reliance on hydrocarbons as well as for characterising firm green transition risks (Sautner et al., 2023). For data on firm-specific characteristics of firms from various databases, we turn to Worldscope.

After matching, the sample includes 7949 unique firms from 70 countries. Table 1 presents the distribution of the data. Panel A of Table 1 reports the country distribution of the sample. Firms from the United States (US), United Kingdom (UK), and Australia represent a significant proportion of the sample. Panel B presents the industry distribution of the sample. Firms from the industrial sector (i.e., manufacturers), consumer discretionary, healthcare, and basic materials are markedly represented. We exclude firms from the financial industry as including them will bias the results. In Panel C of Table 1, we show how years are represented in our sample. Notably, the representation improved over time. The sample covers the period 2002–2021.

3.2. Dependent variable

The dependent variable for this study is bankruptcy likelihood. To measure firm bankruptcy risk, we start by computing the Z-score for each firm year in our sample. To calculate this value, we follow the established literature on financial distress (see for example, Altman, 1968; Boubaker et al., 2020; Richardson et al., 2015) and estimate the Z-score according to the below equation:

$$Zscore = 0.012\frac{WAC}{TA} + 0.014\frac{RetEarn}{TA} + 0.033\frac{EBIT}{TA} + 0.006\frac{MV}{TL} + 0.999\frac{SA}{TA} \quad (1)$$

WAC is defined as the working capital. TA refers to total assets. Ret Earn refers to retained earnings. EBIT is earnings before interest and taxes. MV is the market value of equity. TL is the total liabilities of a firm. Upon estimating the Z Score for a firm, according to the literature, we identify firms with a Z-Score above 1.81 as having a lower likelihood of bankruptcy, whilst those with a Z-score below 1.81 are identified as having a higher risk of bankruptcy(Altman, 1968).

For added rigour, we also compute the ZM score as an alternative indicator of corporate bankruptcy risk. To calculate the ZM score for a firm each year, we follow Zmijewski (1984) by estimating the following equation:

Table 1
Data Distribution
In this Table, we present the distribution of the data used for this study. Panel A reports the country distribution of the sample. Panel B presents the distribution by industry. Panel C reports the year distribution.

Panel A: Country Distribution

Country	Frequency
Argentina	0 %
Australia	7 %
Austria	0 %
Azerbaijan	0 %
Bahrain	0 %
Belgium	1 %
Bermuda	0 %
Brazil	1 %
Cambodia	0 %
Canada	5 %
Cayman Islands	0 %
Chile	0 %
China	3 %
Colombia	0 %
Costa Rica	0 %
Cyprus	0 %
Czech Republic	0 %
Denmark	1 %
Finland	1 %
France	3 %
Germany	3 %
Greece	0 %
Hungary	0 %
Iceland	0 %
India	2 %
Indonesia	0 %
Ireland	1 %
Israel	0 %
Italy	1 %
Japan	6 %
Jordan	0 %
Kazakhstan	0 %
Kenya	0 %
Kuwait	0 %
Luxembourg	0 %
Malaysia	1 %
Malta	0 %
Mexico	0 %
Mongolia	0 %
Morocco	0 %
Netherlands	1 %
New Zealand	1 %
Nigeria	0 %
Norway	1 %
Pakistan	0 %
Panama	0 %
Papua New Guinea	0 %
Peru	0 %
Philippines	0 %
Poland	0 %
Portugal	0 %
Puerto Rico	0 %
Qatar	0 %
Romania	0 %
Russian Federation	1 %
Saudi Arabia	0 %
Singapore	1 %
Slovenia	0 %
South Africa	2 %
Spain	1 %
Sri Lanka	0 %
Sweden	1 %
Switzerland	2 %
Thailand	0 %

Panel B: Industry Distribution

Industry	Frequency
Basic Materials	11 %
Consumer Discretionary	19 %
Consumer Staples	7 %
Energy	8 %
Health Care	12 %
Industrials	21 %
Real Estate	2 %
Technology	10 %
Telecommunications	3 %
Utilities	6 %

Panel C: Yearly Distribution

Year	Frequency
2002	1 %
2003	1 %
2004	2 %
2005	2 %
2006	2 %
2007	2 %
2008	3 %
2009	3 %
2010	4 %
2011	4 %
2012	4 %
2013	5 %
2014	5 %
2015	6 %
2016	7 %
2017	8 %
2018	9 %
2019	10 %
2020	11 %
2021	10 %

(*continued on next page*)

Table 1 (*continued*)

Panel A: Country Distribution		*Panel B: Industry Distribution*	
Country	Frequency	Industry	Frequency
Ukraine	0 %		
United Arab Emirates	0 %		
United Kingdom	11 %		
United States	40 %		
Uruguay	0 %		
Vietnam	0 %		

$$ZMscore = -4.336 - 4.513\frac{NI}{TA} + 679\frac{TL}{TA} + .004\frac{CA}{CL} \tag{2}$$

NI in the equation refers to the net annual income of a company. TA is defined as the firm's total assets each year. TL is the total liabilities of a firm. The CA captures a firm's current assets per year. CL, on the other hand, represents the current liabilities of a firm in a year. To identify firms with a high risk of bankruptcy, according to this method, we adopt a reference score of 0.5. Firms with ZM scores above 0.5 are identified as those with a high risk of default, while those below 0.5 have a lower likelihood of bankruptcy(Habib et al., 2020).

3.3. Independent and control variables

Biodiversity risk refers to risks associated with the loss of ecosystems or ecological degradation (Giglio et al., 2023). To measure firm-level biodiversity risk, Giglio et al. (2023) build on the Bidirectional Encoder Representations from Transformers (BERT) and categorise biodiversity sentences contained in a firm's 10-K filing into either neutral, positive, or negative. The score allotted takes cognisance of the difference between the negative biodiversity sentences and positive biodiversity sentences. We adopt the proxy proposed by Giglio et al. (2023) as our measure of biodiversity risk. In addition to biodiversity risk, we also consider biodiversity regulatory risk. Accordingly, Giglio et al. (2023) capture a firm's biodiversity regulatory risk by identifying concerns raised in a firm's 10-k filing stemming from regulatory concerns. Unlike biodiversity risk, biodiversity regulatory risk characterises firm-level exposure to regulatory changes within the realms of ecological degradation.[1]

For firm exposure to climate-related risk, we adopt multiple measures. The first measure of firms' climate vulnerability we consider is the carbon emissions level of a firm. High-emitting firms are, in general, more dependent on carbon for production and, hence, likely to face more regulatory risk than their low-emitting counterparts (Bolton and Kacperczyk, 2021, 2023). To measure carbon risk, we follow prior studies in the literature by transforming the reported direct and indirect firm carbon emissions to their natural logarithms (Adamolekun et al., 2022; Alam et al., 2022; Azar et al., 2021; Bolton and Kacperczyk, 2021; Konadu et al., 2022; Safiullah et al., 2022).[2]

To ensure our findings are robust, we also consider text-based measures of firms' climate risk. For the text-based measure of climate vulnerabilities, we adopt Sautner et al.'s measures of corporate climate change exposure and corporate climate risk. These metrics capture corporate attention to climate-change-related issues. To measure climate change exposure, Sautner et al. (2023) capture the managerial perception of firm-level exposure to climate change events from the transcripts of quarterly earnings conference calls. The variable identifies the frequency with which climate-related bigrams occur in the transcript of quarterly earnings conference calls. Climate change exposure is defined as follows:

$$\mathrm{CC\,Exposure_{it}} = \frac{1}{\mathrm{B_{it}}}\sum_{\mathrm{b}}^{\mathrm{B_{it}}}(1\,[\,\mathrm{b} \in \mathbb{C}\,) \tag{3}$$

$\mathrm{b} = 0,1\ldots\ldots B_{i,t}$ refer to bigrams in the transcript of firm i at time t. 1[.] refers to the indicator function. One advantage of the corporate climate exposure proxy is that it is more efficient in capturing firm-level variations in climate vulnerabilities than carbon intensities or other green ratings (Sautner et al., 2023).

Firm climate change risk measure is calculated by counting the number of times managers mention climate change bigrams in association with the words "risk" and "uncertainty" or similar synonyms. It is computed using the following equation:

$$\mathrm{CC\,Risk_{it}} = \frac{1}{\mathrm{B_{it}}}\sum_{\mathrm{b}}^{\mathrm{B_{it}}}(\,1\,[\,\mathrm{b} \in \mathbb{C}\,] \times 1[\mathrm{b},\ \mathrm{r}\ \in \mathrm{S}]) \tag{4}$$

S refers to a sentence containing bigrams b 0 $0,1\ldots\ldots\mathrm{B_{it}}$ and r captures the occurrence of the words "risk", "uncertainty" or similar synonyms. The primary difference between climate change risk and climate change exposure is that the bigrams used in climate change risk focus more on issues surrounding climate uncertainties (Sautner et al., 2023). We present further information on the definition of

[1] It is important to note that the data is only available for US firms.

[2] The carbon emissions value reported accounts for both scope 1 (direct) and scope 2 (indirect) emissions.

the variables in Appendix A.

To ensure we account for other covariates that are relevant for modelling corporate bankruptcy risk, we follow prior studies and control for standard variables that drive bankruptcy risk, such as RoA, leverage, market-to-book ratio, size, cash holdings, governance level, dividend, tangibility as well as depreciation and amortization (see for example, Becchetti and Sierra, 2003; Biddle et al., 2022; Darrat et al., 2016; Tian et al., 2015; Verwijmeren and Derwall, 2010).

In Fig. 1, we present the mean of the main variables of interest by continent. The figure demonstrates that firms in South America, on average, have the highest level of climate change exposure, while firms in Africa have the least exposure. Similarly, for climate change risk, firms in South America have the highest exposure while those in North America are less exposed. For the Z-score, on average European Firms are the healthiest, while those in Africa have acute exposure to bankruptcy. According to the ZM score, firms in Oceania are less healthy, while those in Europe are the healthiest.

In Fig. 2, we report the time trend in firm financial distress. The trend indicates a relatively smooth downward trend with slight spikes between 2002 and 2004, 2008 and 2009, and 2013 and 2016. For the ZM score, we document a slightly more volatile trend with a peak between 2012 and 2016.

In Fig. 3, we evaluate the time trend in firms' biodiversity risk and corporate exposure to biodiversity regulatory risk. Firm-level biodiversity risk peaked in 2008. Notably, other peaks were also documented in 2013 and 2018. Biodiversity regulatory risk follows a near-perfect trend as biodiversity risk peaks at similar periods.

In Table 2, we report the country-level mean of the variables of interest. For Z score, according to the sample, firms in Greece have the maximum value on average, with firms in Vietnam and Mongolia having the lowest value. For the ZM score, firms in Australia have the highest average value, while companies in Azerbaijan have the lowest average value. Since some of the reported scores may be driven by socioeconomic and cultural factors peculiar to countries, we account for this factor in our regression models.

