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# Corporate Climate Risk Governance and Environmental Innovation

Md Tanvir Hamim[1] | Sabur Mollah[2]

[1]Department of Banking and Insurance, University of Dhaka, Dhaka, Bangladesh | [2]The University of Sheffield, Sheffield University Management School, Sheffield, UK

**Correspondence:** Sabur Mollah (s.mollah@sheffield.ac.uk)

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## ABSTRACT

The existing body of literature with regard to climate-oriented governance focuses on carbon disclosure and climate change commitments, with a notable omission of an essential aspect of sustainable business practices and decarbonization, that is, environmental innovation. In this study, we examine the effect of climate risk governance on firm-level environmental innovation. Based on a panel of 4378 firm-year observations from the nonfinancial S&P 500 components over the period of 2011–2021, we provide novel empirical evidence that corporate climate risk governance is positively associated with environmental innovation. Firms with strong climate risk governance appear to engage more in environment-friendly innovation to reduce environmental costs and the burden on customers. Further analysis identifies a channel, namely, environmental investment, through which climate risk governance facilitates environmental innovation. Our results remain consistent after we employ an instrumental variable approach and propensity score matching estimates to address potential endogeneity bias. The empirical results also pass a battery of robustness tests with alternative variables and different estimation techniques. This study carries important implications for executive management, regulators, and other stakeholders in relation to reforms in governance structures and the advancement of environmentally sustainable innovation.

## 1 | Introduction

Firms today are increasingly exposed to evolving climate risks, characterized by rising global temperatures and sea levels, extreme weather events, biodiversity loss, and ecosystem disruption (IPCC, 2021). These climate-related risks pose significant financial and operational challenges, as firms face physical risks from climate vulnerabilities and transition risks stemming from stricter carbon policies and shifting market expectations (TCFD, 2017). In response to these challenges, carbon-emitting firms encounter mounting pressure from policymakers and regulators to curb their emissions, enhance their environmental engagements, and comply with disclosure requirements (Safiullah et al., 2021). The escalation of carbon footprints potentially deters firms from relying on high-emission technologies while encouraging them to transition toward more carbon-efficient and environmentally sustainable alternatives (Nguyen and Phan, 2020). Therefore, adopting green technologies and environmentally responsible innovations is an essential strategy for managing climate change risks (Albitar et al., 2022). These innovations mitigate environmental stress (Costantini et al., 2017) and enhance firms' environmental competitiveness and long-term sustainability. Furthermore, investors, shareholders, and other stakeholders increasingly demand greater corporate accountability for carbon emissions and environmental impact, urging firms to demonstrate substantive climate commitments through tangible environmental initiatives (Afrifa et al., 2020; Hollindale et al., 2019).

Sustainable business initiatives aimed at addressing climate change typically encompass investments in renewable energy, pollution prevention, recycling and reusing materials, carbon emission control, and the adoption of energy-efficient production processes (Alam et al., 2019; Atif et al., 2022; Haque and Ntim, 2022; Orazalin et al., 2024). Moreover, long-term business sustainability requires innovation and technological advancements that are environmentally appropriate and of sufficient scale (Shi et al., 2021). Environmental innovation, as underlined by Asongu and Odhiambo (2021), is instrumental in achieving firm-level sustainability by enhancing energy efficiency, mitigating the adverse effects of resource consumption, and reducing environmental risks and pollution. We know that there is broad consensus among environmentalists, regulators, experts, and academics on the necessity of a green economy with a net-zero emissions target. However, such an economy cannot be realized without ecodriven strategies and innovation (Swainson and Mahanty, 2018). Notably, environmental innovation technologies present significant opportunities to enhance manufacturing efficiency. In this regard, Choudhary et al. (2019) provide evidence that integrating lean and green paradigms through the green integrated value stream mapping technique facilitates employee productivity, operational efficiency, and overall environmental sustainability. Despite the growing recognition of environmental innovation, available literature predominantly emphasizes conventional innovation geared toward profit-oriented firm performance (e.g., Bocquet et al., 2017). In contrast, environmental innovation is distinct in its primary aim—improving environmental conditions and ensuring long-term sustainability rather than focusing merely on financial returns.

Gerged et al. (2021) underscore the increasing significance of climate-focused board processes in executive decision-making in response to intensifying socioenvironmental pressures. Bui et al. (2020) also argue that effective climate governance requires moving beyond conventional corporate governance mechanisms, which often inadequately address climate-related responsibilities. Robust firm-level climate risk governance (CRG) mechanisms can reinforce how substantively climate activism is integrated within corporate boardrooms in the context of climate change and its widespread global impact. In addition, corporate boards with a strong focus on climate change risk and sustainability can restrain potential greenwashing attempts (Bui et al., 2020). A climate-focused governance structure might help mitigate the potential harmful impact of climate change (Galbreath, 2010) as well as position firms to harness opportunities arising from an environmentally responsive business model (Drobetz et al., 2023). Conventional governance mechanisms, in contrast, do not sufficiently reflect firm-level climate-focused pledges and actions. Thus far, the limited literature on climate governance rests on carbon disclosure (Bui et al., 2020), carbon emissions (Albitar et al., 2022), and firm-level commitments regarding climate change risk or sustainability (Albitar et al., 2023). While CRG is recognized as a critical component of sustainable business practices and long-term environmental security, its influence on environmental innovation remains largely underexplored. The lack of empirical investigation into how CRG translates into firm-level environmental innovation reveals a significant gap in the broader corporate climate governance and sustainability discourse. This gap raises the following key research questions: (1) To what extent does CRG impact firm-level environmental innovation? (2) Through what mechanism does CRG support environmental innovation? Accordingly, this study is aimed at examining the magnitude and the underlying mechanism through which CRG drives innovation that reduces environmental impact and advances sustainability.

In this study, we investigate the association between CRG and environmental innovation based on a sample of 4378 firm-year observations obtained from 398 nonfinancial firms that are constituents of the S&P 500 index during the period between 2011 and 2021. Our results reveal a significant positive relationship between CRG and environmental innovation consistent with the resource-based view (RBV) and agency theoretical predictions. As is the case, firms with effective CRG tend to be more environmentally aware, and their climate activism within the boardroom increases the potential for environmental innovation. This association is more pronounced for large firms with a strong emphasis on CRG. The use of IV analysis and propensity score matching (PSM) confirms that our results are robust to the endogeneity concerns. As per the findings of our channel analysis, CRG practices result in high environmental expenditures, which in turn supports firm-level environmental innovation. To prevent sample selection bias, we apply two-stage Heckman selection models in this study. We also perform additional tests using various estimation techniques, such as the FE model and GMM regressions. Furthermore, alternative variables were used for the dependent variable. Across all the analyses, our empirical results remain consistent.

Our study makes a valuable contribution to the emerging body of literature in several ways. First, to the best of our knowledge, this study represents a novel empirical investigation into the association between environmental innovation and CRG. Previous climate governance studies have concentrated on carbon-related disclosures (Bui et al., 2020) and commitments to climate protection (Albitar et al., 2023). However, a vital and more dynamic dimension of any efforts to reduce carbon footprints and ensure environmental safety, namely, ecofriendly innovation capacity, has been left unexplored. Therefore, our results are a crucial contribution to the emerging body of literature on climate governance. Second, we look into the mechanism by which CRG affects environmental innovation. We reveal that CRG facilitates environmentally favorable innovations by committing more environmental expenditures to it. Earlier studies have shown that firms with ample cash and related resources tend to invest more in renewable energy consumption and green innovation (Alam et al., 2022; Li et al., 2020; Lyandres and Palazzo, 2016). Therefore, this study extends the existing body of literature. According to the results of our channel analysis, we find evidence that the pursuit of CRG induces firm-level environmental expenditures, which provide support for environmental innovation. Moreover, we analyze subsamples of large and small firms to obtain deeper insights. We offer new evidence that the impact of CRG on ecoinnovation is more notable for large firms than for their smaller counterparts. Third, we are among the first to apply the Refinitiv Eikon Datastream database scores to proxy firm-level environmental innovation. Unlike those used in earlier studies (i.e., Afrifa et al., 2020; Hashmi and Alam, 2019), the environmental innovation scores used in our study do not merely rely on the number of patents the firms hold or the firm-level R&D expenditures as proxies of environmental innovation. Instead, the environmental innovation score covers all ecofriendly innovative business aspects ranging from the patents the firm may possess to all other innovative methods, purchased technological support, and related expertise that do not require patenting. Overall, our empirical findings provide vital insights for firms and regulators seeking to incorporate climate governance mechanisms and embark on more environment-friendly innovations to minimize the effect of climate change.

The remainder of our paper is structured as follows. Section 2 develops the theoretical framework and reviews related literature. Section 3 presents the data, empirical models, and summary statistics, while section 4 reports the empirical results. Finally, Section 5 concludes the paper by presenting the policy implications, limitations, and directions for future research.

## 2 | Theory, Related Literature, and Development of Hypotheses

### 2.1 | Theoretical Foundation

This subsection establishes the theoretical foundation of the study by drawing upon RBV and agency theory to explain the relationship between CRG and environmental innovation. As far as a firm's ability to use internal resources and manage external relations and dependencies is concerned, the RBV and resource dependence theory are at play. Although both theories focus, in a sense, on resources, they differ in their approaches. In the current context, we focus on the RBV. The advocates of RBV argue that a firm's competitive advantage is primarily determined by its ability to effectively utilize both tangible and intangible resources and assets (Alam et al., 2019). The RBV is fundamentally concerned with a firm's internal resources, examining how the unique and valuable resources of the organization can provide a competitive advantage (Barney, 1991; Peteraf, 1993). The operating performance of a firm depends on its capacity to identify, cultivate, and protect its internal resources that are valuable, rare, and nonsubstitutable. Barney (2001) further posits that the RBV stimulates a direct association between firms' valuable, inappropriately mimicable resources, capacities, and competitive advantage that is sustainable for the long term. Similarly, Lee and Min (2015) highlight that competitive superiority emerges from internal resources characterized by heterogeneity and distinctive value. Within the climate change literature, the RBV informs discussion about corporate climate activism, asserting that firms with abundant internal resources are better able to undertake significant climate-related investments (Qiu et al., 2016). However, recent observations suggest that firms may frequently prioritize symbolic environmental actions, such as greenwashing or impression management, rather than substantive improvements in environmental performance (Haque and Ntim, 2020). Bowen (2014) emphasizes that environmental disclosures often fail to accurately reflect actual environmental practices. Similarly, Dragomir (2012) identifies discrepancies and misleading representations of carbon emissions data from highly carbon-intensive firms, calling attention to methodological inconsistencies and potential managerial opportunism. As a result, it is crucial to consider not only the assumption of possessing and exercising control over assets and resources, as per the RBV, but also the intent of top-level management and the ability of firms to efficiently and timely modernize and reconfigure critical resources to adapt to a rapidly changing environment. This ability is commonly known as a dynamic capability (Huang and Li, 2017; Zahra et al., 2022). Simply put, the strategy of moving beyond the traditional resource-based model entails the ability to transform a firm's owned and controlled resources into its primary strength as well as a competitive edge. Given the circumstances, it is reasonable to expect that not all firms possessing ample resources are capable of leveraging them to gain a competitive edge. It is argued that strong organizational factors play an important role in capacity building to address climate change issues by making systematic and actionable use of available resources (Zahra et al., 2022). Likewise, Cai et al. (2016) claim that firms that demonstrate higher levels of environmental engagement and acceptability may experience lower idiosyncratic risk, as they are often better positioned to access critical resources. Thus, we argue that it is corporate CRG, as an organizational factor, that helps make the usage of firm-specific resources and know-how more effective and plausible to realize dynamic capabilities, such as environmental innovation. In the current context, for example, integrating climate-related risks and opportunities into a firm's strategic planning process through CRG aligns with the predictions of RBV by effectively mobilizing internal resources to drive innovation outcomes (Cainelli et al., 2020). Thus, by ensuring that climate considerations are adequately incorporated into decision-making, firms can more effectively leverage their resources to advance environmental innovation. Overall, building on the perspective of RBV, climate-focused governance mechanisms are expected to support the development and strategic management of environmentally sustainable innovation. On the contrary, firms lacking a well-established climate governance framework would struggle to effectively address climate change issues, likely resorting only to symbolic responses.

