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New Research

Special Issue on ESG and Corporate Finance

Environmental, Social, and Governance (ESG) considerations have rapidly moved from the periphery to the center of corporate finance research. What was once treated as a niche concern for socially responsible investors has become a fundamental dimension of how firms are valued, financed, and governed. The growing body of academic evidence suggests that ESG factors are not merely ethical add-ons but carry material implications for corporate performance, capital costs, and asset pricing. At the same time, the proliferation of ESG rating agencies, disclosure frameworks, and regulatory mandates has introduced new complexities, including measurement inconsistencies and informational frictions, that demand rigorous scholarly attention.

This Special Issue brings together eight articles that examine the intersection of ESG and corporate finance from multiple angles. Several papers investigate how ESG performance and disclosure affect firm value, the cost of equity capital, and equity mispricing, offering evidence on the financial materiality of sustainability. Others explore the role of corporate governance mechanisms, such as risk management committees and ownership structures, in shaping ESG outcomes, while a review article provides a systematic assessment of recent developments across this rapidly expanding field. The issue also addresses forward-looking themes: how artificial intelligence may transform corporate sustainability practices under different regulatory environments, how tax incentive policies interact with sustainability strategies, and how principles of ethical finance can contribute to sustainable economic growth. The geographic scope spans from Europe and the Asia-Pacific regions, reflecting the increasingly global nature of the ESG agenda and the particular relevance of these questions for emerging and developing economies where institutional frameworks and market structures are still evolving.

We hope that the findings presented in this issue will stimulate further inquiry into the channels through which ESG considerations reshape corporate financial decisions. As regulatory pressures intensify, investor expectations shift, and new technologies emerge, the need for a deeper understanding of ESG in corporate finance will only grow.

Guest Editor
Kai Wu

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A Review of Recent Developments in ESG and Corporate Finance

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Abstract

The rapid increase of Environmental, Social, and Governance (ESG) investing has given rise to a complex and often contradictory body of research. This review synthesizes the corporate finance literature on ESG by applying a unifying 'Value versus Values' framework, which distinguishes between motivations driven by financial performance and those rooted in non-pecuniary preferences. We document a consensus that the ESG information ecosystem is fractured by divergent ratings and that the primary financial benefit of ESG lies in risk mitigation rather than consistent alpha generation. Furthermore, while evidence of widespread greenwashing highlights a significant gap between rhetoric and reality, we demonstrate that stakeholder pressure and mandatory disclosure regulations are compelling tangible changes in corporate investment, financing, and operational policies. By clarifying central debates and identifying critical gaps, this paper maps the current state of knowledge and charts a course for future research focused on causality, measurement, and policy effectiveness.

Keywords: sustainable finance, literature review, greenwashing, ESG ratings

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Introduction

The dialogue surrounding a corporation's role beyond pure profit maximization is not a new one. For decades, the concept of Corporate Social Responsibility (CSR) has framed this debate, often viewed as a discretionary, philanthropic activity separate from core business strategy. Early CSR research primarily focused on whether firms do well by doing good, grappling with the link between social performance and financial outcomes. However, the transition from CSR to the modern Environmental, Social, and Governance (ESG) framework marks a pivotal shift. ESG is not merely a rebranding of CSR; it represents a fundamental shift towards integrating these non-financial factors into the core of investment analysis and corporate strategy, driven by the belief that they are relevant to long-term financial performance and risk.

Over the past decade, ESG considerations have undergone a dramatic transformation, moving from the periphery of corporate strategy to being the central pillar of modern finance. What was once considered a niche interest for specialized socially responsible investors has become a first-order issue discussed in boardrooms, by investment committees, and among regulators worldwide. This meteoric rise is evidenced by the trillions of dollars in assets currently managed under ESG mandates and the exponential growth in corporate sustainability reporting (Friedman and Ormazabal, 2024) [1]. This paradigm shift reflects mounting pressure from a diverse array of stakeholders who increasingly demand that corporations not only generate financial returns but also account for their broader impact on society and the planet.

As noted by Joe (2023) [2], this moment in history, marked by the growing awareness of climate change, social inequality, and corporate responsibility, demands leadership from academics and practitioners alike to guide this transition. However, the rapid ascent of ESG has outpaced the development of a clear, universally accepted conceptual framework, leading to significant confusion, debate, and even backlash. Many of the current challenges, from divergent ratings to the tension between financial and ethical goals, are rooted in this historical evolution from a loosely defined CSR ethos to a data-driven, investment-focused ESG paradigm. The landscape is crowded with divergent terminologies, including ESG, sustainability, and CSR, and a lack of consensus on their meanings and applications, which creates misunderstandings that hinder productive discourse and effective policymaking.

At the heart of the confusion surrounding sustainable finance lies a fundamental, yet often unarticulated, tension between two distinct motivations, aptly framed by Joe (2023) [2] as Value versus Values. This dichotomy provides a powerful lens through which to analyze the motivations of investors, managers, and regulators, as well as to understand the conflicting evidence on the impact of ESG. While this framework is a useful simplification, it is crucial to recognize its limitations. The line between Value and Values can be blurry, as actions driven by ethical considerations (Values) may ultimately enhance a firm's long-term reputation and resilience, thereby creating financial value. This review uses the dichotomy not as a rigid classification, but as an analytical tool to disentangle the primary drivers behind different phenomena in the ESG landscape.

The value perspective represents the business case for ESG. From this viewpoint, ESG is a framework for identifying and managing a set of financially significant risks and opportunities that are not fully captured by traditional financial analysis. Proponents of this view argue that companies with strong ESG performance may benefit from lower capital costs, an enhanced brand reputation, improved operational efficiency, and better resilience to long-term risks, such as climate change, ultimately driving superior risk-adjusted returns (Edmans and Kacperczyk, 2022) [3]. For these value-driven participants, ESG serves as a tool for maximizing long-term shareholder value and ensuring the financial sustainability of the enterprise.

In contrast, the values perspective is rooted in non-pecuniary preferences, ethics, and the concept of stakeholder welfare. For values-driven investors and managers, financial returns are not the sole objective. They seek to align their capital and corporate activities with a moral compass, avoiding firms that cause social or environmental harm (e.g., externalities such as pollution or labor exploitation) and supporting those that contribute positively to society, regardless of the immediate financial impact (Dechow, 2023) [4]. This approach prioritizes the broader social and global outcomes of corporate activity, arguing that the true purpose of a corporation extends beyond the interests of shareholders to encompass its responsibilities to all stakeholders (Joe, 2023) [2].

The conflation of these two distinct motivations is the primary source of debate. Critics and proponents often talk past each other because they are operating under different assumptions about the ultimate goal of ESG. Is it a tool for generating alpha, or a mechanism for achieving social change? Is a good ESG score an indicator of prudent risk management or moral virtue? As Friedman and Ormazabal (2024) [1] highlights, both financial considerations and intrinsic preferences drive the supply and demand for ESG information, and a failure to disentangle them leads to ambiguous empirical results and flawed policy debates.

The purpose of this review is to provide a structured analysis of the corporate finance literature on ESG, using the value versus values framework to organize and clarify the central debates. While several excellent overviews exist (Friedman and Ormazabal, 2024; Christensen et al., 2022; Edmans and Kacperczyk, 2022) [1; 3; 5], this review synthesizes these contributions through a consistent analytical lens. Our goal is not only to help researchers, students, and practitioners navigate this complex field, but also to distill actionable insights for key decision-makers. For instance, how should asset managers structure portfolios with regard to divergent ESG ratings? How can corporate executives justify ESG expenditures that don't generate immediate financial returns? How might regulators design disclosure man-

dates that curb greenwashing without stifling innovation? By mapping the current state of knowledge, identifying critical gaps, and suggesting promising avenues for future research, we aim to bridge the gap between academic findings and the actual pressing challenges.

The review is structured as follows. We first explore the intersection of ESG with asset pricing and investor preferences, evaluating the debate between alpha generation and risk mitigation. We then examine the ESG information ecosystem, focusing on the critical issues of rating divergence, corporate disclosure, and the credibility gap created by greenwashing. Next, the analysis turns inward to the firm, examining how ESG influences corporate governance, financing decisions, and real operational policies. Subsequently, we assess the impact of external stakeholders and the broader regulatory and political environment, before concluding with a summary of key findings and an agenda for future research.

ESG, Asset Prices, and Investor Preferences

Theoretical Frameworks of Sustainable Investing

Recent theoretical advancements have sought to integrate ESG considerations into the core tenets of financial economics, explaining how these non-financial factors affect asset prices, required returns, and overall market equilibrium. These frameworks move beyond traditional models by incorporating investors' heterogeneous preferences, the informational content of ESG data, and the strategic behavior of firms.

A primary channel through which ESG affects asset prices is investor preferences, or tastes. An equilibrium model has been developed where a segment of investors derives direct advantages from holding green assets (Pástor et al., 2021) [6]. This preference leads them to accept lower expected financial returns, resulting in green assets having negative alphas in equilibrium. This framework establishes a two-factor model where asset returns are explained by the market factor and a distinct ESG factor, which captures unexpected shifts in customers' and investors' tastes for sustainability. Building on portfolio theory, the mean-variance frontier has been generalized to an ESG-efficient frontier, illustrating the three-way trade-off among risk, return, and ESG score (Pedersen et al., 2021) [7]. This framework demonstrates how investors can optimize their portfolios based on their dual financial and ESG objectives, distinguishing between investors who are ESG-aware (using ESG as an information signal), ESG-motivated (driven by taste), and ESG-unaware.

In contrast, a counterintuitive hedging motive has been introduced (Baker et al., 2022) [8]. This model suggests that because polluting firms perform well when environmental damage is high, their stocks can serve as a hedging instrument for environmentalists who suffer the most from negative externalities. This paradox implies that environmentalists should overweight polluters. To reconcile this with real-world divestment, countervailing forces, such as non-pecuniary disutility – a moral or reputational cost associated with holding stocks that are considered sinful, are introduced. These ideas are synthesized through the explicit modeling of two common investor practices: the exclusion of certain assets (e.g., sin stocks) and the integration of ESG scores (Zerbib, 2022) [9]. This approach generates a taste premium from investor preferences and an exclusion premium arising from market segmentation, providing a comprehensive S-CAPM (Sustainable Capital Asset Pricing Model).

The ESG-Return Relationship: The Search for Alpha and Risk Mitigation

Finally, the theoretical lens has expanded to corporate finance and market structure. The ESG Modigliani-Miller theorem has been proposed, arguing that under conditions of linear pricing and additive ESG accounting, a firm cannot lower its overall cost of capital simply by issuing green bonds due to a conservation of greenness: other securities merely become less green (Pedersen et al., 2021) [7]. Meanwhile, the social (S) dimension of ESG has been analyzed as a strategic tool in imperfectly competitive markets, demonstrating that ESG pledges can serve as pro-competitive commitments that under certain conditions can eliminate market power distortions and lead to socially optimal outcomes (Baker et al., 2022) [8].

The empirical relationship between ESG performance and stock returns is a central, yet contentious, area of sustainable finance. Much of the debate stems from significant methodological challenges, including the difficulty of establishing causality, the high dependence on noisy and divergent ESG ratings, and the potential for omitted variable bias where unobserved firm quality drives both ESG performance and returns. While early narratives suggested investors could do well while doing good, a comprehensive body of recent literature challenges the existence of a simple, positive ESG alpha, pointing instead toward a more complex interplay between investor preferences, risk mitigation, and firm fundamentals.

A growing consensus suggests that a direct, persistent ESG alpha is elusive. In one of the most extensive analyses to date, Alves et al. (2025) [10] examines over 16,000 stocks across 48 countries using seven different ESG rating providers and finds very little evidence of a systematic relationship between ESG ratings and future stock returns. This finding holds across various regions, time periods, and model specifications. The apparent outperformance of green assets in recent years is compellingly explained by Pástor et al. (2021) [6] as a result of unexpected positive shocks to environmental concerns rather than high expected returns. Their work on dissecting green returns shows that as the greenium increased, assets became more expensive, implying lower, not higher, future expected returns. This distinction is crucial: high realized returns driven by demand shocks should not be confused with al-

pha. Further challenging the alpha narrative, the outperformance of firms that improve on material ESG issues is argued to be largely attributable to their exposure to fundamental factors, such as profitability and growth (Ahn et al., 2024) [11]. Once these factors are controlled for, the material ESG alpha disappears, suggesting that such firms are simply fundamentally strong companies, and it is not ESG itself that provides an independent source of excess returns. This is reinforced by findings showing that the negative ESG premium is driven by characteristics (i.e., investor tastes) rather than risk-based betas (Ciciretti et al., 2023) [12].

While the search for alpha appears largely inconclusive, a more robust line of inquiry has focused on ESG's role in mitigation of risk, particularly downside risk. Chava et al. (2025) [13] find that while ES ratings have no significant association with average returns, firms with higher ES ratings exhibit significantly lower systematic downside risk, including lower downside beta and tail risk. This suggests that the primary financial benefit of ESG may be insurance-like protection during market downturns. Research has explored the specific mechanisms underlying this risk mitigation, finding that it is the social dimension of ESG – strong relationships with employees, customers, and the community – that is most effective at reducing stock price crash risk, especially in undervalued firms (Dumitrescu and Zakriya, 2021) [14]. In contrast, environmental and governance initiatives are found to have trivial effects. Shareholder engagement provides another causal channel. Hoepner et al. (2024) [15] utilizes proprietary data on institutional investor engagement and finds that successful interventions, particularly those addressing environmental issues such as climate change, result in significant reductions in firms' downside risk, as measured by Value at Risk (VaR). Together, these studies pivot the conversation from a simplistic search for alpha to a more nuanced understanding of ESG as a risk management tool, with its benefits concentrated in mitigating tail events and protecting value during periods of market stress.

Unpacking Investor Beliefs and Preferences

Understanding the motivations driving the surge in sustainable investing is crucial for both asset managers and theorists. The decision to invest in ESG assets is not a unanimous one; it emerges from a complex interplay of financial expectations, ethical considerations, and risk perceptions. Recent research, particularly leveraging large-scale surveys and controlled experiments, has begun to reveal what truly motivates different investor segments.

A foundational insight comes from large-scale surveys of retail investors, which reveal significant heterogeneity in both beliefs and motivations. Giglio et al. (2025) [16] document four key facts from a large panel of Vanguard investors: first, on average, investors actually expect ESG investments to financially underperform the broader market. Second, their primary motivations are highly diverse, with a near-even split between those citing ethical reasons (it is the right thing to do), climate risk hedging, and a substantial portion (nearly half) seeing no specific reason to invest in ESG at all. Only a small fraction is motivated by expectations of outperformance. This contradicts the expert consensus that asset prices systematically underestimate climate risks, suggesting a potential disconnect between retail sentiment and sophisticated financial analysis (Stroebel and Wurgler, 2021) [17].

Experimental evidence has further revealed the nature of these non-financial preferences. A key debate centers on whether investors are impact-seeking (valuing the real-world consequences of their investment) or driven by value alignment (deriving utility simply from owning stocks that align with their moral values). Bonnefon et al. (2025) [18] provides strong evidence for the latter, finding in an experimental setting that investors' willingness to pay a premium for virtuous stocks is not contingent on their investment being pivotal to the positive outcome. This suggests a deontological, rather than consequentialist, motivation: the utility comes from the act of ownership itself, not its direct impact.

While preferences are a primary driver, information and knowledge act as critical gateways to action. Experimental work demonstrates that providing information on either the positive financial returns or the tangible ESG impact of sustainable funds significantly increases investment; however, combining both types of information yields little additional effect (Seifert et al., 2024) [19]. This highlights the importance of framing and communication. However, even with the right information, investors may lack the specific knowledge to navigate the complex landscape of sustainable products. The concept of sustainable finance literacy, distinct from general financial literacy, has been introduced and found to be a significant determinant of holding sustainable assets (Filippini et al., 2024) [20]. These findings suggest that a widespread knowledge gap acts as a major barrier, preventing even well-intentioned investors from translating their preferences into portfolio holdings. Ultimately, the decision to invest sustainably is a multifaceted process where ethical values, financial expectations, and investor literacy converge.