Table 2 also presents the average mean of the measures of corporate carbon risk by country. According to the sample, Bahrain has the highest average natural logarithm of firm carbon emissions, while Malta has the lowest average value reported. For corporate climate risk, Kazakhstan has the highest value, while countries like Uruguay, Panama, Nigeria, and Bahrain have low average values. Czech has the highest value for corporate climate exposure, while countries like Panama, Malta, and Costa Rica have the lowest values. We report the graphical representation of the country-wise distribution of the variables in Appendix B to E.

3.4. Summary statistics

In Table 3, using a threshold of 1.81 as the critical value, we present the summary statistics of the set of firms with high and low bankruptcy risk. We also report the *t*-test that compares the mean of both samples. The *t*-test indicates that firms with a low likelihood of bankruptcy have higher Z-scores, a higher market-to-book ratio (MTB), as well as higher dividends than their counterparts with a high risk of bankruptcy. The summary statistics also demonstrate that firms with low bankruptcy risk have lower-biodiversity risk, biodiversity regulatory risk, corporate climate risk (CCR) and corporate climate exposure (CCE). The Table also indicates that financially healthy firms emit less carbon, are lowly leveraged, smaller, hold less cash, and have fewer tangible assets.

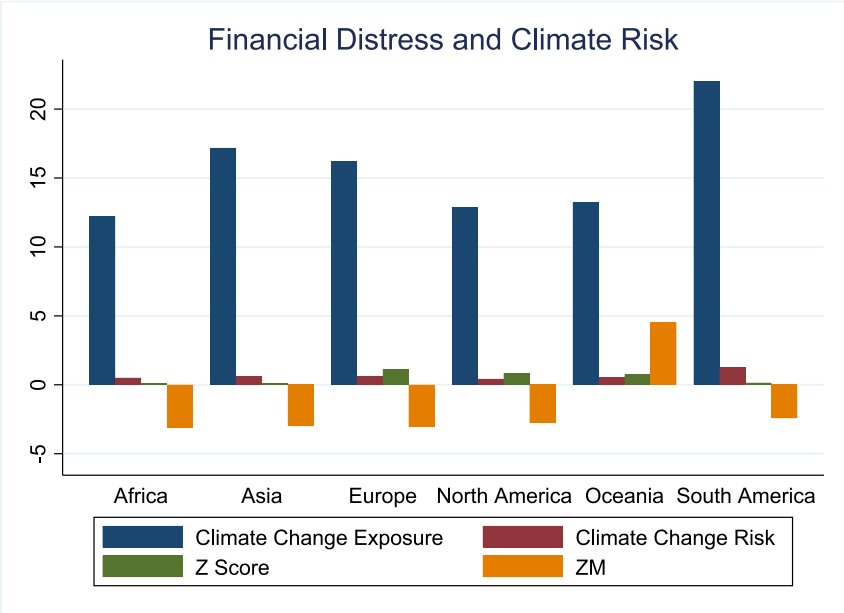


Fig. 1. Financial Distress and Climate Risk.
The figure presents the pictorial representation of climate risk metrics and financial distress proxies by continent.

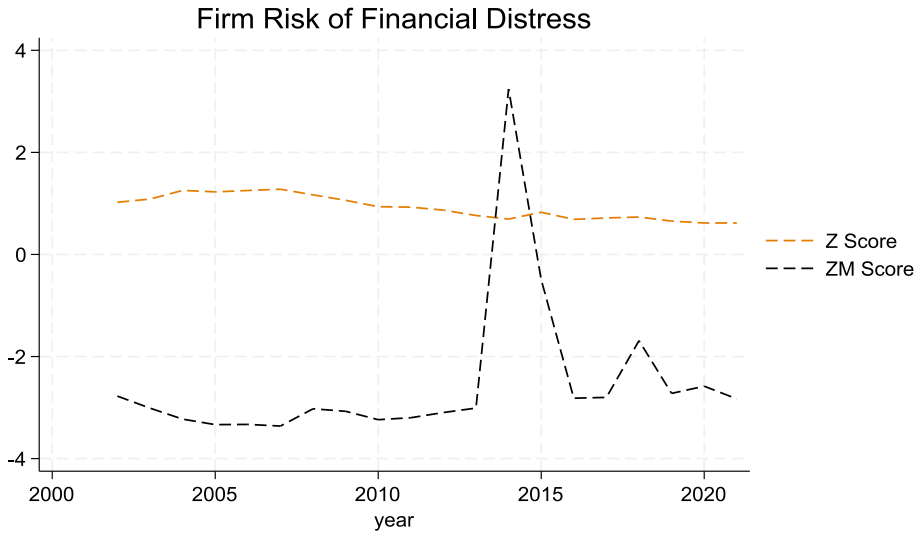


Fig. 2. Firm Risk of Financial Distress.
The graph above depicts the time trend in average firm bankruptcy risk.

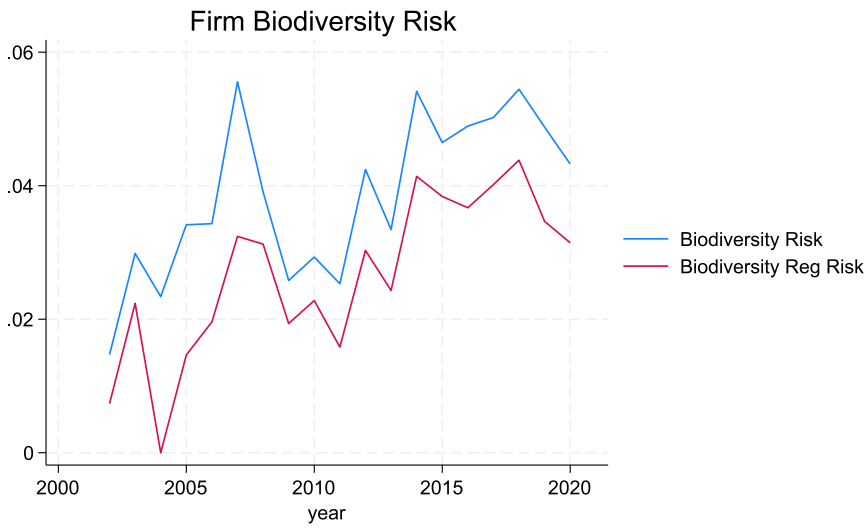


Fig. 3. Firm Biodiversity Risk.
The Figure presents a graphical depiction of the mean firm biodiversity risk every year based on the sample.

3.5. Correlation matrix

Table 4 reports the correlation between the variables used in this study. Focussing on the variables of interest, the preliminary test indicates that the Z score is negatively associated with biodiversity risk, biodiversity regulatory risk, CCR, CCE and carbon emissions. Although this does not confirm causality, it does imply a directional relationship between the variables. The matrix also demonstrates that variables such as ZM score, leverage, size, governance policy score (GPS), and tangibility have a negative relationship with the Z score. In contrast, RoA, MTB, cash holdings, and dividends have a positive relationship with Z score.

3.6. Regression Model

To test our central conjecture, we specify a probit regression defined below:

$$\boldsymbol{Prob}(\boldsymbol{RiskofBankruptcy}_{ijtc} = 1) = \Phi(\partial_0 + \partial_1(\boldsymbol{ER})_{ijtc} + \partial_1(\boldsymbol{X})_{ijtc} + \boldsymbol{\gamma_j} + \boldsymbol{\omega_c} + \boldsymbol{\varphi_t} + \boldsymbol{\varepsilon_{itc}}) \quad (5)$$

Risk of bankruptcy refers to the likelihood that a firm will go bankrupt. It is a binary variable designed according to the Z-score

Table 2
Country Distribution
The Table presents the country-wise distribution of the study. It also reports the mean of key variables used in the study. Further information on variable definition is presented in the Appendix.

Country	Z Score	ZM	Log Co2 Emission	CCR	CCE
Argentina	0.03	−2.40	14.89	1.23	18.15
Australia	0.75	5.34	12.05	0.50	11.84
Austria	1.07	−2.94	12.98	0.91	18.58
Azerbaijan	0.80	−4.96			
Bahrain	1.12	−2.96	16.30	0.00	6.99
Belgium	1.08	−2.69	11.81	0.41	12.76
Bermuda	0.39	−1.63	12.57	0.56	12.48
Brazil	0.22	−2.38	11.78	0.86	16.54
Cambodia	0.01	−3.05	10.26		
Canada	0.52	−2.98	12.91	0.52	16.17
Cayman Islands	0.93	−2.03	9.66	2.01	16.28
Chile	0.01	−2.49	13.95	2.74	40.99
China	0.23	−3.01	12.01	1.00	21.94
Colombia	0.03	−2.36	13.60	1.19	29.17
Costa Rica	0.70	−0.94		0.57	2.94
Cyprus	0.25	−2.26	12.78	0.26	4.67
Czech Republic	0.05	−2.57	16.03	4.48	103.07
Denmark	0.18	−3.07	10.98	0.29	10.85
Finland	1.28	−3.18	12.41	1.64	22.60
France	0.92	−2.83	12.39	0.61	17.35
Germany	1.23	−3.18	12.86	0.74	14.90
Greece	2.47	−2.72	13.57	0.58	9.89
Hungary	0.01	−3.22	11.68	0.38	6.12
Iceland	0.01	−2.37	9.68	0.00	5.64
India	0.03	−2.95	13.58	0.73	18.52
Indonesia	0.01	−2.71	12.79	0.87	10.04
Ireland	1.06	−2.79	12.28	0.25	8.94
Israel	0.25	−3.03	12.37	0.13	5.38
Italy	0.88	−2.64	12.38	1.22	25.80
Japan	0.02	−3.12	13.11	0.40	16.31
Jordan	0.69	−4.95			
Kazakhstan	0.01	−3.83	13.75	6.31	59.13
Kenya	0.02	−3.97	11.00	1.54	8.54
Kuwait	1.88	−3.58	12.85	0.64	5.30
Luxembourg	1.00	−2.89	12.28	0.30	9.00
Malaysia	0.19	−2.77	12.43	0.37	11.78
Malta	0.80	−3.16	7.79	0.20	2.82
Mexico	0.04	−2.58	13.15	0.75	17.19
Mongolia	0.00	−2.74	12.47		
Morocco	0.06	−2.93	12.57	0.36	4.43
Netherlands	1.17	−2.97	12.31	0.31	9.00
New Zealand	0.55	−3.03	10.64	0.80	22.91
Nigeria	0.01	−2.84	14.85	0.00	30.80
Norway	0.11	−2.88	11.69	0.62	23.65
Pakistan	0.01	−3.52			
Panama	0.48	−2.40	15.49	0.00	2.13
Papua New Guinea	0.14	−2.12	13.68	0.84	16.00
Peru	0.18	−2.81	12.57	0.52	6.78
Philippines	0.02	−2.25	13.18	1.03	25.17
Poland	0.29	−3.15	14.36	1.18	30.28
Portugal	1.12	−2.23	13.81	1.97	35.47
Puerto Rico	0.50	−1.54		0.22	3.70
Qatar	0.12	−2.97	11.13	0.72	5.50
Romania	0.13	−4.26	15.25		
Russian Federation	0.03	−2.73	15.57	0.63	15.74
Saudi Arabia	0.15	−2.83	15.92	2.20	31.00
Singapore	0.53	−3.07	12.02	0.85	23.12
Slovenia	0.84	−4.88	11.12		
South Africa	0.12	−3.10	12.81	0.49	12.40
Spain	0.85	−2.70	12.70	1.94	39.93
Sri Lanka	0.01	−2.40	12.77		
Sweden	0.14	−2.87	10.51	0.29	10.15
Switzerland	1.01	−3.24	11.47	0.36	11.59
Thailand	0.09	−2.43	13.62	0.21	12.44
Ukraine	0.08	−2.45	13.89	1.53	11.24
United Arab Emirates	0.30	−3.09	12.25	0.90	16.92

(*continued on next page*)

Table 2 (*continued*)

Country	Z Score	ZM	Log Co2 Emission	CCR	CCE
United Kingdom	1.55	−3.25	11.43	0.47	14.00
United States	0.90	−2.74	13.22	0.41	12.51
Uruguay	0.22	−2.90	9.75	0.00	5.05
Vietnam	0.00	−2.62	12.25		

Table 3
Summary Statistics
This Table presents the descriptive statistics of all the variables used in the analysis. We split the firms according to their exposure to bankruptcy risk. We also report the result of the *t*-test for the means of both samples.

