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# Environmental innovation and climate risk awareness: The moderating role of SDG13

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ABSTRACT

Our study examines the relationship between a firm's climate risk awareness and environmental innovation, aiming to determine how climate risk influences its competitive advantage. We further highlight the importance of SDG13: Climate Action in this relationship. Based on a sample of 22,820 firm-year observations from 45 counties during 2013–2022, the results show a positive relationship between a firm's climate risk awareness and environmental innovation. Climate risk awareness accounts for a firm's engagement in product- and process-based environmental innovations. However, SDG13 is only relevant in shaping a firm's product environmental innovation in the presence of climate risk awareness. These results confirm the disciplinary effect of climate risk on firm innovation. Our findings provide regulators and other stakeholders with a better understanding of creating an enabling environment for a beneficial climate risk management process.

## 1. Introduction

Climate risk awareness has become a key focus in managing corporate sustainability initiatives after the release of IFRS S2 on climate-related disclosures in June 2023.[1,2] This trend has persisted since the inclusion of climate-related action in the Sustainable Development Goals (SDGs) of the United Nations (UN). Additionally, the potential adverse effects of climate risk for corporations and investors alike have called for its integration into the business strategies of firms (Huang et al., 2022). Huang et al. (2022) have highlighted the mitigating effect of climate risk business strategy for unfavourable loan terms. Furthermore, Huang et al. (2018) have asserted the relevance of climate risk for firm performance. In view of these developments, it has become important to understand whether a firm's climate risk awareness has implications for non-financial organisational outcomes, considering its limited focus in prior literature. This issue is particularly important to regulators and other stakeholders in framing a much more holistic agenda for climate risk management for a better future. A deeper understanding of the impact of climate risk, whether positive or negative, on corporate outcomes offers valuable insights for shaping regulatory requirements that ensure proper disclosure and effective management of climate risk.

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[1] IFRS S2 is effective on or after 1 January 2024.
[2] It reflects a firm's awareness of its vulnerability to extreme weather conditions (Krueger et al., 2020).

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We address the research gap by focusing on the potential interaction between a firm's climate risk awareness and environmental innovation, and further determine which specific type of environmental innovation is related to a firm's awareness of its climate risk exposure. Additionally, we assess the complementary role of a firm's signatory to sustainability development goal 13 (SDG13: Climate Action) in shaping its environmental innovation. The extant literature has noted the relevance of climate risk/change for financial outcomes (Ahmad et al., 2023; Akhtaruzzaman et al., 2022, 2023; Battiston et al., 2021; Garel and Petit-Romec, 2022; Ginglinger and Moreau, 2023; Siddique et al., 2021), climate regulation (Bryant et al., 2020; Kumarasiri and Gunasekarage, 2017; Seltzer et al., 2022) and sustainability performance (Banerjee et al., 2024; Boubaker et al., 2024a, 2024b; Huang and Lin, 2022; Liu et al., 2024; Mbanyele and Muchenje, 2022; Mehedi et al., 2024a, 2024b). For instance, Ahmad et al. (2023) have indicated the disciplinary effect of climate risk on working capital, noting the effective and efficient management of working capital in the presence of climate risk. Huang et al. (2018) have also reported that climate risk accounts for poor financial performance. They have asserted a negative relationship between climate risk and firm earnings. Furthermore, Huang and Lin (2022) have reported that climate risk perception is positively related to corporate social responsibility. Premised on these findings, we argue that a firm's awareness of its climate risk exposure may affect its environmental innovation decisions and that a firm's signatory to SDG13 may moderate this relationship. Firms may be incentivised to improve their environmental innovation if they are aware of their exposure to climate risk. Conversely, a firm's environmental innovation may be unrelated to its awareness of firm climate risk. Rather, it may enfold to achieve other firm benefits (e.g., better reputation). In this context, climate risk awareness may not necessarily drive environmental innovation. Thus, in our study, we seek to determine whether management's awareness of climate risk coupled with implemented policies account for firm environmental innovation and provide some empirical evidence on firm behaviour that is contingent on climate-related issues. Specifically, we provide answers to the following research questions: 1. Does a firm's climate risk awareness and its associated policies influence firm environmental innovations?; 2. If so, is a firm's climate risk awareness and its associated policies relevant in determining the type of environmental innovations it pursues?; 3. Finally, does a firm's support for SDG13 affect the relationship between a firm's climate risk awareness and its associated policies and firm environmental innovations? Our focus on environmental innovation in this study is further substantiated by its relevance to firm survival in a highly uncertain business environment. For instance, Zaman et al. (2021) asserted that environmental innovation accounted for a 17.62 % reduction in stock price crash risk for firms whose environmental innovation increased from the 25th to 75th percentile. This observation, among others, creates the need to further our understanding of the environmental innovation profile of a firm over time.

Our study contributes to the literature in several ways. First, we focus on climate risk awareness as a potential driver of environmental innovation, a non-financial organisational outcome. Although Huang and Lin (2022) and Mbanyele and Muchenje (2022) provide some insights from a sustainability performance perspective, they do not address the specific internal changes firms make due to their climate risk exposure. Second, we consider the potential impact of an external climate-related sustainability framework on managerial behaviour, which has not been examined in previous studies. Third, our paper extends the literature (Hossain and Masum, 2022; Huang and Lin, 2022; Ozkan et al., 2023) on climate risk and its relationship with sustainability-related outcomes. These studies focus on a disclosure perspective to highlight the relevance of climate risk for an organisational outcome. We extend the discussion to the domain of environmental innovation to present a competitive advantage angle to climate risk. Specifically, we provide insight into the relevance of climate risk awareness in promoting environmental innovation, highlighting how a firm's climate risk awareness shapes its innovative activities for better environmental outcomes. Additionally, we provide a better understanding of the specific type of environmental innovation that benefits from climate risk awareness among firms. In particular, our findings indicate that climate risk awareness accounts for a greater propensity for firms to engage in product and process environmental innovative activities. These findings provide a better understanding and insight into how the internal activities of firms are modified in response to their awareness of their climate risk exposure.

Finally, our findings show how climate risk awareness interacts with externally generated climate risk framework to impact the internal activities of firms in the context of environmental innovation. Specifically, while a firm's signatory to SDG13 mitigates its product environmental innovation in the presence of a firm's climate risk awareness, it does not have any implication for the overall environmental innovation and process-based environmental innovation. These findings provide a deeper understanding of the contextual nature within which the external climate risk framework is operationalised. Furthermore, the insights gained from the findings of our study provide regulators and practitioners with a better understanding of how and why climate risk affects the internal dynamics of corporate activities and processes. This fundamental knowledge will enhance the ability of regulators to formulate and develop a holistic approach to legislate climate risk-related issues. On the other hand, practitioners and other stakeholders are provided with a better insight for informed decision-making in their resource allocation process.