The ESG Information Ecosystem: Ratings and Disclosure

The Divergence and Quality of ESG Ratings

A central challenge in sustainable finance is the significant divergence among the ESG ratings provided by different agencies. This aggregate confusion, as termed by Berg et al. (2022) [21], is not random noise but a systematic issue stemming from differences in how raters define the scope of ESG (which attributes are measured), how they measure those attributes, and how they weigh them in aggregate scores. Their research found that the average correlation across major rating providers was only around 0.54, a stark contrast to the high agreement seen among credit rating agencies.

Counterintuitively, greater corporate disclosure appears to exacerbate this issue rather than resolve it. Research indicates that increased ESG disclosure results in greater disagreement among raters (Christensen et al., 2022) [5]. This occurs because disclosure provides more subjective information that can be interpreted differently, particularly for ambiguous outcome metrics (e.g., actual environmental impact) compared to more straightforward input metrics (e.g., the existence of a climate policy).

This divergence has profound implications for asset prices and risk. Avramov et al. (2022) [22] demonstrates that ESG rating disagreement serves as a form of uncertainty, weakening the relationship between ESG scores and stock returns; a clear ESG-return premium or discount emerges only for firms where raters largely agree. For asset managers, this finding transforms ESG investing from a simple score-based screening exercise into a complex due diligence challenge. It implies that relying on a single provider is fraught with risk, necessitating proprietary analysis or a multi-provider approach to truly understand a firm's underlying ESG profile. Furthermore, the disagreement itself may be a priced risk factor. It has been found that firms with higher rating disagreement experience more negative stock price reactions to negative ESG news, suggesting that disagreement captures unpriced risk that the market only incorporates when new information arrives (Serafeim and Yoon, 2023) [23].

However, the quality of ESG ratings is not static. Chen et al. (2025) [24] find that increased competition among rating agencies acts as a disciplining mechanism. Exploiting the entry of Sustainalytics into the market, they demonstrate that competition leads to lower disagreement among incumbent raters and enhances their ability to predict future negative ESG incidents. This suggests that market forces can encourage convergence and enhance rating quality over time. Nonetheless, the challenge remains significant, as a comprehensive global study confirms the weak and inconsistent relationship between ESG ratings and stock returns across numerous countries and rating agencies, underscoring that divergence remains a critical hurdle for investors seeking to systematically integrate ESG into their strategies (Alves et al., 2025) [10].

Determinants and Biases in ESG Ratings

Recent research has moved beyond documenting ESG rating divergence to scrutinizing the underlying determinants and systematic biases that influence rating outcomes. A primary area of investigation involves conflicts of interest stemming from the financial relationships between rating agencies, their owners, and the firms they rate. Direct evidence of this issue demonstrates that after major credit rating agencies (CRAs) like Moody's and S&P acquired ESG raters, they began issuing higher ESG ratings to their existing credit rating clients (Li et al., 2024b) [25]. This suggests that the lucrative issuer-pay model from the credit rating business creates incentives to favor commercial partners, ultimately leading to inflated ESG scores and a deterioration in rating quality.

The ownership structure of the rating agency itself is an equally powerful, yet distinct, source of bias. The study by Tang et al. (2025) [26] finds that sister firms, companies that share major institutional shareholders with the ESG rating agency, consistently receive higher ratings from that agency compared to others. This common ownership effect is more pronounced when the owner has a larger stake and greater influence over the rater. Crucially, these firms with artificially elevated ratings tend to exhibit poorer future ESG performance, confirming that the higher ratings are not reflective of superior fundamentals but are instead driven by the owner's influence.

Corporate ESG Disclosure: Drivers, Content, and Consequences

Beyond direct financial conflicts, broader competitive and market pressures also shape rating methodologies. Through an ethnographic study, van Weeren and Bluntz (2025) [27] documents how an ESG rating agency transformed its epistemic practices, shifting from producing an accurate and holistic representation of sustainability to providing a usable reference for investors. This shift was driven by the need to meet market expectations for comparability, speed, and alignment with financial risk vocabulary, ultimately hollowing out the rating's potential to reflect genuine, complex sustainability performance.

The landscape of corporate reporting has been fundamentally reshaped by the increasing demand for ESG information, prompting extensive research into the drivers, content, and consequences of these disclosures. A central theme is the distinction between mandatory and voluntary disclosure regimes. Examining the former, large-scale evidence shows that mandatory worldwide ESG disclosure regulations significantly improve stock liquidity, suggesting that these mandates reduce information asymmetry and enhance the capital market environment (Krueger et al., 2024) [28].

Beyond regulation, external events can act as powerful catalysts of voluntary disclosure. Huang et al. (2022) [29] find that firms located near areas struck by natural disasters increase their ESG disclosure transparency. This is consistent with heightened risk salience for both managers and investors, prompting a strategic response to a perceived increase in investor demand for such information. However, the decision to disclose is not always straightforward. In a theoretical contribution, Bond and Zeng (2022) [30] argues that when firms are uncertain about their audience's preferences (e.g., investors who value ESG versus regulators who might penalize certain outcomes), silence is safest because it minimizes the variance of the firm's payoffs. This helps explain why some firms strategically withhold ESG information even when disclosure is costless.

As firms increasingly disclose more information, its nature has evolved. An analysis of over 210,000 annual reports

globally reveals that E&S disclosures have increased in length but also become more generic over time, while their specificity has decreased (Lin et al., 2024b) [31]. This study also reveals a thematic shift, with topics like climate change and human capital gaining prominence. The channels of disclosure are also expanding beyond traditional reports. Boulland et al. (2025) [32] proposes and validates a novel measure based on company websites, which captures a wealth of information targeted at a broad range of stakeholders and is particularly useful for studying private firms. Researchers are also developing original methods to measure specific exposures, such as the linguistic analysis of annual reports by Nagar and Schoenfeld (2024) [33], which constructs a firm-level measure of weather exposure. This demonstrates its forward-looking ability to predict stock returns in the aftermath of extreme weather events.

To structure this burgeoning disclosure environment, voluntary standards have emerged as crucial coordinating devices. For example, the development of investor-oriented SASB standards led to a significant increase in the discussion of industry-specific, material ESG topics in earnings calls (Bochkay et al., 2025) [34]. This suggests that standards can reduce market friction by coordinating expectations between firms and investors about which ESG issues are the most relevant. Theoretically, the primary function of this coordinated disclosure is to enhance investment efficiency. This link has been formalized in a model that characterizes how optimal ESG disclosure precision can channel investors' ESG tastes into the firm's investment decisions, potentially aligning firm behavior with shareholder preferences without direct intervention (Xue, 2025) [35].

The Credibility Gap: Assurance, Greenwashing, and Symbolic Actions

A significant body of research investigates the credibility gap between firms' ESG pronouncements and their actual performance, revealing a widespread tendency toward greenwashing, social washing, and the use of symbolic actions to manage stakeholder perceptions. This research distinguishes between substantive changes that genuinely enhance ESG outcomes and opportunistic communications intended to create a favorable impression without incurring the costs of fundamental operational shifts.

A prominent greenwashing strategy involves the strategic reallocation of assets. Research finds that firms facing intense environmental pressures often divest their most pollutive plants (Duchin et al., 2025) [36].

This allows the divesting firm to improve its reported environmental footprint and ESG ratings. However, these assets are typically sold to private firms or those facing weaker environmental scrutiny, resulting in a simple transfer of ownership without any net reduction in overall pollution. Similarly, a theoretical model demonstrates that in the absence of robust regulation, such as a mandatory taxonomy, the market for sustainable investments is prone to a race to the bottom, where greenwashing becomes the dominant strategy to attract investor capital (Inderst and Opp, 2025) [37].

The strategic divestiture of carbon-intensive assets highlights a critical systemic issue: ESG arbitrage between public and private markets. As public firms face mounting pressure from investors, regulators, and rating agencies, they have a strong incentive to sell their most polluting assets. These assets are often acquired by private equity firms or privately-held companies that operate under a different disclosure regime and face less public scrutiny. While this transaction improves the ESG score of the divesting public firm, it often fails to reduce, and may even worsen, aggregate global emissions, as private owners may have fewer incentives to invest in cleaner technologies or may operate the assets more intensively.

This phenomenon raises fundamental questions about the effectiveness of market-based ESG pressure that is focused on public equities. It suggests that without consistent regulatory frameworks that cover both public and private entities, ESG efforts may simply shift polluting activities into less transparent corners of the economy rather than eliminate them. Future research should therefore focus on quantifying the scale of this public-to-private asset flow, assessing the subsequent operational and environmental performance of these assets under private ownership, and exploring policy mechanisms, such as broader carbon pricing or consumption-based emissions accounting, which could mitigate this form of regulatory and reputational arbitrage.

The gap between rhetoric and reality extends beyond environmental issues. The term diversity washing has been coined to describe companies that excessively discuss diversity, equity, and inclusion (DEI) relative to their actual workforce diversity (Baker et al., 2024) [38]. These firms successfully obtain higher ESG ratings and attract more ESG-focused investment, despite exhibiting worse employee outcomes, such as a higher likelihood of incurring discrimination violations. In a related finding, Huang and Lu (2025) [39] demonstrates that firms voluntarily disclosing more information about gender diversity ahead of a UK mandate subsequently revealed worse gender pay gaps, consistent with legitimacy theory, which suggests that firms with poorer performance use disclosure to manage their reputations. This strategic use of symbolic actions is a recurring theme. Lara et al. (2025) [40] distinguishes between substantive and symbolic CSR, finding that after industrial disasters, affected firms prioritize symbolic gestures, such as improving human rights or diversity metrics, rather than making substantive investments to address the core environmental issues at the root of the disaster. In the banking sector, social washing has been identified, where high-ESG-rated banks deploy prosocial rhetoric while lending less to poor communities, thus shirking a key social responsibility (Basu et al., 2022) [41].

The financial products designed to promote ESG are also implicated in this credibility gap. Raghunandan and Rajgopal (2022) [42] find that self-labeled ESG mutual funds hold portfolios with worse compliance records on labor

and environmental laws and higher carbon emissions compared to non-ESG funds from the same asset managers. Examining sustainability-linked loans (SLLs), Kim et al. (2025) [43] find that while high-transparency SLLs serve a certification purpose, low-transparency SLLs are associated with greenwashing, as borrowers' ESG performance often deteriorates after issuance.

To bridge this credibility gap, ESG assurance has emerged as a key verification mechanism. A dramatic increase in the use of ESG assurance in the U.S., associated with higher-quality disclosures, improved ESG ratings, and a larger institutional investor base has been documented (Gipper et al., 2025) [44]. This suggests that third-party verification can serve as a valuable signaling device for firms genuinely committed to sustainability, helping stakeholders distinguish substantive action from mere symbolic gestures.

ESG in Corporate Decision-Making and Governance

ESG and the Boardroom

The board of directors serves as the central nexus for shaping and implementing a firm's ESG strategy. While Environmental and Social issues often capture headlines, the Governance (G) pillar acts as the foundational architecture that enables credible E&S performance. It extends traditional corporate governance concerns – such as board independence and shareholder rights – to encompass a broader set of stakeholder-oriented principles. This includes oversight of issues like business ethics, data privacy, lobbying activities, and executive accountability for non-financial targets. Effective ESG performance is therefore not merely a function of external investor pressure, but is deeply rooted in the board's internal structure, composition, and accountability mechanisms, which are specifically adapted to a multi-stakeholder world. Foundational research by Dyck et al. (2023) [45] posits that substantive renewable governance is a prerequisite for environmental improvement. They argue that mechanisms powerful enough to renew the board's thinking—such as the adoption of majority voting and the introduction of female directors—are essential for aligning firm policies with investor preferences on sustainability.

The composition of the board itself is a critical determinant of ESG outcomes. Specific director attributes can either foster or hinder progress. For example, He et al. (2023) [46] finds that Generation X directors, whose formative years coincided with the rise of major social and environmental movements, are associated with enhanced engagement in value-adding ESG activities. Conversely, internal board dynamics can create dysfunction; Hoang et al. (2025) [47] demonstrates that political polarization among directors hampers collective decisionmaking, resulting in a significant reduction in a firm's ESG performance. This highlights that both demographic characteristics and ideological cohesion within the boardroom are influential.

Board oversight also involves enforcing accountability, particularly at the executive level. A key finding from Colak et al. (2024) [48] is that boards are increasingly holding CEOs accountable for ESG-related misbehavior. Their research reveals that CEO turnover increases significantly following severe ESG incidents, even when there is no immediate negative impact on the stock price, suggesting that non-pecuniary reputational concerns are a powerful driver of board action. However, the impetus for these board-level changes is complex. While shareholders publicly advocate for diversity, a key tenet of ESG, their actions may not align with their words. Analysis of voting patterns shows that shareholders provide only modest additional voting support for diverse directors, which is often insufficient to alter election outcomes (Gow et al., 2023) [49]. This suggests that while boards may be responding to a perceived mandate for ESG, the direct pressure through shareholder voting is weak. A more tangible incentive may be financial; strong ESG performance, as a proxy for social capital, provides bond market benefits, such as lower credit spreads during financial crises, creating a clear business case for robust board oversight (Amiraslani et al., 2023) [50].

Incentivizing ESG: Executive Compensation and Managerial Discretion

A primary mechanism for aligning managerial actions with ESG goals is the integration of ESG metrics into executive compensation contracts. The rapid global adoption of this practice, as documented by Cohen et al. (2023) [51], is driven by multiple rationales, including efficient contracting and aligning with shareholder preferences. Their research finds that tying pay to ESG is associated with improvements in key ESG outcomes, like reduced carbon emissions, but not with enhanced short-term financial performance, highlighting a potential trade-off.

This trade-off, however, may create new avenues for managerial opportunism. The research of Flugum and Souther (2025) [52] suggests that managers strategically use stakeholder value as a convenient excuse to deflect from poor financial performance. They find that firms are significantly more likely to cite stakeholder-focused objectives following missed earnings announcements, and that doing so weakens CEO turnover-performance sensitivity, effectively reducing managerial accountability.

Theoretical models formalize the conditions under which ESG-linked pay is optimal. According to Chaigneau and Sahuguet (2025) [53], boards only resort to explicit ESG incentives when their preferred level of social investment exceeds the level that maximizes the stock price. Under these conditions, managers may be incentivized to game the metrics, distorting social investments to meet a target rather than achieve the underlying goal. Despite these challenges, well-designed contracts can be effective. From a dynamic contracting perspective, properly structuring incentives for ESG investing can enhance overall contract efficiency and mitigate information asymmetries, improving investment value (Zhang and Yang, 2024) [54]. Taken together, the literature suggests that while ESG-linked compensation is a powerful tool for driving ESG perfor-

mance, its effectiveness hinges on robust contract design that can overcome the potential for managerial discretion and gaming.

ESG and Corporate Financing

The integration of ESG considerations has profoundly reshaped corporate financing landscapes, influencing firms' access to and cost of capital across various instruments like traditional debt, equity, and green bonds.

ESG performance plays a significant role in traditional debt markets. Houston and Shan (2022) [55] demonstrates that banking relationships foster corporate ESG policies, with banks being more likely to lend to borrowers with similar ESG profiles and positively influencing their subsequent ESG performance. This is partly driven by the fear of subsequent exit. Research indicates that ESG-rated firms reduce their target leverage ratios and reallocate financing from public debt to bank loans, reducing information asymmetry (Asimakopoulos et al., 2024) [56]. Lee et al. (2024) [57] observe that higher bond ownership by insurance companies correlates with higher future ESG ratings, indicating bondholder influence. Furthermore, credit default swap (CDS) trading has been shown to have a positive impact on ESG performance, an effect attributed to reduced lender monitoring incentives, which grant corporate managers greater flexibility to implement ESG improvements (Zhao and Zhu, 2024) [58].

Green bond issuance significantly impacts equity markets. Tang and Zhang (2020) [59] find that stock prices positively respond to green bond announcements, leading to increased institutional ownership and improved stock liquidity. These effects are attributed to investor attention and firm fundamentals, as green bonds signal valuable investment opportunities and a commitment to sustainable development.