	Low Bankruptcy Risk					High Bankruptcy Risk					
	count	Mean	SD	p25	p75	count	Mean	SD	p25	p75	*t*-test
Z Score	4528	2.85	6.05	2.02	3.01	45,300	0.58	0.65	0.15	0.93	2.26**
ZM	4528	−2.03	105.15	−4.39	−2.96	45,300	−2.38	75.70	−3.77	−2.19	0.36
Biodiversity Risk	1002	0.01	0.12	0.00	0.00	8398	0.04	0.20	0.00	0.00	−0.03**
Biodiversity Reg Risk	1002	0.01	0.08	0.00	0.00	8398	0.03	0.17	0.00	0.00	−0.02**
CCR	2996	0.34	1.43	0.00	0.00	29,560	0.53	1.96	0.00	0.00	−0.20**
CCE	2996	8.77	19.09	1.10	7.43	29,560	14.64	30.61	1.62	12.57	−5.86**
Co2 Log	1996	11.97	2.45	10.43	13.66	22,558	12.57	2.70	10.92	14.35	−0.60**
RoA	4528	−0.25	23.30	0.03	0.14	45,300	−0.10	16.77	0.00	0.07	−0.15
Leverage	4528	0.20	0.20	0.07	0.28	45,300	0.26	0.21	0.11	0.37	−0.06**
MTB	4528	2.62	10.65	0.70	2.59	45,300	1.36	2.28	0.27	1.66	1.26**
Size	4528	21.27	1.62	20.14	22.36	45,300	22.46	2.58	20.75	23.80	−1.19**
Cash Holdings	4527	0.14	0.14	0.05	0.19	45,288	0.18	0.20	0.05	0.22	−0.04**
GPS	4528	50.33	21.25	33.32	67.22	45,238	50.06	22.23	32.24	67.99	0.27
Dividend	4528	0.75	0.44	0.00	1.00	45,300	0.66	0.47	0.00	1.00	0.09**
Tangibility	4527	0.24	0.18	0.09	0.35	45,256	0.31	0.26	0.09	0.48	−0.06**
Depreciation and Amortization	4528	0.07	2.05	0.02	0.05	45,300	0.04	0.07	0.02	0.05	0.03**

threshold of 1.81. Firms with a high risk of bankruptcy are denoted 1 while those with a low risk of bankruptcy are denoted 0. Φ refers to the cumulative distribution of the standard normal distribution. ER indicates our variables of interest. It is used interchangeably to mean, biodiversity risk, biodiversity regulatory risk, firm carbon emissions level, corporate climate risk and corporate climate exposure. The vector X captures other important control variables such as leverage, RoA, market-to-book ratio, size, GPS, cash holdings, R & D, tangibility, dividends, depreciation and amortization, $\varphi_t, \gamma_j, and \omega_c$ indicates the year, industry and country effects. The indexes *ijtc* refer to firm, industry, year and country. ε is the error term.

4. Discussion and findings

We present the result of the baseline model in Table 5. Model 1 of Table 5 reports the relationship between biodiversity risk and firm bankruptcy risk. The results reveal that biodiversity risk is positively associated with firm bankruptcy risk. This implies that exposure to biodiversity risk could exacerbate a firm's risk of financial distress. In addition, we report the regression estimation that examines the relationship between biodiversity regulatory risk and firm bankruptcy risk in Model 2 of Table 5. Similarly, we find a positive relationship between biodiversity regulatory risk and firm bankruptcy risk. Put together, the findings indicate that firms with exposure to risks that emanate from ecological degradation are exposed to severe financial distress.

The findings corroborate the burgeoning conversation on the implications of biodiversity exposure (Bassen et al., 2024; Carvalho et al., 2023). In particular, the findings complement the work of Carvalho et al. (2023) by detailing one of the channels through which biodiversity exposure destroys enterprise value. Degradation of ecosystems could disrupt operations and supply chains, distorting cash flows and ultimately exacerbating default risk. Confirming this assertion, Bassen et al. (2024).

Reveal that installing a robust biodiversity management structure lessens the occurrence of stock price crashes.

Model 3 reports the results of the relationship between climate change exposure (CCE) and bankruptcy risk. The findings indicate that climate change exposure is positively associated with financial distress. This aligns with the proposition of Feng et al. (2024), who demonstrate that climate change exposure worsens bankruptcy risk. In model 4, we explore the association between climate change risk and bankruptcy risk. The result suggests that there is a positive relationship between climate change risk and bankruptcy risk. In effect, the higher a firm's exposure to climate change-related risk, the higher the probability of bankruptcy. Notably, the coefficient of relationship is seemingly higher for climate change risk when compared to that of climate change exposure.

Lastly, we examine the relationship between carbon emissions level and the risk of bankruptcy and report the results in model 5 of Table 5. The findings imply that firms that rely heavily on carbon could be acutely exposed to bankruptcy risk. One way through which carbon-intensive firms may be disadvantaged is in accessing finance in the debt (Kacperczyk and Peydro, 2021). Subdued credit lines could inevitably threaten firms' financial health. The increased cost of debt that carbon-dependent companies are exposed to could further exacerbate cash flow risks (Jung et al., 2018). Notably, the impact of this credit discrimination will be more acute for firms in

Table 4
Correlation Matrix
In this table, we report the correlation for all key variables used in this study. ** and *** represent significance at below 5 % and 1 % respectively.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Z-Score	1														
2	ZM	−0.281***	1													
3	Biodiversity Risk	−0.101***	0.0763***	1												
4	Biodiversity Reg Risk	−0.106***	0.0817***	0.867***	1											
5	CCR	−0.270***	0.117***	0.104***	0.0939***	1										
6	CCE	−0.166***	0.0711***	0.108***	0.0826***	0.592***	1									
7	Co2 Log	−0.117***	0.0664***	0.134***	0.113***	0.330***	0.225***	1								
8	RoA	0.216***	−0.399***	−0.117***	−0.116***	−0.143***	−0.0974***	−0.0975***	1							
9	Leverage	−0.232***	0.950***	0.0429*	0.0492**	0.0787***	0.0444**	0.0406*	−0.0918***	1						
10	MTB	0.132***	−0.221***	−0.117***	−0.111***	−0.220***	−0.150***	−0.352***	0.492***	−0.0734***	1					
11	Size	−0.172***	0.0218	−0.0464**	−0.0546**	0.111***	0.0826***	0.634***	−0.00409	0.0239	−0.183***	1				
12	Cash Holdings	0.000817	−0.267***	−0.0942***	−0.0816***	−0.217***	−0.151***	−0.376***	0.226***	−0.215***	0.403***	−0.172***	1			
13	GPS	−0.00469	0.0279	0.0474**	0.0556***	0.0975***	0.0826***	0.227***	0.0122	0.0350*	−0.0760***	0.201***	−0.108***	1		
14	Dividend	0.0522**	0.0790***	0.0289	0.0119	0.0805***	0.0724***	0.316***	0.0372*	0.0994***	−0.125***	0.330***	−0.246***	0.192***	1	
15	Tangibility	−0.206***	0.189***	0.260***	0.263***	0.413***	0.279***	0.555***	−0.219***	0.132***	−0.286***	0.177***	−0.407***	0.153***	0.166***	1
16	Depreciation and Amortization	−0.0228	0.0301	0.154***	0.173***	−0.0967***	−0.0511**	0.186***	−0.166***	−0.0240	−0.0442**	0.00836	−0.105***	0.0572***	−0.0802***	0.392***

Table 5
Baseline Regression
This table presents the main probit regression that examines the relationship between firms' climate change vulnerabilities and bankruptcy risk. We report the T-statistics in parentheses. **, and *** implies significance at 10%, and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)
Biodiversity Risk	0.2695***				
	(1.97)				
Biodiversity Reg Risk		0.4511***			
		(2.52)			
Climate Change Exposure			0.0021***		
			(3.85)		
Climate Change Risk				0.0157***	
				(2.11)	
CO2 Natural Log					0.0381***
					(4.85)
ROA	−1.9923***	−1.9914***	−0.6134***	−0.6163***	−0.2708***
	(−7.99)	(−7.99)	(−7.64)	(−7.68)	(−2.25)
Leverage	2.0806***	2.0735***	0.6215***	0.6209***	0.6780***
	(15.62)	(15.57)	(11.51)	(11.50)	(9.19)
Market to Book	0.0240***	0.0240***	−0.0005	−0.0005	−0.0229***
	(1.97)	(1.97)	(−0.21)	(−0.20)	(−2.60)
Size	0.1320***	0.1334***	0.0562***	0.0566***	0.0085
	(7.76)	(7.83)	(7.43)	(7.48)	(0.71)
Cash Holdings	1.6453***	1.6434***	0.5157***	0.5164***	0.2140**
	(9.21)	(9.21)	(6.93)	(6.94)	(1.91)
Governance Pillar Score	−0.0033***	−0.0033***	−0.0013***	−0.0013***	−0.0007
	(−3.20)	(−3.21)	(−2.84)	(−2.82)	(−1.14)
Dividends	−0.1402***	−0.1426***	−0.1014***	−0.1015***	−0.1720***
	(−3.01)	(−3.06)	(−4.17)	(−4.17)	(−4.76)
Tangibility	0.2041**	0.1964**	−0.2917***	−0.2850***	−0.5864***
	(1.77)	(1.70)	(−5.93)	(−5.79)	(−9.39)
Depreciation and Amort	−1.8326***	−1.8300***	2.7249***	2.6857***	4.0808***
	(−4.31)	(−4.31)	(7.89)	(7.78)	(6.93)
Constant		0.4511***	0.4079	0.4073	1.3094
		(2.52)	(1.02)	(1.02)	(1.51)
Industry Effect	−1.7617***	−1.7834***	Yes	Yes	Yes
Year Effect	(−4.35)	(−4.40)	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	8408	8408	35,444	35,444	26,553
Pseudo R^2	0.173	0.173	0.334	0.334	0.387

asset-heavy industries operating with thin margins. Ultimately, the high cost of borrowing will narrow corporate liquidity, heightening the likelihood of bankruptcy.