We use data for a sample of firms from 45 countries from 2013 to 2022. We find that firms whose management is aware of climate risk and implement climate risk-related policies are associated with better environmental innovation performance. Additionally, such firms tend to engage in product- and process-oriented environmental innovations. Our findings confirm the disciplinary effect of climate risk on firm innovation. Furthermore, firms' engagement in product environmental innovation is mitigated by their signatory to SDG13 in the presence of climate risk awareness, highlighting the non-complementary nature of the relationship between a firm's climate risk awareness and its signatory to SDG13. We employ a Two-Stage Least Squares instrumental variable (2SLS IV) approach, lead-lag analysis, and difference-in-difference (DID) analysis to address potential issues of endogeneity associated with our results. Our results remain consistent for all of these models.

The remainder of the paper is organised as follows: Section 2 discusses the literature and hypothesis development. Section 3 highlights the methodology. Section 4 presents the results, while Section 5 concludes the paper.

## 2. Literature review and hypothesis development

From a theoretical perspective, we refer to the agency and stakeholder theories in highlighting the potential link between climate risk awareness and environmental innovation (see Huang and Lin, 2022; Mbanyele and Muchenje, 2022). Premised on the arguments of Jensen and Meckling (2019), managerial actions may be predicated on either their opportunistic gains or their genuine concern for stakeholders. While their genuine concern for stakeholder interest will support actions with long-term benefits (Jensen and Meckling, 2019), opportunistic actions tend to be associated with short-term benefits that might be detrimental to firm value (Tang et al., 2024). Thus, how climate risk awareness would impact environmental innovation is dependent on managerial orientation to its decision-making process around climate risk management. Similarly, from the perspective of ethical stakeholder theory, and with a commitment to all stakeholders, management of climate risk may contribute positively to organisational outcomes (Freeman et al., 2010). On the other hand, managerial stakeholder theory may account for an adverse impact on organisational outcomes when management is only concerned with the interest of its relevant and powerful stakeholders (Freeman et al., 2010) who have a bias towards financial outcomes.

Accordingly, management's orientation towards climate risk awareness may either promote or limit its implications for organisational outcomes. Climate risk exposes a firm to physical and/or transition risk. These types of risks may adversely impact the physical assets of a firm and further increase their cost of operation due to the need to transition to a lower carbon emission rate. These outcomes create a sense of urgency for a firm with management either seeking to act opportunistically or ethically to minimise the overall climate risk exposure for efficient resource allocation and utilisation. For instance, in the presence of physical climate risk, management may be incentivised to enact innovative policies that will limit the adverse impact of climate risk for firm survival. Furthermore, the transition risk associated with climate risk creates a need for management to seek out innovative products and processes to adequately manage climate risk for better organisational outcomes (Khanra et al., 2022; D. Zhang et al., 2022). Specifically, Khanra et al. (2022) argued that as a firm becomes more aware of its climate risk exposure, it resorts to green innovation as a mechanism for attaining operational efficiency and a competitive edge. Thus, with the need to ensure the survival of a firm, climate risk awareness presents an opportunity for management to pursue environmental innovation. Additionally, Moscona and Sastry (2023) and Ren et al. (2022) have indicated an increase in green research and development in the presence of climate risk for firms.

Consequently, in a scenario where climate risk awareness is conceptualised as a genuine concern for stakeholder interest, it is likely to account for positive organisational outcomes. For instance, Krueger et al. (2020) have indicated that investors prefer a holistic management process for climate risk that is geared towards long-term value creation. Kenney et al. (2015) have likewise reported that a well-managed climate risk reflects the interest of stakeholders aimed towards the attainment of long-term environmental outcome. On the other hand, where management's orientation to climate risk is opportunistic in nature, the management of climate risk may adversely impact organisational outcomes. Thus, premised on the agency and stakeholder perspectives, management's climate risk awareness may lead to either positive or negative organisational outcomes.

Some studies (Kumarasiri and Gunasekarage, 2017; Mbanyele and Muchenje, 2022) have noted the positive effect of climate risk. For instance, Kumarasiri and Gunasekarage (2017) has indicated that climate risk exposure accounts for a proactive mindset among managers to avoid adverse regulatory changes. Additionally, Climate risk exposure has been noted to account for an improvement in CSR standards of firms (Mbanyele and Muchenje, 2022). Nonetheless, Huang et al. (2022) and Huang et al. (2018) have indicated the negative effects of climate risk for corporations. Both studies have asserted a negative relationship between climate risk and financial performance and financing needs. Similarly, Agoraki et al. (2024) argued that firms with high exposure to climate risk face a higher cost of capital and reduced investment activity. Berkman et al. (2024) also suggested that a US news-based measure of climate change concerns is negatively associated with the long-term returns on hedge portfolios. The mixed results from previous empirical analysis seem to reflect management's mindset towards its climate risk exposure and the policies enacted to manage it.

Predicated on the theoretical and empirical assertions discussed above, we expect a firm's climate risk awareness to be related to its environmental innovation and thus, argue for a relationship between a firm's climate risk awareness and environmental innovation. We propose our first hypothesis as follows:

$H_1$: Awareness of firm climate risk and its associated policy are related to firm environmental innovations.

Furthermore, we consider the type of environmental innovation which is related to firm climate risk. Fritsch and Meschede (2001) have suggested that a firm's innovative approach may be product-centred and/or process-centred. They further argued that firms tend to show different levels of commitment to product and process innovation based on their level of operation (Fritsch and Meschede, 2001). Premised on these assertions, we argue that a firm's climate risk awareness may impact its product and process environmental innovations either differently or equally. For firms whose climate risk exposure is likely to have greater implications for product demand, a firm's climate risk awareness and its associated policies will be geared towards product viability for sustainable growth. This notion is consistent with the submissions of Kumarasiri and Gunasekarage (2017) for the management of a firm's climate risk exposure. Conversely, where climate risk exposure is likely to have greater implications for the processes and procedures of firms, process environmental innovation will be the focus of a firm's climate risk awareness and its associated policies. However, both product and process environmental innovations are likely to be addressed equally if a firm's climate risk has implications for its products and procedures concurrently. In line with these arguments, we expect a firm's climate risk awareness and its associated policies to be related to product and process environmental innovations. We formulate our second and third hypotheses as follows:

$H_2$: A firm's climate risk awareness and its associated policy have an association with product environmental innovations

$H_3$: A firm's climate risk awareness and its associated policy have an association with process environmental innovations

Additionally, we consider the implication of a firm's signatory to SDG13 in its management of firm climate risk. SDG13 is a climate action sustainable development goal of the UN which emphasises the need for firms to urgently take actions that will manage climate change and mitigate its impact (The United Nations, 2023).[3] We focus on SDG13 for several reasons. Firstly, since its inception in 2015, nearly 70 % of firms have adopted SDGs and referenced them in their reporting process (PricewaterhouseCoopers, 2019). Secondly, SDGs have been tagged as an essential element of the 2030 global agenda for sustainable development. These observations highlight the prominence of SDGs in the sustainability debate as well as their importance in the business community relative to other climate-related guidance. As the SDG13 framework provides guidance for firms regarding their climate change targets, it is likely to complement their climate risk awareness and associated policies to enhance their capabilities to achieve positive organisational outcomes. However, if a firm's signatory to SDG13 is performative in nature, it may weaken the potential relationship between a firm's climate risk awareness and environmental innovation. We thus formulate our hypotheses as follows:

$H_{4a}$: The relationship between a firm's climate risk awareness and its associated policy and environmental innovation is likely to be stronger or weaker in the presence of SDG13.