Agency theory, as posited by Jensen and Meckling (1976), investigates the conflicts of interest between principals and their delegated agents. Central to the theory is the notion that monitoring mechanisms, compliance measures, and incentive structures are essential to align the interests of shareholders and managers, thereby mitigating agency problems. A strong alignment between shareholder interests and managerial priorities can enhance environmentally sustainable and substantive outcomes (Haque, 2017). In the context of climate change, corporate governance mechanisms influenced by agency theory emphasize the creation of board-level environmental or environmental, social, and governance (ESG) committees, which play a crucial role in ensuring that climate-related actions are effectively monitored and reported (Peters and Romi, 2013; Jensen and Berg, 2012). These governance structures help reduce information asymmetry by facilitating transparent reporting on climate change efforts, which is critical for improving accountability and promoting environmental innovation. Further supporting this argument, agency theory suggests that external control mechanisms, such as government-mandated reporting obligations and regulatory frameworks, are instrumental in reducing agency problems (Tauringana and Chithambo, 2015). These mechanisms provide managers with clear incentives to align their climate-related actions with shareholder interests, as managers are more likely to engage in sustainability-driven innovation when their performance is incentivized (Cordeiro and Sarkis, 2008; Haque and Ntim, 2020). Additionally, agency theory highlights the importance of external validation and systematic sustainability reporting, which reduces information asymmetry between shareholders and managers (Moroney et al., 2012; Al-Shaer, 2020). Such mechanisms build transparency and trust, thereby enabling firms to pursue more ambitious environmental innovation without fearing shareholder disapproval due to perceived risks or uncertain returns.

In summary, from a resource-based perspective, firms that adopt CRG are expected to leverage their existing resources and capabilities to drive environmental innovation that surpasses that of their competitors. In addition, agency theory suggests that effective monitoring, a robust compliance mechanism, and well-designed incentives are key elements that support the development of a resilient CRG framework. Drawing from this discussion, the RBV and agency theory lay the relevant theoretical foundation for our study. Therefore, we follow, among others, de Villiers et al. (2011), Mallin and Michelon (2011), and Haque (2017) in utilizing the RBV and agency theory to explain the association between CRG and environmental innovation.

## 2.2 | CRG and Environmental Innovation

The primary challenge faced by carbon-intensive firms is an excessive level of carbon emissions. As an alternative, environmental innovation—defined as a firm's capability to develop new ecofriendly technologies and processes aimed at reducing costs and creating new market opportunities by improving current operations—is increasingly recognized as essential for reinforcing environmental protection and stability. Available literature widely acknowledges environmental innovation directed toward sustainability as a viable remedy to escalating climate change concerns by limiting environmental liabilities, conserving energy, and facilitating waste reduction and recycling (Cainelli et al., 2020; Krieger and Zipperer, 2022). Specifically, Mensah et al. (2018) highlight that environmentally sustainable innovation significantly enhances carbon mitigation performance in OECD nations. In alignment, Ali et al. (2016) demonstrate that investments in sophisticated, ecofriendly technologies can substantially reduce carbon footprints and enhance environmental quality. Additionally, Lee and Min (2015) emphasize that a firm's competitive advantage can improve through the development of sustainable products and technologies. However, existing literature predominantly focuses on general factors influencing environmental innovation, overlooking specific governance-related drivers that can motivate firms to actively pursue such innovation. Notably, there is limited exploration into what precise mechanisms within governance could effectively stimulate environmental innovation in carbon-intensive firms.

Furthermore, firms may lack motivation to adopt environmental innovation due to the dual external effects, associated uncertainties, and market inefficiencies highlighted within environmental policy and economic frameworks (Horbach et al., 2012). Therefore, identifying a resilient and climate-centric driver that could significantly motivate firms toward environmentally sustainable innovation is vital and remains inadequately addressed in prior studies. Specifically, there is a notable gap concerning the investigation of climate-focused governance mechanisms and the likely effect they might have on environmental innovation. Again, the literature addressing the relationship between conventional corporate governance mechanisms and environmental innovation is particularly sparse. Surprisingly, among various governance attributes, the current body of research has mostly explored several limited dimensions, such as board gender diversity (Nadeem et al., 2020), governance shocks and institutional ownership (Amore and Bennedsen, 2016), and overall corporate governance ratings (Makpotche et al., 2024). Hence, it is apparent that typical corporate governance measures may not consistently drive ecofriendly innovation within firms effectively. In addition, there tends to be a conceivable threshold beyond which conventional governance mechanisms become insufficient, and this critical friction remains mostly unexplored. Taking this void into account, we attempt to focus on alternative governance mechanisms specifically tailored to address climate change.

The academic debate on corporate climate responsibility increasingly stresses the significance of CRG in addressing climate change risks, formulating effective carbon control strategies, and promoting sustainable business practices. A firm's dedication to CRG can be evaluated based on the integration of climate-specific concerns into board-level decision-making processes. Ntim and Soobaroyen (2013) suggest that robust climate-focused governance mechanisms effectively prevent carbon-intensive firms from evading compliance responsibilities and environmental accountability. Specifically, climate governance can involve establishing dedicated board-level subcommittees explicitly accountable for climate change issues and providing incentives to executives to promote ecofriendly initiatives (Ioannou et al., 2016). Yet, despite these insights, a clear gap persists in the relevant literature regarding how climate-centric governance mechanisms directly influence firms' scope and capacity for environmental innovation. Moreover, while some prior research has recognized the limitations of conventional governance characteristics (e.g., gender diversity, board size, and board independence) in effectively translating climate activism into sustainability outcomes (Bui and de Villiers, 2017; Bui et al., 2020), empirical studies have yielded inconsistent findings regarding the relationship between these governance attributes and environmental outcomes, particularly carbon performance (Haque, 2017; Moussa et al., 2019; Luo, 2019). Jain and Zaman (2020) further suggest that different governance attributes may exert varying influences on distinct environmental and sustainability performance metrics. Consequently, a significant research gap remains in understanding whether and how climate-specific governance structures, in contrast to conventional governance characteristics, contribute to environmental innovation.

Based on the above reasoning, our study emphasizes the necessity to explore CRG[1] as a critical and underexamined driver of environmental innovation. We argue that this direction promises original understanding and actionable insights into how firms can effectively embed substantive climate activism into their governance structure to advance environmental innovation. Therefore, our first hypothesis is:

**Hypothesis 1.** *Ceteris paribus, CRG is associated with higher firm-level environmental innovation.*

Based on the discussions above, we propose a conceptual model illustrated in Figure 1.

### 2.3 | CRG and Ecoinnovation: The Role of Environmental Investment as a Mechanism

It is argued that adequate investment always plays a crucial role in boosting environmental engagement and sustainability performance (Betts et al., 2018; Li and Ramanathan, 2020; Pekovic et al., 2018). Similarly, environmental investment can help firms to implement environment-friendly strategies (Alam et al., 2022). This is because firm-level investment in sustainable business practices may increase energy efficiency and reduce carbon emissions (Tolliver et al., 2020; Journeault et al., 2016), which ultimately helps to accelerate environmental engagements. Firms, thus, spend money to overcome the cost and knowledge hurdles of innovation (Andries and Hünermund, 2020). Environmental spending primarily entails allocating funds to support the development of sustainable business actions. The primary goal is to reduce harmful environmental effects and contribute to environmental well-being. The extant literature, in this regard, informs us that spending on environmental initiatives is likely to accelerate technological progress directly by improving product design as well as indirectly through sustainable transition and innovation (Fischer and Newell, 2008). Therefore, based on the above line of reasoning, it is plausible to consider that the higher the environmental expenditure, the greater the potential for environmentally friendly innovative capacity.

Since the CRG framework is expected to significantly explain firm-level environmental innovation, an important follow-up question arises regarding the channel through which CRG supports such innovation. To address this, we argue that CRG facilitates systematic and credible investments in environmental initiatives, thus acting as a critical mechanism by which CRG stimulates environmental innovation at the firm level. A robust and resilient CRG framework impacts corporate sustainability strategies and associated investments through several well-defined mechanisms. These include comprehensive assessment of climate-related risks and opportunities, establishment and operation of dedicated environmental committees (Liao et al., 2015), sustainability reporting accompanied by external assurance (Junior et al., 2014), and sustainability-linked incentives (Flammer et al., 2019). Integrating climate risks and opportunities into corporate strategic planning enables firms to recognize environmental issues as tangible financial risks, motivating proactive and targeted investments in sustainability initiatives (Krueger et al., 2020). Environmental committees contribute significantly to ensuring accountability, developing strategic objectives, and guiding the allocation of resources toward sustainability-focused expenditures (Walls et al., 2012). Furthermore, sustainability reporting and external assurance practices enhance transparency and investor confidence, reinforcing responsible environmental investment decisions (Simnett et al., 2009). Sustainability-linked incentives closely align corporate sustainability objectives with financial targets, providing a strong rationale for firms to design and implement effective environmental strategies (Flammer et al., 2019). Together, these mechanisms encourage firms to commit to systematic and credible environmental investments[2], fostering innovation that is environmentally sustainable and beneficial. Therefore, we propose the following hypothesis:

**Hypothesis 2.** *Ceteris paribus, CRG supports firm-level environmental innovation through increased environmental investment.*