The greenium, a lower cost of capital for green bonds, is a central, yet debated, aspect. While a green premium has been identified, no significant pricing difference was found in within-firm comparisons (Tang and Zhang, 2020) [59]. Focusing on municipal bonds, Larcker and Watts (2020) [60] conclude that the greenium is economically trivial, arguing that marginal investors are unwilling to sacrifice returns for non-pecuniary benefits. However, the capital structure irrelevance theory (ESG-Modigliani-Miller) has been challenged by findings that green bonds can lower the overall cost of capital, implying segmented markets or inconsistent ESG attribution (Feldhütter and Pedersen, 2025) [61]. This is supported by a model showing how green bonds can lower financing costs but also lead to fragmentation, resulting in rationing (Bongaerts and Schoenmaker, 2024) [62]. A significant greenium has also been found for eligible green bonds following the ECB's Pandemic Emergency Purchase Programme (PEPP), suggesting central bank policies can promote climate-friendly investments (Zaghini, 2024) [63]. This heterogeneity highlights that the greenium's existence and magnitude depend on market context, methodology, and policy interventions.

ESG and Real Corporate Policies

The increasing pressure from ESG factors has led firms to fundamentally reevaluate and adjust their core operations, influencing decisions across investment, innovation, and environmental and social performance.

Firms are facing growing scrutiny regarding their environmental impact, which can directly influence their operational policies. Research investigating the trade-off between short-term earnings targets and long-term environmental benefits finds that U.S. firms tend to increase pollution to meet earnings benchmarks (Thomas et al., 2022) [64]. Surprisingly, this effect is stronger for firms with higher environmental ratings, suggesting that these firms use pollution slack built through good track records to manage short-term performance. Similarly, Lin et al. (2025) [65] demonstrates that robust supply chain ESG is associated with higher future accounting performance and stock returns, as it helps reduce negative incidents and improve supply chain stability. This highlights the importance of effective supply chain ESG management in mitigating both reputational and financial risks.

Environmental regulations are key drivers of green technological innovation. Lin et al. (2024a) [66] demonstrates that environmental regulatory pressure on customer firms is transmitted to their supplier firms, prompting suppliers to increase their green patent applications. This effect is particularly pronounced when supplier firms have stronger financial positions, operate in highly marketized regions, receive fewer R&D government subsidies, or boast higher ESG ratings. This highlights the indirect but powerful influence of regulatory pressure through supply chain relationships on fostering green innovation. Different forms of state ownership also impact corporate innovation in China, with findings indicating that central state-owned enterprises (SOEs) exhibit the best innovation performance, particularly when engaging in more ESG practices, during periods of high economic policy uncertainty, and with lower levels of corruption (Lin et al., 2021) [67].

Workplace safety, a critical social dimension of ESG, is also influenced by corporate policies and governance. A reduced threat of shareholder litigation is associated with higher workplace injury rates in U.S. firms, suggesting that legal accountability plays a crucial role in promoting safer work environments (Gong et al., 2023) [68]. This effect is more pronounced for firms with higher ex-ante derivative litigation risk, less product market competition, and in industries with lower union coverage. Loncan (2025) [69] further examines the role of employee welfare policies (EWPs) in shielding workers from employment fluctuations. The study finds that EWPs are associated with a weaker pass-through of industry sales shocks to firm employment growth, particularly during negative economic shocks, suggesting EWPs act as an insurance mechanism for workers.

Beyond operational aspects, ESG factors are increasingly integrated into financial and investment strategies. Corporate tax cuts have been shown to enhance firms' CSR

performance, particularly for financially constrained firms and those with stronger corporate governance (Chang et al., 2025) [70]. This suggests that internal funds freed by tax reductions are prioritized for CSR investments, reflecting a sticky commitment to social responsibility.

The Role of Stakeholders and External Pressures

Institutional Investors: Engagement vs. Exit

Institutional investors play a pivotal role in shaping corporate ESG practices through two primary mechanisms: engagement and exit. These strategies, ranging from active monitoring and voting to divestment, represent varied approaches to influencing firm behavior and achieving sustainability objectives.

Engagement involves direct interaction with portfolio companies to encourage improved ESG performance. Azar et al. (2021) [71] demonstrates that large institutional investors, particularly the Big Three (BlackRock, Vanguard, and State Street Global Advisors), actively engage with firms to reduce carbon emissions. Their influence is more pronounced in larger firms and those with higher initial CO_2 emissions, suggesting the need for targeted efforts to drive change. Evidence also shows that BlackRock's Dear CEO letters, a form of broad-based public engagement, effectively influence the public disclosures and lobbying activities of portfolio firms to align with BlackRock's ESG preferences (Pawliczek et al., 2021) [72]. This indicates that public advocacy by powerful investors can lead to tangible changes in corporate behavior, even without direct ownership control.

Shareholder voting is another critical engagement tool. Dikolli et al. (2022) [73] shows that U.S. mutual funds with stated ESG objectives are more likely to vote in favor of environmental and social (ES) shareholder proposals compared to non-ESG funds. This walk-the-talk behavior is more pronounced in index funds due to their trading constraints, which amplify the importance of voting as a mechanism of influence. Furthermore, foreign institutional investors have been found to positively moderate the CSR-value relationship in Chinese firms, enhancing innovation through their monitoring and advising roles, especially for non-state-owned enterprises and firms with higher customer awareness (Li et al., 2025) [43]. The exit strategy, primarily through divestment, involves selling companies that do not meet ESG criteria. Berk and van Binsbergen (2025) [74] investigates the impact of divestment strategies on the cost of capital. They conclude that, at current participation levels, divestment has a minimal impact on firms' real investment decisions. Instead, they argue that socially conscious investors should use primary markets (impact investing) or exercise control rights through engagement to effect meaningful change. This finding challenges the effectiveness of traditional divestment as a standalone ESG strategy.

Despite commitments to responsible investing, greenwashing remains a concern. Hedge funds endorsing the United Nations Principles for Responsible Investment (PRI) have been found to underperform other hedge funds after risk adjustment; however, they attract greater investor flows and fee revenues (Liang et al., 2022) [75]. This underperformance is attributed to an agency problem, particularly among low-ESG signatories who may opportunistically endorse PRI to pander to investor preferences. This is corroborated by findings showing that socially responsible investment (SRI) funds primarily select firms with better E&S conduct but do not significantly improve their E&S behavior, a phenomenon termed impact washing (Heath et al., 2023) [76]. This highlights a disconnect between stated intentions and actual impact, raising questions about the credibility of certain SRI claims.

Retail Investors, Media, and Public Sentiment

The interplay between retail investors, media coverage, and public sentiment has emerged as a powerful force shaping corporate behavior and valuation. Societal trends and movements, amplified by the media, increasingly prompt firms to take stances on social issues, leading to diverse responses from investors and customers.

The MeToo movement, for instance, dramatically transformed investor beliefs about the costs and benefits of corporate culture, particularly concerning gender inclusivity. It was documented that firms that have historically excluded women from their boards experienced negative abnormal returns as the movement gained momentum, while inclusive firms saw positive returns (Billings et al., 2022) [77]. This market reaction, as further explored by Lins et al. (2024) [78], stemmed from shifts in non-monetary investor preferences. Firms with a non-sexist corporate culture, often proxied by the presence of women in top executive positions rather than just on the board, earned additional returns. This suggests that societal attitudes towards sexism permeated capital markets, prompting institutional investors, especially those with lower prior ESG focus, to increase holdings in non-sexist firms. Companies responded by enhancing gender diversity to meet these evolving investor preferences.

Similarly, the Black Lives Matter (BLM) campaign highlighted the reactions of retail investors to corporate sociopolitical activism. Retail investor attention to companies supporting BLM increased; however, this attention translated into increased stock holdings only when firms demonstrated credible commitment, such as monetary donations, especially if they already had black directors on their board (Brownen-Trinh and Orujov, 2023) [79]. This suggests that retail investors' investment decisions are driven by moral sentiment and credibility rather than mere rhetoric.

Beyond investor responses, public social stances also influence customer behavior. Jin et al. (2025) [80] examined customer reactions to firms speaking out against Georgia's

voting reform laws. They found that customer visits and spending decreased for speaking-out firms, particularly in Republican-dominated counties and when conservative media emphasized the firm's stance. Conversely, the negative impact was less pronounced in counties with higher Black populations, suggesting a correlation between values. Despite these shifts in customer traffic, aggregate firm-level financial performance and equity market responses were not significantly affected, implying offsetting effects from different customer segments.

The broader question of why retail investors respond to ESG information remains a topic of debate. It has been demonstrated that retail investor trading increases significantly around ESG news events, particularly those related to leadership and governance (Li et al., 2024a) [81]. This evidence suggests that the average U.S. retail investor primarily trades on ESG information when it is deemed financially material, benefiting from incorporating this pecuniary information into their decisions. However, as Li et al. (2024a) [81] points out in his discussion, research designs focused on short-term trading reactions to financially material ESG news may not be ideally suited to capture non-pecuniary preferences, which often manifest through longer-term investment strategies, such as screening or thematic investing.

The Ecosystem of Intermediaries: Analysts, Auditors, and Employees

The growing emphasis on ESG factors has created a complex ecosystem where various intermediaries, sell-side analysts, auditors, and employees play crucial roles in monitoring, shaping, and communicating corporate ESG performance. These actors provide distinct yet interconnected perspectives that influence both financial markets and public perception.

Sell-side analysts, for instance, are increasingly incorporating ESG risks into their valuation models. Research indicates that analysts' outputs, including stock recommendations and target prices, are negatively correlated with future negative ESG incidents (Park et al., 2025) [82]. This indicates that analysts possess valuable insights into financially material ESG risks and integrate these into their assessments, not only by adjusting future cash flow expectations (the numerator effect) but also by modifying discount rates (the denominator effect). This suggests that analysts view ESG risks as potentially systematic, influencing a firm's value.

Auditors also play a significant, albeit evolving, role in managing ESG-related reputation risk. A positive association has been found between heightened ESG risk (proxied by abnormal negative media coverage) and the purchase of audit-related non-audit services (Asante-Appiah and Lambert, 2023) [83]. Importantly, these services are positively associated with future firm value, suggesting that auditors' ESG expertise helps mitigate reputational damage and enhance long-term performance. However, auditor involvement in ESG assurance can also have unintended consequences. Douthit et al. (2024) [84] find that when auditors provide assurance over a firm's prosocial activities, reporters (clients) tend to take more aggressive initial negotiation positions in subsequent financial reporting, potentially biasing final outcomes. This moral licensing effect is particularly pronounced in collaborative assurance settings.

Through their internal perspectives, employees offer another vital signal of managerial ability and corporate culture. Welch and Yoon (2023) [85] provide evidence that high-ability managers, as rated by employee opinions on Glassdoor, allocate resources to ESG efforts in a way that enhances shareholder value. Firms with both high ESG ratings and highly rated senior managers exhibit significantly higher future stock returns, indicating that managerial ability is a necessary condition for ESG efforts to create value. This suggests that employee sentiment provides an informative signal not captured by traditional ESG data vendors.

Besides financial intermediaries, ESG assurance also impacts consumers. Hampton et al. (2025) [86] investigates how negative accounting news events (e.g., restatements) influence consumer purchasing intentions for credence goods with ESG claims (like cage-free eggs). They find that such negative news decreases purchasing intentions, particularly for severe irregularities. Voluntary ESG product-quality assurance can mitigate these negative effects, especially when provided by a government agency or an audit firm unaffiliated with the financial statement audit, as consumers tend to distinguish between providers based on their perceived reliability.

Finally, conference call tones serve as a dynamic communication channel reflecting how firms manage ESG-related information. Firms with poor Environmental and Social (ES) performance have been documented to exhibit more negative managerial tones in earnings conference calls (DeLisle et al., 2024) [87]. Research also shows that the market prices soft information (tone differences between management and analysts) less efficiently for firms with poor ES performance, leading to subsequent price drift or reversals. This highlights that ES performance affects a firm's information environment and pricing efficiency, even beyond traditional governance measures.

Regulation, Politics, and the Macro-Environment

The Real Effects of ESG Regulation

Mandatory ESG regulation has spurred extensive academic inquiry, moving beyond early focus on voluntary reporting to document significant real effects on firm behavior, capital allocation, and social outcomes. This body of research investigates the interplay between mandatory disclosure rules, environmental monitoring systems, and political pressures in shaping corporate policy and financial performance.

At the facility level, disclosure mandates have a demonstrable influence on core operations and compliance strategies. Tomar (2023) [88] finds that public greenhouse gas

(GHG) disclosure in the U.S. leads to a 7.9% reduction in emissions, primarily by enabling benchmarking behavior among peers concerned about the prospect of future climate legislation. Measurement alone is insufficient; public disclosure is key. Other regulatory approaches leverage financial intermediaries or specialized institutions to enforce environmental standards. For example, mandatory ESG disclosure imposed on banks has been shown to create powerful transmission effects down the lending chain, prompting borrowers to improve their E&S performance through stricter loan covenants and screening (Wang, 2023) [89]. Similarly, the establishment of environmental courts in China has been found to serve as a judicial deterrent, enhancing corporate environmental engagement and resulting in a reduced cost of equity for heavily polluting firms (Zeng et al., 2024) [90]. In the context of global supply chains, Baik et al. (2024) [91] documents that transparency rules (Section 1502 of the Dodd-Frank Act) induce enhanced responsible sourcing practices, increasing the use of certified smelters and mitigating mineral-related conflicts, highlighting that public attention and reputational costs are key levers for achieving real social impact. Even cutting-edge technology facilitates compliance, as demonstrated by the substantial reduction in pollutant concentrations (SO_2, NO_2, and CO) in Chinese cities that have adopted blockchain-based monitoring (Cong et al., 2025) [92], owing to enhanced verification rigor.

These compliance changes have a direct impact on financial outcomes, resulting in shifts in investor behavior and market metrics. Gibbons (2024) [93] establishes that mandatory nonfinancial disclosure attracts long-term, E&S-preferring institutional owners (a clientele effect), which, in turn, has material real effects on firms, specifically accelerating R&D investment and new equity issuance. It has been further confirmed that mandatory CSR expenditure in India significantly improves stock market liquidity and attracts greater investment from specific foreign institutional investors (FIIs), suggesting that disclosure fosters social and reputational capital (Roy et al., 2022) [94]. Furthermore, the market quickly recognizes the value of regulatory clarity. Bassen et al. (2025) [95] reveals a significant stock return premium for companies aligned with the EU Taxonomy Regulation (TR), an effect amplified by investor attention to the new official standard, underscoring the market's preference for standardized definitions over traditional, potentially inconsistent ESG ratings. Despite these tangible benefits, the policy implications remain complex. Cong et al. (2025) [92] caution that highly stringent local monitoring can induce a regulatory trade-off: local pollution mitigation is achieved at the cost of firm relocation to non-adopting regions (regulatory arbitrage), potentially increasing aggregate pollution. A skeptical counterpoint has also been offered, arguing that evidence of widespread material investor demand or pricing bias for mandated ESG items remains minimal, suggesting that disclosure requirements must be rigorously justified based on financial materiality rather than social or political objectives (Frankel et al., 2025) [96]. Collectively, these studies underscore that while targeted transparency mandates trigger real changes in firm behavior, regulators must navigate complex trade-offs between environmental benefits, economic costs, and the alignment of disclosure goals with core investor protection mandates.

The Broader Context: Political Activism, Sovereign Risk, and Cultural Norms

The effectiveness and direction of firm-level ESG activities are deeply intertwined with macro-level political shifts, sovereign risk, and country-specific institutional norms, extending far beyond simple compliance metrics. This broader context helps explain heterogeneity in corporate behavior and investor reactions to sustainability issues (Garavaglia et al., 2024) [97].

Political activism and communication form one critical layer. Research investigating whether firms' public sociopolitical claims (e.g., on diversity or the environment) align with their corporate political action committee (PAC) contributions finds that while firms generally donate more to politicians aligned with their interests, the majority of contributions still flow to politicians with low overall ESG approval ratings, suggesting that general political alignment is limited and that trade-offs exist between public image and strategic political access (Preuss and Max, 2024) [98].