$H_{4b}$: The relationship between a firm's climate risk awareness and its associated policy and product environmental innovation is likely to be stronger or weaker in the presence of SDG13.

$H_{4c}$: The relationship between a firm's climate risk awareness and its associated policy and process environmental innovation is likely to be stronger or weaker in the presence of SDG13.

## 3. Research method

### 3.1. Sample selection

We employ the Refinitiv ESG Active Universe list as our sample frame. We make use of the Refinitiv ESG Active Universe list to ensure that our sample consists of global firms which have meaningfully engaged in environmental, social and governance-related activities. This ensures that our sample appropriately reflects relevant firms from a diverse geographical context for a meaningful generalisation of our findings. However, the use of the Refinitiv ESG Active Universe list limits our sample to the use of large firms, which has the potential to adversely affect our ability to generalise our findings to the context of small firms. We focus on a sample period from 2013 to 2022 as the UN SDGs were established in 2012. The initial sample is made up of 9960 firms with 99,600 firm-year observations. We exclude 1930 financial firms as well as 4152 firms with missing data which are associated with a total of 60,820 firm-year observations. Finally, we delete 15,960 firm-year observations with missing data. Our final sample has 3878 firms with firm-year observations of 22,820.

The data used in our study is primarily sourced from the Refinitiv Eikon Database except for data on Gross Domestic Products (GDP), which is sourced from the World Bank database. Specifically, ESG-related data are obtained from the Refinitiv ESG database, while governance and accounting fundamental variables are obtained from Worldscope.

Table 1 describes the sample selection process and highlights the sample distribution by industry and country. In terms of industry distribution, 24.59 % of the firm-year observations belong to business equipment while 18.46 % of the firm-year observations belong to manufacturing. Telephone and Television Transmission is the industry sector with the least firm-year observation of 1.43 %. Furthermore, our sample is dominated by firms from the United States (US) with 7690 firm-year observations followed by China with 3288 firm-year observations.

### 3.2. Dependent variables

We use environmental innovation score (hereafter EIS) as the measure of firm environmental innovation performance. EIS captures a firm's ability to employ new environmental technologies and processes or eco-designed products. EIS ranges between a minimum score of 0 and a maximum score of 100. Additionally, we use the type of environmental innovation as another dependent variable for our study. This is represented by product environmental innovation (hereafter PRDEIS) and process environmental innovation (hereafter PRCEIS). A dummy variable is assigned a value of 1 for PRDEIS, indicating the presence of product features, applications, or services that promote responsible, efficient, cost-effective, and environmentally preferable use; otherwise, it is assigned a value of 0. A dummy variable is set to 1 for PRCEIS, indicating the presence of take-back procedures and recycling programs designed to reduce the potential risks of products entering the environment; otherwise, it is set to 0.

### 3.3. Explanatory variable

The explanatory variable of interest in our study is climate risk awareness (hereafter CLIR). CLIR measures a company's awareness of climate change and its implementation of policies to manage associated risks and opportunities. If the company reports on its climate risk awareness and associated policies, CLIR is captured as a dummy of 1 or otherwise coded as 0. Table 2 presents the definition of variables.

[3] https://sdgs.un.org/goals/goal13

**Table 1**
Sample selection process and distribution by industry.

| **Panel A: Sample selection process** | | | |
|---|---|---|---|
| **Sample Selection Process** | **No. of firms** | **Firm-year observations** | |
| Initial sample of ESG Active Universe list | 9960.00 | 99,600.00 | |
| Excluded list of financial institutions | 1930.00 | 19,300.00 | |
| Excluded list of firms with missing data | 4152.00 | 41,520.00 | |
| Excluded firm-years observations with missing data | | 15,960.00 | |
| **Final sample** | **3878.00** | **22,820.00** | |
| **Panel B: Sample distribution by industry** | | | |
| Industry classification | Frequency | Percentage | |
| Consumer Nondurables | 1615.00 | 7.08 | |
| Consumer Durables | 1371.00 | 6.01 | |
| Manufacturing | 4212.00 | 18.46 | |
| Oil, Gas, and Coal Extraction and Production | 665.00 | 2.91 | |
| Chemicals and Allied Products | 1539.00 | 6.74 | |
| Business Equipment | 5612.00 | 24.59 | |
| Telephone and Television Transmission | 327.00 | 1.43 | |
| Utilities | 556.00 | 2.44 | |
| Wholesale, Retail, and Some Services | 703.00 | 3.08 | |
| Healthcare, Medical Equipment, and Drug | 3135.00 | 13.74 | |
| Other | 3085.00 | 13.52 | |
| | **22,800.00** | **100.00** | |
| **Panel C: Sample distribution by country** | | | |
| **Country** | **Frequency** | **Country** | **Frequency** |
| Argentina | 7.00 | Luxembourg | 49.00 |
| Australia | 496.00 | Malaysia | 93.00 |
| Austria | 128.00 | Mexico | 15.00 |
| Belgium | 127.00 | Netherlands | 135.00 |
| Bermuda | 19.00 | New Zealand | 61.00 |
| Brazil | 148.00 | Norway | 107.00 |
| Canada | 380.00 | Peru | 15.00 |
| Chile | 19.00 | Philippines | 38.00 |
| China | 3288.00 | Poland | 21.00 |
| Colombia | 10.00 | Portugal | 4.00 |
| Denmark | 161.00 | Russian Federation | 29.00 |
| Finland | 246.00 | Saudi Arabia | 42.00 |
| France | 440.00 | Singapore | 70.00 |
| Germany | 822.00 | South Africa | 154.00 |
| Greece | 24.00 | Spain | 93.00 |
| Hong Kong | 285.00 | Sweden | 203.00 |
| India | 648.00 | Switzerland | 535.00 |
| Indonesia | 45.00 | Taiwan | 923.00 |
| Ireland | 200.00 | Thailand | 16.00 |
| Israel | 137.00 | Turkey | 196.00 |
| Italy | 29.00 | United Kingdom | 1021.00 |
| Japan | 2823.00 | United States | 7690.00 |
| Korea (South) | 828.00 | | |

It presents sample selection process and sample distribution by industry. The ESG Active Universe List is used sample frame for the study. Fama-French 12 industry classification is applied for the sample industry and country distributions.