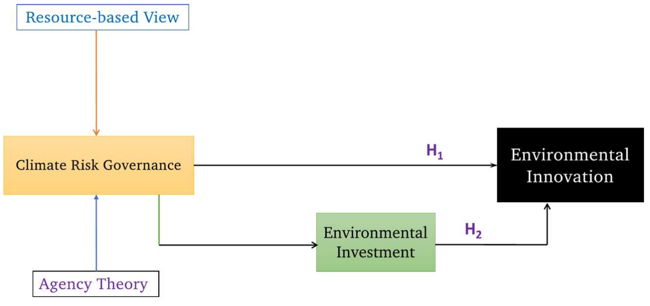


**FIGURE 1** | The conceptual model of the study.

## 3 | Data, Variables, and Empirical Models

We focus on the S&P 500 index, including the largest publicly traded firms listed on the New York Stock Exchange (NYSE) or National Association of Securities Dealers Automated Quotations (NASDAQ). Firms with significant capitalization are assumed to play a leading role in climate activism and get responsibly involved in environment-friendly innovation and technological advancements. Even though small-cap firms and financial institutions often face significant environmental challenges and regulatory pressures, our focus is on the carbon-sensitive components of the S&P 500. This emphasis is motivated by the fact that the largest firms are consistently at the forefront of societal expectations, facing scrutiny from diverse stakeholders and regulatory bodies. In the United States[3] and other industrialized nations, carbon-intensive nonfinancial firms—such as those within the S&P 500—face greater pressure than their smaller counterparts to transition to renewable energy sources and reduce their carbon footprints (Bui and de Villiers, 2017; Wang and Sueyoshi, 2018). Accordingly, our investigation incorporates 4378 firm-year observations from 398 nonfinancial S&P constituents between 2011 and 2021 after we drop banks and other financial institutions[4] from the initial sample. It is also pertinent to mention that we focus on firms that are liable for direct $CO_2$ emissions as part of their regular business functions and are regarded as carbon-intensive[5]. These carbon-intensive companies are responsible for $CO_2$ emissions classified as Scope 1[6] (direct emissions). In addition, we consider nonfinancial firms that are prone to Scope 2[7] (indirect) emissions. Consistent with Cheng et al. (2024) and Roy and DasGupta (2025), we select the study period from 2011 to 2021. Two key reasons justify this selection. First, the selection of 2011 as the starting point for our sample period effectively sidesteps any complications stemming from the global financial crisis and its aftermath. Second, since the postcrisis period, the top-level management of nonfinancial firms has demonstrated increased awareness of climate change issues and the importance of ecofriendly approaches, responding to national climate change policies and related global accords.

### 3.1 | Dependent Variable: Environmental Innovation

The extant literature (i.e., Kesidou and Demirel, 2012; Lin and Zhu, 2019) informs us that environmental innovation can enhance energy efficiency and reduce energy consumption and carbon footprints of manufacturing and distribution. As a result, there has been a growing emphasis on ecofriendly products and services and more ecologically sustainable production processes (Hole and Hole, 2019). According to Zhang and Walton (2017), environmental innovation[8] has been acknowledged as a practical approach to addressing climate change issues. Environmental innovation can consistently deliver practicable solutions for ecosystem issues. This approach enables firms to modify their production methods and efficiently manage their resource consumption and pollution levels (Pan et al., 2020). Hence, firms must develop more ecodriven approaches to remain environmentally sustainable in their business actions. However, it has been argued that assessing environmental innovation can be challenging. Several studies employ R&D expenses as a proxy for innovation, but firms are not subject to any regulatory requirement to disclose their expenditure on environment-focused R&D, and only a handful of firms are found to have reported on environmental R&D. Thus, consistent with Albitar et al. (2022), Nadeem et al. (2020), and Zaman et al. (2021), we use the environmental innovation score from the Refinitiv Eikon Datastream database. The environmental innovation score accumulated from Refinitiv Eikon Datastream refers to a firm's capability to develop new environmental technologies and processes to lower its environmental costs and the burdens for its customers. This allows the firms to create new market opportunities by improving existing environmental technologies and processes or by developing ecofriendly products or services. It also shows how efficiently firms are advancing their research and development into ecofriendly products and services. The score for environmental innovation ranges from 0 to 100.

### 3.2 | Independent Variable: CRG

First, a board's awareness of climate change risks, opportunities, and regulatory directives is the cornerstone of the climate governance configuration. Climate change issues are anticipated to generate business threats and create potential opportunities. Therefore, it is the responsibility and commitment of the board to remain informed of the climate change risk factors, opportunities, and potential courses of action. For instance, when a board is accountable for the risks and opportunities stemming from climate change, the executive management might develop new environmentally sustainable products, services, or business solutions to accommodate the variations and control the resulting impact. Therefore, if the firm is aware of the commercial risks and opportunities arising from climate change, we assign one and zero otherwise.

Second, the available literature indicates that executive compensation is associated with firms' environmental performance. For example, Campbell et al. (2007) argue that a well-planned sustainable compensation policy can encourage executives to increase their involvement in environmental initiatives, eventually resulting in substantive environmental performance. We intend to observe whether sustainability-linked incentives for executive managers spur firm-level ecofriendly innovation. Hence, a firm will be awarded one if it confers executive incentives or compensation for substantial climate change actions or contributions, and zero otherwise.

Third, relevant studies (i.e., Liao et al., 2015; Peters and Romi, 2013) have found that corporate environmental committees as a component of the board are positively related to the likelihood of sustainability or $CO_2$ disclosure. It is also argued that although independent directors may not possess the authority or scope to mandate that powerful executives commit significant long-term resources (financial and otherwise) to carbon mitigation, a board-level sustainability or environmental committee will consistently promote the incorporation of environmental strategies and practices within the organization (Albitar et al., 2023). H. Huang et al. (2024) and Ioannou et al. (2016) also claim that any specialized committee can better manage and advise on climate-related issues. In the same vein, we argue that an environmental committee can be an effective governance measure to promote innovation and improve the quality and strength of overall CRG. Hence, we consider the board-level environmental or ESG-related committee to be a component of the CRG index.

Fourth, over the past two decades, sustainability reporting has received enormously increasing attention, which is more noticeable in highly polluting countries worldwide. Firms now publish environmental impact reports or sustainability reports to demonstrate their commitment to transparency (Al-Shaer, 2020). These reports also offer detailed insights into how the firm allocates its resources and leverages its capabilities to address climate-related challenges. Socially responsible firms are expected to prepare and publish such reports, and due to regulatory and stakeholder pressure, this is crucial for firms accountable for both Scope 1 and Scope 2 emissions. Sustainability reporting is intended to communicate a substantive and fair stance on firms' long-term sustainability performance and to reflect on the climate protection initiatives likely to trigger environmental innovation. Therefore, we consider sustainability reporting as one of the components of CRG.

Finally, we focus on the external assurance of the sustainability, ESG, or environmental reports to be a component as external validation authenticates the climate activism and reduces the potential for greenwashing in disclosure and compliance. In this respect, we follow Simnett et al. (2009) and Moroney et al. (2012) by incorporating external assurance into the index. Firms that get their reports or disclosures externally assured or audited receive one and zero otherwise. Overall, the CRG index includes firm-specific governance mechanisms to deal with climate change and sustainability, with a higher climate governance score indicating superior climate activism by the firm. As our index comprises five indicator variables, the possible score of each firm falls between 0 and 5.

### 3.3 | Control Variables

Having considered the related literature, we select the below control variables as potential drivers of environmental innovation. We use board size (the size of the board), which is measured as the number of directors serving on the board (Lim et al., 2007). Consistent with previous studies (i.e., Haque and Ntim, 2020; Bui et al., 2020), we also control for board independence. Board independence is defined as the number of independent directors as a percentage of the board size. Further, following de Villiers et al. (2011), Luo et al. (2012), Haque (2017), and Haque and Ntim (2020), we control for several firm-specific characteristics, such as firm size (the natural logarithm of total assets), leverage (the ratio of total debt to total assets), and profitability (proxied by return on assets). Following earlier works (Albitar et al., 2023; Nadeem et al., 2020), we include capital intensity, categorized as a firm's capital expenditures scaled by total sales. Following Leyva-de la Hiz et al. (2019) and Konadu et al. (2022), we also add liquidity (the ratio of current assets to current liabilities) to our models. Finally, we control for market to book, the ratio of market price to book value of the firm (Albitar et al., 2023; Safiullah et al., 2021).

### 3.4 | Empirical Model

This study employs univariate and multivariate analyses to examine the effects of CRG on firm-level ecofriendly innovation. The following empirical model includes CRG[9] as the main explanatory variable, together with firm-specific control variables:

$$\begin{aligned}\boldsymbol{Environmental\ innovation}_{it} &= \beta_0 + \beta_1 \mathrm{CRG}_{it} \\ &+ \beta_2 \text{Board Independence}_{it} + \beta_3 \text{Board Size}_{it} \\ &+ \beta_4 \text{Firm Size}_{it} + \beta_5 \text{Capital Intensity}_{it} + \beta_6 \text{Leverage}_{it} \\ &+ \beta_7 \text{Liquidity}_{it} + \beta_8 \mathrm{MTB}_{it} + \beta_9 \text{Profitability}_{it} \\ &+ \beta_{10} \text{Industry fixed effects}_{it} + \beta_{11} \text{Year fixed effects}_{it} + \varepsilon_{it}\end{aligned} \tag{1}$$

We apply the ordinary least squares estimate as the baseline regression while controlling for industry and year effects. Both the industry and year-fixed effects allow us to control for any time and industry-specific differences (Shen et al., 2021; Siddique et al., 2021). We also employ different estimation techniques to check the robustness of our baseline results and address the endogeneity bias. Table A1 presents the definitions of the variables.

## 4 | Empirical Analysis

### 4.1 | Summary Statistics and Baseline Estimations

Table 1 presents the descriptive statistics of all the variables used in our empirical model. The mean value of the environmental innovation score is 31.96, with a standard deviation of 32.36, which is qualitatively consistent with prior research (Albitar et al., 2022). The environmental innovation score ranges from 0 to 100, with a maximum value of 99.70. The average score on the CRG index stands at 2.498, with a standard deviation of 1.719. The range of CRG values spans from 0 to 5, as our CRG index is comprised of five components. With regard to the governance variables, we find that an average of 77% of the directors are independent, which is comparable to the figure presented by Alam et al. (2022). In addition, in line with the findings in Haque and Ntim (2018) and Tauringana and Chithambo (2015), the boards of our sample firms are, on average, served by nine members. We also detect that the average firm size is 16.47, which is calculated as the natural logarithm of the total assets. Among other firm-specific control variables, the average values of capital intensity, leverage, and market-to-book ratio are 6.964%, 28.90%, and 3.773, respectively. The observed mean liquidity (current ratio) value of our sample firms is 1.665. Finally, the summary statistics of profitability indicate that the average return on assets of the sample firms is 8.107%.