In summary, across the three measures of climate risk, the common theme is that exposure to biodiversity risk and climate risk exacerbates the chances of financial distress. This reverberates the assertion that firm risk exposure to adverse climate events could threaten revenue, operating margins, and corporate earnings (Pankratz et al., 2023).

4.1. Additional analysis

4.1.1. Biodiversity risk, climate vulnerabilities, and bankruptcy likelihood

Motivated by the assertion that Biodiversity risk to a large extent is distinct from climate-related risks (Giglio et al., 2023), we examine how the combination of both risk components affects firm bankruptcy risk. We report the result of this regression analysis in Table 6. The findings from the analysis indicate that the combination of biodiversity risk and climate risk could exacerbate bankruptcy risk. The findings indicate that when a firm is heavily dependent on carbon, higher exposure to biodiversity worsens its financial health. We also demonstrate that firms with acute exposure to climate change risk that are jointly facing challenges with regard to biodiversity are exposed significantly to the risk of increased financial distress. The findings call for drastic measures for firms jointly exposed to both categories of risks.

4.1.2. Climate vulnerabilities, financial constraint and bankruptcy likelihood

In Table 7, we investigate if financial constraint mitigates or exacerbates the relationship between our various measures of corporate climate vulnerabilities, biodiversity risk and financial distress. We measure financial constraints by estimating the time-varying HP index for each firm (Hadlock and Pierce, 2010). To test this conjecture, we interact the various metrics of firm climate vulnerabilities and biodiversity risk with financial constraints. In Model 1, we find no evidence that biodiversity risk significantly worsens or improves firm bankruptcy risk when "interacted" with financial constraints. Table 7, model 2 suggests that biodiversity regulatory risk exacerbates bankruptcy risk when "interacted" with financial constraints. This suggests that the regulatory pressure

Table 6
Biodiversity Risk, Climate Vulnerabilities and Firm Bankruptcy Risk
This Table presents the results of the probit regression which examines the relationship between biodiversity risk, firms' climate change vulnerabilities, and bankruptcy risk. We report the T-statistics in parentheses. **, and *** imply significance at 10%, and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)	(6)
Biodiversity Risk	−2.8498**		0.2691		0.2339	
	(−1.88)		(1.60)		(1.17)	
CO2 Natural Log	−0.0074	0.0004				
	(−0.20)	(0.01)				
Biodiversity Risk # CO2 Natural Log	0.2442***					
	(1.99)					
Biodiversity Reg Risk		−2.1638		0.2291		−0.4802
		(−0.83)		(1.17)		(−1.44)
Biodiversity Reg Risk # CO2 Natural Log		0.2047				
		(1.04)				
Climate Change Risk			0.0311	0.0264		
			(0.93)	(0.82)		
Biodiversity Risk			0.0237			
			(0.15)			
Biodiversity Reg Risk # Climate Change Risk				0.0000		
				(0.00)		
Climate Change Exposure					0.0037**	0.0033
					(1.75)	(1.59)
Biodiversity Risk # Climate Change Exposure					0.0044	
					(0.36)	
Biodiversity Reg Risk # Climate Change Exposure						0.2120***
						(2.11)
Constant	−0.4005	−0.4100	−1.6680***	−1.6698***	−1.7070***	−1.6711***
	(−0.47)	(−0.48)	(−3.64)	(−3.64)	(−3.72)	(−3.63)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2568	2568	6299	6258	6299	6299
Pseudo R^2	0.166	0.165	0.137	0.136	0.138	0.140

embedded in biodiversity regulation could have cash flow and liquidity implications. This lends support to proponents of the climate finance literature that advocate for regulatory intervention in managing the green transition.

We report the results of the same investigation for corporate climate-related vulnerabilities in Models 3–5. Accordingly, we document in Model 3 that financial constraint worsens the impact of carbon emissions. The findings suggest that carbon-dependent firms that are financially constrained face higher exposure to bankruptcy risk. One potential explanation for this finding is that carbon-dependent firms are asset-heavy (Azar et al., 2021) and as such, may operate on very thin margins. Therefore, they are sensitive to any form of cash flow risk. The result confirms the position of prior studies, which contend that exposure to carbon risk could be exacerbated by financial constraints, which could limit organic green transition (Cui et al.,2023). In employing other measures of climate-related vulnerabilities, we find mixed results. In Model 4, the impact of financial constraint is insignificant for climate change exposure. In Model 5, the result indicates that the risk of bankruptcy is reduced for financially constrained firms with exposure to climate change. One crucial difference between this measure of climate risk and others is self-awareness. For climate change risk, managers raise awareness of this risk during earnings calls. Therefore, they are more likely to have taken pre-emptive actions to mitigate the cash flow implications of their risk exposure. In Appendix F, we also perform an alternative analysis using the KZ index which confirms that financial constraint is an important consideration. The result from our analyses confirms that financial constraints have profound implications for corporate transition to the low carbon economy.

4.1.3. Climate change threats, growth opportunities and bankruptcy likelihood

Next, in Table 8, we evaluate the role of growth opportunity in mitigating or exacerbating bankruptcy risk that emerges from firm exposure to biodiversity or climate change events. Our proxy for growth opportunity is R & D intensity. This approach is one of the proxies suggested by (Stowe and Xing, 2006). The results in Models 1 and 2 of Table 8 suggest that the interaction of biodiversity risk and growth opportunity has an insignificant impact on bankruptcy risk. This implies that growth opportunity may not necessarily be a valuable tool for hedging exposure to biodiversity risk, nor can it catalyse risks associated with ecological degradation. The results reported in Model 3 of Table 8 also demonstrate that growth opportunity is not an important consideration for firms with climate change exposure.

However, the results reported in Models 4 and 5 of Table 8 demonstrate that indeed, the growth disposition of a firm lessens the impact of carbon dependency/climate risk on bankruptcy likelihood. One explanation for this is that high-growth firms may be more agile in navigating their risk exposures since they have numerous unexercised growth opportunities. Consequently, discontinuing operations or divesting from one business to the other as result of unfavourable risk conditions would be easier for them when

Table 7
Climate Change, Financial Constraint (FC) and Bankruptcy Risk
This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, financial constraints and bankruptcy risk. FC refers to financial constraint. We report the T-statistics in parentheses. **, and *** imply significance at 10%, and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)
Biodiversity Risk	−0.2350				
	(−0.45)				
Biodiversity Risk # FC	0.0933				
	(0.84)				
Biodiversity Reg Risk		−1.4109			
		(−1.52)			
Biodiversity Reg Risk# FC		0.4470**			
		(1.81)			
CO2 Natural Log			−0.1597***		
			(−7.92)		
CO2 Natural Log # FC			0.0065**		
			(1.85)		
Climate Change Exposure				0.0012	
				(0.94)	
Climate Change Exposure # FC				−0.0003	
				(−1.16)	
Climate Change Risk					0.0263
					(1.42)
Climate Change Risk # FC					−0.0077***
					(−2.29)
Financial Constraint(FC)	−0.6516***	−0.6375***	−0.4086***	−0.2720***	−0.2661***
	(−4.75)	(−4.63)	(−3.30)	(−4.21)	(−4.11)
ROA	−2.1649***	−2.1685***	−0.1355	−0.8630***	−0.8647***
	(−6.64)	(−6.64)	(−1.00)	(−9.17)	(−9.19)
Leverage	1.9370***	1.9281***	1.4792***	1.1828***	1.1853***
	(13.18)	(13.12)	(13.85)	(16.23)	(16.26)
Market to Book	0.0348***	0.0347***	−0.0520***	−0.0154***	−0.0153***
	(2.15)	(2.14)	(−5.08)	(−2.28)	(−2.27)
Size	0.9056***	0.8897***	0.6226***	0.4330***	0.4266***
	(5.52)	(5.41)	(5.65)	(5.81)	(5.72)
Cash Holdings	1.4900***	1.4852***	0.3349***	0.9238***	0.9254***
	(7.46)	(7.43)	(2.02)	(9.29)	(9.30)
Governance Pillar Score	−0.0027***	−0.0028***	−0.0031***	−0.0051***	−0.0051***
	(−2.46)	(−2.50)	(−3.89)	(−8.56)	(−8.54)
Dividend	−0.1734***	−0.1736***	−0.2239***	−0.0512**	−0.0512**
	(−3.32)	(−3.32)	(−4.99)	(−1.78)	(−1.78)
Tangibility	0.2354**	0.2146**	0.7735***	0.4312***	0.4318***
	(1.85)	(1.69)	(7.81)	(6.56)	(6.56)
Depreciation and Amort	−0.7168	−0.7121	0.0487	−0.0577	−0.0585
	(−1.18)	(−1.17)	(0.33)	(−0.43)	(−0.44)
Constant	−15.8034***	−15.4996***	−8.4659***	−6.8419***	−6.7260***
	(−5.26)	(−5.14)	(−4.45)	(−5.05)	(−4.95)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	6597	6597	16,858	27,010	27,010
Pseudo R^2	0.153	0.154	0.257	0.201	0.201

compared to counterparts that have no exercisable growth opportunities. This finding deepens the understanding of the interaction between firm productivity and bankruptcy risk. Prior studies contend that firm productivity can alleviate the risk of bankruptcy (for example, Bryan et al., 2013). We demonstrate that productivity could be deployed to circumvent bankruptcy risk amidst severe corporate exposure to adverse climate events and carbon risk.[3]

4.1.4. Climate Hazards, carbon intensity and bankruptcy likelihood

Table 9 details how carbon intensity affects the dynamics of the relationship between biodiversity, climate vulnerabilities and bankruptcy risk. To identify carbon-intensive firms, we follow the approach of prior studies in the literature (Adamolekun et al., 2024; Konadu et al., 2022). Models 1 and 2 indicate that the impact of biodiversity is insignificant for carbon-intensive firms. The findings

[3] In addition to this measure, we also adopt an alternative measure of growth opportunities as proposed by (Lang et al., 1996). The robustness test confirms our assertion that growth opportunity is a valuable consideration in the context of bankruptcy risk that emanates from firm climate risk exposure.