Sovereign risk provides an exogenous shock that reveals underlying priorities. Boumparis et al. (2025) [99] employs the sovereign ceiling rule to investigate how a country's credit rating downgrade impacts firms that are bound by the sovereign rating (i.e., those rated at or above the sovereign's rating). They find that bound firms subsequently exhibit a decline in ESG performance, which is concentrated in countries with a shareholder-centric orientation and is not driven by financing constraints. This suggests that when faced with macroeconomic shocks, managers prioritize shareholder value over ESG commitments, treating ESG spending as discretionary.

Finally, country-specific factors, such as ownership structure and legal traditions, significantly moderate ESG outcomes. Using a global sample, research demonstrates that corporate ownership structure is systematically related to ESG performance (Villalonga et al., 2025) [100]. These findings show that firms with founding families or individual owners tend to underperform on ESG metrics, whereas those with non-family management or government ownership tend to outperform. This suggests that the identity of material owners drives different ESG orientations. However, some non-profit structures successfully promote sustainability: Schröder and Thomsen (2025) [101] finds that foundation-owned companies exhibit significantly higher ESG performance (especially on environmental and social scores) compared to non-foundation-owned firms, and they maintain these commitments even during the 2008 financial crisis, highlighting the stabilizing role of purposeful ownership in pursuing long-term ESG goals.

Conclusion and Avenues for Future Research

The corporate finance literature on ESG has evolved from a niche inquiry into a central pillar of economic research. This review, organized through the clarifying lens of Value versus Values (Joe, 2023) [2], reveals a field rich in complexity and contradiction. Several key takeaways emerge. First, the ESG information ecosystem remains fundamentally fractured. The persistent divergence among rating agencies, driven by systematic differences in scope, measurement, and weighting, creates significant uncertainty for investors and undermines the reliability of ESG data as a consistent signal (Berg et al., 2022) [21]. Second, the initial narrative of doing well by doing good has been largely revised. The search for a consistent ESG alpha has proven elusive, with a growing consensus that ESG's primary financial benefit lies in risk mitigation, particularly in protecting against downside and tail risks, rather than generating excess returns (Chava et al., 2025) [13]. Third, the gap between corporate rhetoric and substantive action is wide. Overwhelming evidence documents the prevalence of greenwashing and social washing, where firms engage in symbolic disclosures and strategic asset divestitures to manage perceptions without making costly operational changes (Duchin et al., 2025) [36]. Finally, despite these challenges, ESG has a real and undeniable impact. Stakeholder pressure, most notably, as well as mandatory disclosure regulations are compelling firms to alter their investment, financing, and operational policies, leading to tangible outcomes such as reduced emissions and improved supply chain oversight (Krueger et al., 2024; Tomar, 2023) [28; 88].

These academic insights translate into critical practical guidance for market participants. For asset managers, the evidence suggests a strategic shift away from chasing elusive alpha towards using ESG as a risk management tool, particularly for identifying downside risk. The fractured rating landscape necessitates a move beyond headline scores to a deeper, fundamental analysis of material ESG factors. For corporate leaders and CFOs, the message is twofold: stakeholder and regulatory pressures are real and have tangible impacts on financing and operations, making ESG a strategic imperative. However, the prevalence of greenwashing highlights the challenge of demonstrating credible, substantive action over symbolic gestures, demanding robust internal metrics to quantify the long-term value of ESG initiatives. For regulators, the research underscores the power of mandatory disclosure in driving real change, but it also cautions against a one-size-fits-all approach, highlighting the risks of regulatory arbitrage and the need to ground disclosure requirements in financial materiality to protect investors.

While our understanding has deepened, critical questions remain, pointing toward exciting avenues for future research. A recurring theme throughout this review is the challenge of robust causal inference. Many documented relationships remain correlational, making it challenging to determine whether ESG initiatives drive outcomes or are merely undertaken by already successful firms. A primary task is to move beyond correlation and establish causality in the real effects of ESG. Future research must employ more robust identification strategies, such as quasi-natural experiments from regulatory shifts or instrumental variable approaches, to isolate the causal pathways from specific ESG pressures to firm behavior and market outcomes. This challenge is compounded by the critical need for better measurement. The reliance on subjective, disclosure-based ESG scores remains a fundamental weakness in the literature. Research is needed to develop more objective and standardized metrics that capture actual ESG performance and impact, moving beyond disclosure-based scores to assess meaningful real-world change. Beyond refining measurement, the interplay of different regulatory approaches offers another fertile ground for inquiry. Future studies should explore the complementarity of disclosure mandates with other policy tools, such as carbon taxes or product standards, to understand the most effective policy mix. Furthermore, the long-term macroeconomic consequences of a large-scale, ESG-driven reallocation of capital are still largely unknown; research could investigate whether this shift creates asset bubbles or alters market-wide risk premia. Finally, emerging technologies offer powerful new tools for addressing these issues. Future work should examine the potential of AI and blockchain to enhance monitoring, verification, and assurance, combat greenwashing, and increase the credibility of corporate ESG claims. Answering these questions is essential for building a more sustainable and efficient global economy and ensuring that the integration of ESG into finance delivers on its promise of both value and values.

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AI-Driven Corporate Sustainability: Exploring the Moderating Role of External Regulation

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Abstract

This paper investigates Artificial Intelligence's (AI) systemic impact on corporate Environmental, Social, and Governance (ESG) performance. Analyzing Chinese-listed companies from 2013 to 2022, we find that AI adoption significantly promotes ESG outcomes. Both 'soft' regulation (investor attention) and 'hard' regulation (environmental regulation) significantly strengthen this contribution. Notably, investor attention exhibits a complex threshold effect: at lower levels of attention, AI adoption negatively impacts ESG performance, suggesting that firms may prioritize efficiency over sustainability in the absence of public scrutiny. The facilitative effect only emerges once investor attention surpasses a critical threshold, highlighting AI's 'double-edged sword' nature. For 'hard' regulation, environmental regulation positively moderates AI's impact on environmental and governance performance but lacks a similar effect on social performance. Furthermore, AI primarily drives social and governance goals in non-state-owned enterprises (non-SOEs), while its impact in state-owned enterprises (SOEs) is concentrated in the environmental dimension. These results underscore that AI's transformative potential is contingent upon regulatory frameworks and ownership-specific institutional logics.

Keywords: artificial intelligence, ESG, investor attention, environmental regulation, moderating effects, SOEs

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Introduction

Balancing social development with environmental sustainability has become a critical challenge in the face of a growing global population. Human activities have led to environmental pollution, global warming, resource depletion, and biodiversity loss, which now hinder societal progress and create substantial barriers to sustainable development. In this context, ESG practices have become essential mechanisms for tackling global climate challenges and achieving carbon neutrality, forming the cornerstone of sustainable development strategies worldwide. For corporations, which are an important component of national economic development, ESG transformation is not only a matter of corporate value [1] and sustainability [2], but also an integral part of national economic progress and international reputation. Thus, corporations are now expected to balance financial performance with sustainable development goals.

As of June 10, 2024, 2,090 publicly listed companies in China's A-share market had issued ESG reports, representing 38.9% of all A-share companies. Despite this progress, as the largest emerging market globally, China remains in the early stages of ESG development. Encouraging broader participation in ESG practices has become a key challenge in achieving the nation's sustainability goals. With the increasing global emphasis on ESG, several studies have explored the factors influencing ESG performance. Internal factors like firm size [3], financial performance [4], governance structure [5; 6], and ownership structure [7] have been shown to impact ESG outcomes. External influences, including market competition [8], fintech adoption, government policies [9; 10], regulatory enforcement, media coverage [11], and investor attention [12], have also been extensively examined.

In addition to these factors, digital transformation has garnered significant attention for its positive impact on ESG performance [13–16]. However, the impact of AI, a more advanced subset of digital technology, remains in an exploratory phase in terms of its application at the corporate level. AI integrates theories, technologies, and practical applications designed to mimic, enhance, and expand human intelligence [17], thereby enabling deeper data collection and interaction [18]. As a key driver of productivity across industries [19], AI is reshaping business operations and models [20]. Although studies have shown that AI significantly enhances processes, increases efficiency, reduces costs, and improves competitiveness [21; 22], research on AI's impact on corporate ESG remains limited.

The European Union's 'Expert Group's Policy and Investment Recommendations for Trustworthy AI' (the Guidelines) underscore the necessity of acknowledging a diverse array of stakeholders – including society at large, living organisms, and the natural environment – across the entire lifecycle of an AI system. These Guidelines advocate for the integration of sustainability and ecological considerations in AI applications [23]. To date, much of the research on AI's influence on sustainability has focused on specific macro-level domains [24] like the labor market [25], carbon emissions [16; 26; 27], pollution control [28], and pollution forecasting [29]. In contrast, data at the corporate level remains relatively scarce [30], with studies being more fragmented and not drawing consistent conclusions. Another major limitation of the existing literature is its tendency to view AI as a collection of isolated task-automation tools, rather than a General-Purpose Technology (GPT) that permeates systemic organizational routines.

Several studies have concluded that AI holds significant potential in promoting corporate environmental sustainability [31; 32], optimizing employee work environments and fairness [33; 34], enhancing customer satisfaction [35], and strengthening internal governance efficiency [36]. However, it has also been shown to present significant challenges related to ESG factors, encompassing issues such as corporate governance, human rights, labor practices, environmental ramifications, equitable business operations, and consumer rights [37]. These challenges underscore a potential "digitalization paradox" where firms, driven by managerial myopia, may prioritize technological efficiency over sustainable development [38; 39]. Consequently, the net impact of AI on corporate ESG is not inherently positive but is contingent upon the firm's external institutional environment and internal governance logic. The balance between AI's potential contributions and the ESG risks it introduces remains the subject of a critical inquiry.

Given the inherent trade-offs between technological efficiency and social externalities, corporate sustainability cannot be achieved in an institutional vacuum [40]. In emerging markets like China, characterized by voluntary ESG disclosure and high information asymmetry, the governance of advanced technologies requires a synergistic blend of formal and informal oversight. Specifically, governmental environmental regulation (hard regulation) provides a mandatory compliance floor, while investor attention (soft regulation) serves as a potent informal monitoring mechanism that disciplines managerial short-termism and opportunistic behavior [41]. We contend that these regulatory forces function as essential institutional anchors that determine the 'strategic direction' of AI adoption. In an environment with robust oversight, the reputational and political costs of non-compliance are significantly heightened, compelling firms to channel AI's analytical power toward substantive sustainability improvements rather than narrow profit maximization. Despite the critical importance of these regulatory moderators, empirical evidence on how they interact with the technological dividends of AI to shape multi-dimensional ESG outcomes remains absent from the current literature.

This paper makes several contributions:

First, it provides a novel and comprehensive analysis of AI's role in improving ESG performance, exploring both its potential and challenges and addressing the fragmented insights in existing research. While most prior studies have focused on AI's impact on economic or environmental outcomes, this research uniquely explores AI's effects across all three ESG dimensions at the corporate level. Second, this paper examines the moderating effects of external reg-

ulation – both hard (governmental environmental regulation) and soft (investor attention) – on the link between AI implementation and ESG. This exploration sheds light on how external governance mechanisms influence the effectiveness of AI in driving sustainable development, providing a nuanced perspective on the interaction between technological innovation and regulatory environments. This theoretical advancement emphasizes the critical role of external regulation in shaping AI's contributions to sustainable development. Thirdly, this study provides a deeper heterogeneity analysis by exploring how divergent institutional logics (SOEs vs. non-SOEs) shape the strategic implementation of AI. The study uncovers significant differences in AI's impact on ESG performance across firms with varying ownership structures due to different regulatory and competitive pressures. This result provides practical guidance for tailoring AI-driven strategies across different firm types.

Literature review and research hypotheses

The impact of artificial intelligence on ESG

This study conceptualizes Artificial Intelligence (AI) not merely as a collection of isolated software applications, but as a General-Purpose Technology (GPT) that functions as a systemic catalyst for corporate ESG transformation. Unlike traditional Information Technologies (IT) that focus on specific task automation, AI is characterized by its pervasiveness, capacity for continuous improvement, and ability to generate innovative complementarities across diverse business functions [42; 43].

At the theoretical level, we define a firm's AI adoption as a systemic strategic orientation. According to the Attention-Based View (ABV) of the firm, the issues that command the strategic attention of top decision-makers determine the direction of organizational resource allocation and subsequent corporate behavior [44]. Therefore, the intensity of a firm's commitment to AI represents a high-order organizational capability – aggregate digital intelligence intensity – which permeates the firm's strategic infrastructure and organizational routines. Drawing on the Resource-Based View (RBV), we argue that this capability enables firms to transcend the traditional trade-offs between economic efficiency and sustainability goals [45; 46]. AI-driven ESG transformation operates through three core theoretical mechanisms:

First, the enhancement of information processing capabilities. According to Information Processing Theory, the complexity of ESG management stems from the vast, unstructured, and multi-dimensional nature of sustainability data [47]. AI provides the computational power necessary to internalize these social externalities by converting massive datasets into actionable strategic insights. By reducing information asymmetry between internal management and external stakeholders, a robust AI orientation enables firms to identify latent environmental risks and social needs more precisely, thereby improving the quality and transparency of ESG disclosures.

Second, the optimization of resource allocation and the "Green Digital Twin" effect. AI shifts the firm's production possibility frontier by enabling hyper-efficiency. Through predictive analytics and intelligent coordination, AI allows for a "digital-sustainability twin transition", where technological optimization directly translates into resource conservation and emission reduction [48]. This systemic optimization extends from shop-floor energy management to complex global supply chain auditing, fostering a holistic approach to value creation that satisfies both shareholders and broader stakeholders.

Third, the mitigation of agency costs and decision-making biases. Corporate governance often suffers from the bounded rationality of human managers and the agency problems inherent in the separation of ownership and control. AI functions as an "augmented intelligence layer" for the board and management, providing an objective, data-driven perspective that curbs managerial short-termism and cognitive biases [36; 49]. By automating compliance and monitoring executive behavior, AI enhances organizational integrity, which is a cornerstone of robust ESG performance.

However, the theoretical relationship between AI and ESG is not purely linear. As a double-edged sword, the deployment of AI involves significant institutional and environmental costs, such as a massive energy footprint and the potential for algorithmic opacity [50; 51]. We contend that the net effect of AI on ESG is a dynamic balance between these technological dividends and systemic costs. In an ideal institutional environment, as suggested by the Innovation Compensation Effect [52], the long-term gains from AI-driven green innovation are expected to outweigh the inherent costs of implementation. Therefore, we propose:

Hypothesis 1: *Artificial intelligence improves corporate overall ESG performance.*

The role of AI in shaping environmental performance

Artificial Intelligence (AI) presents a dual environmental impact: while it provides innovative solutions to reduce emissions and increase the efficiency of pollution and waste management, its deployment also generates significant energy consumption and emissions [53], creating a disruptive effect on the environment.

At the operational core, AI serves as a critical tool for advancing energy efficiency and cleaner production. By deploying machine learning algorithms for real-time monitoring of energy consumption patterns, firms can significantly reduce resource intensity and carbon emissions [31; 32; 54]. AI technologies enable precise forecasting of energy demand and optimize the scheduling of clean energy systems, thereby reducing the carbon footprint of internal manufacturing processes [26; 55]. Furthermore, AI-driven waste management systems allow for the precise tracking of pollutants and packaging materials, minimizing toxic emissions at the source [56]. However, AI's envi-

ronmental contributions come at a cost. According to the rebound effect theory, AI's application improves energy efficiency and reduces costs, which leads to an expansion of overall energy demand, ultimately exacerbating pollution. Furthermore, the infrastructure required for AI demands substantial energy and leads to the increase of electronic waste, thus creating a large carbon footprint [50] as well as hazardous materials like lead, arsenic, mercury, and cadmium [37; 57], posing considerable environmental risks.