Table 2 shows the matrix of correlations for the independent and control variables included in our analysis. The correlation coefficient between CRG and environmental innovation is positive and significant at the 1% level. As expected, the CRG index is

**TABLE 1** | Summary statistics.

| **Summary statistics** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| **Variables** | ***N*** | **Mean** | **Std. deviation** | **Min** | **Max** |
| Environmental innovation | 4378 | 31.96 | 32.36 | 0 | 99.70 |
| Climate risk governance | 4378 | 2.498 | 1.719 | 0 | 5 |
| Board independence | 4378 | 77.12 | 23.77 | 0 | 100 |
| Board size | 4378 | 9.994 | 3.471 | 1 | 18 |
| Firm size | 4378 | 16.47 | 1.121 | 14.69 | 18.17 |
| Capital intensity | 4378 | 6.964 | 6.696 | 1.310 | 22.44 |
| Leverage | 4378 | 28.90 | 17.91 | 0 | 58.01 |
| Liquidity | 4378 | 1.665 | 0.826 | 0.68 | 3.29 |
| MTB | 4378 | 3.773 | 2.870 | 0.340 | 9.820 |
| Profitability | 4378 | 8.107 | 5.200 | 0.570 | 17.23 |

**TABLE 2** | Matrix of correlations.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| (1) Environmental innovation | 1.000 | | | | | | | | | |
| (2) Climate risk governance | 0.445* | 1.000 | | | | | | | | |
| (3) Board independence | 0.299* | 0.457* | 1.000 | | | | | | | |
| (4) Board size | 0.355* | 0.518* | 0.773* | 1.000 | | | | | | |
| (5) Firm size | 0.330* | 0.585* | 0.310* | 0.482* | 1.000 | | | | | |
| (6) Capital intensity | 0.004 | 0.232* | 0.079* | 0.110* | 0.291* | 1.000 | | | | |
| (7) Leverage | 0.071* | 0.192* | 0.186* | 0.230* | 0.214* | 0.181* | 1.000 | | | |
| (8) Liquidity | −0.040* | −0.189* | 0.001 | −0.088* | −0.329* | −0.211* | −0.236* | 1.000 | | |
| (9) MTB | 0.012 | −0.002 | 0.154* | 0.114* | −0.144* | −0.202* | 0.058* | 0.088* | 1.000 | |
| (10) Profitability | 0.006 | −0.054* | 0.091* | 0.020 | −0.244* | −0.279* | −0.090* | 0.329* | 0.383* | 1.000 |

*Note:* This table reports the pairwise correlation coefficients between the variables employed in our study.
*Statistical significance for the correlation estimates at the 1% level.

positively associated with firm-level environment-friendly innovation, which is in line with our argument. We also perform the variance inflation factor (VIF) test to check for potential multicollinearity issues. The mean VIF score is 1.77, and the VIF values for our model variables range from 1.11 to 3.04. Any value of VIF above 10 indicates the presence of multicollinearity (Chatterjee and Hadi, 2006; Lardaro, 1993). Hence, our VIF results suggest that multicollinearity does not tend to be a concern for our study, and the econometric techniques we apply are likely to produce unbiased results.

Table 3 illustrates the baseline estimates for CRG and environmental innovation. Here, Column 1 reports the estimated coefficient for CRG without the presence of the control variables, while Column 2 shows the regression estimates after including all the control variables. We account for year and industry effects based on the assumption that unobserved factors particular to years and industries may influence firms' environmentally sustainable innovative capacity to a considerable extent. Accordingly, Column 3 presents the estimated results after controlling for industry and year effects. Finally, Column 4 exhibits the results by incorporating 1-year-lagged values of all the explanatory variables. According to the reported results, as anticipated, CRG reveals a strong positive relationship with the dependent variable, which is statistically significant at the 1% level. This finding suggests that the greater the extent of firm-level climate-focused governance activism, the more environmentally friendly the innovative approaches will be. In simpler terms, we argue that executing climate-focused governance mechanisms enables firms to leverage market prospects by improving existing environmental technologies and creating environmentally sustainable products or services. Our findings support the predictions of the RBV and agency theory, demonstrating that a strong monitoring function, backed by necessary compliance, active involvement through dedicated committees, systematic reporting, external validation, and executive incentives tied to sustainability performance, collectively motivates firms to prioritize a climate-oriented governance arrangement that facilitates environmental innovation. Furthermore, as an organizational factor, CRG ensures the optimal use of available resources, thereby enhancing the firm's ability to allocate resources to promote environmental innovation. Our empirical result is in line with those of earlier studies showing that a higher level of climate governance activism is associated with stronger commitments to addressing climate change (Albitar et al., 2023) and carbon disclosure (Bui et al., 2020). Among the control variables, board size is significant and positively related to firm-level environmental innovation. This indicates that firms with larger boards appear to be environmentally innovative. Further, we find that firm size and liquidity are positively related to environmental innovation across all the models. Overall, this empirical evidence confirms our first hypothesis.

### 4.2 | Tests for Robustness

In order to determine the robustness of the baseline results, we analyze the effect of CRG on environmental performance. Following prior literature (i.e., Lys et al., 2015; Albitar et al., 2023), we treat the environmental pillar score as an alternative to the dependent variable and re-estimate the baseline tests. The environment pillar score is an environmental performance measure sourced from the Refinitiv Eikon Datastream database. The database explains "The environmental pillar evaluates a firm's impact on living and nonliving natural systems, including the air, land, and water, as well as complete ecosystems." Column 1 of Table 4 reports the estimated coefficients. Similar to the baseline models, we use the same set of control variables. Our results reveal that the CRG index is statistically significant at the 1% level and strongly affiliated with the environmental pillar. Therefore, consistent with the baseline results, the outcomes of the robustness test with the alternative dependent variable reveal that CRG drives the environmental performance of a firm. In addition, we also examine whether CRG affects firm-level product design with the objective of recycling or reusing them in order to limit environmental concerns.

**TABLE 3** | Baseline estimates.

| Baseline estimates | (1) Environmental innovation Without controls | (2) Environmental innovation Without industry/ year effects | (3) Environmental innovation With industry/ year effects | (4) Environmental innovation One-year lagged variables |
|---|---|---|---|---|
| Climate risk governance | 8.382*** | 6.423*** | 5.361*** | 3.929*** |
| | (0.255) | (0.333) | (0.340) | (0.352) |
| Board independence | | 0.032 | 0.043 | 0.037 |
| | | (0.029) | (0.029) | (0.030) |
| Board size | | 1.201*** | 0.980*** | 0.677*** |
| | | (0.215) | (0.214) | (0.220) |
| Firm size | | 3.207*** | 5.252*** | 6.143*** |
| | | (0.533) | (0.527) | (0.545) |
| Capital intensity | | −0.545*** | −0.863*** | −0.780*** |
| | | (0.070) | (0.086) | (0.084) |
| Leverage | | −0.042 | −0.049* | −0.026 |
| | | (0.030) | (0.030) | (0.031) |
| Liquidity | | 1.695*** | 3.506*** | 3.689*** |
| | | (0.584) | (0.578) | (0.597) |
| MTB | | −0.199 | −0.031 | −0.094 |
| | | (0.166) | (0.163) | (0.168) |
| Profitability | | 0.036 | −0.047 | −0.049 |
| | | (0.096) | (0.094) | (0.098) |
| Constant | 11.036*** | −48.716*** | −88.375*** | −108.471*** |
| | (0.772) | (8.583) | (8.833) | (9.368) |
| Industry FE | — | — | Included | Included |
| Year FE | — | — | Included | Included |
| Adj $R$-squared | 0.198 | 0.245 | 0.308 | 0.257 |
| $N$ | 4378 | 4378 | 4378 | 4377 |

*Note:* This table presents the baseline regression estimates examining the effect of climate risk governance on environmental innovation. In all four columns, environmental innovation serves as the dependent variable. Column 1 reports the regression estimates without including any control variables. Column 2 presents the results without controlling for industry and year effects. Column 3 incorporates all control variables as well as industry and year-fixed effects. Finally, Column 4 reports the results using 1-year lagged independent variables. The control variables included in the analysis are board independence, board size, firm size, capital intensity, leverage, liquidity, MTB (market-to-book ratio), and profitability. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Accordingly, we apply ecodesigned product data, which is an indicator variable equal to one if a firm provides information on products specifically designed to reuse, recycle, or reduce environmental impact. Column 2 of Table 4 presents the regression results from the effects of CRG on ecodesigned products. All the other control variables remain the same as in the baseline models. The results align with the baseline estimates, as the coefficient of CRG is positive and statistically significant at the 1% level. In addition, in Column 3 of Table 4, we examine the impact of CRG on a firm's ESG performance. The results indicate a strong and statistically significant association between CRG and overall firm-level ESG performance, suggesting that effective CRG contributes significantly to enhancing ESG outcomes. Overall, our findings are robust to the use of alternative measures of firm-level environmental innovation.

Now, as part of using alternative estimation methods to ensure the robustness of the baseline results, we employ a fixed effects panel data estimator[10], including firm and year effects. The application of the fixed effects analysis helps to minimize the potential threat of estimation bias and control the omitted variable bias (Wooldridge, 2020; Hsiao, 2007). In addition, fixed-effect models can capture the unobserved heterogeneity over time and between individual items (Hsiao, 2007). Table 5 (Column 1)

**TABLE 4** | Robustness tests with alternative outcome variables.

| Robustness tests with alternative measures | (1) Environment pillar | (2) Ecodesigned products | (3) ESG score |
|---|---|---|---|
| Climate risk governance (CRG) | 10.310*** | 0.024*** | 6.328*** |
| | (0.212) | (0.004) | (0.157) |
| Board independence | 0.014 | −0.000 | 0.343*** |
| | (0.018) | (0.000) | (0.013) |
| Board size | 0.729*** | 0.006** | 0.328*** |
| | (0.133) | (0.003) | (0.099) |
| Firm size | 5.699*** | 0.033*** | −1.644*** |
| | (0.328) | (0.007) | (0.244) |
| Capital intensity | −0.199*** | −0.009*** | −0.164*** |
| | (0.054) | (0.001) | (0.040) |
| Leverage | −0.015 | 0.001 | 0.022 |
| | (0.018) | (0.000) | (0.014) |
| Liquidity | 0.568 | 0.045*** | −0.738*** |
| | (0.360) | (0.007) | (0.267) |
| MTB | 0.299*** | −0.000 | 0.048 |
| | (0.102) | (0.002) | (0.075) |
| Profitability | 0.276*** | 0.001 | 0.211*** |
| | (0.059) | (0.001) | (0.044) |
| Constant | −94.116*** | −0.640*** | 19.458*** |
| | (5.498) | (0.111) | (4.083) |
| Industry FE | Included | Included | Included |
| Year FE | Included | Included | Included |
| Adj *R*-squared | 0.677 | 0.117 | 0.669 |
| *N* | 4378 | 4377 | 4377 |

*Note:* This table presents the robustness tests for the impact of climate risk governance (CRG). The regression coefficients of CRG are displayed in Columns 1 and 2. In Column 1, the environmental pillar is employed as an alternative measure for environmental innovation, while Column 2 utilizes ecodesigned products as an alternative outcome variable. Both columns maintain the same set of control variables as specified in the baseline models. Standard errors are reported in parentheses. Statistical significance is denoted by ***, **, and * at the 1%, 5%, and 10% levels, respectively.

presents the empirical results of the firm fixed effects regression model. The results are consistent with our baseline findings, as the coefficient for CRG remains highly significant at the 1% level and is positively associated with environmental innovation. Furthermore, Column 2 of Table 5 presents the regression outputs from a high-dimensional fixed-effects (HDFE) model, which incorporates three-way fixed effects—year, firm, and industry. The HDFE approach inherently clusters standard errors at the firm level, ensuring robust inference. This methodological advantage makes HDFE regression more effective than pooled OLS when accounting for three-way fixed effects. The result from the HDFE model aligns with the baseline estimates, as the coefficient for CRG remains highly significant at the 1% level.