### *3.4. Model specification*

We estimate an OLS panel regression to test the hypotheses formulated for our study. Pertaining to $H_1$, $H_2$ and $H_3$, we use the following specified model to test for the potential relationship between CLIR and EIS as well as PRDEIS and PRCEIS.

$$EI_{i,t} = a_0 + a_1 CLIR_{i,t} + \Sigma a_{1+k} Controls_{i,t} + Industry, year, country\ fixed\ effects + \varepsilon_{i,t} \quad (1)$$

where $EI_{i,t}$ represents *EIS*, *PRDEIS* or *PRCEIS* for firm *i* at time *t,* and *CLIR* is as defined previously for firm *i* at time *t*. Based on $H_1$, $H_2$, and $H_3$, we expect $a_1$ to be significant. $Controls_{i,t}$ refer to the control variables for our study. Consistent with prior studies (Brunnermeier and Cohen, 2003; Ghisetti and Pontoni, 2015; Horbach, 2008), we include control variables for corporate governance and firm characteristics. We control for the effectiveness of corporate governance (GOV), firm size (FSIZE), firm age (FAGE), leverage (LEV), liquidity (LIQ), research and development (RAD), workforce quality (WRKF) and gross domestic product (GDP).

To test $H_{4a}$, $H_{4b}$, and $H_{4c}$, we include SDG13 and an interaction term (CLIR×SDG13) in the first equation. The expanded equation is stated as follows:

$$EI_{i,t} = a_0 + a_1 CLIR_{i,t} + a_2 SDG13_{i,t} + a_3 CLIR_{i,t} \times SDG13_{i,t} + \Sigma a_{3+k} Controls_{i,t} + Industry, year, country\ fixed\ effects + \varepsilon_{i,t} \quad (2)$$

**Table 2**
Definition of variables.

| Variables | Definition (Data is sourced from Refinitiv Eikon unless otherwise stated) |
|---|---|
| Dependent variables | |
| EIS | Environmental innovation category score which reflects a company's capacity to reduce the environmental costs and burdens for its customers, and thereby creating new market opportunities through new environmental technologies and processes or eco-designed products. |
| PRDEIS | A dummy variable of 1 for product environmental innovation which is indicative of the presence of product features and applications or services that will promote responsible, efficient, cost-effective, and environmentally preferable use or otherwise 0. |
| PRCEIS | A dummy variable of 1 for process environmental innovation which is indicative of the presence of take-back procedures and recycling programmes meant for a reduction in the potential risks of products entering the environment or otherwise 0. |
| Test variables | |
| CLIR | This is measure which reflects a firm's awareness of the fact that climate change can represent commercial risks and/or opportunities and implement policies for its appropriate management. |
| CLIRˆ | Fitted values for CLIR estimated using the first stage model specified by the 2SLS IV approach. |
| CLIR×SDG13 | The product of CLIR and SDG13 which is an interaction term. |
| Control variables | |
| SDG13 | A dummy variable of 1 for firms that support the UN Sustainable Development Goal 13 (SDG 13) Climate Action. |
| FSIZE | This is represented by the natural logarithm of total assets of a firm. |
| FAGE | This is represented by the natural logarithm of 1 plus the number of years of incorporation for a firm. |
| LEV | This is represented by the ratio of long-term debt to common equity of a firm. |
| LIQ | This represented by the ratio of cash and cash equivalent to total current liability of a firm. |
| RAD | This variable is measured as the ratio of research and development to total assets of a firm. |
| GOV | The score for the effectiveness of corporate governance processes of a firm. |
| WRKF | The score for a firm's workforce quality. |
| LGDP | This variable represents the natural logarithm of a country's gross domestic product. |
| Variables used for endogeneity tests | |
| TREAT | A dummy variable 1 for firms that switched from non-CLIR to CLIR firm for the sample period of the study, otherwise 0. |
| POST | A dummy variable of 1 for periods after the inception of COVID–19, otherwise 0 |

where *SDG13* is a dummy variable for firms that have signed on to the UN SDGs and specifically support SDG13, and *CLIR*×*SDG13* is the product of *CLIR* and *SDG13*. All the remaining components of the model are defined as previously stated. We expect $a_3$ to be significant for H4a, H4b, and H4c.

## 4. Regression results

### 4.1. Summary statistics

Table 3 reports the summary statistics of the variables used in the specified model for analysis. For EIS, an average score of 28.47 was recorded, which is indicative of the low level of environmental innovation among the firms included in the sample. However, the higher standard deviation value of 32.04 shows that the firms differ significantly in their individual capabilities in their environmental innovation performance. In the context of the type of environmental innovation pursued by firms, while 51.8 % of firm-year observations indicate firms' engagement in product environmental innovations, and 56.6 % were involved in process environmental innovations. Premised on the crosstabulation analysis under Panel B, it can be said most of the firms tend to engage in both product and process environmental innovations. Regarding *CLIR*, only 41.4 % of the firms in our sample indicated their awareness of climate risk with associated policies for its appropriate management, and furthermore, 33.7 % of the firms have adopted SDG13 in their climate risk management framework. Our sample is constituted of relatively large firms with a high level of liquidity for the sample period of analysis. However, RAD is relatively low (5.8 % of total assets) among the firms in our sample. GOV and WRKF recorded average values of 49.19 and 53.78, respectively.

From Table 4, we employ a correlation matrix as a bivariate analysis to highlight the initial relation between CLIR and EIS, PRDEIS and PRCEIS, respectively. We record correlation coefficients of 0.41 (CLIR and EIS), 0.39 (CLIR and PRDEIS), and 0.36 (CLIR and PRCEIS) which are statistically significant at 1 % level. We further explore the possibility of multicollinearity issues impacting our model using the variance inflation factor (VIF). We record a mean VIF value of 1.09, which is below the threshold of 10, above which an issue of multicollinearity would be deemed to be present.

### 4.2. Multivariate analysis for $H_1$, $H_2$, and $H_3$

The regression results for $H_1$, $H_2$, and $H_3$ are presented in Table 5. Under column 1, the result for $H_1$ indicates a positive and significant relationship between a firm's climate risk awareness and environmental innovation score. With a regression coefficient of 10.898, firms' climate risk awareness and its associated policy account for a 10.898 increase in their environmental innovation score. This is indicative of a better performance for environmental innovation for firms that are aware of their climate risk and establish policies for its management compared to firms that are not aware of their climate risk exposure and do not establish any policy for its management. This observation is consistent with the findings of Khanra et al. (2022) and Zhang et al. (2022) who posit a positive relationship between climate risk and green research and development. However, our findings contradict the observations of Huang et al. (2022) who noted a negative effect of climate risk on cost of capital. This inconsistency in findings is premised on the difference in