Beyond internal boundaries, AI reshapes environmental performance through enhanced supply chain transparency and coordination. By improving demand forecasting and logistics routing, AI minimizes inventory waste and logistics-related carbon emissions [56; 58; 59]. More importantly, AI-enabled monitoring allows firms to evaluate the environmental credentials of upstream suppliers more accurately, reducing the ecological footprint of the entire value chain. This collaborative green synergy ensures that environmental gains are not localized but are distributed across the supply network, fostering a holistic approach to waste reduction and carbon management [60].

On a broader level, the integration of AI facilitates sustainable practices throughout the product lifecycle, from smart location planning to post-market recycling systems [56]. These technologies support firms in aligning their environmental output with regional and national sustainability goals, such as China's carbon peaking and carbon neutrality objectives [55; 61]. By providing data-driven insights into product lifecycle impacts, AI enables companies to transition from reactive pollution control to proactive environmental stewardship.

In summary, although the pathways through which AI affects the environment are multi-dimensional, encompassing internal efficiency, supply chain transparency, and societal alignment, these mechanisms are fundamentally driven by the firm's overall digital intelligence capacity. We contend that the frequency of AI-related keywords in annual reports reflects the depth of a firm's strategic commitment to embedding these technologies into its sustainability framework.

However, it is crucial to recognize that the net environmental contribution of AI is not an automatic outcome; it represents a dynamic balance between technological dividends and inherent energy costs. The realization of AI's green potential is contingent upon whether the efficiency gains can effectively offset the rebound effect and the heavy energy footprint of digital infrastructure. This balance is often dictated by the external institutional environment and monitoring intensity, which determine whether AI is deployed for narrow production expansion or meaningful green transformation. In the absence of sufficient oversight, firms may prioritize short-term efficiency over long-term ecological integrity. Nevertheless, assuming a baseline level of corporate responsibility and the overarching trend of green digitalization, we argue that higher AI integration provides the necessary systemic advantage to optimize environmental management. Therefore, we propose:

Hypothesis 2: *Artificial intelligence improves corporate environmental performance.*

The role of AI in shaping social performance

Within the organization, AI functions as a critical asset for fulfilling internal social responsibilities. By substituting human labor in hazardous, toxic, or high-risk environments, AI fundamentally enhances workplace safety and reduces occupational hazards [33; 62]. Moreover, the automation of repetitive and high-intensity tasks through AI-driven systems reduces the physical and mental workload of employees, thereby contributing to enhanced job satisfaction and overall well-being [34; 49; 62]. Beyond efficiency, AI-enabled text mining and emotional analysis allow for a more dynamic understanding of employee morale, facilitating proactive management of the work environment [63]. While concerns regarding algorithmic bias in recruitment and potential privacy infringements through surveillance persist [64–66], the strategic integration of AI typically signifies a move toward more data-driven and safety-oriented human resource management.

At the supply chain level, AI acts as a mechanism for ethical oversight and transparency. Real-time monitoring capabilities enable firms to trace the sourcing of raw materials with unprecedented precision, ensuring that upstream partners adhere to ethical labor standards and human rights policies. This systemic traceability mitigates risks associated with labor exploitation and strengthens the integrity of the entire supply chain. Furthermore, AI enhances a firm's responsiveness to consumer needs by capturing real-time feedback through sentiment analysis. This customer-centric orientation allows firms to align their operational strategies with the evolving social expectations of their stakeholders, thereby improving post-sales support and the overall customer experience [67].

On a broader societal level, the impact of AI is characterized by the tension between productivity enhancement and labor disruption. Existing theories suggest that AI can catalyze societal well-being by improving service quality and fostering economic growth. Although the current trajectory of AI development often prioritizes automation, potentially reducing opportunities for low-skilled workers and exacerbating income inequality [68], it also creates a productivity effect that can stimulate labor demand in new, high-value-added sectors [69, 70]. The net social impact of AI at the societal level thus depends on a firm's capacity to balance technological efficiency with its broader commitment to community welfare and human rights [71–73].

In conclusion, while the social implications of AI are multi-faceted and involve significant ethical trade-offs, they are fundamentally driven by the firm's aggregate digital intelligence capability. A higher intensity of AI adoption indicates a more robust infrastructure for monitoring safety, ensuring supply chain ethics, and responding to stakeholder feedback. Despite the risks of algorithmic bias or privacy concerns, we argue that AI's potential for systematic social coordination provides a net positive contribution to corporate social performance. Therefore, we propose the following hypothesis:

Hypothesis 3: *Artificial intelligence improves corporate social performance.*

The role of AI in shaping governance performance

The influence of AI on corporate governance represents a systemic shift from traditional human-centric oversight to a data-driven governance paradigm. Within the framework of corporate sustainability, AI transcends its role as a functional tool to become a strategic asset that optimizes internal power structures and decision-making efficiency [74]. This study contends that a firm's aggregate AI strategic orientation, captured by its AI keyword intensity, serves as a robust proxy for the modernization and transparency of its governance infrastructure.

At the core of modern governance is the challenge of making sound business judgments amidst high complexity. AI facilitates this by harnessing powerful data analytics and forecasting capabilities, allowing boards to capture critical insights that remain obscured in traditional reporting [49]. By automating the processing of extensive corporate data, AI helps to flatten organizational management, reduce internal information asymmetry, and improve the overall accuracy of strategic decisions [75; 76]. Furthermore, AI provides corporate managers with an external perspective, reducing cognitive biases and subjectivity in major governance choices [77]. As suggested by Hilb [36], AI-driven decision-making supports the evolution of governance processes by providing a more scientifically grounded basis for long-term development.

However, the integration of AI into governance also introduces specific technological risks. The black-box nature of complex algorithms can create opacity, potentially leading to accountability issues and reducing stakeholder trust in AI-driven outcomes. Moreover, there is a risk of managerial manipulation, where management might selectively control AI inputs or data sources to align with self-serving interests, potentially compromising the integrity of internal controls [78].

Despite these risks, we argue that a higher intensity of AI adoption indicates that a firm has invested in the necessary digital infrastructure to automate compliance and optimize board oversight. These systemic improvements in information transparency are expected to outweigh the risks of algorithmic opacity, leading to higher overall governance scores. Thus, we propose:

Hypothesis 4: *Artificial intelligence improves corporate governance performance.*

The moderating effect of investor attention

ESG inherently carries significant positive externalities, reflecting a firm's contributions to long-term sustainability and broader social and environmental goals. However, these positive externalities are often accompanied by increased short-term costs, which may deter companies from voluntarily undertaking these initiatives in the absence of external incentives or regulations. Furthermore, the inherent tension between a company's short-term profit objectives and ESG's long-term sustainability goals often leads firms to prioritize using AI technologies to optimize operating efficiencies and profitability while underinvesting in ESG-related applications. However, investor attention serves as an informal supervisory mechanism [79] that can exert compliance pressure on publicly listed companies [12], safeguard the rights of stakeholders, and compel firms to assume greater responsibility for their ESG performance [80].

The extensive adoption of the Internet and social media has played a key role in increasing institutional pressure on firms to fulfill their corporate social responsibility [81; 82]. The significant public pressure generated by increased attention acts as a form of external soft supervision. This external supervision reduces information asymmetry, decreases the likelihood of corporate misconduct [83; 84], and curbs opportunistic behavior by management [85], compelling firms to realign their behavior to align with social ethics, thereby enhancing their environmental and social responsibility [12; 84; 86; 87], encouraging firms to leverage AI technology to enhance ESG performance and expedite long-term sustainable development goals.

Moreover, increased investor attention enhances transparency and accountability, thus mitigating information asymmetry and building investor confidence, which can positively influence a company's access to financial resources [88]. These additional resources can be strategically directed toward the adoption and implementation of AI technologies that enhance ESG efforts, such as real-time monitoring of environmental impacts or optimizing governance frameworks. By leveraging both financial and technological resources, firms can better integrate ESG principles into their operations and achieve more sustainable long-term development [82].

Based on this rationale, this study proposes the following hypothesis:

Hypothesis 5: *Investor attention positively moderates the relationship between AI and corporate ESG performance.*

Hypothesis 6: *Investor attention positively moderates the relationship between AI and corporate environmental performance.*

Hypothesis 7: *Investor attention positively moderates the relationship between AI and corporate social performance.*

Hypothesis 8: *Investor attention positively moderates the relationship between AI and corporate governance performance.*

The moderating role of environmental regulation

Environmental resources possess the characteristics of public goods and externalities, so when penalties for non-compliance are minimal, companies are rationally inclined to adopt a "pollute first, mitigate later" strategy [89]. Ample evidence suggests that in the early 21st century, Chinese companies preferred paying fines for breaching national standards instead of investing in wastewater treatment facilities to manage and reduce pollution [90]. However, as local governmental pressure for environmental regulation intensified, companies became more likely to implement

proactive pollution prevention measures instead of solely relying on end-of-pipe solutions [91]. Consequently, without strict legal environmental regulations, the efficacy of AI in enhancing ESG performance may be constrained.

Complying with environmental policies is not only a legal obligation but also a strategic move for businesses [92]. Motivated by compliance, companies are more likely to apply AI technologies in environmental management, leveraging AI to drive green innovation, enhance smart pollution control, and improve resource and energy efficiency to avoid non-compliance risks. However, some studies suggest that while environmental regulation can improve environmental performance, it also raises the cost of environmental management for firms [93], leading to substantial compliance costs that may crowd out productive expenditures [93; 94], which, in turn, could reduce firms' investment in social responsibility and compliance governance [93]. Conversely, other research indicates that environmental regulation can improve the overall performance of ESG [95].

Despite these differing views, we hypothesize that environmental regulation positively moderates the relationship between AI adoption and ESG performance. This hypothesis is grounded in the notion that environmental regulation acts as a critical signal, reflecting the government's prioritization of sustainability and long-term economic strategy. By capturing this signal, firms are incentivized to not only comply with environmental policies but also recognize the broader value of social responsibility and governance reforms. Regulatory pressure encourages firms to deploy AI technologies more holistically across ESG dimensions to ensure rapid response to government strategies and alignment with policy objectives and to avoid compliance risks.

Based on these considerations, the following hypotheses are proposed.

Hypothesis 9: *Environmental regulation positively moderates the relationship between AI and corporate ESG performance.*

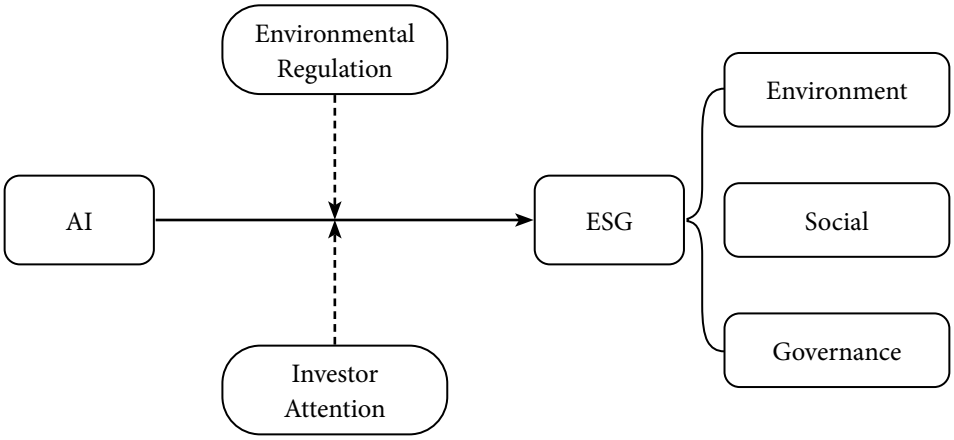
Hypothesis 10: *Environmental regulation positively moderates the relationship between AI and corporate environmental performance.*

Hypothesis 11: *Environmental regulation positively moderates the relationship between AI and corporate social performance.*

Hypothesis 12: *Environmental regulation positively moderates the relationship between AI and corporate governance performance.*

Based on the above hypotheses, the research model is depicted in Figure 1.

Figure 1. Research model



Research design

Data sources

This study focuses on A-share listed companies from 2013 to 2022 to investigate the influence of AI on ESG performance. The year 2013 was chosen as the starting year because it represents a critical moment in the evolution of deep learning technology, which has become foundational to modern AI advancements. Additionally, 2013 marks the beginning of China's 4G network construction, which, alongside the rapid development of mobile internet technology, provided crucial infrastructure and data support for AI applications [96]. AI data were manually collected by the research team, while other related data came from the Wind financial terminal and CSMAR databases. The sample selection follows these criteria: 1) excluding samples with insufficient data; 2) excluding financial and insurance companies due to their particular characteristics [97–99]; 3) excluding ST, PT, and *ST companies [100; 101]; 4) to reduce the impact of outliers, all continuous variables were adjusted using winsorization at the 1 and 99% [102; 103]. Since Bloomberg only provides ESG ratings for a subset of Chinese listed companies, the final sample size is relatively small. The final dataset includes 1148 companies with a total of 8906 observations. All empirical analyses were conducted using Stata 17.0 software.

Description of variables

Dependent variable: This study utilizes Bloomberg's ESG database as the primary data source of ESG variables. First, Bloomberg's ESG database adopts one of the most comprehensive approaches for evaluating companies' ESG activities and outcomes, offering a rigorous and systematic evaluation framework [104]. Second, Bloomberg has been conducting ESG ratings since 2008, providing a long time span that ensures consistent and reliable data for the study [105]. The database encompasses over 2,000 data points in areas ranging from air quality and climate change to water and energy management, employee health and safety, and board structure, among others. These rich and diverse data points enable a comprehensive analysis of firms' performance across the different dimensions of ESG.

To ensure the robustness of our findings, we use Huazheng ESG ratings instead of Bloomberg ESG ratings for robustness checks. Huazheng ESG rating is one of the most advanced ESG indices in China and has been widely used in multiple studies to assess firms' ESG performance [106–108]. This rating system ranks companies from AAA to C across nine levels, with assessments conducted quarterly, thus providing more timely data. For this study, we assigned values from 1 to 9 according to these ratings, using the annual average score as the firm's ESG performance for each year.