We also run the dynamic two-step system GMM regression following the proposition of Arellano and Bond (1991). Similar to Martínez-Ferrero and Frías-Aceituno (2015) and Haque and Ntim (2018), we assume the lagged dependent variable is endogenous and use GMM estimates to test the association between CRG and environmental innovation. Accordingly, as reported in Table 5 (Column 3), the environmental innovation of firm *i* in the year *t* is a function of the first lag of environmental innovation (L.Environmental innovation) accompanied by the main variable of interest. All the other right-hand side variables remain the same as in the baseline regression. As mentioned earlier, we account for the total environmental innovation score sourced from Refinitiv Eikon Datastream as a proxy for environmental innovation. To determine the instrument's validity[11], we run the Hansen test that addresses the overidentifying restrictions. Our findings align with the baseline analysis, which implies that CRG is a significant driver of environmentally sustainable innovation.

**TABLE 5** | Robustness tests with alternative estimation methods.

| Robustness tests | FE model (1) Environmental innovation | HDFE model (2) Environmental innovation | GMM regression (3) Environmental innovation |
|---|---|---|---|
| L.Environmental innovation | | | 0.953*** |
| | | | (0.098) |
| CRG | 3.373*** | 3.373*** | 4.955*** |
| | (0.317) | (0.592) | (1.813) |
| Board independence | 0.073*** | 0.073* | −0.138 |
| | (0.025) | (0.039) | (0.179) |
| Board size | 0.381** | 0.381 | 2.093* |
| | (0.185) | (0.277) | (1.080) |
| Firm size | 0.301 | 0.301 | −5.479 |
| | (0.787) | (1.487) | (7.149) |
| Capital intensity | −0.246** | −0.246 | −5.901* |
| | (0.116) | (0.177) | (3.502) |
| Leverage | 0.013 | 0.013 | 1.030 |
| | (0.033) | (0.052) | (1.002) |
| Liquidity | −0.393 | −0.393 | 8.200 |
| | (0.629) | (0.885) | (25.911) |
| MTB | 0.062 | 0.062 | −2.942 |
| | (0.143) | (0.204) | (3.156) |
| Profitability | 0.186** | 0.186** | −5.905* |
| | (0.077) | (0.093) | (3.181) |
| Constant | 48.381*** | 9.396 | 126.956 |
| | (14.252) | (25.106) | (175.485) |
| Firm FE | Included | Included | Included |
| Year FE | Included | Included | Included |
| Industry FE | | Included | |
| Arellano–Bond test (*AR*-1) | | | 0.003 |
| Arellano–Bond test (*AR*-2) | | | 0.104 |
| Sargan's test (*p* value) | | | 0.117 |
| Hansen's test (*p* value) | | | 0.231 |
| *N* | 4378 | 4378 | 3980 |

*Note:* This table presents additional robustness tests assessing the impact of climate risk governance (CRG). Column 1 reports the results using firm fixed effects, while Column 2 provides the regression results after controlling for triple fixed effects (firm, industry, and year) under the HDFE approach. Column 3 presents estimates from the generalized method of moments (GMM) regression model. In the GMM specification, the lagged dependent variable (L.Environmental innovation) is considered endogenous. Environmental innovation serves as the dependent variable in both columns. The analysis includes the same set of control variables as in the baseline models. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

### 4.3 | Channel Analysis

Our baseline results reveal that CRG is positively associated with firm-level environmental innovation scores. However, a natural follow-up question is about the channel by which CRG supports environmental innovation. In order to answer this question, we argue that climate risk measures encourage firms to commit larger amounts of environmental spending, which in turn increases firm-wide capacity and the potential for environmental innovation. Using the channel analysis technique, we assess a potential mechanism (environmental investment) through which CRG tends to facilitate environmental innovation. The prevailing consensus suggests that the development and adoption of ecofriendly technologies and approaches require a credible and systematic financial commitment. Accordingly, this study seeks to examine whether this firm-level spending on environmental initiatives serves as a potential channel through which CRG influences environmental innovation. Following previous studies (Alam et al., 2022; Miller and del Carmen Triana, 2009; Safiullah et al., 2021), we perform the channel analysis in two steps. The channel analysis approach operates as a causal chain, considering the mediation effect. The fundamental concept of mediation posits that the mediator ($M$) transmits the effect of the independent variable ($X$) on the outcome variable ($Y$). In the first stage, we investigate the association between the CRG index and environmental investments, and in the second stage, we analyze the effect of CRG on environmental innovation after controlling for environmental investment. Notably, consistent with Atif et al. (2022) and Pekovic et al. (2018), environmental investment is measured using the natural logarithm of firm-level annual environmental expenditure.

Table 6 reports the empirical results of the channel analysis based on firm-level environmental investment. In Column 1, the dependent variable is environmental investments, and we obtain evidence that CRG exhibits a strong positive relationship with environmental investments as the estimated coefficient is significant at the 1% level. This result suggests that the more firm-level climate-focused governance activism

**TABLE 6** | Channel analysis.

| Channel analysis | (1) Environmental investment | (2) Environmental innovation |
|---|---|---|
| Environmental investment | | 2.703*** |
| | | (0.970) |
| Climate risk governance | 0.572*** | 3.922*** |
| | (0.077) | (0.619) |
| Board independence | 0.020*** | 0.005 |
| | (0.007) | (0.032) |
| Board size | 0.013 | 0.979*** |
| | (0.048) | (0.213) |
| Firm size | 0.983*** | 2.882*** |
| | (0.120) | (1.001) |
| Capital intensity | 0.008 | −0.865*** |
| | (0.020) | (0.086) |
| Leverage | 0.012* | −0.079** |
| | (0.007) | (0.031) |
| Liquidity | 0.303** | 2.907*** |
| | (0.131) | (0.616) |
| MTB | 0.051 | −0.144 |
| | (0.037) | (0.168) |
| Profitability | 0.039* | −0.128 |
| | (0.021) | (0.099) |
| Constant | −19.076*** | −44.874** |
| | (2.003) | (17.938) |
| Industry FE | Included | Included |
| Year FE | Included | Included |
| Adjusted $R$-squared | 0.277 | 0.309 |
| $N$ | 4378 | 4378 |

*Note:* This table presents the results of the channel analysis, examining environmental investment as the mediating variable. Panel A reports the regression estimates of climate risk governance (CRG) on environmental investment. Panel B presents the regression estimates of environmental innovation on CRG while controlling for environmental investment. The analysis includes the same set of control variables as in the baseline models. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

there is, the higher the level of environmental spending. In other words, a robust CRG framework is positively associated with a higher level of environmental spending. Column 2 in Table 6 shows the estimated results of the impact of CRG on environmental innovation after controlling for environmental investments. The coefficient of environmental investment is positive and statistically significant at the 5% level. All the other right-hand side variables remain the same in Columns 1 and 2 as in the baseline models. The channel analysis results indicate that firms more committed to CRG tend to invest

**TABLE 7** | Analysis of the impact of CRG components.

| Analysis of CRG components | (1) Environmental innovation | (2) Environmental innovation |
|---|---|---|
| Climate risk and opportunities | 8.725*** | 5.369*** |
| | (1.218) | (1.208) |
| Sustainability/environmental committee | 12.201*** | 9.739*** |
| | (1.301) | (1.276) |
| Sustainability reporting | 11.571*** | 7.847*** |
| | (1.277) | (1.274) |
| External assurance | 2.992*** | 2.465** |
| | (1.094) | (1.074) |
| Sustainability-linked incentives | 1.432 | −0.644 |
| | (0.971) | (0.960) |
| Board independence | | 0.042 |
| | | (0.029) |
| Board size | | 0.929*** |
| | | (0.212) |
| Firm size | | 4.977*** |
| | | (0.526) |
| Capital intensity | | −0.866*** |
| | | (0.086) |
| Leverage | | −0.048* |
| | | (0.029) |
| Liquidity | | 3.338*** |
| | | (0.575) |
| MTB | | −0.095 |
| | | (0.163) |
| Profitability | | −0.058 |
| | | (0.094) |
| Constant | 4.122* | −82.896*** |
| | (2.120) | (8.827) |
| Industry FE | Included | Included |
| Year FE | Included | Included |
| Adj $R$-squared | 0.270 | 0.318 |
| $N$ | 4378 | 4378 |

*Note:* This table presents the regression estimates for five specific components of climate risk governance (CRG). The components analyzed include climate risk and opportunities, sustainability/environmental committee, sustainability reporting, external assurance, and sustainability-linked incentives. Environmental innovation serves as the dependent variable in both Columns 1 and 2. The same set of control variables as in the baseline models is included in Column 2. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

**TABLE 8** | Analysis of subsamples (small vs. large firms).

| Subsample analysis | Column 1: Small_Firms Environmental innovation | Column 2: Small_Firms Environmental innovation | Column 3: Large_Firms Environmental innovation | Column 4: Large_Firms Environmental innovation |
|---|---|---|---|---|
| Climate risk governance (CRG) | 2.935*** | | 3.383*** | |
| | (0.418) | | (0.492) | |
| Climate risk and opportunities | | −0.904 | | 3.222** |
| | | (1.143) | | (1.588) |
| Environmental committee | | 7.364*** | | 8.787*** |
| | | (1.273) | | (1.646) |
| Sustainability reporting | | 4.854*** | | 4.796*** |
| | | (1.079) | | (1.615) |
| External assurance | | 3.822*** | | 1.448* |
| | | (1.396) | | (1.255) |
| Sustainability-linked incentives | | −1.686 | | −0.956 |
| | | (1.062) | | (1.089) |
| Board independence | 0.135*** | 0.141*** | 0.065 | 0.060 |
| | (0.032) | (0.032) | (0.042) | (0.042) |
| Board size | −0.392 | −0.467* | 0.920*** | 0.844*** |
| | (0.257) | (0.255) | (0.266) | (0.265) |
| Firm size | −4.393*** | −4.495*** | 1.929 | 1.685 |
| | (1.106) | (1.097) | (1.545) | (1.536) |
| Capital intensity | −0.587** | −0.575** | −0.055 | −0.054 |
| | (0.248) | (0.246) | (0.127) | (0.126) |
| Leverage | 0.103*** | 0.113*** | −0.101 | −0.086 |
| | (0.036) | (0.035) | (0.068) | (0.068) |
| Liquidity | 0.091 | 0.039 | −1.341 | −1.627 |
| | (0.680) | (0.675) | (1.312) | (1.305) |

(Continues)

**TABLE 8** | (Continued)

| Subsample analysis | Column 1: Small_Firms Environmental innovation | Column 2: Small_Firms Environmental innovation | Column 3: Large_Firms Environmental innovation | Column 4: Large_Firms Environmental innovation |
|---|---|---|---|---|
| MTB | 0.311** | 0.239 | −0.429 | −0.457 |
| | (0.148) | (0.148) | (0.295) | (0.294) |
| Profitability | 0.077 | 0.083 | 0.251* | 0.235 |
| | (0.087) | (0.086) | (0.145) | (0.144) |
| Constant | 103.929*** | 106.070*** | 21.080 | 24.534 |
| | (17.791) | (17.681) | (27.657) | (27.490) |
| Firm fixed effects | Yes | Yes | Yes | Yes |
| Year-fixed effects | Yes | Yes | Yes | Yes |
| Adjusted $R$-squared | 0.766 | 0.771 | 0.740 | 0.743 |
| $N$ | 2233 | 2233 | 2156 | 2156 |

*Note:* This table presents a subsample analysis based on firm size, distinguishing between small and large firms. Columns 1 and 3 report the regression estimates of the overall climate risk governance (CRG) index on the small and large subsamples, respectively. Similarly, Columns 2 and 4 highlight the effects of the five individual CRG components on the small and large subsamples, respectively. The same set of control variables as in the baseline models is included across all specifications. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

more in environmental initiatives, which serves as the mechanism linking CRG and environmental innovation at the firm level. Hence, this empirical evidence provides support for our second hypothesis.