Table 8
Climate Change, Growth Opportunities(GO) and Bankruptcy Risk
This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, growth opportunities and bankruptcy risk. GO refers to growth opportunities. We report the T-statistics in parentheses. **, and *** imply significance at 10%, and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)
Biodiversity Risk	0.3155***				
	(2.08)				
Biodiversity Risk#GO	0.0000				
	(0.0)				
Biodiversity Reg Risk		0.5012***			
		(2.56)			
Biodiversity Reg Risk#GO		0.0000			
		(0.0)			
Climate Change Exposure			−0.1728***		
			(−13.63)		
Climate Change Exposure # GO			−0.0139		
			(−1.07)		
Climate Change Risk				0.0034***	
				(3.71)	
Climate Change Risk # GO				−0.0098***	
				(−8.83)	
CO2 Natural Log					0.0282***
					(2.16)
CO2 Natural Log # GO					−0.1006***
					(−6.16)
Growth Opportunity(GO)	1.1221***	1.1238***	0.9795***	0.9536***	0.8828***
	(19.85)	(19.92)	(5.95)	(30.88)	(30.42)
ROA	−2.0256***	−2.0247***	−0.2627***	−0.7077***	−0.7181***
	(−6.00)	(−5.99)	(−2.00)	(−7.55)	(−7.66)
Leverage	1.7659***	1.7572***	1.3830***	1.2024***	1.1906***
	(11.77)	(11.71)	(13.70)	(16.64)	(16.51)
Market to Book	−0.0092	−0.0091	−0.0639***	−0.0331***	−0.0331***
	(−0.55)	(−0.55)	(−6.39)	(−4.86)	(−4.89)
Size	0.1213***	0.1230***	0.2982***	0.1136***	0.1146***
	(6.07)	(6.15)	(17.12)	(11.51)	(11.62)
Cash Holdings	1.0594***	1.0503***	0.3429***	0.5270***	0.5327***
	(5.11)	(5.06)	(2.11)	(5.28)	(5.35)
Governance Pillar Score	−0.0040***	−0.0040***	−0.0038***	−0.0057***	−0.0055***
	(−3.37)	(−3.38)	(−4.93)	(−9.47)	(−9.18)
Dividends	−0.1776***	−0.1788***	−0.1944***	−0.0489**	−0.0540**
	(−3.29)	(−3.32)	(−4.45)	(−1.70)	(−1.88)
Tangibility	0.6883***	0.6796***	1.3093***	0.6951***	0.7051***
	(5.16)	(5.10)	(13.04)	(10.63)	(10.80)
Depreciation and Amort	−2.1648***	−2.1628***	0.0861	−0.1203	−0.1215
	(−2.92)	(−2.92)	(0.66)	(−0.96)	(−0.97)
Constant	−1.6999***	−1.7258***	−3.2688***	−1.4903***	−1.4950***
	(−3.53)	(−3.58)	(−8.32)	(−5.98)	(−6.01)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	6533	6558	18,302	28,329	28,329
Pseudo R^2	0.235	0.236	0.295	0.252	0.250

corroborate the position of recent proponents in the literature who argue that biodiversity risk and climate vulnerabilities are distinct (Giglio et al., 2023).

Contrastingly, we document that firm susceptibility to climate-related risk, as implied from climate change risk and climate change exposure, alleviates the likelihood of bankruptcy. Therefore, firms with this disposition are less exposed to this ordeal than their counterparts that employ a less carbon-intensive production process. Various arguments explain these findings. Firstly, it is possible that since capital market participants are aware of the risk exposure of this category of firms, they price it in capital raising. Therefore, it is not new information. However, for their counterparts that are exposed to climate risk but are not carbon intensive, this may be considered new information and could hamper the quality of credit they access in the capital market. An alternative or additional explanation is that since both measures of climate risk mirror managerial awareness of climate risk, it is plausible that carbon-intensive

Table 9
Climate Change, Carbon Intensity (CI) and Bankruptcy Risk
This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, carbon intensity and bankruptcy risk. CI refers to carbon intensity. We report the T-statistics in parentheses. **, and *** imply significance at 10%, and 5% respectively Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)
Biodiversity Risk	0.1906				
	(0.80)				
Biodiversity Risk# CI	0.1171				
	(0.40)				
Biodiversity Reg Risk		0.7024**			
		(1.81)			
Biodiversity Reg Risk# CI		−0.3272			
		(−0.75)			
Climate Change Exposure			0.0079***		
			(6.13)		
Climate Change Exposure # CI			−0.0072***		
			(−5.12)		
Climate Change Risk				0.0856***	
				(5.73)	
Climate Change Risk # CI				−0.0916***	
				(−5.57)	
CO2 Natural Log					0.0101
					(1.10)
CO2 Natural Log # CI					0.0608***
					(5.90)
Carbon Intensive Firms	0.1824	0.1958	0.0653	0.0556	−0.7888***
	(1.50)	(1.61)	(0.70)	(0.60)	(−4.47)
ROA	−1.9946***	−1.9881***	−0.7774***	−0.7776***	−0.1611
	(−8.00)	(−7.97)	(−8.44)	(−8.44)	(−1.23)
Cash Holdings	2.0806***	2.0730***	0.5243***	0.5240***	0.2486***
	(15.61)	(15.57)	(7.04)	(7.03)	(2.22)
Governance Pillar Score	0.0240***	0.0240***	−0.0013***	−0.0013***	−0.0006
	(1.97)	(1.96)	(−2.76)	(−2.80)	(−0.98)
Dividends	0.1318***	0.1340***	−0.1027***	−0.1028***	−0.1772***
	(7.74)	(7.86)	(−4.21)	(−4.22)	(−4.90)
Tangibility	1.6416***	1.6479***	−0.2981***	−0.2860***	−0.5879***
	(9.18)	(9.23)	(−6.06)	(−5.81)	(−9.43)
Depreciation and Amort	−0.0033***	−0.0033***	2.7094***	2.6676***	4.2321***
	(−3.20)	(−3.21)	(7.84)	(7.72)	(7.17)
Constant	−1.9412***	−1.9878***	0.3948	0.3944	1.5344**
	(−4.73)	(−4.84)	(0.97)	(0.97)	(1.76)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	8408	8408	35,444	35,444	26,553
Pseudo R^2	0.173	0.173	0.335	0.335	0.388

firms have taken actions to limit the potential downside risk of their exposure.

In model 5 of Table 9, we report the results of the relationship between carbon emissions, intensity of firm carbon dependency and bankruptcy risk. The findings also reveal a positive relationship between carbon emissions, carbon intensity and bankruptcy likelihood. The findings demonstrate that firms with high carbon dependency operating in carbon-intensive industries are exposed to a higher likelihood of bankruptcy. Our results shed more light on how various decarbonisation drives affect firms in carbon-intensive industries. Indeed, the value of carbon-intensive firms could be adversely affected because of a lacklustre decarbonisation drive (Liu and Qiao, 2021). One probable explanation for this result is that the competitive advantage of firms in carbon-intensive industries is their dependency on hydrocarbons, which exacerbate their climate risk. Therefore, failure to transition away from heavy reliance on hydrocarbons manifests as a higher likelihood of bankruptcy.

4.1.5. Does the continent of operation Matter?

In this section, we explore the role of a firm's continent of operation. Motivated by the argument that continental disparity can affect the occurrence of bankruptcy (Claessens and Klapper, 2005), we examine if the geographical location of firms is an important consideration. The results of this set of analyses are reported in Tables 10, 11 and 12. For climate change exposure, we present the

Table 10
Continental Effect, Climate Change Exposure and Bankruptcy Risk
This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, climate change exposure and bankruptcy risk. We report the T-statistics in parentheses. **, and *** imply significance at 10%, and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(Asia)	(Europe)	(North America)	(Oceania)	(South America)
Climate Change Exposure	0.0047	−0.0005	0.0045***	0.0075***	0.0215**
	(1.28)	(−0.61)	(4.82)	(2.09)	(1.83)
ROA	0.3846	−0.2137	−0.7252***	−2.2870***	−5.1680
	(0.51)	(−1.55)	(−6.40)	(−2.58)	(−0.58)
Leverage	0.1376	0.6655***	0.7009***	1.7784***	−1.6059
	(0.35)	(5.84)	(10.52)	(4.67)	(−1.12)
Market to Book	0.0239	−0.0187	−0.0003	0.0122	−0.4321
	(0.35)	(−1.55)	(−0.12)	(0.38)	(−0.56)
Size	0.0702	0.0608***	0.0548***	0.1250***	0.0574
	(1.62)	(3.95)	(5.63)	(2.71)	(0.21)
Cash Holdings	−0.3546	−0.0258	1.0319***	−1.3199***	−6.6608***
	(−0.84)	(−0.16)	(10.49)	(−3.23)	(−3.74)
Governance Pillar Score	0.0061***	−0.0022***	−0.0007	−0.0113***	0.0053
	(2.24)	(−2.39)	(−1.16)	(−4.11)	(0.48)
Dividends	0.3138**	−0.1301***	−0.1415***	−0.6299***	−0.2365
	(1.73)	(−2.55)	(−4.74)	(−2.95)	(−0.41)
Tangibility	−1.7742***	−0.0189	−0.3229***	−0.7032***	−5.6439***
	(−5.67)	(−0.20)	(−4.94)	(−3.04)	(−5.01)
Depreciation and Amort	16.3793***	0.0826	2.8005***	12.4406***	62.8063***
	(4.20)	(0.39)	(6.73)	(5.01)	(2.65)
Constant	0.5390	0.2267	0.5040**	−1.8553**	−0.0639
	(0.52)	(0.48)	(1.73)	(−1.76)	(−0.01)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	2426	9351	21,006	1551	427
Pseudo R^2	0.667	0.336	0.323	0.471	0.738

Table 11
Continental Effect, Climate Change Risk and Bankruptcy Risk
This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, climate change risk and bankruptcy risk. We report the T-statistics in parentheses. **, and *** imply significance at 10% and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(Asia)	(Europe)	(North America)	(Oceania)	(South America)
Climate Change Risk	0.0136	−0.0107	0.0779***	0.0043	0.4210***
	(0.37)	(−1.01)	(5.04)	(0.12)	(2.39)
ROA	0.3518	−0.2154	−0.7385***	−2.2465***	−2.5507
	(0.47)	(−1.56)	(−6.52)	(−2.54)	(−0.30)
Leverage	0.1689	0.6682***	0.7063***	1.7288***	−1.7169
	(0.44)	(5.87)	(10.58)	(4.57)	(−1.17)
Market to Book	0.0291	−0.0186	−0.0003	0.0098	−0.7690
	(0.42)	(−1.55)	(−0.13)	(0.31)	(−1.00)
Size	0.0731**	0.0613***	0.0547***	0.1317***	0.0402
	(1.71)	(3.98)	(5.62)	(2.86)	(0.14)
Cash Holdings	−0.3781	−0.0263	1.0361***	−1.3255***	−7.2361***
	(−0.90)	(−0.17)	(10.52)	(−3.26)	(−3.74)
Governance Pillar Score	0.0061***	−0.0022***	−0.0007	−0.0116***	0.0069
	(2.22)	(−2.38)	(−1.14)	(−4.21)	(0.58)
Dividends	0.3141**	−0.1301***	−0.1438***	−0.6445***	−0.3709
	(1.74)	(−2.55)	(−4.81)	(−3.04)	(−0.61)
Tangibility	−1.7524***	−0.0204	−0.3106***	−0.6439***	−6.2856***
	(−5.61)	(−0.21)	(−4.75)	(−2.79)	(−4.65)
Depreciation and Amort	16.1281***	0.0825	2.7431***	12.5661***	70.6715***
	(4.14)	(0.39)	(6.60)	(5.01)	(2.65)
Constant	0.5882	0.2125	0.5080**	−1.5479	0.3295
	(0.56)	(0.45)	(1.74)	(−1.48)	(0.04)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	2426	9351	21,006	1551	427
Pseudo R^2	0.666	0.336	0.323	0.468	0.750