Explanatory variable: Artificial Intelligence (AI). The growing use of text analytics and machine learning in economics has made it possible to utilize big data text mining to assess AI adoption in publicly listed companies through their annual reports. Referring to existing literature [109–111], this study constructs a firm-level AI index using machine learning and text analysis techniques. The words used in a company's annual report can reflect its business philosophy and developmental trajectory [38]. This approach allows for an accurate capture of a firm's actual investment in and application of AI technologies, offering a precise representation of the depth and breadth of AI utilization within the company. Based on Yao et al.'s [112] study that identified 73 AI-related keywords (see Table 1), we applied the open-source Python "jieba" Chinese word segmentation tool to analyze annual reports from 2013 to 2022. To avoid ambiguity caused by the broad meanings of some commonly used words, this study manually filtered out words that were less relevant to AI applications. For example, the term "artificial intelligence" was matched with the phrase "Artificial Intelligence Co., Ltd.", and its frequency was calculated. Then, such expressions were excluded from the overall frequency of the "artificial intelligence" keyword. This process was repeated to obtain the final adjusted frequency for each term. Then we calculated the frequency of AI-related terms (including their abbreviations) within the reports and determined the total number of words in the report. The ratio of AI-related terms to the total word count was then logarithmically transformed, providing a proxy for the level of AI application. That is:

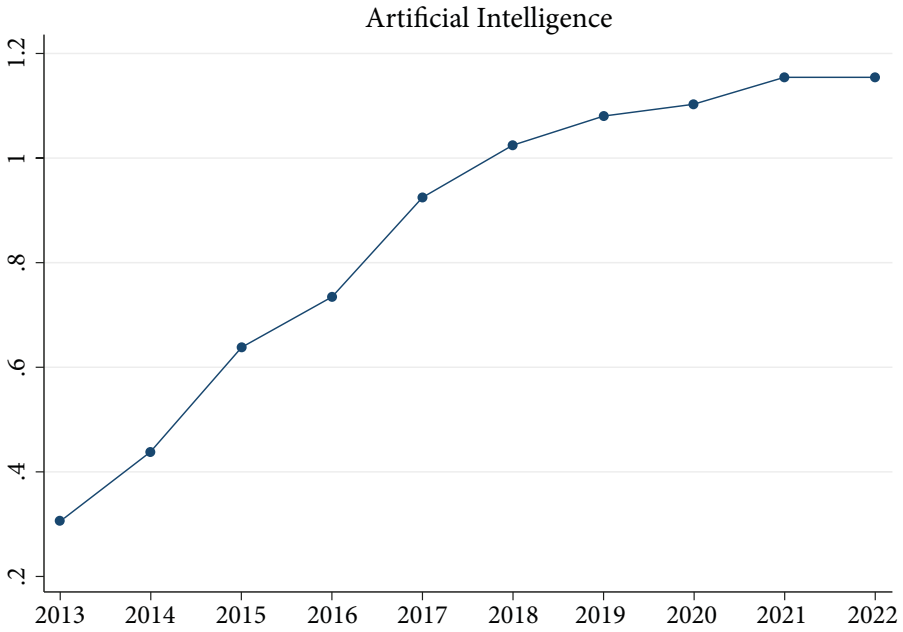
$$AI = \ln\left[\frac{\left(\sum_{n}^{73} Keyword\ frequency\right)}{total\ words} + 1\right] . \quad (1)$$

Table 1. Keywords for Artificial Intelligence

Keyword thesaurus				
Artificial Intelligence (AI)	Computer Vision	Image Recognition	Knowledge Graph	Intelligent Education
Augmented Reality (AR)	Intelligent Government	Feature Extraction	Business Intelligence	Smart Elderly Care
Support Vector Machine (SVM)	Knowledge Representation	Pattern Recognition	Internet of Things (IoT)	Human-Computer Dialogue
AI Products	Human-Computer Interaction	Data Mining	Smart Banking	Intelligent Customer Service
Virtual Reality (VR)	Autonomous Driving	Driverless Driving	Smart Finance	Big Data Marketing
Long Short-Term Memory (LSTM)	Smart Chips	Edge Computing	Cloud Computing	Deep Neural Networks (DNN)
AI Chips	Deep Learning	Feature Recognition	Smart Insurance	Intelligent Retail

Keyword thesaurus				
Intelligent Healthcare	Smart Transportation	Smart Home	Recurrent Neural Networks (RNN)	Big Data Risk Control
Robotic Process Automation (RPA)	Wearable Products	Big Data Platform	Augmented Intelligence	Big Data Operations
Machine Translation	Neural Networks	Speech Synthesis	Human-Machine Collaboration	Smart Agriculture
Natural Language Processing (NLP)	Convolutional Neural Networks (CNN)	Question Answering System	Reinforcement Learning	Big Data Analysis
Smart Speaker	Big Data Management	Intelligent Computing	Voice Interaction	Machine Learning
Biometric Recognition	Smart Environmental Protection	Intelligent Regulation	Intelligent Investment Advisor	Speech Recognition
Voiceprint Recognition	Facial Recognition	Intelligent Agent	Big Data Processing	Distributed Computing
Intelligent Sensors	Intelligent Search	Smart Voice		

Figure 2. Average AI adoption trend at listed companies in China, 2013–2022



The trend in average AI adoption levels of companies from 2013–2022 is shown in Figure 2, with the vertical axis showing the AI keyword frequency ratio. In 2013, the sample average was 0.307, while in 2022, it was 1.154.

Moderator variable: Investor Attention (Inv_Att). Web search volume reflects the search behavior of Chinese netizens and serves as a direct and effective measure of public attention [113; 114]. By March 2024, China had

1.232 billion active mobile internet users, making search volume a widely accepted indicator of investor attention. Retail investors, who dominate China's capital market, often face information asymmetries and primarily use web searches to gather company-related information for investment decisions. Based on previous research [115-117], we manually collected data from the "Baidu Index" (https://index.baidu.com) for this variable. Specifically, we entered stock codes, company abbreviations, and full company names into the Baidu Index platform to retrieve the number of searches during a specified period and summed the search values for these keywords, applying a natural logarithm transformation. This approach is adapted from Da's [118] study on manually collecting Google search volume. Higher web search volume indicates that the company has likely attracted greater investor attention [113; 119].

Environmental Regulation (ER). Consistent with Liu et al. [99], we measure the intensity of ER using the ratio of investment in wastewater and air pollution control to industrial output in the provinces where listed firms are located. This ratio reflects the local government's efforts and enforcement strength in environmental management. A higher ratio indicates stronger environmental regulation in that area. Relevant data are from the China Provincial Database.

Control variables: Based on existing studies [97; 100], we incorporate the following control variables: to capture profitability, we use return on assets (ROA) and revenue growth rate (Growth). Future growth opportunities are measured by Tobin's Q (TobinQ). We also incorporate firm-level characteristics such as firm size (Size), firm age (Age), and leverage ratio (Lev) to control for the impact of financial indicator changes on ESG. We also introduce governance variables, including board of directors (Boa_Dir), board of directors' independence (Ind), shareholding concentration (Top 1), and CEO duality (CEO_duality). These variables collectively provide a comprehensive framework for analyzing the factors affecting ESG metrics. The definitions and quantification of all variables are presented in Table 2.

Table 2. Variable definitions

Variable Type	Variable Name	Variable Symbol	Variable Description
Dependent variables	Bloomberg ESG performance	ESG	Bloomberg ESG combined score
	Environmental performance	Environment	Bloomberg ESG environment score
	Social performance	Social	Bloomberg ESG social score
	Governance performance	Governance	Bloomberg ESG governance score
	Huazheng ESG	ESG_hz	Huazheng ESG combined score
Explanatory variable	Artificial Intelligence	AI	The ratio of the word frequency of AI-related keywords to the total word frequency of the annual report is log-transformed.
Moderator variables	Investor Attention	Inv_Att	The logarithmic transformation of web search volumes for company-related keywords
	Environmental regulation	ER	Proportion of the amount invested in wastewater and exhaust gas pollution control in the provinces where listed firms are located to the industrial output value in the current year, and taking natural logarithms.

Control variables	Enterprise size	Size	ln (Total assets)
	Enterprise age	Age	Years of observation minus the year of listing and taking natural logarithms
	Gearing	Lev	Total liabilities divided by total assets
	Return on total assets	ROA	Net profit divided by total assets
	Growth rate of revenue	Growth	(Current operating income minus previous operating income) divided by previous operating income
	Future growth opportunities	TobinQ	Market value of assets divided by replacement cost of assets
	Board of directors	Boa_Dir	Number of Board of Directors
	Board independence	Ind	Number of independent directors divided by number of directors
	Shareholding concentration	Top1	Proportion of shares held by the largest shareholder of the enterprise
	CEO duality	CEO_duality	When the CEO of a company simultaneously holds the position of chairman of the board of directors, it is referred to as CEO duality, which takes the value "1", otherwise, it takes the value "0".

Note: The table comprehensively explains and quantifies all the variables used in the empirical analysis.

Table 3. Descriptive statistics of the variables

Variables	Obs	Mean	Std. Dev	Min	Max
ESG	8.906	30.37	10.35	0	73.38
Environment	8.906	13.35	15.63	0	76.71
Social	8.906	14.67	8.217	0	63.09
Governance	8.906	67.09	15.46	0	96.12
AI	8.906	0.464	0.543	0	1.914
ESG_hz	8.906	4.398	1.021	1	8
Inv_Att	8.906	3.356	4.008	0	17.02
ER	8.906	9.054	3.220	0	12.07
Size	8.906	23.32	1.410	20.55	28.15
Age	8.906	1.740	0.511	0.693	2.398
Lev	8.906	0.478	0.205	0.0750	0.929
ROA	8.906	5.572	5.273	-5.167	25.04
Growth	8.906	0.346	0.866	-0.630	5.832
Tobin Q	8.906	1.995	1.459	0	8.909
Boa_Dir	8.906	8.975	1.913	3	19
Ind	8.906	0.376	0.056	0.167	0.8
Top 1	8.906	0.358	0.159	0.034	0.90
CEO_duality	8.906	0.269	0.443	0	1

Descriptive statistics of the variables

Table 3 presents descriptive statistics for the dataset's 8,906 observations. The average ESG score is 30.37, with a standard deviation of 10.35, indicating substantial variation in ESG performance in the sample. The average for AI is 0.464, signifying that the average frequency share of AI-related keywords is 0.87%, with a range from 0 to 5.78%. The average scores for environmental performance and social performance are 13.35 and 14.67, respectively, while the average governance performance score is 67.09, indicating a significant performance gap between different dimensions, with Chinese listed companies performing much better in governance than in environmental and social performance. The average Huazheng ESG rating is 4.398, indicating ESG's average rating between B and BB. The distributions of other financial and corporate governance variables fall within reasonable ranges.

Model design

Two-way fixed-effects model regressions can effectively control for the effects of year- and firm-related unobservable variables, reduce potential estimation bias, and improve the statistical reliability of regression results [120; 121]. Firms' ESG performance is not only strongly related to industry characteristics [122], but also affected by internal factors such as corporate culture [123], which are often difficult to observe directly but can systematically bias the results. Therefore, this study used a two-way fixed effects model to provide robustness and credibility to the results.

To test the correlation of AI and ESG, a regression model (1) was constructed.

$$ESG_{i,t} = \alpha_0 + \alpha_1 AI_{i,t} + \alpha_2 Controls_{i,t} + \sum Year + \\ + \sum Firm + \varepsilon_{i,t}. \quad (1)$$

Here, subscript denotes the firm, t represents time, $ESG_{i,t}$ indicates the performance of ESG of firm i at year t, and $AI_{i,t}$ indicates the level of Artificial Intelligence of firm i at year t. $Controls_{i,t}$ indicates a set of control variables, $\sum Year$ and $\sum Ind$ represent the time fixed effects and firm fixed effects of the firm. $\varepsilon_{i,t}$ is the exogenous disturbance term, which follows a normal distribution with mean 0 and variance $\sigma^{\wedge 2}$. According to the theoretical analysis, the coefficient α_1 of $AI_{i,t}$ is expected to be significantly positive because AI improves firms' ESG performance.

To validate the moderating effects of Inv_Att and ER on the correlation of AI and ESG, our research constructs models (2) and (3), drawing on the moderating effect model [124; 125].

$$ESG_{i,t} = \beta_0 + \beta_1 AI_{i,t} + \beta_2 Inv\_Att_{i,t} + \beta_3 Inv\_Att_{i,t} \times AI_{i,t} + \beta_4 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t}; \quad (2)$$

$$ESG_{i,t} = \gamma_0 + \gamma_1 AI_{i,t} + \gamma_2 ER_{i,t} + \gamma_3 ER_{i,t} \times AI_{i,t} + \gamma_4 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t}. \quad (3)$$

Here, $Inv\_Att_{i,t} \times AI_{i,t}$ and $ER_{i,t} \times AI_{i,t}$ are the interaction terms. If they are significant, it means that the moderating effect exists. According to the theoretical analysis, the coefficients β_3 and γ_3 are expected to be significantly positive.

Results and discussion

Correlation analysis

Table 4 presents the pairwise Pearson correlations among ESG performance, AI adoption, firm characteristics, and corporate governance variables. ESG is positively and significantly associated with AI adoption (r = 0.1805***), firm size (r = 0.4454***), leverage (r = 0.1335***), board independence (r = 0.0331***), and board size (r = 0.1143***), indicating that technologically advanced, larger, and well-governed firms tend to achieve better ESG performance. Conversely, ESG performance is negatively associated with environmental regulation (r = –0.3419***), firm age (r = –0.5642***), and Tobin's Q (r = –0.0386***). These results suggest that firms subject to stricter regulations, older firms, and those with higher market valuations tend to exhibit weaker ESG performance, possibly due to legacy constraints, lower adaptability, or different strategic priorities. All correlation coefficients remain below the conventional threshold of 0.8, with most well below 0.5, indicating that multicollinearity is unlikely to bias the regression analyses that follow.

Additionally, we calculated the variance inflation factors (VIFs) and found that the highest VIF value among the variables is 2.47, with an average VIF value of 1.55, both lower than the threshold of 10. Thus, multicollinearity does not appear to be an issue in this section of the study.

Table 4. Correlation matrix

	ESG	Environment	Social	Governance	Inv_Att	ER	AI	Size	Age	Lev	ROA	Growth	TobinQ	Boa_Dir	Ind	Top1	CEO_duality
ESG	1																
Environment	0.6532***	1															
Social	0.7600***	0.5418***	1														
Governance	0.6652***	0.3710***	0.3069***	1													
Inv_Att	0.1533***	0.0976***	0.1371***	0.0966***	1												
ER	-0.3419***	-0.2069***	-0.2437***	-0.2464***	-0.1222***	1											
AI	0.1805***	0.0864***	0.1460***	0.1774***	0.1045***	-0.0890***	1										
Size	0.4454***	0.3085***	0.3513***	0.3121***	0.3782***	-0.1344***	0.1304***	1									
Age	-0.5642***	-0.3775***	-0.3618***	-0.4506***	0.0658***	0.6737***	-0.2354***	-0.2162***	1								
Lev	0.1335***	0.0594***	0.0895***	0.1090***	0.1555***	-0.0284***	-0.0067	0.5801***	-0.0244**	1							
ROA	0.0128	0.0426***	0.0250**	-0.0242**	-0.0178*	0.0227**	0.012	-0.1221***	0.0112	-0.2928***	1						
Growth	-0.0049	0.0166	-0.0155	0.0059	-0.0114	0.0095	0.0013	0.0092	0.0067	0.0042	0.0025	1					
TobinQ	-0.0386***	-0.007	-0.0278***	-0.0313***	0.0088	0.0264**	0.0299***	-0.2631***	0.0218**	-0.2662***	0.7436***	-0.0041	1				
Boa_Dir	0.1143***	0.0647***	0.1195***	0.0610***	0.1686***	-0.0021	-0.0174	0.3400***	0.0342***	0.2179***	-0.0655***	-0.0112	-0.1040***	1			
Ind	0.0331***	0.0266**	0.0221**	0.0390***	0.0333***	-0.0499***	0.0481***	0.0277***	-0.0445***	-0.0153	0.0280***	0.0096	0.0362***	-0.3849***	1		
Top1	0.0128	0.0211**	0.0042	-0.0159	-0.0979***	0.0102	-0.1591***	0.0910***	0.0778***	0.0327***	0.0288***	-0.0115	-0.0566***	-0.0299***	0.0486***	1	
CEO_duality	-0.0145	-0.0077	-0.0059	-0.0163	-0.0094	0.0383***	-0.0084	-0.0376***	0.0247**	-0.0294***	0.0107	-0.007	0.0049	-0.0293***	-0.0007	-0.0106	1

Main effect regression analysis

Table 5 presents that AI has a significantly positive effect on overall ESG performance as well as its individual dimension at the 1% significance level, indicating that AI could improve ESG performance. In contrast, the positive impact on social performance is more modest, with a 0.802 increase. These findings suggest that AI is particularly effective in reducing corporate energy consumption, lowering emissions, optimizing green production management, and improving governance efficiency and transparency. However, in the social dimension, while AI contributes to improving working conditions, customer satisfaction, and product safety, the challenges it poses, like job displacement, privacy concerns, human rights violations, and other social inequalities, partially offset the positive effect of AI on the social dimension.

The regression results in Table 5 demonstrate that AI significantly enhances overall ESG performance and its subdimensions (Environmental, Social, and Governance), with all coefficients being positive and statistically significant at the 1% level, confirming Hypotheses 1–4. Firm size and market valuation (Tobin's Q) also exhibit strong positive effects on ESG outcomes, particularly in the Environmental and Social dimensions, while firm age and leverage show significant negative impacts, indicating that older and more leveraged firms tend to underperform in ESG.