**Table 3**
Summary statistics.

| Panel A: Variables used in regression models specified in our study | | | | | | |
|---|---|---|---|---|---|---|
| **Variables** | **N** | **Mean** | **Std Dev.** | **p25** | **Median** | **p75** |
| EIS | 22,820 | 28.457 | 32.037 | 0.000 | 17.060 | 52.560 |
| PRDEIS | 22,820 | 0.518 | 0.500 | 0.000 | 1.000 | 1.000 |
| PRCEIS | 12,494 | 0.566 | 0.496 | 0.000 | 1.000 | 1.000 |
| SDG13 | 13,090 | 0.337 | 0.473 | 0.000 | 0.000 | 1.000 |
| CLIR | 22,820 | 0.414 | 0.493 | 0.000 | 0.000 | 1.000 |
| FSIZE | 22,820 | 14.854 | 1.863 | 13.661 | 14.908 | 16.062 |
| FAGE | 22,820 | 3.304 | 0.864 | 2.833 | 3.258 | 3.970 |
| LEV | 22,820 | 58.764 | 112.690 | 2.150 | 25.950 | 65.165 |
| LIQ | 22,820 | 42.540 | 26.064 | 21.540 | 37.155 | 60.400 |
| RAD | 22,820 | 0.058 | 0.101 | 0.006 | 0.022 | 0.062 |
| GOV | 22,820 | 49.181 | 22.453 | 31.100 | 49.030 | 67.500 |
| WRKF | 22,820 | 53.789 | 29.038 | 28.930 | 55.660 | 79.500 |
| LGDP | 22,820 | 29.242 | 1.415 | 28.369 | 28.989 | 30.600 |

| Panel B: Crosstab analysis for types of environmental innovations | | | | |
|---|---|---|---|---|
| | | PRCEIS | | Total |
| | | 0 | 1 | |
| PRDEIS | 0 | 6114.00 | 376.00 | 6490.00 |
| | 1 | 4.00 | 7859.00 | 7863.00 |
| **Total** | | **6118.00** | **8235.00** | **14,353.00** |

It presents the descriptive statistics of the variables used in the regression models. Additionally, the table highlights interactions between product environmental innovations and process environmental innovations of firms in the sample. Except for indicator variables, all the continuous variables at winsorised at 1 % and 99 %. Table 1 presents the definitions for the variables used in the study.

the conceptualisation of climate risk in the respective analysis of our study relative to that of Huang et al. (2022). In terms of economic significance, a one standard deviation increase in a firm's climate risk awareness (i.e., an increase in CLIR of 0.493) is expected to lead to a 0.168 standard deviation increase in the environmental innovation score (EIS), resulting in an EIS increase of 5.37 (0.168[4] * 32.037). This implies an economic significance for the relationship between a firm's climate risk awareness and environmental innovation. This outcome suggests that environmental innovation presents an opportunity for firms to safeguard the economic well-being of their operations from a climate risk perspective. Moreover, Andries and Stephan (2019) and Rennings and Rammer (2011) confirm the economic significance of environmental innovation for a firm financial performance from a stakeholder and resource-based perspective of a firm. Thus, environmentally innovative firms tend to be associated with higher financial performance as indicated in prior studies which is consistent with the economic significance of our findings.

In determining whether firms in our sample have a preference for a particular type of environmental innovation, column 2 shows the results for the likelihood of a firm to undertake product-based environmental innovations premised on a firm's climate risk awareness. The result for $H_2$ indicates that a firm's climate risk awareness accounts for a firm engagement in product environmental innovation. We record a logit regression coefficient of 0.853, which suggests that the logit odds of being in favour of pursuing product environmental innovation increase by 0.853 when firms are aware of their climate risk and establish policies for their management. Furthermore, a firm's climate risk awareness accounts for 1.95 times of PRDEIS engagement for firms that are aware of their climate risk relative to those firms which are not aware of their exposure to climate risk.[5] For a marginal effect, a switch non-CLIR firm to CLIR firm accounts for a 9.05 % increase in the probability for a firm to engage in PRDEIS.

Moreover, a firm's climate risk awareness accounts for a higher propensity to engage in PRCEIS for firms that are aware of their associated climate risk exposure relative to firms that are not aware of their climate risk exposure. Specifically, we record a logit

[4] (10.898 *(0.493/32.037) = 0.168 is computed from Standardised regression co-efficient of *CLIR*= Regression co-efficient of *CLIR** (Standard Deviation of *CLIR*/Standard Deviation of EIS).

[5] The estimated odd ratio for the specified logistic regression model used in our study.

**Table 4**
Correlation matrix.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) EIS | 1.00 | | | | | | | | | | | | |
| (2) PRDEIS | **0.82** | 1.00 | | | | | | | | | | | |
| (3) PRCEIS | **0.79** | **0.95** | 1.00 | | | | | | | | | | |
| (4) SDG13 | **0.40** | **0.38** | **0.33** | 1.00 | | | | | | | | | |
| (5) CLIR | **0.41** | **0.39** | **0.36** | **0.49** | 1.00 | | | | | | | | |
| (6) FSIZE | **0.45** | **0.43** | **0.40** | **0.40** | **0.42** | 1.00 | | | | | | | |
| (7) FAGE | **0.32** | **0.30** | **0.27** | **0.26** | **0.23** | **0.34** | 1.00 | | | | | | |
| (8) LEV | **0.08** | **0.08** | **0.06** | **0.07** | **0.10** | **0.20** | **−0.00** | 1.00 | | | | | |
| (9) LIQ | **−0.33** | **−037** | **−0.29** | **−0.25** | **−0.24** | **−0.34** | **−0.35** | **−0.12** | 1.00 | | | | |
| (10) RAD | **−0.25** | **−0.29** | **−0.19** | **−0.24** | **−0.22** | **−0.51** | **−0.30** | **−0.06** | **0.48** | 1.00 | | | |
| (11) GOV | **0.28** | **0.27** | **0.26** | **0.29** | **0.35** | **0.35** | **0.19** | **0.05** | **−0.20** | **−0.18** | 1.00 | | |
| (12) WRKF | **0.36** | **0.32** | **0.36** | **0.47** | **0.48** | **0.45** | **0.20** | **0.04** | **−0.16** | **−0.13** | **0.39** | 1.00 | |
| (13) LGDP | **−0.21** | **−0.21** | **−0.17** | **−0.32** | **−0.21** | **−0.10** | **−0.25** | **0.04** | **0.21** | **0.20** | **−0.11** | **−0.27** | 1.00 |

The values in bold are significant at 1 %.