In addition, we perform a specialized $t$-test called the Sobel test to assess the significance of the mediation effect in the context of the channel analysis. The Sobel test score indicates that the mediation effect of environmental investment in the relationship between corporate CRG and environmental innovation is statistically significant. The Sobel $Z$-score of 2.81 corresponds to a $p$-value of 0.0049, which is well below the conventional threshold of 0.01 ($p < 0.05$). This finding provides strong evidence to reject the null hypothesis, confirming that the indirect effect of CRG on ecoinnovation through environmental investment is significant. Overall, this evidence suggests that environmental investment serves as a significant mediator in the relationship between CRG and environmental innovation. Depending on the strength of the direct effect, spending on environmental initiatives may partially or fully mediate this association.

### 4.4 | Analysis of CRG Components and Subsamples

It is argued that climate-focused governance components are better suited when integrated to form an index (Bui et al., 2020). Nevertheless, we look into the individual CRG components as part of our further analysis. Accordingly, to obtain further insights, we include all the CRG components separately as the right-hand side variables to examine how impactful they are in explaining firm-level environmental innovation. Table 7 presents the estimated results, and as in the baseline model, we also use all the other control variables. We find that climate risk opportunities and risks, sustainability committees, sustainability reporting, and external assurance exhibit a positive association with environmental innovation. The results in Columns 1 and 2 of Table 7 reveal that all four coefficients are statistically significant, suggesting that each of these climate governance components plays a vital role individually in strengthening environmental innovation. Our results align with those of Albitar et al. (2023) as they document a positive relationship between the presence of a board-level sustainability committee, sustainability reporting, and greater corporate commitments to handling climate change issues. However, unlike Albitar et al. (2023), we detect that sustainability-linked executive compensation is not statistically significant as a standalone driver of environmental innovation. This finding is comparable to that of Haque (2017), who reports that ESG-based compensation does not affect actual carbon performance.

Although the constituents of the S&P 500 are widely recognized for their substantial market capitalizations, there are significant variations in their sizes. For this reason, it is not irrational to anticipate that the size of a firm is likely to affect the complex association in force. Hence, to gain a deeper understanding of the link between our variables of interest, we break down our entire sample into large and small firms (as denoted by firm size) and conduct sample-split analysis[12]. First, we examine the relationship between the overall CRG

**TABLE 9** | Instrumental variable (2SLS) approach.

| IV analysis | (Panel 1) First stage CRG | (Panel 2) Second stage Environmental innovation |
|---|---|---|
| UNGC | 0.966*** | |
| | (0.055) | |
| Climate risk governance (CRG)—fitted | | 7.683*** |
| | | (1.317) |
| Board independence | 0.0160*** | 0.0260 |
| | (0.00151) | (0.0329) |
| Board size | 0.0664*** | 0.897*** |
| | (0.0112) | (0.230) |
| Firm size | 0.717*** | 4.303*** |
| | (0.0255) | (0.958) |
| Capital intensity | 0.0200*** | −0.883*** |
| | (0.0045) | (0.0877) |
| Leverage | 0.00172 | −0.0551* |
| | (0.0016) | (0.0296) |
| Liquidity | −0.0414 | 3.608*** |
| | (0.0304) | (0.580) |
| MTB | 0.00856 | −0.0634 |
| | (0.00859) | (0.163) |
| Profitability | 0.0226*** | −0.0671 |
| | (0.005) | (0.093) |
| Constant | −12.29*** | −71.54*** |
| | (0.426) | (16.31) |
| Industry FE | Included | Included |
| Year FE | Included | Included |
| *N* | 4378 | 4378 |
| **Model fits** | | |
| *F*-statistic | | 54.03*** |
| Anderson canon. corr. LM statistic | | 292.233*** |
| Weak identification test | | 311.705 |
| Cragg–Donald Wald *F*-statistic | | [0.001] |
| Stock–Yogo weak ID test critical values: 10% maximal IV size | | 16.38 |

*Note:* This table presents the results of the instrumental variable approach used to address potential endogeneity. The United Nations Global Compact (UNGC) serves as the exogenous instrument in this analysis. In the first stage, CRG is the dependent variable, while in the second stage, the fitted values of CRG are employed to predict environmental innovation. The same set of control variables as in the baseline models is included. Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

score and environmental innovation. We report the results in Columns 1 and 3 of Table 8. We find no qualitative difference between the estimated coefficients of CRG for small and large firms as the results are statistically significant at the 1% level, and the magnitudes of the coefficients are nearly identical. We then evaluate the impact of individual components of CRG on environmental innovation in Columns 2 and 4 of Table 8. However, the analyses of individual CRG components for the subsamples indicate that, relative to their larger counterparts,

**TABLE 10A** | Propensity score matching estimates.

| Propensity score matching | Panel A Industry above-avg dummy | Panel B Environmental innovation |
|---|---|---|
| Climate risk governance | | 6.241*** |
| | | (1.471) |
| Board independence | −0.009*** | −0.0224 |
| | (0.0018) | (0.108) |
| Board size | 0.125*** | 3.434*** |
| | (0.0120) | (0.618) |
| Firm size | 0.301*** | 12.21*** |
| | (0.0286) | (1.401) |
| Capital intensity | −0.013*** | −1.238*** |
| | (0.0040) | (0.210) |
| Leverage | 0.007*** | −0.245*** |
| | (0.0018) | (0.0875) |
| Liquidity | −0.215*** | −1.110 |
| | (0.0365) | (1.844) |
| MTB | 0.0149 | −0.374 |
| | (0.0093) | (0.394) |
| Profitability | 0.037*** | 0.217 |
| | (0.0058) | (0.259) |
| Constant | −6.758*** | −212.6*** |
| | (0.490) | (27.10) |
| Likelihood ratio ($chi^2$)/*F*-statistics | 568.88*** [0.000] | 11.20*** [0.000] |
| Pseudo *R*-squared | 0.1501 | |
| Adjusted *R*-squared | | 0.221 |
| *N* | 4378 | 683 |

*Note:* This table presents the results of the propensity score matching (PSM) analysis. Panel A reports the prematching estimates based on the full sample, while Panel B presents the postmatch regression results using paired firm-year observations. In Panel A, the outcome variable is a dummy indicating whether a firm's CRG score is above the industry average. In Panel B, environmental innovation serves as the main dependent variable. The same set of control variables as in the baseline models is included across all regressions. Standard errors are reported in parentheses. Statistical significance is denoted by ***, **, and * for the 1%, 5%, and 10% levels, respectively.

smaller firms are less aware of climate change risk and opportunities. Our results also reveal that the presence of an environmental committee, sustainability reporting, and external assurance of sustainability reporting appear to be significant drivers of environmental innovation, irrespective of the size of the firms.

Further, we do not detect any linkage between executive incentives for sustainability or environmental performance and environmental innovation for either large or small groups of firms, which is in line with the findings of Albitar et al. (2023). In sum, our results imply that when individual CRG components are compared, the effect of corporate CRG on environmental innovation is more pronounced for large firms. This may be because large firms tend to have limited financial challenges and a better mix of resources, allowing them to recognize and cope with environmental worries more effectively (de Villiers et al., 2011), giving rise to their environmental innovation. Large firms also face greater societal pressure and are subject to a strict regulatory compulsion to get involved in environmentally friendly projects or green initiatives than their smaller counterparts (Wang and Sueyoshi, 2018).

### 4.5 | Identifications

Our empirical results may indicate correlation rather than causation due to the endogeneity bias. We assume that our test variable, CRG, may suffer from an omitted variable and sample selection problems, and as a consequence, it might not reflect a systematic relationship with the dependent variable (environmental innovation). Therefore, to overcome this identification challenge, we employ two specific econometric techniques, that is, IV analysis and a PSM model, to check the causal association between CRG and environmental innovation.

IV analysis calls for an instrument that is correlated with the endogenous regressor (i.e., CRG) but which does not exert any direct impact on the explained variable (environmental innovation) except through that endogenous regressor (Atif et al., 2021). To achieve this, following Haque and Ntim (2018) and Xue et al. (2019), we use the United Nations Global Compact (UNGC) in this study as an exogenous instrument to run the IV analysis. The intuition behind the selection of the UNGC as an instrument is that firms that are signatories to the UNGC are more likely than others to address climate change issues and integrate climate-focused components into their governance frameworks. The UNGC is considered a comprehensive policy directive for firms to align strategies and operations with universal principles on human rights, labor, the environment, and anticorruption[13]. Thus, it is reasonable to believe that becoming a signatory of the UNGC, which is voluntary, will not directly affect firm-level environmental innovation.

We conduct the IV analysis using a two-stage least squares (2SLS) estimate. Through the first-stage regression in Column 1 of Table 9, we examine the relevance of our instrument. In line with the requirements for a good instrument, we find that the exogenous variable UNGC is positively linked to CRG in Column 1, and the coefficient of UNGC is statistically significant at the 1% level. The *F*-statistic value is high, and the CD F weak instrument test is 0.001, rejecting the null hypothesis that the instrument is weak (Cragg and Donald, 1993; Stock and Yogo, 2005). Then, the results of the second-stage regression are shown in Column 2 of Table 9. We use the predicted CRG (fitted CRG values) from the first-stage estimation to regress environmental innovation. The estimated coefficient on the predicted CRG is significant at the 1% level in Column 2. All the other right-hand side variables are the same in the IV models as in the baseline tests. Industry and year-fixed effects are also controlled. Therefore, our main empirical result remains robust and confirms a positive and significant relationship between CRG and environmental innovation.