Table 5. Main effect regression analysis

	Main effect regression				Robustness test
	ESG	Environmental	Social	Governance	ESG_hz
AI	0.851*** (3.42)	1.092*** (2.75)	0.802*** (3.16)	1.054*** (2.77)	0.011** (2.02)
Size	2.676*** (8.99)	3.339*** (7.33)	2.859*** (9.93)	0.321 (0.79)	0.063*** (13.62)
Age	–9.601*** (–35.08)	–9.358*** (–21.36)	–4.090*** (–14.48)	–14.502*** (–35.05)	0.057*** (10.54)
Lev	–6.714*** (–5.81)	–6.499*** (–3.82)	–5.959*** (–5.34)	–7.246*** (–4.02)	–0.186*** (–9.11)
ROA	0.037 (1.44)	0.040 (1.08)	0.020 (0.76)	–0.030 (–0.80)	–0.001*** (–2.99)
Growth	–0.108 (-1.17)	0.173 (1.09)	–0.141 (–1.59)	0.022 (0.16)	–0.003 (–1.29)
TobinQ	0.411*** (4.76)	0.506*** (3.77)	0.435*** (4.81)	0.178 (1.54)	0.006*** (3.01)
Boa_Dir	0.088 (0.83)	0.196 (1.19)	0.010 (0.09)	0.124 (0.76)	–0.002 (–0.95)
Ind	0.050** (2.10)	0.088** (2.27)	0.040* (1.72)	0.031 (0.82)	0.002*** (3.83)
Top1	0.055*** (3.04)	0.046* (1.79)	0.048*** (2.75)	0.052** (2.26)	–0.000 (–0.59)
CEO_duality	0.263 (1.26)	0.195 (0.60)	0.146 (0.68)	–0.032 (–0.09)	0.018*** (4.06)
Constant	–19.386*** (–2.72)	–54.754*** (–5.05)	–45.921*** (–6.62)	76.500*** (7.89)	–2.813*** (–5.23)
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Observations	8.906	8.906	8.906	8.906	8.906
R^2–within	0.561	0.399	0.313	0.420	0.045
R^2–between	0.458	0.200	0.159	0.377	0.101
R^2–overall	0.465	0.295	0.230	0.347	0.080

Note: The T statistic is in parentheses; *, **, and *** represent 10%, 5%, and 1% significance levels, respectively.

Robustness test

Based on previous studies [107; 126], this section of the study replaces ESG with ESG_hz in the baseline regression model to verify the robustness of our research. The results in Table 5 indicate that the estimated coefficient of AI level on ESG_hz is significantly positive at the 5% level, indicating that the study's conclusions remain robust.

Moderating effect of investor attention

Table 6 presents the results of the moderating effect of investor attention. The interaction term (AI×Inv_Att) is significantly positive for overall ESG performance ($\beta_3 = 0.574$, $p < 0.01$) and its three sub-dimensions, suggesting that investor attention significantly strengthens the positive correlation between AI adoption and ESG outcomes.

However, a more nuanced picture emerges when observing the direct effect of AI. Upon including the interaction term, the main effect coefficient of AI becomes significantly negative ($\beta_1 = -3.258$, $p < 0.05$). This negative baseline coefficient indicates that when investor attention is absent or at an extremely low level, AI adoption may actually exert a detrimental impact on corporate ESG performance. By calculating the inflection point ($-\beta_1/\beta_3$), we find that the impact of AI on ESG only turns positive when investor attention exceeds the threshold of 5.68. Similarly, the specific thresholds for the Environmental, Social, and Governance dimensions are 6.07, 5.94, and 5.53, respectively.

This finding uncovers a critical digitalization paradox in corporate sustainability [38]. Without sufficient external soft regulation, the deployment of AI often serves as a tool for narrow profit maximization rather than holistic value creation. From an environmental perspective, the substantial energy footprint and resource intensity required to maintain AI infrastructure can lead to a rebound effect, where technological efficiency gains are eclipsed by increased ecological burdens [51]. In the social dimension, in the absence of public scrutiny, firms are more likely to implement the "wrong kind of AI" – prioritizing labor-displacing automation over task-enhancing innovation, which adversely affects employee welfare and social equity [127]. Furthermore, the high initial costs of AI may trigger managerial myopia, leading firms to redistribute resources away from long-term ESG initiatives to offset technological expenses.

In summary, investor attention, measured by the Baidu Index, functions as a vital informal governance mechanism. It creates a reputational pressure that compels management to move beyond the efficiency-only paradigm. High levels of public scrutiny incentivize firms to leverage AI's precision for green innovation and transparent governance, effectively transforming AI from a potential sustainability risk into a powerful driver of corporate ESG transformation.

Table 6. Moderating effect of investor attention

	ESG	Environmental	Social	Governance
AI	−3.258** (−2.10)	−6.071*** (−2.84)	−3.898** (−2.45)	−3.565* (−1.79)
Inv_Att	−0.113 (−0.42)	−0.378 (−1.07)	−0.456* (−1.91)	−0.423 (−1.61)
AI × Inv_Att	0.574*** (2.66)	1.000*** (3.32)	0.656*** (2.94)	0.645** (2.38)
Size	2.674*** (8.91)	3.370*** (7.33)	2.920*** (9.99)	0.376 (0.92)
Age	−9.544*** (−34.74)	−9.285*** (−21.13)	−4.070*** (−14.38)	−14.479*** (−34.78)
Lev	−6.744*** (−5.85)	−6.531*** (−3.85)	−5.956*** (−5.35)	−7.247*** (−4.02)
ROA	0.037 (1.43)	0.040 (1.09)	0.021 (0.79)	−0.029 (−0.78)
Growth	−0.110 (−1.19)	0.167 (1.05)	−0.148* (-1.66)	0.015 (0.11)

	ESG	Environmental	Social	Governance
TobinQ	0.403*** (4.65)	0.501*** (3.72)	0.442*** (4.86)	0.183 (1.57)
Boa_Dir	0.096 (0.92)	0.210 (1.28)	0.018 (0.17)	0.132 (0.81)
Ind	0.050** (2.13)	0.090** (2.31)	0.041* (1.78)	0.032 (0.85)
Top1	0.054*** (2.99)	0.044* (1.71)	0.045*** (2.58)	0.049** (2.15)
CEO_duality	0.261 (1.25)	0.191 (0.59)	0.144 (0.67)	–0.035 (–0.10)
Constant	–18.720*** (–2.61)	–53.035*** (–4.88)	–44.155*** (–6.31)	78.156*** (8.00)
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	8.906	8.906	8.906	8.906
R^2–within	0.562	0.399	0.314	0.421
R^2–between	0.456	0.195	0.159	0.379
R^2–overall	0.466	0.294	0.230	0.348

Note: The T statistic is in parentheses; *, **, and *** represent 10%, 5%, and 1% significance levels, respectively.

Moderating effect of environmental regulation

Table 7 shows that government environmental regulation positively moderates the relationship between AI and overall ESG performance, as well as between AI and environmental and governance performance. However, it has no significant moderating effect on the relationship between AI and social performance. This could be because stringent environmental regulation increases corporate investment in environmental management, leading to a focus on AI application in environmental management while reducing attention to social responsibility, which partly confirms the findings of Yan et al. [93]. However, unlike the results of that research, our results show that stricter environmental regulations also encourage greater AI adoption in corporate governance. This divergence can be attributed to the critical role of compliance and transparent governance in addressing the scrutiny and accountability demands posed by external regulatory bodies. Effective governance frameworks can enhance a firm's ability to comply with regulatory standards, mitigating risks associated with environmental regulation and supporting more robust and informed environment-related decision-making [128–130].

Table 7. Moderating effect of environmental regulation

	ESG	Environmental	Social	Governance
AI	0.051 (0.11)	–0.475 (–0.68)	0.855 (1.58)	0.266 (0.55)
ER	0.034 (0.33)	–0.113 (–0.81)	0.230* (1.94)	–0.182 (–1.18)
AI×ER	0.087** (2.06)	0.171*** (2.89)	–0.011 (–0.23)	0.088** (2.13)
Size	2.681*** (9.04)	3.427*** (7.59)	2.912*** (10.14)	0.324 (0.79)
Age	–10.031*** (–14.89)	–9.102*** (–9.58)	–5.383*** (–6.92)	–13.659*** (–13.50)
Lev	–7.641*** (–6.61)	–7.444*** (–4.37)	–6.976*** (–6.23)	–7.384*** (–4.07)
ROA	–0.029* (–1.93)	–0.038* (–1.74)	–0.034** (–2.25)	–0.042** (–2.35)
Growth	0.000*** (3.65)	0.000*** (8.94)	0.000 (1.20)	0.000*** (7.47)
TobinQ	0.130** (2.12)	0.232** (2.51)	0.173*** (2.72)	0.095 (1.44)
Boa_Dir	0.099 (0.94)	0.201 (1.23)	0.017 (0.17)	0.127 (0.78)
Ind	0.053** (2.23)	0.091** (2.32)	0.043* (1.83)	0.032 (0.85)
Top1	0.054*** (2.97)	0.046* (1.79)	0.048*** (2.76)	0.051** (2.22)
CEO_duality	0.301 (1.43)	0.253 (0.78)	0.168 (0.78)	–0.008 (–0.02)
Constant	–17.661** (–2.49)	–54.860*** (–5.08)	–45.321*** (–6.56)	76.540*** (7.81)
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	8.906	8.906	8.906	8.906
R2 – within	0.560	0.398	0.312	0.421
R2 – between	0.459	0.199	0.158	0.383
R2 – overall	0.465	0.295	0.229	0.348

Note: The T statistic is in parentheses; *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively.

Endogeneity test

Although the two-way fixed effects model reduces estimation bias, endogeneity issues may still persist, particularly due to potential unobserved variables or omitted variable bias between AI and ESG performance. To mitigate these potential endogeneity problems, this study introduces the lagged Digital Economy Index (DEI_{t-1}) at the city level and the lagged AI application level (AI_{t-1}) as instrumental variables, using a two-stage least squares (2SLS) regression. The DEI is calculated using the approach proposed by Tao et al. [131] based on data from the China City Statistical Yearbook and the Local Statistical Yearbooks for cities at the prefecture level and above.

The rationale for selecting these two instrumental variables (DEI_{t-1} and AI_{t-1}) is as follows: First, the level of AI adoption within a firm is closely linked to the level of digital development in the region where the firm operates. The relevant literature suggests that when other firms in the same region experience rapid digital economic growth, the likelihood and extent of digital technology adoption by an individual firm also increase [132]. Therefore, DEI_{t-1} satisfies the relevance condition through technological spillovers. Second, AI_{t-1} strongly predicts current AI usage due to technological path dependency.

To ensure the validity of the exclusion restriction, we provide a multi-layered justification. A potential concern is that regional digital infrastructure (DEI_{t-1}) might influence firm-level ESG through alternative channels like human capital aggregation or improved access to green technologies. We mitigate these concerns, first, through a "channel blocking" effect, whereby these alternative pathways are largely internalized by our extensive control variables (e.g., firm size and governance) and firm-year fixed effects, which absorb macro-level technological and regulatory shocks. Second, we argue that AI serves as the essential "downstream execution" mechanism; while a city's digital ecosystem provides the external opportunity, the actual translation of infrastructure into improved ESG outcomes–such as real-time carbon tracking–requires the strategic deployment of AI within the firm [133].

Regarding the exclusion restriction of AI_{t-1}, we argue that potential persistent effects from past technological adoption do not systematically bias our estimates for two reasons.

First, the control of Firm Fixed Effects. By incorporating firm-level fixed effects, our model effectively absorbs time-invariant firm-specific characteristics, including the firm's baseline technological level. Consequently, the regression identifies the impact of incremental changes in AI strategic intensity on ESG improvements, rather than level-based persistence.

Second, the Transmission Mechanism through Current Adoption. In line with technological path-dependency, the influence of AI_{t-1} on current ESG performance is predominantly manifested through its high correlation with current-year AI strategic prioritization (AI_t). Therefore, the 'direct' impact of past adoption is largely internalized by the endogenous regressor itself.

Empirically, our instrumental variable strategy is supported by robust diagnostic statistics. In Table 8, the coefficients of DEI_{t-1} and AI_{t-1} are significant at the 5% and 1% levels, respectively, indicating a strong correlation between the instrumental variables and AI. In Column (3), the Kleibergen-Paap rk LM statistic shows a p-value below 0.01, rejecting the null hypothesis of "under-identification of instrumental variables." Both the Cragg-Donald Wald F statistic and the Kleibergen-Paap rk Wald F statistic exceed the critical threshold at the 10% level (19.93), indicating no issue of weak instrumental variables. Furthermore, the p-values for both the Hansen J-test and Sargan test were greater than 0.1, confirming no over-identification concerns. In the second stage, AI's coefficient remains significantly positive at the 1% level (2.059), indicating that AI continues to have a substantial positive impact on ESG performance, and this effect is larger after accounting for endogeneity compared to the ordinary least squares results.

Table 8. Endogeneity test

	First stage		Second stage
	AI	AI	ESG
AI			2.059***
			(2.59)
DEI_{t-1}	0.013**		
	(2.04)		
AI_{t-1}		0.254***	
		(20.51)	
Size	0.095***	0.075***	2.647***
	(7.58)	(6.18)	(10.56)

	First stage		Second stage
	AI	AI	ESG
Age	–0.156*** (–12.76)	–0.107*** (–8.90)	–4.148*** (–6.20)
Lev	–0.104* (–1.95)	–0.087* (–1.68)	–5.237*** (–5.77)
ROA	–0.001 (–1.44)	–0.001 (–0.78)	0.022* (1.41)
Growth	–0.004 (–0.63)	–0.003 (–0.63)	–0.100 (–1.26)
TobinQ	0.001 (0.20)	0.002 (0.38)	0.334*** (4.49)
Boa_Dir	0.001 (0.18)	–0.001 (–0.20)	0.137* (1.76)
Ind	0.001 (0.81)	0.001 (0.58)	0.058*** (3.04)
Top1	–0.002*** (–3.12)	–0.002** (–2.11)	0.031** (2.45)
CEO_duality	0.013 (1.28)	0.012 (1.22)	0.204 (1.24)
Constant	–1.515*** (–4.99)	–1.176*** (–4.01)	–19.507*** (–3.94)
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Observations	7.221	7.221	7.221
R^2–within	0.147	0.202	0.594
R^2–between	0.039	0.612	0.472
R^2–overall	0.059	0.467	0.459
Kleibergen-Paap rk LM statistic			233.293[0.000]
Kleibergen-Paap rk Wald F statistic			129.469
Cragg-Donald Wald F statistic			212.113
Sargan test			0.686[0.4076]
Hansen J test			0.624[0.4294]

Note: The T statistic is in parentheses; *. **. and *** represent 10%. 5%. and 1% significance levels. respectively; the P value is in brackets.

Heterogeneity analysis

The impact of AI on ESG performance may vary depending on a firm's ownership structure, which dictates its strategic priorities, resource allocation logic, and institutional environment. To explore this, we categorize the sample into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). As shown in Table 9, while AI significantly promotes overall ESG performance in both groups, a distinct "functional specialization" emerges: AI primarily drives environmental (E) performance in SOEs, whereas its facilitative effect is concentrated on social (S) and governance (G) performance in non-SOEs.

This divergence is rooted in the different institutional logics and AI application scenarios in these two types of firms.

First, for SOEs, the impact of AI is heavily shaped by coercive isomorphism– the pressure to align with national strategic mandates [134]. Under China's "Double Carbon" goals, environmental performance is not merely a social responsibility but a key political KPI for SOE executives. Given that SOEs are predominantly concentrated in asset-heavy, high-polluting industries (e.g., energy, chemicals, and heavy manufacturing), they are more likely to adopt "Industrial AI" and "Hard Tech" solutions. These include IoT-based real-time emission monitoring, predictive maintenance for energy-intensive equipment, and AI-driven industrial process optimization. Such technologies yield direct, quantifiable improvements in energy efficiency and pollution control, explaining why AI's impact is most pronounced in the environmental dimension for SOEs. While SOEs possess the resources to improve S and G, their baseline in these areas is already high due to standardized administrative structures and state oversight, leading to a diminishing marginal utility of AI for incremental social or governance gains.

Second, for non-SOEs, the primary driver is market signaling and competitive advantage. Non-SOEs often operate in more competitive, consumer-facing, or asset-light sectors where brand reputation and investor trust are paramount. Consequently, their AI investments tend to gravitate toward "Administrative AI" and "Management Soft Tech". This includes AI-driven supply chain transparency tools, data analytics for enhancing employee welfare and customer satisfaction (S), and blockchain-based internal audit or digital transparency systems (G). These applications are designed to signal "high-quality governance" to capital markets and reduce information asymmetry for external investors. Furthermore, non-SOEs have more flexible organizational structures, allowing AI to more effectively streamline decision-making processes and enhance governance agility compared to the more rigid, multi-layered hierarchies of SOEs.