**Table 5**
Main analysis.

| | (1) | (2) | (3) |
|---|---|---|---|
| | **EIS** | **PRDEIS** | **PRCEIS** |
| CLIR | 10.898 * ** | 0.853 * ** | 0.846 * ** |
| | (23.303) | (18.580) | (12.840) |
| FSIZE | 3.437 * ** | 0.316 * ** | 0.444 * ** |
| | (24.875) | (20.210) | (19.890) |
| FAGE | 2.754 * ** | 0.245 * ** | 0.291 * ** |
| | (11.416) | (9.490) | (8.270) |
| LEV | −0.001 | 0.000 | −0.000 |
| | (−0.322) | (0.220) | (−0.370) |
| LIQ | −0.111 * ** | −0.017 * ** | −0.017 * ** |
| | (−13.835) | (−18.340) | (−13.570) |
| RAD | 12.466 * ** | −0.622 | 2.300 * ** |
| | (8.531) | (−1.900) | (5.090) |
| GOV | 0.080 * ** | 0.009 * ** | 0.010 * ** |
| | (9.450) | (10.340) | (8.290) |
| WRKF | 0.129 * ** | 0.011 * ** | 0.010 * ** |
| | (17.282) | (13.500) | (8.340) |
| LGDP | −0.400 | −0.062 * * | 0.007 |
| | (−1.573) | (−2.290) | (0.180) |
| Constant | −77.404 * ** | −5.715 * ** | −10.358 * ** |
| | (−10.545) | (−6.700) | (−8.700) |
| Observations | 22,820 | 22,760 | 12,444 |
| Adj $R^2$ | 0.398 | | |
| Pseudo $R^2$ | | 0.384 | 0.403 |
| F-stat | 356.02 | | |
| Wald $chi^2$ | | 6177.68 | 3528.40 |
| Fixed effect: | | | |
| Year Dummies | Yes | Yes | Yes |
| Industry Dummies | Yes | Yes | Yes |
| Country Dummies | Yes | Yes | Yes |

t-values are in parentheses for column 1 and z-values are in parentheses for columns 2 and 3 * ** p < .01, * * p < .05, * p < .1

regression coefficient of 0.846, which is statistically significant at 1 % level. This implies that a firm's climate risk awareness accounts for a 0.846 increase in the likelihood of a firm's engagement in PRCEIS. Using the odd ratio, climate risk awareness results in 1.85 times of PRCEIS engagement for the firm's climate risk awareness. For marginal effect, a switch from a non-CLIR firm to a CLIR firm accounts for an 8.03 % increase in the probability of a firm engaging in PRCEIS.

Overall, a firm's climate risk awareness enhances the environmental innovation performance of firms in our sample and further promotes product and process environmental innovations, respectively. Our findings confirm the disciplinary effect of climate risk and further align with the ethical stakeholder theory perspective to managerial decision-making. Additionally, a genuine concern for stakeholder interests under agency theory provides further theoretical explanation for the findings of our study.

With respect to the control variables used in our study, both FSIZE and FAGE are positively and significantly related to EIS, PRDEIS, and PRCEIS, which confirms the positive benefits of economies of scale and learning curves for environmental innovation. RAD, GOV and WRKF have a positive and statistically significant relationship with EIS, PRDEIS and PRCEIS, respectively. These findings are consistent with both the theoretical and empirical narratives on RAD, GOV, and WRKF. On the other hand, LIQ is negatively associated with EIS, PRDEIS, and PRCEIS. This observation is consistent with the findings of Fang et al. (2014) regarding stock liquidity and firm innovation. Lastly, all of our models are statistically significant, with minimum Pseudo $R^2$ of 38.4 %.

### *4.3. Additional tests*

In spite of the inclusion of fixed effects in our specified models, our results may still be impacted by endogeneity issues. In view of this, we employ other specification approaches to address potential endogeneity issues. These include the Two-stage IV approach (2SLS IV), the lead-lag model, and the Difference-in-Difference (DID) approach.

We use 2SLS IV to address the potential issues of omitted variables and simultaneity. We determine an Instrument Variable (IV) which is correlated with a firm's climate risk awareness but not related to environmental innovation, product environmental innovation, and process environmental innovation. However, it will likely affect environmental, product, and process environmental innovation through a firm's climate risk awareness. We utilise COVID–19 (IV) as our exogenous variable, and the reason is that it is likely to be related to CLIR, as the pandemic had implications for the overall risk faced by firms. COVID–19 (IV) is operationalised as a dummy variable of 1 for the pandemic period (after 2019) or 0 for the pre-pandemic period. We subsequently implement our 2SLS IV approach by specifying the following model for our first-stage analysis:

$$\Pr(CLIR)_{i,t} = \beta_0 + \beta_1 IV_{i,t} + \Sigma\beta_{1+k} Controls_{i,t} + Industry, year, country\ fixed\ effects + \varepsilon_{i,t} \tag{3}$$

All the variables included in Eq. 3 are defined as previously discussed. Table 6 presents the results of our 2SLS IV approach. From column 1, the IV has a significant relationship with CLIR which is consistent with our expectation.

For the second stage model, we use the predicted values estimated from the first stage model to represent our explanatory variable of interest (CLIRˆ) and re-estimate Eq. 1 using CLIRˆ. From columns 2–4, CLIRˆ has a positive and statistically significant relationship with EIS, PRDEIS, and PRCEIS, respectively. Overall, the findings of the 2SLS IV approach are consistent with our main analysis, implying that our main findings might not be susceptible to issues of omitted variables and simultaneity.

Additionally, we employ a lead-lag model to determine the causal relationship between CLIR and EIS, PRDEIS, and PRCEIS, respectively. We re-run Eq. 1 using $CLIR_{t-1}$ in place of CLIR. Our results are presented in Table 7 under columns 1–3. $CLIR_{t-1}$ is positively and significantly related to EIS, PRDEIS, and PRCEIS. This implies that climate risk awareness in previous period (*t-1*) accounts for a better environmental innovation performance in the current period (*t*). These results are also consistent with our main findings.

Moreover, we further employ a quasi-experimental approach to explore the nature of the causal relationship between CLIR and EIS, PRDEIS, and PRCEIS, respectively. We make use of a DID approach to achieve this goal. In this regard, we determine whether a firm that switches from non-CLIR to CLIR firm is associated with greater change in environmental innovation after the inception of COVID–19 that must be statistically significant. We identify our treatment firm-year observations based on firms that switched from non-CLIR firms to CLIR firms after the inception of the COVID–19 pandemic, with control firm-year observations that are based on firms that remained non-CLIR for the entire sample period of our study. We operationalise our treatment and control firm-year observations as a dummy variable of 1 and 0, respectively and reference the dummy variable as TREAT for the purpose of our DID analysis. We then determine our POST variable as a dummy variable of 1 for the period after the inception of COVID–19 or 0 otherwise. We then create an interaction term for the TREAT and POST variables (TREAT×POST), which becomes the explanatory variable of interest in our DID analysis. We expect the coefficients of TREAT×POST to be positive and statistically significant to confirm our previous arguments.