We also employ a PSM estimator (Atif et al., 2021; Alam et al., 2019) to address endogeneity concerns that may originate from the misspecification of empirical models. To start with, we calculate the above-average industry dummy variable, which is set to 1 if the CRG value is above the industry average value and 0 otherwise. Then, in the first stage, we apply probit regression to explain the above-average industry indicator variable. Like the baseline models, we use all the right-hand side explanatory variables in this prematch first-stage estimation. The PSM

**TABLE 10B** | *t*-tests on firm characteristics between the treatment and control groups.

| | Mean | | | | |
|---|---|---|---|---|---|
| **Variable** | **Treated** | **Control** | **Mean difference** | ***t*-statistic** | **$p > \|t\|$** |
| Board independence | 82.098 | 83.056 | −0.958 | −1.39 | 0.164 |
| Board size | 11.614 | 11.613 | 0.001 | 0.01 | 0.990 |
| Firm size | 17.06 | 17.087 | −0.027 | −0.53 | 0.599 |
| Capital intensity | 7.1771 | 7.4992 | −0.3229 | −0.87 | 0.384 |
| Leverage | 32.232 | 31.739 | 0.493 | 0.62 | 0.533 |
| Liquidity | 1.4017 | 1.4398 | −0.0373 | −0.95 | 0.342 |
| MTB | 4.1066 | 4.0791 | 0.0276 | 0.16 | 0.875 |
| Profitability | 8.5139 | 8.5675 | −0.0534 | −0.19 | 0.852 |

*Note:* This table reports the *t*-test statistics and corresponding *p*-values for firm attributes (i.e., all control variables) comparing the treatment and control groups to assess the quality of propensity score matching (PSM).

estimates are reported in Table 10A. Column 1 of Table 10 presents the results of the prematch estimates with the full sample. We estimate the propensity score utilizing the nearest neighbor matching with a 1% radius matching technique (Shipman et al., 2017). After the investigation, 683 firm-year observations for the industry above-average dummy have been matched. We finally run the postmatch regression based on the paired firm-year observations through an OLS model. Column 2 of Table 10 shows the estimated results, revealing that CRG strongly affects firm-level environmental innovation as the coefficient of CRG in the postmatch diagnostic regression is significant at the 1% level. We find that both the likelihood ratio in the probit model and the *F*-statistic in the postmatch regression are statistically significant with a *p*-value of 0.000, which ensures the model fit and validity of the association between the regressors and the outcome variable (Chib, 1998). The *t*-test results, presented in Table 10B, confirm that the treatment and control groups are well-balanced. The firm characteristics (covariates) show no

**TABLE 11** | Heckman's model for sample selection.

| Heckman's selection model | Stage 1—Probit<br>Above-average CRG | Stage 2—OLS model<br>Environmental innovation |
|---|---|---|
| Industry_AVG | −0.260** | |
| | (0.118) | |
| Climate risk governance (CRG) | | 5.213*** |
| | | (0.317) |
| Board independence | 0.013*** | 0.010 |
| | (0.001) | (0.026) |
| Board size | 0.073*** | 1.007*** |
| | (0.009) | (0.186) |
| Firm size | 0.652*** | 6.116*** |
| | (0.021) | (0.792) |
| Capital intensity | 0.013*** | −0.987*** |
| | (0.004) | (0.117) |
| Leverage | 0.000 | −0.107*** |
| | (0.001) | (0.035) |
| Liquidity | −0.038 | 3.085*** |
| | (0.026) | (0.629) |
| MTB | 0.006 | −0.019 |
| | (0.007) | (0.143) |
| Profitability | 0.017*** | −0.086 |
| | (0.004) | (0.077) |
| IMR (inverse Mills ratio) | | −34.811*** |
| | | (5.120) |
| Constant | −11.030*** | 4.936 |
| | (0.356) | (12.658) |
| Industry FE | Included | Included |
| Year FE | Included | Included |
| Wald's chi$^2$ | 0.000*** | |
| Adjusted $R$-squared | | 0.313 |
| $N$ | 4378 | 4375 |

*Note:* This table presents the results of the two-stage Heckman selection model. Stage 1 reports the first-stage probit model, which uses industry above-average climate risk governance (CRG) values as the exclusion restriction to estimate the probability of a firm having an industry above-average CRG score. To address sample selection bias, the inverse Mills ratio is derived from the estimated coefficients in the first stage. In the second stage, the inverse Mills ratio is incorporated as an additional control variable to explain environmental innovation. The same set of control variables as in the baseline models is included across all regressions. Standard errors are reported in parentheses. Statistical significance is denoted by *, **, and *** for the 10%, 5%, and 1% levels, respectively.

**TABLE 12** | Investigation of reverse causality.

| Test for reverse causality | (1) | (2) |
|---|---|---|
| **Variables** | **Environmental innovation** | **Environmental innovation** |
| Climate risk governance $_{t-2}$ | 3.359*** | |
| | (0.317) | |
| Climate risk governance $_{t-3}$ | | 2.638*** |
| | | (0.299) |
| Board independence | 0.069** | 0.083*** |
| | (0.030) | (0.030) |
| Board size | 0.805*** | 0.854*** |
| | (0.219) | (0.220) |
| Firm size | 6.523*** | 7.130*** |
| | (0.536) | (0.528) |
| Capital intensity | −0.776*** | −0.760*** |
| | (0.085) | (0.085) |
| Leverage | −0.034 | −0.038 |
| | (0.031) | (0.031) |
| Liquidity | 3.699*** | 3.641*** |
| | (0.598) | (0.600) |
| MTB | −0.121 | −0.096 |
| | (0.169) | (0.169) |
| Profitability | −0.039 | −0.016 |
| | (0.098) | (0.098) |
| Constant | −117.339*** | −126.785*** |
| | (9.139) | 0.083*** |
| Industry FE | Included | Included |
| Year FE | Included | Included |
| Adj $R$-squared | 0.255 | 0.249 |
| $N$ | 4376 | 4375 |

*Note:* This table presents the regression results from the lagged variable analysis conducted to mitigate concerns of reverse causality. In Column 1, the two-period lagged value of CRG is used as the independent variable, while Column 2 employs the three-period lagged CRG variable. Environmental investment serves as the dependent variable in both columns. The same set of control variables as in the baseline models is included across all regressions. Standard errors are reported in parentheses. Statistical significance is denoted by *, **, and *** for the 10%, 5%, and 1% levels, respectively.

significant differences between the groups after matching, as indicated by the higher $p$-values. This suggests that the firm-year observations in both groups are comparable with respect to observable attributes.

Overall, the empirical evidence from our PSM analysis[14] suggests that CRG has a substantial impact on the capacity of firms to engage in environmental innovation; hence, we conclude that our baseline estimates are not influenced by endogeneity bias.

### 4.6 | Heckman's Model and Tests for Reverse Causality

Although we address the endogeneity concerns through two different identification strategies, another issue could arise in the sample selection as our sample selection process is not random. For this reason, we run the two-step Heckman selection model to remedy potential issues linked to sample selection. In the first stage, as reported in Column 1 of Table 11, we employ the probit model that utilizes the CRG index as the dependent variable. All the other control variables remain the same as in the baseline tests. We calculate the inverse Mills ratio (IMR) using the parameters estimated in the first stage. We then control for the sample selection issue via the IMR by incorporating it as an independent variable in the second-stage estimates derived from an FE model in Column 2 of Table 11. The empirical results are compatible with the baseline findings, suggesting a positive and significant relationship between CRG and environmental innovation approaches. Hence, we argue that our empirical results are unlikely to be driven by sample selection bias.

We also investigate concerns associated with reverse causality. Faleye et al. (2014) argue that using a time lag of more than 1 year for the main explanatory variables can effectively mitigate any potential issues related to reverse causality. Moreover, it is argued that if the distantly lagged explanatory variables exhibit statistical significance, reverse causality becomes less apparent, as evidenced by earlier studies (Faleye, 2007; Cheng, 2008). Following this argument, we run additional tests to eliminate the issue of reverse causality. Table 12 reports the empirical results, where in Column 1, we use two-period lagged values of the main variable of interest, CRG. In Column 2, we include the three-period lagged values of CRG. In accordance with the baseline models, we employ the same set of control variables along with industry and year-fixed effects. Both models use one-period lagged versions of these control variables. The dependent variable in both models is environmental innovation. Our results remain consistent across the models, as 2-year and 3-year lagged CRG variables are positive and statistically significant at the 1% level. Overall, this evidence suggests that the reverse causality issue is not likely to have an impact on our findings.

## 5 | Discussion and Conclusion

### 5.1 | Discussion of Key Findings

Climate change has attracted mounting interest from academics, practitioners, and regulators over the past decade due to the vast increase in the levels of carbon emissions and particularly their adverse effects on the environment, socioeconomic structure, and overall ecosystems. In this connection, it has also been frequently argued that firm-level environmentally sustainable innovative processes, along with responsible business policies, can contribute substantially to carbon reduction, environmental safety, and long-term sustainability. In this study, we investigate the effects of corporate CRG mechanisms on environmental innovation using 4378 firm-year observations collected from nonfinancial carbon-sensitive US firms between 2011 and 2021. Drawing on the RBV and agency theory, our study reveals that a higher level of CRG activism leads to greater environmental innovation. However, this association is more pronounced for large firms in contrast to their smaller counterparts. Our baseline findings remain robust after we introduce alternative variables and different estimation techniques. Our results are consistent with previous studies linking climate governance activism to stronger climate change commitments (Albitar et al., 2023) and carbon disclosure (Bui et al., 2020). Next, by applying channel analysis, this study presents unique empirical evidence that CRG facilitates environmentally sustainable innovations through the mechanism of environmental investment. Therefore, this finding contributes to the current body of knowledge (Alam et al., 2022; Li et al., 2020; Lyandres and Palazzo, 2016), suggesting that the pursuit of CRG encourages firm-level expenditure on environmental initiatives, thereby increasing firm-level scope and capacity for environmental innovation. By looking into the individual components of CRG, we show that awareness of climate risk and opportunities, a board-level sustainability committee, sustainability reporting, and external assurance of sustainability reporting are positively and significantly related to environmental innovation. Our results align with Albitar et al. (2023), who document a positive relationship between board-level sustainability committees, sustainability reporting, and stronger corporate commitments to addressing climate change. However, sustainability-linked executive compensation does not show a positive association with environmental innovation in US firms, consistent with Haque (2017), which suggests that this type of compensation does not influence actual carbon performance. Further, we employ an instrumental variable approach and the PSM method to address potential endogeneity concerns. The empirical results from the identification strategies confirm that endogeneity concerns are unlikely to influence the baseline results. Our study extends the available climate governance literature by offering novel empirical evidence that CRG activism has a significantly positive effect on environmental innovation.