Table 12
Continental Effect, Corporate Carbon Emissions and Bankruptcy Risk
This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, firm carbon emissions and bankruptcy risk. We report the T-statistics in parentheses. **, and *** imply significance at 10%, and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(Asia)	(Europe)	(North America)	(Oceania)	(South America)
CO2 Natural Log	0.0688**	−0.0031	0.1052***	0.0576	−0.4007***
	(1.90)	(−0.28)	(7.14)	(1.28)	(−2.27)
ROA	1.2867	−0.2350**	0.3181	−1.9929**	3.2465
	(0.80)	(−1.79)	(1.00)	(−1.78)	(0.29)
Leverage	0.2853	0.6445***	1.4683***	2.3681***	−0.3524
	(0.63)	(6.55)	(10.12)	(4.02)	(−0.21)
Market to Book	−0.5375***	−0.0447***	−0.0009	0.0646	−0.2251
	(−4.01)	(−4.23)	(−0.34)	(0.84)	(−0.39)
Size	−0.0576	0.0670***	−0.0503***	−0.0750	0.3788
	(−0.97)	(4.12)	(−2.20)	(−0.98)	(1.14)
Cash Holdings	0.9303**	0.0458	1.0987***	0.6561	−9.0023***
	(1.71)	(0.30)	(4.43)	(1.06)	(−3.33)
Governance Pillar Score	0.0007	−0.0006	0.0004	−0.0120***	0.0032
	(0.26)	(−0.68)	(0.38)	(−3.14)	(0.24)
Dividends	0.1102	−0.0956***	−0.4628***	−0.0342	1.9228***
	(0.46)	(−2.02)	(−6.54)	(−0.14)	(2.24)
Tangibility	−3.7889***	−0.2290***	−0.8415***	−0.0816	1.5276
	(−11.81)	(−2.62)	(−6.53)	(−0.30)	(1.00)
Depreciation and Amort	33.2561***	1.5361***	8.6991***	5.7018***	8.6746
	(6.87)	(2.12)	(6.20)	(1.97)	(0.37)
Constant	1.5368	0.1499	2.0856***	4.3380***	−8.4863
	(1.16)	(0.37)	(4.03)	(3.02)	(−0.97)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	4506	11,059	7901	1224	283
Pseudo R^2	0.728	0.322	0.379	0.579	0.599

results in Table 10. The findings from the analysis indicate that climate change exposure is not an important consideration for firms in Europe and Asia. However, for firms in Oceania, North America and South America, climate change exposure is positively associated with the risk of bankruptcy.

Table 11 explores the interplay between firm continental location, climate change risk and bankruptcy likelihood. We find that climate change risk is irrelevant for modelling bankruptcy risk for firms situated in Asia, Europe, and Oceania. However, for firms in North America and South America, location appears to exacerbate the relationship between climate change risk and bankruptcy risk. One possible explanation for the findings is market design. The degree of market integration could hamper or enhance market discipline. For North American firms, with most of them situated in the US, enforcing market discipline vis-a-vis investment premium is much easier to enforce. However, for firms situated in Europe, Asia and Africa, because of the heterogeneous nature of capital markets, it is challenging for market participants to enforce market discipline in the debt market or stock markets. In addition, continents or countries that have experienced climate-induced events such as wildfires, floods, and droughts are likely to pursue a more aggressive decarbonisation policy. This stance will therefore, manifest in the capital market.

Table 12 examines the relationship between continent, firm carbon emissions and bankruptcy likelihood. We demonstrate that the continent of operation is not an important consideration for firms in Europe and Oceania. For firms in Asia, North America, and South America, firm carbon emissions level has varying effects on bankruptcy risk. The impact of carbon emissions on bankruptcy likelihood is negative for firms in South America. However, for firms in Asia and North America, the impact is positive with varying levels of significance. One potential explanation for our findings is that the result may be indicative of the varying levels of stakeholder attention and perception of carbon emissions across continents. For firms in North America and Asia, over-reliance on hydrocarbons harms financial health since it indicates that a firm may harbour some green transition risk. Whereas, for firms in South America, this reduces the likelihood of bankruptcy risk.

4.2. Robustness test

To ensure our results are robust, we construct another measure of bankruptcy risk (ZM score) as in equation (2). Using the ZM score as our measure of bankruptcy risk, we specify a logistic regression of the following form:

Table 13
Robustness Test
This table presents the robustness test for the main logit regression results examining the relationship between firms' climate change vulnerabilities and bankruptcy risk. In this Table, we measure bankruptcy risk using ZM Score. We report the T-statistics in parentheses. **, and *** implies significance at 10%, and 5% respectively. Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)
Biodiversity Risk	4.6641**				
	(1.87)				
Biodiversity Reg Risk		4.6703**			
		(1.87)			
CO2 Natural Log			0.1922		
			(1.50)		
Climate Change Risk				0.1144***	
				(2.31)	
Climate Change Exposure					0.0030
					(0.94)
ROA	−74.6189***	−74.6189***	−29.7053***	−16.8327***	−16.7660***
	(−3.36)	(−3.36)	(−8.19)	(−19.94)	(−19.88)
Leverage	165.0504***	165.0504***	41.8960***	21.3251***	21.2473***
	(3.48)	(3.48)	(7.55)	(21.23)	(21.10)
Market to Book	2.7499***	2.7499***	0.7440***	0.2962***	0.2944***
	(3.04)	(3.04)	(3.87)	(4.47)	(4.43)
Size	−0.3391	−0.3391	−0.2397	−0.4015***	−0.3991***
	(−0.87)	(−0.87)	(−1.29)	(−5.63)	(−5.59)
Cash Holdings	−8.8625***	−8.8625***	0.2158	0.3737	0.3881
	(−2.38)	(−2.38)	(0.07)	(0.57)	(0.59)
Governance Pillar Score	−0.0712***	−0.0712***	−0.0042	−0.0065	−0.0067
	(−2.47)	(−2.47)	(−0.41)	(−1.58)	(−1.63)
Tangibility	−15.4833***	−15.4833***	−1.2082	0.1475	0.1633
	(−2.90)	(−2.90)	(−1.50)	(0.43)	(0.48)
Depreciation and Amort	68.2569***	68.2569***	3.1297***	1.6820***	1.6714***
	(3.33)	(3.33)	(6.63)	(9.75)	(9.71)
Dividend	0.5231	0.5231	0.6268	0.6794***	0.6852***
	(0.26)	(0.26)	(1.43)	(3.79)	(3.84)
Constant	−1.4e + 02***	−1.4e + 02***	−29.7633***	−6.6097***	−6.5955***
	(−3.18)	(−3.18)	(−5.04)	(−3.14)	(−3.13)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Observations	5757	5757	17,666	27,767	27,767
Pseudo R^2	0.953	0.953	0.885	0.814	0.813

$$\boldsymbol{Prob}(\boldsymbol{RiskofBankruptcy}_{ijtc} = 1) = \Phi(\partial_0 + \partial_1(\boldsymbol{ER})_{ijtc} + \partial_1(\boldsymbol{X'})_{ijtc} + \boldsymbol{\gamma_j} + \boldsymbol{\omega_c} + \boldsymbol{\varphi_t} + \boldsymbol{\varepsilon_{itc}}) \tag{6}$$

We report the results of the regression in Table 13. The results of the further analysis indicate that biodiversity risk, and climate change vulnerabilities could exacerbate firm bankruptcy risk. For both biodiversity risk and biodiversity regulatory risk, we find a positive relationship with bankruptcy risk. Furthermore, across the three measures of corporate climate vulnerability, we find convincing support that the relationship between both phenomena is positive. This confirms the view that corporate climate vulnerabilities have implications for firm financial health. In sum, exposure to ecological degradation and adverse climate events strains corporate financial health and ultimately increases the likelihood of bankruptcy.

5. Conclusion

Mounting evidence in the financial economics literature demonstrates how ecological degradation and adverse climate events affect corporate outcomes (Krueger et al., 2020; Sautner et al., 2023; Bassen et al., 2024; Carvalho et al., 2023). In this study, we join this burgeoning conversation by examining the impact of corporate biodiversity risks, and climate-related vulnerabilities on bankruptcy likelihood. Using an international data set of firms from 70 countries, we demonstrate that firm exposure to biodiversity risk worsens firm financial well-being. The joint exposure to climate and biodiversity risk also worsens firm bankruptcy risk. The results also indicate that corporate susceptibility to climate challenges increases the probability of bankruptcy. Furthermore, the impact of carbon emissions is more pronounced for financially constrained firms. However, we document that for financially constrained firms that are aware of their climate risk, it mitigates their exposure to bankruptcy risk. The findings suggest that high growth opportunities

could reduce the bankruptcy risk associated with climate risk and carbon emissions. For firms in carbon-intensive industries, the likelihood of firms' exposure to climate-related challenges affecting bankruptcy diminishes.

We also document that the continent of operation is an important consideration. For example, climate change exposure exacerbates bankruptcy risk for firms in North America, Oceania, and South America. However, we find that climate change exposure is not an important consideration for firms in Asia and Europe. We document similar results for firms with climate change risk, with its positive impact only evident in firms located in North America and South America. In exploring the impact of carbon emissions on bankruptcy risk across continents, we find that carbon dependency increases bankruptcy risk for firms in Asia and North America. However, for firms in South America, carbon dependency decreases bankruptcy likelihood. Put together, the continental analyses indicate that there is no consensus agreement among corporate stakeholders on the implications of firm climate vulnerabilities in the world.

The central message of our study is that firm biodiversity risk and firm climate challenges have wider implications for corporate outcomes. This will worsen as the conversation around green transition intensifies. We advocate for a concerted approach to climate and biodiversity regulation from a policy stance since the current evidence suggests that stakeholder perception and attention differ across continents. For firms, we appeal to managers to decouple their biodiversity risk from their climate vulnerabilities. Prior studies like Giglio et al. (2023) reveal that biodiversity and climate risks are distinct.

Managers of firms should consider evaluating how various components of their supply chain may be impacted by ecological degradation since this has wide-ranging implications for corporate survival. Although most managers are aware of the physical climate risk they face, modelling the consequences of the resulting transition climate risk may be nuanced. Managers need to pay attention to both components. Beyond attention to climate change risk, investors should consider their portfolio exposure to biodiversity risk since we document that consequences from acute exposure could be devastating. Lastly, for regulators, notably, unlike climate regulation, there has been less emphasis on laws targeting environmental conservation and ecosystem restoration despite ecological degradation being equally devastating as climate change risk. As such, we call for more environmental conservation and ecosystem restoration regulation.