To derive our matched sample for the DID approach, we further implement a propensity score matching (PSM) approach with the nearest-in-neighbour technique. We use a caliper of 0.00001 to obtain a sample of treatment and control firm-year observations that are statistically similar in terms of the control variables used in our specified model. Our PSM approach generates a sample size of 1024 for the treatment and control samples. We determine the validity of our PSM approach using a *t*-test to determine differences in the mean for the firm characteristics of the treatment and control samples. Panel A of Table 8 shows the results of the *t*-test for differences

**Table 6**
Two-stage IV approach.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | **Pr(CLIR)** | **EIS** | **PRDEIS** | **PRCEIS** |
| IV | 0.485 * ** | | | |
| | (7.680) | | | |
| CLIRˆ | | 15.846 * ** | 2.178 * ** | 2.407 * ** |
| | | (16.240) | (19.620) | (14.650) |
| FSIZE | 0.251 * ** | 0.183 | −0.164 | −0.088 * |
| | (24.050) | (0.630) | (−5.090) | (−1.93) |
| FAGE | −0.055 * ** | 3.185 * ** | 0.290 | 0.309 * ** |
| | (−3.22) | (12.130) | (10.250) | (8.140) |
| LEV | −0.000 | 0.000 | 0.000 | 0.000 * |
| | (−1.230) | (0.310) | (1.100) | (1.800) |
| LIQ | −0.002 * ** | −0.060 * ** | −0.009 * ** | −0.007 * ** |
| | (−3.540) | (−6.210) | (−8.010) | (−4.290) |
| RAD | −0.946 * ** | 29.399 * ** | 2.092 * ** | 5.320 * ** |
| | (−4.140) | (15.570) | (5.660) | (10.020) |
| GOV | 0.008 * ** | −0.029 * * | −0.007 * ** | −0.007 * ** |
| | (13.130) | (−2.350) | (−5.120) | (−3.820) |
| WRKF | 0.014 * ** | −0.036 * * | −0.013 * ** | −0.018 * ** |
| | (25.330) | (−2.320) | (−7.860) | (−7.260) |
| LGDP | −0.036 * | 0.005 | 0.015 | 0.079 * |
| | (−1.720) | (0.100) | (0.570) | (1.770) |
| Constant | −2.218 * ** | −6.046 | −1.607 * | −4.446 * ** |
| | (−3.330) | (−0.700) | (−1.720) | (−3.240) |
| Observations | 19,541 | 19,488 | 19,459 | 10,646 |
| Adj $R^2$ | | 0.390 | | |
| Pseudo $R^2$ | 0.383 | | 0.392 | 0.409 |
| F-stat | | 308.36 | | |
| Wald $chi^2$ | 5584.98 | | 5266.65 | 3028.85 |
| Fixed effects: | | | | |
| Year Dummies | Yes | Yes | Yes | Yes |
| Industry Dummies | Yes | Yes | Yes | Yes |
| Country Dummies | Yes | Yes | Yes | Yes |

t-values are in parentheses for column 2 except for columns 1, 3, and 4 with z-values in parentheses.
* ** p < .01, * * p < .05, * p < .1

**Table 7**
Lead-lag analysis.

| | (1) | (2) | (3) |
|---|---|---|---|
| | EIS | PRDEIS | PRCEIS |
| $CLIR_{t-1}$ | 10.859 * ** | 0.829 * ** | 0.796 * ** |
| | (21.258) | (16.800) | (10.990) |
| $FSIZE_{t-1}$ | 3.472 * ** | 0.318 * ** | 0.455 * ** |
| | (22.909) | (18.950) | (18.530) |
| $FAGE_{t-1}$ | 2.521 * ** | 0.219 * ** | 0.257 * ** |
| | (9.821) | (8.180) | (7.010) |
| $LEV_{t-1}$ | −0.000 | 0.000 | −0.000 |
| | (−0.112) | (0.220) | (−0.390) |
| $LIQ_{t-1}$ | −0.122 * ** | −0.017 * ** | −0.0159 * ** |
| | (−13.787) | (−17.450) | (−11.760) |
| $RAD_{t-1}$ | 12.608 * ** | 0.468 | 2.332 * ** |
| | (7.536) | (−1.360) | (4.810) |
| $GOV_{t-1}$ | 0.074 * ** | 0.008 * ** | 0.010 * ** |
| | (8.022) | (8.650) | (7.150) |
| $WRKF_{t-1}$ | 0.126 * ** | 0.010 * ** | 0.008 * ** |
| | (15.344) | (11.590) | (6.860) |
| $LGDP_{t-1}$ | −0.677 * * | −0.096 * ** | −0.006 |
| | (−2.411) | (−3.350) | (−0.130) |
| Constant | −69.528 * ** | −4.467 * ** | −9.834 * ** |
| | (−8.617) | (−4.890) | (−7.710) |
| Observations | 20,168 | 20,122 | 11,053 |
| Adj $R^2$ | 0.390 | | |
| Pseudo $R^2$ | | 0.378 | 0.396 |
| F-stat | 319.909 | | |
| Wald $Chi^2$ | | 5377.97 | 3070.88 |
| Fixed effects: | | | |
| Year Dummies | Yes | Yes | Yes |
| Industry Dummies | Yes | Yes | Yes |
| Country Dummies | Yes | Yes | Yes |

t-values are in parentheses for column 1 and z-values for columns 2 and 3 * ** $p < .01$, * * $p < .05$, * $p < .1$

in mean. The results indicate that the treatment and control samples are not significantly different from each other.

Regarding the DID analysis, Panel B presents the results of our analysis. The interaction term, TREAT×POST, has a positive and statistically significant coefficient for EIS but is only marginally significant for PRDEIS and PRCEIS. Impliedly, the change in environmental innovation after the inception of COVID–19 is statistically greater than the change in environmental innovation for firms that switched from non-CLIR to CLIR relative to firms that remained non-CLIR for our sample period. These findings provide further support for our main findings.

### 4.4. *Results for H4a, H4b, and H4c*

Table 9 presents the results for our moderating analysis regarding the moderating effect of SDG13. For EIS and PRCEIS, SDG13 does not moderate the relationship between CLIR and EIS and PRCEIS, respectively. However, SDG13 weakens the relationship between CLIR and PRDEIS. This may indicate the performative nature of firms' inclusion of SDG13 in their climate change management processes.

## 5. Conclusion

As climate risk has become a topical issue for firms and their relevant stakeholders, the need to understand its implications for firm behaviour has become essential as well. In light of this, climate risk exposure and its incidental issues have received a lot of attention from regulators and other stakeholders with the key goal of devising regulations and frameworks for the effective management of climate risk aimed towards sustainable development. However, there are limited studies that explore the relevance of climate risk in shaping firm innovation for sustainable development. In view of this, we explore the relevance of climate risk awareness for firm environmental innovation to provide evidence on the importance of climate risk for firm behaviour in the context of innovation. Specifically, we provide evidence on the role of climate risk awareness in shaping environmental innovation and further highlight the moderating role of SDG13. We expect a firm's climate risk awareness to be related to environmental innovation and to further observe a moderating effect of SDG13.

Using firms included in the ESG Active Universe list, we observe a positive relationship between a firm's climate risk awareness and environmental innovation, specifically for overall performance, product environmental innovation, and process environmental innovation. Additionally, the moderating effect of SDG13 is only relevant in the context of product environmental innovation.