### 5.2 | Policy Implications

This study provides noteworthy insights to corporate board members, chief executive officers, and other senior executive managers about the likely review and reorganization of the conventional governance structure, with an explicit focus on climate change issues, compliance with the regulatory framework, and implementing environmentally sustainable business actions. In addition, executive management needs to recognize that an effective CRG framework plays a pivotal role in ensuring credible and systematic investment in environmental initiatives. This, in turn, fosters environmentally sustainable innovation and also reduces the likelihood of greenwashing practices. Considering the empirical evidence, policymakers and regulators should establish clear and legally binding targets to promote substantive climate governance activism at the firm level, focusing on five CRG mechanisms and environmentally sustainable innovation, specifically for high-carbon emitting firms. In parallel, they should develop strong monitoring driven by critical expertise, transparency, and accountability. More importantly, since sustainability-linked executive compensation policy does not appear to function as an individual determinant of environmental innovation, policymakers should develop specific guidelines for firms that offer such compensation. These guidelines should include compulsory targets that categorically contribute to the firm's sustainability performance, environmental impact reduction, and innovation. In this regard, a robust enforcement mechanism needs to be established to monitor compliance and impose penalties for persistent noncompliance. Further, the insights from this research are expected to persuade relevant government authorities to provide targeted support and incentives for firms that prioritize environmental innovation, thereby supporting long-term sustainability and advancing decarbonization efforts. Similarly, lenders, including banks and other financial institutions, should assess carbon-sensitive firms' environmental awareness and CRG profiles. Based on this evaluation, they could offer favorable financial services such as lower-interest loans, green bonds, and other customized financial assistance. These measures would help carbon-sensitive firms spend on environmental initiatives to support sustainable innovation. Another potential policy implication of this study would be to encourage collaboration between the private sector, academia, and public entities to facilitate knowledge-sharing and capacity-building. CRG strategies might be more effective when firms share best practices, exchange information resources, and collaborate for further improvement. To make the most of this collaboration, it would be beneficial to establish industry consortia or innovation hubs. Our findings also strongly urge politicians, environmentalists, and related stakeholders in the leading economies and the major polluting nations to substantially increase their investments in environmental initiatives, with the goal of promoting environmental innovation in alignment with the Paris Agreement. Overall, this study makes a valuable contribution to the ongoing global discussion regarding corporate climate-responsible governance and its impact on managing real-world climate change issues.

### 5.3 | Limitations and Future Directions

While this study provides unique insights into the positive association between corporate CRG and environmental innovation, it also has several limitations that suggest potential avenues for future research. We lay the groundwork for prospective scholars interested in this area by providing the first empirical evidence of the relationship between CRG and environmental innovation based on the data obtained from US firms. To obtain new insights, future research could extend our work by performing a multicountry comparison, particularly by looking at the United Kingdom, Canada, China, and other major European nations. Moreover, our study is based on publicly traded S&P 500 firms that are responsible for both Scope 1 and Scope 2 emissions. For this reason, our empirical findings are not likely to be generalizable to small-cap, mid-sized, and unlisted firms. Therefore, future research could offer unique insights by investigating whether the takeaways this study provides hold for small-cap, mid-sized, or unlisted firms. It would also be beneficial for future researchers to explore other relevant factors such as climate change accords, environmental legislation, and the cultural and ethnic diversity of both members of the sustainability committee and the CEO. Once the necessary data become available, future studies might also investigate the impact of artificial intelligence and robotics on ecoinnovation capacity and environmental sustainability. These factors might be able to influence environmental innovation alongside climate-focused governance mechanisms. Finally, since we depend on publicly available data to measure indicators such as CRG, environmental innovation, and other firm-level control variables, these measures might not accurately represent real-world sustainability practices and firm performance. Hence, future studies could benefit from practical investigations into how the CRG components function in a realistic context, specifically from the perspective of carbon-sensitive firms. Such investigations should differentiate between firms that have effectively implemented the CRG, those that have not prioritized it, and those with minimal engagement. Gathering these diverse perspectives would provide valuable insights into the actual scenario of CRG quality, managerial perceptions, and stakeholder expectations. In this regard, structured interviews, focused group discussions, and relevant case studies could facilitate in-depth analyses.


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### Endnotes

[1] Table A1 defines all the CRG components, while Table A2 lists the CRG components along with the relevant references.

[2] Environmental investment is operationally defined as the natural logarithm of a firm's annual environmental expenditure (Atif et al., 2022; Pekovic et al., 2018).

[3] Regional alliances in the United States, policymakers, and environmental advocates are intensifying efforts to encourage corporate adoption of comprehensive ESG disclosures and environmentally sustainable practices. For instance, the Regional Greenhouse Gas Initiative (RGGI) is a market-based regulatory program involving several eastern states, including New York, New Jersey, and Massachusetts among others, aimed at reducing greenhouse gas emissions. Further advancing corporate accountability, California's climate accountability package, enacted in October 2023, mandates private firms and investors to disclose climate-related financial risks. This initiative underscores the emphasis on corporate transparency and responsibility in addressing climate change.

[4] Banks and other financial institutions are not included in our final sample because they are not liable for direct carbon emissions. Furthermore, due to the regulatory framework imposed on banks and other financial institutions, they adhere to governance mechanisms different from those of nonfinancial firms (Luo and Tang, 2020; Orazalin, 2020).

[5] https://www.greenelement.co.uk/blog/carbon-footprint-scope-1-2-3/ (Accessed on January 30, 2024)

[6] Scope 1: This encompasses all types of direct emissions from owned or controlled sources.

[7] Scope 2: The reporting firm categorizes indirect emissions, which include the production of purchased electricity, cooling, steam, and heating. Scope 2, for example, includes electricity from energy suppliers to power up computers.

[8] Upon examining environmental R&D expenditures and the number of environment-related patents as a proxy of environmental innovation, we face significant challenges related to data availability. A critical issue lies in the absence of regulatory mandates requiring US firms to report these variables, leading to inconsistent and incomplete datasets. Further, we observe numerous instances of missing data, even among prominent carbon-sensitive nonfinancial firms expected to prioritize environmental innovation.

[9] Tables A1 and A2 list all five CRG components with definitions and references respectively.

[10] We also conduct a Fisher-type (ADF-Fisher) test for the unit root. The test results confirm that the unit root is not an issue in our dataset, as the variables used in the panel fixed-effects model meet stationarity conditions. The stationarity feature of our panel data forms a strong empirical foundation for the panel fixed-effects model. This feature also ensures that our findings are not driven by spurious relationships.

[11] The main conditions for a valid instrument are relevance (Corr $[Z, X] \neq 0$) and exogeneity (Corr $[Z, u] = 0$). This diagnostic test will validate whether the instrument is exogenous. Hence, Ho = instrument is exogenous. And, if $H_0$ cannot be rejected because of a higher $p$-value, it will prove the instrument's validity.

[12] Apart from the above, we conduct additional subsample analysis to examine cross-sectional differences between firms. Specifically, we have categorized firms based on the strength of their climate risk governance, distinguishing those with high scores for climate risk governance from those with low scores in climate risk governance. Our findings indicate that firms with stronger climate risk governance are more likely to drive environmental innovation, whereas those with weaker climate risk governance fail to yield statistically significant results. Although we do not present these results in a tabulated form, this analysis underscores the critical role of robust climate risk governance in fostering environmentally friendly innovation.

[13] https://www.unglobalcompact.org/what-is-gc (Accessed on July 25, 2023).

[14] In addition to the propensity score matching (PSM) estimate discussed above, we run additional PSM regressions using two other commonly employed matching methods: kernel matching and caliper matching. This procedure ensures the robustness of our findings. Consistent with the nearest-neighbor matching approach, further analysis reveals that climate risk governance is positively associated with environmental innovation for the matched sample. These results are statistically significant. The postmatch regression outcomes are presented in Table A3, where Column 1 reports the estimates based on kernel matching and Column 2 presents the results derived from caliper matching.

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## Appendix

**TABLE A1** | Definitions of variables used in this study.

| Variable name | Definition |
|---|---|
| Environmental innovation | Environmental innovation score refers to firms' capability to develop new environmental technologies and processes to lower environmental costs and burdens for their customers, which allows firms to create new market opportunities by improving existing environmental technologies and processes or by developing ecofriendly products or services. This score ranges from 0 to 100 |
| Climate risk governance (CRG) | The climate risk governance index embodies firm-specific governance mechanisms to address climate change and sustainability issues. This index comprises the following five indicator components; hence, the possible score of each firm will fall between 0 and 5<br>1. Board's awareness of climate change risk and opportunities: A dummy variable will equal to 1 if the firm is aware of the commercial risk and opportunities arising from climate change, and 0 otherwise<br>2. Board-level environmental or sustainability committee: A dummy variable will equal to 1 if the firm has an environmental or ESG-related committee, and 0 otherwise<br>3. Sustainability or environmental reporting: A dummy variable will equal to 1 if the firm publishes sustainability or environmental impact reports, and 0 otherwise<br>4. External assurance of disclosures or environmental reporting: A dummy variable will equal to 1 if the firm's published reports or disclosures are externally assured, and 0 otherwise<br>5. Executive compensation or incentives for sustainability-linked performance and climate activism: A dummy variable will equal to 1 if the company provides executive compensation for ESG performance or climate change actions, and 0 otherwise |
| Board independence | The number of independent directors as a percentage of the board size |
| Board size | The number of directors serving on the board |
| Firm size | The natural logarithm of total assets of the firm |
| Capital intensity | Firm's capital expenditures scaled by total sales |
| Leverage | The ratio of total debt to total assets |
| Liquidity | The ratio of current assets to current liabilities |
| MTB ratio | The ratio of market price to book value of the firm |
| Profitability | Return on assets |

**TABLE A2** | List of CRG components with references.

| Climate risk governance (CRG) | Reference |
|---|---|
| 1. Board's responsiveness/awareness of climate change risk and opportunities | Bui et al. (2020) |
| 2. Board-level environmental or ESG committee | Orazalin et al. (2024), Liao et al. (2015), Peters and Romi (2013) |
| 3. Sustainability or environmental reporting | Al-Shaer (2020) |
| 4. External assurance of sustainability disclosures and reporting | Simnett et al. (2009) and Moroney et al. (2012) |
| 5. Executive compensation for climate change activism | Haque and Ntim (2020) |

**TABLE A3** | Additional propensity score matching (PSM) estimates.

| Additional PSM estimates | (1) Kernel matching | (2) Caliper matching |
|---|---|---|
| **Variables** | **Environmental innovation** | **Environmental innovation** |
| Climate risk governance | 6.303*** | 5.099*** |
| | (1.404) | (0.778) |
| Board independence | −0.020 | −0.001 |
| | (0.0939) | (0.0629) |
| Board size | 3.358*** | 2.835*** |
| | (0.587) | (0.442) |
| Firm size | 12.24*** | 8.199*** |
| | (1.324) | (1.121) |
| Capital intensity | −1.242*** | −0.693*** |
| | (0.199) | (0.157) |
| Leverage | −0.237*** | −0.0914 |
| | (0.0882) | (0.0684) |
| Liquidity | −1.018 | −0.326 |
| | (1.776) | (1.378) |
| MTB | −0.391 | −0.468 |
| | (0.407) | (0.332) |
| Profitability | 0.201 | 0.215 |
| | (0.267) | (0.222) |
| Constant | −211.0*** | −143.0*** |
| | (24.46) | (20.24) |
| *F*-statistics | 33.08*** | 34.02*** |
| Adjusted *R*-squared | 0.238 | 0.196 |
| *N* | 680 | 672 |

*Note:* This table presents the results of the additional propensity score matching (PSM) analysis. Column 1 reports the postmatch regression results using paired firm-year observations under the kernel matching approach, while Column 2 presents the postmatch results using the caliper matching method. Environmental innovation is the dependent variable in both models. The same set of control variables from the baseline models is included across the regressions. Standard errors are shown in parentheses, and statistical significance is indicated by ***, **, and * for the 1%, 5%, and 10% levels, respectively.