We leave the question of why carbon-intensive firms can avoid the negative consequences of carbon dependency in their finances to future researchers. Subsequent studies can explore the role of governance structure in mitigating firm climate vulnerabilities and biodiversity risks. Furthermore, future studies can shed more light on effective corporate strategies for minimising firm-level climate and biodiversity risk exposure.

CRediT authorship contribution statement

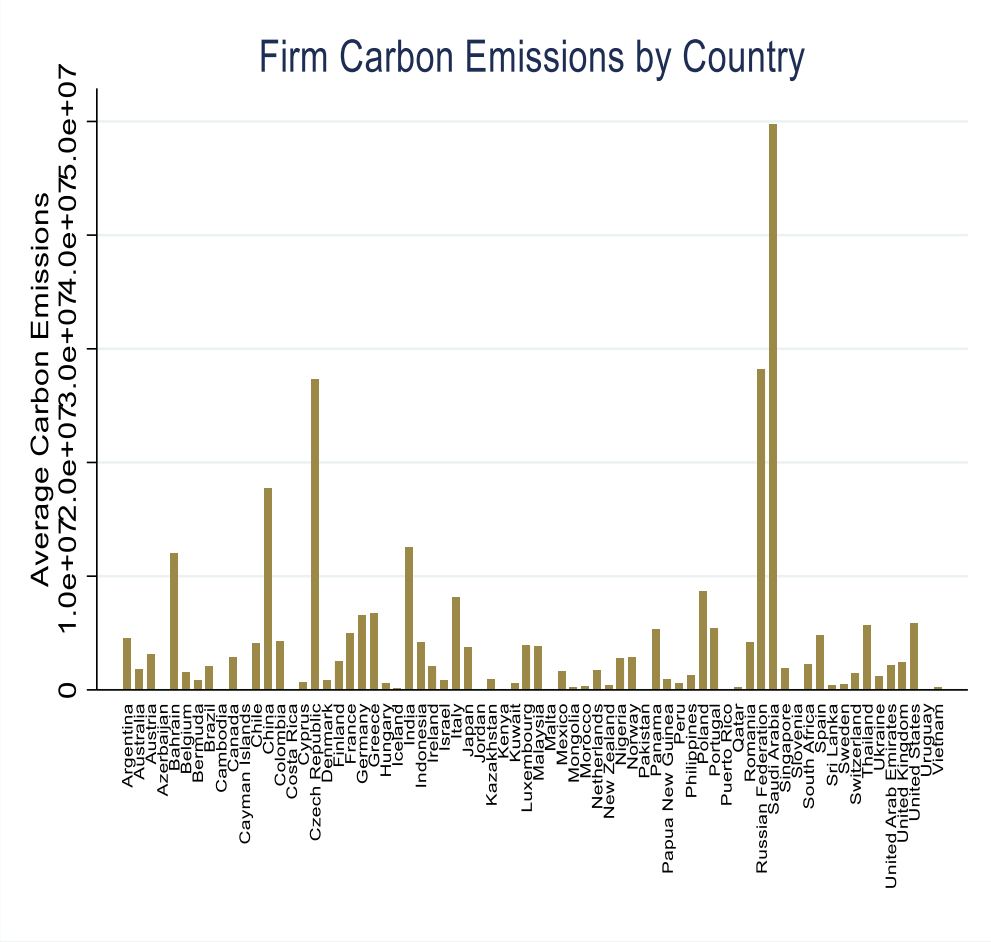
Gbenga Adamolekun: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization.

Appendix A

The Table presents the definition of the key variables used in this study.

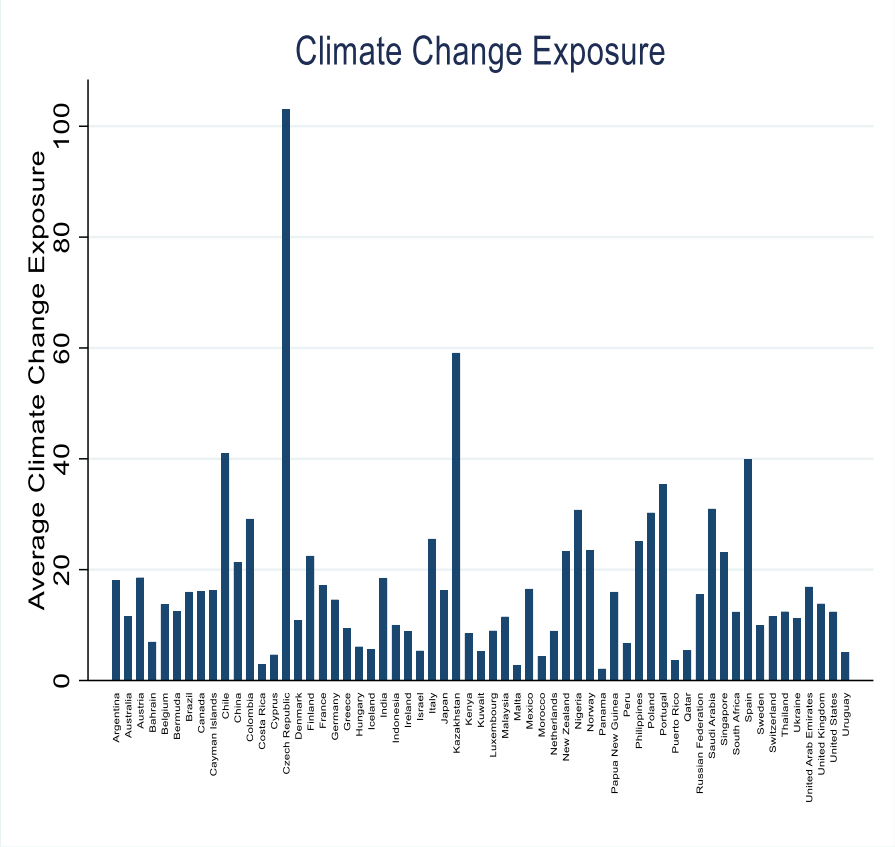
Variable	*Definition*	*Source*
Biodiversity Risk	Biodiversity risk is computed using the Bidirectional Encoder Representations from Transformers (BERT). It categorises biodiversity sentences in a firm's 10 K filing into neutral, positive, or negative.	Giglio et al. (2023)
Biodiversity Regulatory Risk	This captures biodiversity regulatory risk by identifying concerns raised in a firm's 10 k filing stemming from regulatory worries.	Giglio et al. (2023)
Bankruptcy Risk	This is defined as a firm's likelihood of bankruptcy. It is calculated using a firm's Z-score/ZM score in a year.	Worldscope
Z-Score	The Z score is computed using a firm's working capital, retained earnings, EBIT, market value, and sales. The results indicate the degree of exposure of a firm to financial distress.	Worldscope
ZM-Score	The ZM score estimates firms' financial health using a combination of variables (i.e., net income deflated by total assets, total liabilities deflated by total assets, and current assets deflated by current liabilities).	Worldscope
Climate Change Exposure	This captures the degree of exposure of a firm to climate-related vulnerabilities using bigrams from transcripts of their conference calls.	Sautner et al. (2023)
Climate Change Risk	This is a proxy for corporate exposure to climate-related vulnerabilities using bigrams from transcripts of their conference call that identify issues to do with climate-related uncertainties.	Sautner et al. (2023)
CO2 Log	This refers to the natural logarithm of a firm's scope 1 and scope 2 emissions.	LSEG
Cash Holdings	This is simply a firm's cash holdings deflated by total assets.	Worldscope
Governance Pillar Score	This captures the quality of governance in a firm, it is an index that accounts for corporate governance structures that have been identified as valuable for firms.	LSEG
RoA	This is simply earnings before interest, tax, depreciation, and amortization (EBITDA) divided by the total assets	Wordscope
Size	This is the natural log of the total assets of a firm.	Wordscope
Leverage	This is defined as the total debt of a firm deflated by the total assets	Wordscope
Market to Book	This refers to the market value of equity divided by the book value of equity.	Wordscope
R & D	This is the R&D expenses of a company deflated by total assets.	Wordscope
Dividends	This is a dummy variable that captures whether a firm pays dividends or not.	Wordscope
Tangibility	This is defined as the fixed assets of a firm divided by total assets.	Wordscope
Depreciation and Amort	This captures depreciation and amortization divided by total assets.	Wordscope

Appendix B



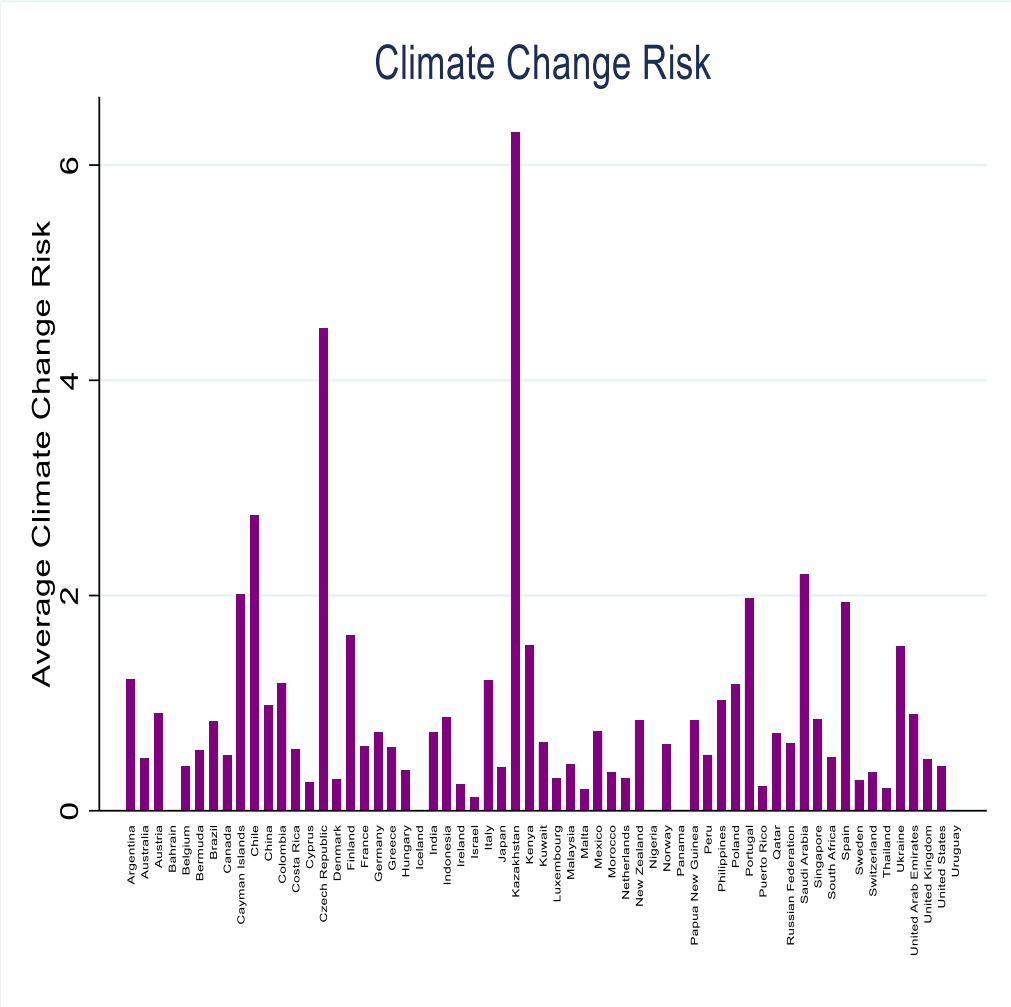
Firm Carbon Emissions Level by Country.