We employ 2SLS IV, lead-lag model and DID approach to address the potential issues of endogeneity. Our results from these

**Table 8**
Difference-in-difference analysis for propensity score matching sample.

| Panel A. Differences in Mean | | | | | | |
|---|---|---|---|---|---|---|
| | **N** | **Treatment** | **Control** | **difference** | **t value** | **p value** |
| FSIZE | 1024 | 14.807 | 14.755 | 0.052 | 0.75 | 0.467 |
| FAGE | 1024 | 3.271 | 3.288 | 0.018 | 0.50 | 0.630 |
| LEV | 1024 | 62.128 | 55.072 | 7.055 | 1.35 | 0.170 |
| LIQ | 1024 | 39.849 | 40.782 | −0.932 | −0.85 | 0.392 |
| RAD | 1024 | .043 | .047 | −0.005 | −1.30 | 0.200 |
| GOV | 1024 | 47.983 | 48.128 | −0.144 | −0.15 | 0.881 |
| WRKF | 1024 | 50.136 | 50.859 | −0.723 | −0.60 | 0.545 |
| LGDP | 1024 | 29.295 | 29.205 | 0.090 | 1.45 | 0.147 |

| **Panel B. Difference-in-difference analysis** | | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| | EIS | PRDEIS | PRCEIS |
| TREAT | 5.315 * ** | 0.501 * ** | 0.446 * |
| | (3.260) | (2.760) | (1.790) |
| POST | 4.316 | 0.280 | 0.142 |
| | (1.190) | (0.760) | (0.280) |
| TREAT×POST | 6.959 * ** | 0.457 * | 0.726 * |
| | (2.920) | (1.800) | (1.890) |
| FSIZE | 3.369 * ** | 0.296 * ** | 0.538 * ** |
| | (5.870) | (4.460) | (5.450) |
| FAGE | 2.154 * * | 0.066 | 0.209 |
| | (2.120) | (0.610) | (1.430) |
| LEV | 0.006 | 0.000 | −0.001 |
| | (1.130) | (0.600) | (−1.160) |
| LIQ | −0.068 * * | −0.009 * * | −0.012 * * |
| | (−2.220) | (−2.410) | (−2.110) |
| RAD | 13.684 * | 1.846 | 7.951 * ** |
| | (1.71) | (1.360) | (4.680) |
| GOV | 0.096 * ** | 0.014 * ** | 0.017 * ** |
| | (2.87) | (4.020) | (3.430) |
| WRKF | 0.168 * ** | 0.018 * ** | 0.016 * ** |
| | (5.790) | (5.690) | (3.460) |
| LGDP | −0.143 | −0.010 | 0.193 |
| | (−0.150) | (−0.110) | (1.310) |
| Constant | −80.197 * ** | −7.749 * * | −16.669 * ** |
| | (−2.790) | (−2.370) | (−3.680) |
| Observations | 1643 | 1594 | 851 |
| Adj $R^2$ | 0.318 | | |
| Pseudo $R^2$ | | 0.355 | 0.400 |
| F-stat | | | |
| Wald $chi^2$ | | 445.31 | 257.66 |
| Fixed effect: | | | |
| Year Dummies | Yes | Yes | Yes |
| Industry Dummies | Yes | Yes | Yes |
| Country Dummies | Yes | Yes | Yes |

*t*-values are in parentheses for column 1 and *z*-values are in parentheses for columns 2 and 3 * ** p < .01, * * p < .05, * p < .1

robustness tests are consistent with our main findings. Despite the rigorous methodology applied in our study, our findings may still be limited by inherent measurement issues associated with the proxies used in our study. Additionally, the findings may not apply to firms that are distinct from the firms included in the ESG Active Universe list. Regardless of these potential shortcomings, our findings provide relevant insights that would be helpful to both regulators and other relevant stakeholders in their quest to understand climate risk and its associated implications for firm behaviour.

In context of future research, consideration should be given to the role of corporate behavour in shaping climate risk successful organisational outcome. Furthermore, impact of climate risk exposure on human capital efficiency should be explored due to its critical impact on firm innovation.

**Table 9**
Moderation effect of SDG13.

| | (1) | (2) | (3) |
|---|---|---|---|
| | EIS | PRDEIS | PRCEIS |
| CLIR | 7.289 * ** | 0.670 * ** | 0.616 * ** |
| | (10.390) | (9.360) | (6.220) |
| SDG13 | 6.115 * ** | 0.750 * ** | 0.557 * ** |
| | (5.960) | (7.430) | (4.060) |
| CLIR×SDG13 | 0.275 | −0.330 * ** | −0.029 |
| | (0.230) | (−2.760) | (−0.018) |
| FSIZE | 3.444 * ** | 0.302 * ** | 0.412 * ** |
| | (19.000) | (14.770) | (14.130) |
| FAGE | 2.934 * ** | 0.315 * ** | 0.353 * ** |
| | (8.700) | (8.420) | (7.120) |
| LEV | 0.002 | 0.000 | 0.000 |
| | (0.940) | (0.900) | (0.710) |
| LIQ | −0.121 * ** | −0.016 * ** | −0.017 |
| | (−11.560) | (−13.220) | (−10.490) |
| RAD | 8.338 * | −1.644 * * | 1.521 * * |
| | (4.630) | (−3.750) | (2.440) |
| GOV | 0.074 * ** | 0.009 * ** | 0.009 * ** |
| | (6.640) | (7.460) | (5.230) |
| WRKF | 0.089 * ** | 0.006 * ** | 0.007 * ** |
| | (8.970) | (5.380) | (4.160) |
| LGDP | −0.179 | −0.054 | 0.031 |
| | (−0.54) | (−1.510) | (0.600) |
| Constant | −83.794 * ** | −5.950 * ** | −11.011 * ** |
| | (−7.260) | (−4.750) | (−6.720) |
| Observations | 13,090 | 13,046 | 7095 |
| Adj $R^2$ | 0.413 | | |
| Pseudo $R^2$ | | 0.395 | 2091.69 |
| F-stat | 236.66 | | |
| Wald $chi^2$ | | 3804.82 | 0.410 |
| Year Dummies | Yes | Yes | Yes |
| Industry Dummies | Yes | Yes | Yes |
| Country Dummies | Yes | Yes | Yes |

*t*-values are in parentheses for column 1 and *z*-values for columns 2 and 3 * ** p < .01, * * p < .05, * p < .1

## Author statement

We, the undersigned, declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We are confirming that there are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that no other persons have satisfied the criteria for authorship but are not listed.

We further confirm that all have approved the order of authors listed in the manuscript. We guarantee that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication. In so doing, we confirm that we have followed the regulations of our institutions concerning intellectual property.

We confirm that all authors have contributed significantly to the conception, design, execution, or interpretation of the reported study.

We understand that the Corresponding Author is the sole contact for the Editorial process (including the Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address that is accessible by the Corresponding Author, and which has been configured to accept emails from *Research in International Business and Finance.*

## CRediT authorship contribution statement

**Md Akhtaruzzaman:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sabri Boubaker:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Pandula Gamage:** Writing – review & editing, Supervision, Resources, Investigation, Conceptualization. **Victoria Obeng:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## Data availability

Data will be made available on request.

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