Appendix C



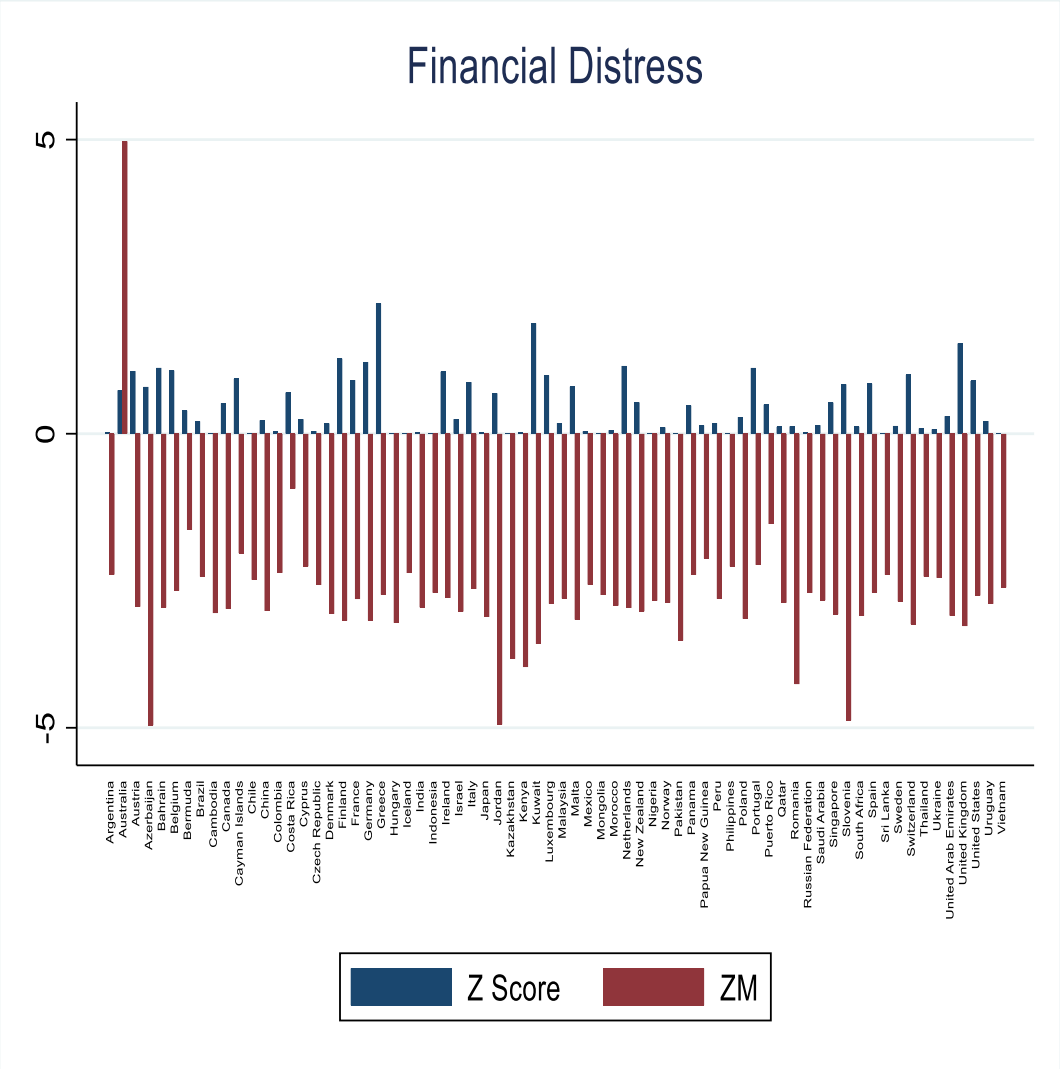
Firm Climate Change Exposure by Country.

Appendix D



Firm Climate Change Risk by Country.

Appendix E



Firm Financial Distress Level by Country.

Appendix F:. Climate Change, Financial Constraint (FC) and bankruptcy risk

This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, financial constraints and bankruptcy risk. FC refers to financial constraint. We report the T-statistics in parentheses. **, and *** imply significance at 10 %, and 5 % respectively. Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)
Biodiversity Risk	0.2446				
	(1.61)				
Biodiversity Risk#FC	0.0000				
	(1.33)				
Biodiversity Reg Risk		0.4168***			
		(2.11)			
Biodiversity Reg Risk# FC		−0.0000			
		(−0.36)			

(continued on next page)

(*continued*)

	(1)	(2)	(3)	(4)	(5)
Climate Change Exposure			0.0028***		
			(4.64)		
Climate Change Exposure # FC			0.0000***		
			(3.33)		
Climate Change Risk				0.0169**	
				(1.86)	
Climate Change Risk # FC				0.0000	
				(0.27)	
CO2 Natural Log					0.0356***
					(4.36)
CO2 Natural Log # FC					−0.0000
					(−0.04)
Financial Constraint(FC)	0.0000	0.0000	0.0000	0.0000**	−0.0000
	(1.33)	(1.32)	(1.13)	(1.95)	(−0.05)
ROA	−1.9373***	−1.9373***	−0.5537***	−0.5727***	−0.2882***
	(−7.58)	(−7.59)	(−6.68)	(−6.91)	(−2.35)
Leverage	2.0952***	2.0879***	0.6155***	0.6176***	0.6659***
	(15.67)	(15.62)	(11.37)	(11.41)	(9.00)
Market to Book	0.0260***	0.0260***	−0.0003	−0.0004	−0.0242***
	(2.09)	(2.09)	(−0.14)	(−0.19)	(−2.61)
Size	0.1306***	0.1321***	0.0540***	0.0551***	0.0102
	(7.67)	(7.75)	(7.08)	(7.23)	(0.84)
Cash Holdings	1.6582***	1.6562***	0.5318***	0.5335***	0.2175**
	(9.27)	(9.26)	(7.09)	(7.10)	(1.93)
Governance Pillar Score	−0.0033***	−0.0033***	−0.0013***	−0.0013***	−0.0006
	(−3.15)	(−3.16)	(−2.74)	(−2.69)	(−1.07)
Dividends	−0.1148***	−0.1172***	−0.0878***	−0.0901***	−0.1722***
	(−2.26)	(−2.30)	(−3.49)	(−3.56)	(−4.57)
Tangibility	0.2018**	0.1941**	−0.3108***	−0.3023***	−0.6045***
	(1.75)	(1.68)	(−6.29)	(−6.13)	(−9.63)
Depreciation and Amort	−1.8241***	−1.8216***	2.7346***	2.6878***	4.0781***
	(−4.35)	(−4.35)	(7.90)	(7.77)	(6.90)
Constant	−1.8238***	−1.8454***	0.4575	0.4398	1.0946***
	(−4.46)	(−4.51)	(1.15)	(1.10)	(3.55)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	8406	8406	35,367	35,367	26,493
Pseudo R^2	0.174	0.174	0.335	0.334	0.388

Appendix G:. Climate Change, growth Opportunities(GO) and bankruptcy risk

This Table presents the probit regression results that examine the relationship between firms' climate change vulnerabilities, growth opportunities and bankruptcy risk. GO refers to growth opportunities. We report the T-statistics in parentheses. **, and *** imply significance at 10 %, and 5 % respectively. Definitions of variables and data sources are provided in Appendix A.

	(1)	(2)	(3)	(4)	(5)
Biodiversity Risk	−0.0905				
	(−0.38)				
Biodiversity Risk#GO	6.7067				
	(1.59)				
Biodiversity Reg Risk		0.0508			
		(0.16)			
Biodiversity Reg Risk#GO		6.7135			
		(1.27)			
Climate Change Exposure			−0.0003		
			(−0.31)		
Climate Change Exposure # GO			0.0501***		
			(3.39)		
Climate Change Risk				0.0087	
				(0.79)	
Climate Change Risk # GO				0.1486	
				(0.88)	
CO2 Natural Log					0.0130
					(1.41)

(*continued on next page*)

(*continued*)

	(1)	(2)	(3)	(4)	(5)
CO2 Natural Log # GO					0.5540***
					(5.31)
Growth Opportunities(GO)	1.2108**	1.2623**	−0.4486**	−0.1321	−6.6486***
	(1.67)	(1.74)	(−1.66)	(−0.51)	(−5.35)
ROA	−2.0464***	−2.0441***	−0.6096***	−0.6109***	−0.2616***
	(−8.16)	(−8.15)	(−7.57)	(−7.60)	(−2.17)
Leverage	2.1026***	2.0985***	0.6197***	0.6212***	0.6989***
	(15.65)	(15.62)	(11.47)	(11.49)	(9.44)
Market to Book	0.0221**	0.0219**	−0.0005	−0.0005	−0.0227***
	(1.81)	(1.80)	(−0.22)	(−0.20)	(−2.58)
Size	0.1354***	0.1367***	0.0557***	0.0563***	0.0090
	(7.89)	(7.96)	(7.35)	(7.43)	(0.74)
Cash Holdings	1.6688***	1.6709***	0.5118***	0.5154***	0.2109**
	(9.29)	(9.31)	(6.88)	(6.93)	(1.88)
Governance Pillar Score	−0.0033***	−0.0033***	−0.0013***	−0.0013***	−0.0006
	(−3.20)	(−3.21)	(−2.85)	(−2.85)	(−1.09)
Dividends	−0.1362***	−0.1390***	−0.1018***	−0.1011***	−0.1799***
	(−2.92)	(−2.98)	(−4.18)	(−4.15)	(−4.96)
Tangibility	0.0185	0.0144	−0.2888***	−0.2762***	−0.5695***
	(0.12)	(0.10)	(−5.22)	(−5.00)	(−8.33)
Depreciation and Amort	−1.9706***	−1.9749***	2.7729***	2.7091***	3.9633***
	(−3.96)	(−3.94)	(7.87)	(7.70)	(6.54)
Constant	−1.8238***	−1.8454***	0.4289	0.4173	1.5449**
	(−4.46)	(−4.51)	(1.07)	(1.05)	(1.78)
Industry Effect	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes	Yes
Observations	8406	8406	35,417	35,417	26,539
Pseudo R^2	0.174	0.174	0.334	0.334	0.388

Data availability

Data will be made available on request.

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