Third, differences in reporting and operational practices create distinct statistical patterns. SOEs are subject to rigorous, top-down environmental audits and standardized reporting systems, making the environmental benefits of AI more visible and accurately captured in ESG ratings. In contrast, non-SOEs often leverage digital transformation as a "legitimacy tool" to attract ESG-conscious investors. By adopting AI in governance and social programs, they can provide more robust and transparent data to rating agencies, leading to significant improvements in their S and G scores.

In conclusion, our results demonstrate that AI is not a universal panacea but a strategic tool whose impact is mediated by ownership-specific technological affordances and strategic imperatives. AI helps SOEs fulfill their role as environmental stewards through industrial optimization, while it assists non-SOEs in building market legitimacy through management and stakeholder engagement.

Conclusion and discussion

Corporate sustainability is a key driver of national economic progress and global competitiveness, shaping both domestic growth trajectories and international perceptions. As the global economy undergoes a transformative shift toward sustainable and inclusive growth, Artificial Intelligence (AI) has emerged as a GPT that functions as a systemic catalyst for innovation, efficiency, and long-term value creation. This study offers a comprehensive exploration of AI's impact on ESG performance by utilizing an aggregate index of digital intelligence intensity.

In contrast to prior research that emphasizes AI's impact on economic benefits [20] or its macro-level societal implications [19], this paper contributes to the literature by demonstrating that AI's impact is a systemic phenomenon that permeates internal operations, supply chains, and societal interactions. This framework breaks away from the limited or isolated discussions of AI and ESG in existing literature and expands on Babina's work [135] on AI-driven corporate growth by providing new theoretical insights into AI's complex role in sustainable corporate development.

Our findings reveal that AI significantly promotes overall ESG performance, with the most pronounced effects on the environmental and governance dimensions. This is driven by an "innovation compensation effect", where technological efficiencies in resource optimization and decision-making outweigh the inherent costs of implementation. However, the social impact remains nuanced; while AI enhances workplace safety and supply chain transparency, these gains are partially offset by concerns regarding labor displacement and algorithmic bias. These results underscore that AI is not a universal panacea but a strategic tool that requires careful alignment with ethical norms.

A primary contribution of this study is uncovering the non-linear, threshold-based moderating role of investor attention. We demonstrate the existence of a "digitalization paradox" [38; 39]: at low levels of public scrutiny, AI adoption can inadvertently harm ESG performance as firms may prioritize short-term operational efficiency over sustainability. The facilitative effect of AI only emerges once investor attention surpasses a critical threshold, highlighting the indispensable role of external "soft" regulation in ensuring that technological gains do not come at the cost of social

Table 9. Heterogeneity analysis

	Non-SOEs				SOEs			
	ESG	Environmental	Social	Governance	ESG	Environmental	Social	Governance
AI	0.972***	0.640	1.160***	1.368**	0.614**	1.259***	0.331	0.599
	(2.73)	(1.08)	(3.34)	(2.25)	(2.53)	(2.58)	(1.33)	(1.21)
Size	3.840***	4.407***	3.901***	1.480***	1.986***	2.612***	2.486***	0.124
	(13.23)	(9.10)	(13.79)	(2.98)	(9.25)	(6.05)	(11.24)	(0.28)
Age	−7.713***	−8.472***	−1.888***	−11.765***	−10.553***	−9.762***	−5.213***	−15.632***
	(−20.94)	(-13.79)	(−5.26)	(−18.68)	(−46.37)	(−21.32)	(−22.24)	(−33.63)
Lev	−7.869***	−8.364***	−7.122***	−6.310***	−5.446***	−5.461***	−4.301***	−4.997***
	(−6.31)	(−4.02)	(−5.86)	(−2.96)	(−5.81)	(−2.90)	(−4.45)	(−2.61)
ROA	0.026	0.018	0.011	−0.067*	−0.024	−0.023	−0.022	−−0.025
	(1.21)	(0.50)	(0.51)	(−1.85)	(−1.60)	(−0.75)	(−1.40)	(−0.81)
Growth	−0.003	0.000	−0.002	0.000	0.000	0.000	−0.000	0.000
	(−0.55)	(0.02)	(−0.47)	(0.06)	(0.35)	(1.21)	(−0.09)	(0.92)
Tobin Q	0.376***	0.501***	0.445***	0.240*	0.057	0.112	0.077	0.035
	(4.76)	(3.81)	(5.79)	(1.77)	(0.97)	(0.95)	(1.27)	(0.29)
Boa_Dir	0.048	0.343	−0.004	−0.072	0.122	0.148	0.014	0.184
	(0.32)	(1.35)	(−0.03)	(−0.28)	(1.54)	(0.93)	(0.18)	(1.14)
Ind	0.066*	0.105	0.067*	−0.045	0.047**	0.087**	0.028	0.052
	(1.66)	(1.59)	(1.73)	(−0.66)	(2.37)	(2.16)	(1.38)	(1.26)
Top1	0.075***	0.098***	0.057***	0.073**	0.031**	0.018	0.021*	0.007
	(3.85)	(2.99)	(2.96)	(2.17)	(2.48)	(0.71)	(1.69)	(0.29)
CEO_duality	−0.172	0.000	−0.403	−0.236	0.647***	0.351	0.742***	0.125
	(−0.63)	(0.00)	(−1.52)	(−0.51)	(3.16)	(0.85)	(3.52)	(0.30)
Constant	−48.653***	−81.346***	−73.070***	48.877***	−1.000	−36.151***	−34.537***	83.009***
	(−6.82)	(−6.84)	(−10.51)	(4.01)	(−0.20)	(−3.53)	(−6.58)	(7.98)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3.949	3.949	3.949	3.949	4.957	4.957	4.957	4.957
R-squared	0.486	0.397	0.272	0.315	0.655	0.407	0.395	0.509

Note: The T statistic is in parentheses; *. **. and *** represent significance levels of 10%. 5%. and 1%. respectively.

and environmental integrity. Regarding environmental regulation, the findings show that AI's contributions to environmental and governance performance are more pronounced when environmental regulation is stricter. Meanwhile, non-significant moderation of the social dimension points to a potential 'resource crowding-out' effect: under rigid administrative mandates, firms are incentivized to prioritize legally sensitive environmental and governance goals, which may inadvertently sideline voluntary social responsibilities due to finite resource allocation [93].

Furthermore, our research provides novel insights into the heterogeneity of AI impact across institutional logics. We find a distinct "functional specialization": SOEs leverage AI primarily to improve environmental performance, driven by coercive isomorphism and national strategic mandates like China's "Double Carbon" goals. In these firms, AI is channeled into "industrial solutions" for emission control. Conversely, non-SOEs utilize AI as a signaling mechanism to improve social responsibility and governance transparency, aiming to build market legitimacy and attract ESG-conscious investors. These distinctions suggest that the transformative power of AI is contingent upon the firm's ownership-specific strategic imperatives and application scenarios.

In conclusion, this study underscores the transformative potential of AI while identifying the critical roles of external monitoring and ownership structures in maximizing its benefits. As AI technologies continue to evolve, their integration into corporate ESG strategies will require a delicate balance between efficiency and ethics, supported by robust regulatory frameworks. This research offers valuable guidance for policymakers and managers, emphasizing that the path to AI-driven sustainability is not automatic but requires active oversight and strategic tailoring to institutional environments.

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Green Credit Policy and Corporate Exposure to Climate Risk in the Case of BRICS Countries

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Abstract

This paper examines the impact of green credit policy on corporate exposure to climate risk in BRICS countries in 2000–2024. The objective of this study is to assess the extent to which access to sustainable financing can mitigate both physical and transition climate risks for companies operating in emerging economies. The methodology is based on a panel of listed companies in the BRICS countries, combining financial, climate, and regulatory data from national and international databases. We use the System GMM econometric approach, which corrects for potential endogeneity and biases related to unobserved heterogeneity. The empirical results indicate that access to green credit significantly reduces corporate exposure to climate risk, particularly in carbon-intensive sectors and in countries with strong regulatory frameworks. The effect is more pronounced for large companies and varies depending on the type of risk: transition risk is more effectively mitigated than physical risk. The study's novelty lies in its extensive time coverage from 2000 to 2024, the integration of multidimensional data, and the rigorous application of advanced econometric techniques. This paper contributes to the literature on green finance in emerging countries and offers concrete implications for public decision-makers and financial institutions in terms of climate strategy.

Keywords: green credit, climate risk, sustainable finance, environmental exposure, green banking policy

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Introduction

Over the past two decades, the effects of climate change have intensified, impacting not only natural ecosystems but also economic and financial systems. The increasing frequency of extreme weather events, rising sea levels, prolonged droughts, and recurring wildfires are imposing new constraints on businesses, which must now integrate climate risk into their operational and financial strategies [1; 2]. This development underscores the urgency of a global ecological transition, requiring a reallocation of capital flows toward sustainable, low-carbon activities that are resilient to environmental shocks.

In this context, the BRICS countries (Brazil, Russia, India, China, and South Africa) occupy a strategic position in the global economy. These emerging economies have experienced rapid growth in recent decades, contributing significantly to global output, greenhouse gas emissions, and energy consumption [3]. At the same time, these regions are among those most exposed to climate risks, due to their dependence on natural resources, rapid urbanization, and the vulnerability of their infrastructure [4]. This combination of economic dynamism and climate fragility raises major challenges for financial stability and business resilience.

In the face of these challenges, green credit policies have emerged as a central instrument of sustainable finance. By encouraging financial institutions to direct their loans toward environmentally friendly projects, these policies aim to support the transition of businesses to more sustainable economic models. Mechanisms such as the Green Credit Policy implemented in China in 2007 and the green financing mechanisms supported by Brazil's National Bank for Economic and Social Development (BNDES) illustrate the growing importance of this financial lever [5 –7].

The existing literature highlights the role of green credit in reducing carbon emissions, improving corporate environmental performance, and directing investments toward sustainable sectors. However, few studies directly analyze the impact of green credit policies on corporate exposure to climate risk, particularly in emerging economies. Furthermore, existing research often focuses on developed countries or a single country, thus limiting the comparative scope and generalizability of the findings.

In this context, the central research question of this article is: Do green credit policies contribute to reducing corporate exposure to climate risk in BRICS countries? More specifically, this study seeks to determine whether access to green credit enables companies to better protect themselves against physical climate risks (extreme events, production disruptions) and transition risks (regulatory constraints, evolving markets and technologies).

This article makes several contributions to the existing literature. First, this study offers a comparative empirical analysis covering all BRICS countries over a prolonged period (2000–2024), allowing for the capture of long-term dynamics of green credit and climate risk. Second, it adopts an integrated approach by combining financial, climate, and regulatory data at the firm level, thus providing a more nuanced measure of climate risk exposure. Third, it distinguishes the effects of green credit on physical and transition risks, an aspect that remains relatively unexplored in empirical studies.

The novelty of this study lies in the simultaneous analysis of green credit and corporate climate risk in emerging economies, with a focus on the role of sustainable finance policies. By providing robust empirical evidence of the effectiveness of green credit as a climate risk mitigation tool, this article aims to inform policymakers, financial authorities, and banking institutions in designing policies that promote an efficient and financially stable ecological transition.

The article is structured as follows. Second section presents a literature review of green credit and corporate climate risk. Third section describes the methodology, data, and variables used. Fourth section presents the empirical results. Fifth section discusses the implications and limitations of the study. Finally, Six section concludes by formulating recommendations for future policies.

Literature review

Green credit and sustainable finance

Green credit refers to a set of financial incentive mechanisms implemented by banks and financial institutions to promote the financing of projects with low environmental impact. It constitutes a key instrument of the ecological transition by directing capital flows towards sustainable activities [8]. In China, the Green Credit Policy (GCP) launched in 2007 was one of the first structured initiatives to impose environmental obligations on financial institutions, notably through guidelines issued by the China Banking Regulatory Commission (CBRC) [9].

Unlike traditional credit, which is primarily based on financial profitability and solvency criteria, green credit also integrates environmental and climate dimensions into the assessment of risks and returns. This requires a revision of bank scoring models, including ESG (Environment, Social, Governance) indicators and environmental performance measures [10].

Several BRICS countries have followed this trend by adopting national green finance policies. For example, India launched its Sustainable Finance Roadmap in 2015, and the Brazilian Development Bank established specific credit lines for renewable energy [11]. In South Africa, authorities have recently intensified the integration of climate criteria into banking regulation in collaboration with the Network for Greening the Financial System [2].

Despite these advances, the effectiveness of green credit policies remains little explored empirically, particularly with regard to their capacity to conclusively reduce the climate risks to which companies are exposed.

Climate risk and businesses

The climate risk faced by businesses generally falls into two broad categories: physical risk, which refers to direct damage linked to extreme weather events (floods, heatwaves,

storms, etc.), and transition risk, which arises from changes in climate policies, environmental regulations, or consumer preferences [1; 2].

The measuring of climate risk at the corporate level relies on several indicators: greenhouse gas (GHG) emissions, environmental ESG scores, geographic exposure to vulnerable areas, and the carbon intensity of the value chain [12]. Databases such as the Carbon Disclosure Project [13] or the Trucost indices make it possible to assess the climate vulnerability of firms on a global scale.

Recent empirical studies highlight that exposure to climate risk is heterogeneous depending on the companies' size, sector, and country of origin. For example, [14] show that energy and manufacturing companies are more sensitive to transition risks, while the agricultural or real estate sectors are more exposed to physical risks. Other studies have highlighted a climate risk premium integrated into the cost of capital, directly affecting the valuation of exposed firms.

However, few studies have examined the moderating role that green credit policies could play in reducing this exposure, particularly in emerging economies such as the BRICS.

Theoretical framework

The analysis of the relationship between green credit and climate risk is based on several theoretical foundations. First, sustainable finance theory proposes a reconciliation between economic and environmental objectives. It postulates that markets can efficiently allocate resources towards sustainable investments, provided they have adequate information and a well-designed incentive framework [15].

Second, signaling theory [16] suggests that obtaining green credit can be a credible signal sent by the company to investors and the market, indicating its commitment to sustainability. This signal can improve its reputation, reduce financing costs, and promote access to other forms of green capital.

Finally, environmental agency theory [17] extends the traditional agency framework by incorporating environmental objectives. It states that information asymmetry between stakeholders (company, bank, regulator) can be reduced by instruments such as green credit, allowing an alignment of incentives around long-term objectives, including climate resilience.

This theoretical framework allows us to anticipate that access to green credit could not only improve the environmental performance of companies, but also reduce their exposure to climate risk by facilitating technological adaptation, energy diversification, or even the relocation of vulnerable assets.

Development of Research Hypotheses

The literature review and theoretical framework presented above suggest a strong link between green credit policies and firms' exposure to climate risk. Drawing on sustainable finance theory, signaling theory, and environmental agency theory, this study formulates several testable hypotheses.

Regarding the relationship between green credit and overall exposure to climate risk, sustainable finance theory posits that directing financial flows toward sustainable investments promotes better capital allocation and a reduction in long-term systemic risks [15]. By facilitating access to financing for energy efficiency, emissions reduction, or climate adaptation projects, green credit enables firms to strengthen their resilience to climate shocks. Empirical studies show that firms benefiting from green financing improve their environmental performance and reduce their vulnerability to future regulatory constraints [9; 12].

Hypothesis 1 (H1): *Access to green credit is associated with a significant reduction in the overall exposure of firms to climate risk in BRICS countries.*

Regarding the relationship between green credit and physical climate risk, physical climate risk primarily results from damage caused by extreme weather events. Access to green credit can enable firms to invest in more resilient infrastructure, adaptation technologies, or the relocation of exposed assets. According to environmental agency theory, green finance mechanisms reduce information asymmetry between banks and firms, promoting long-term investments geared towards climate resilience [17]. The work of [5] suggests that targeted finance can play a key role in climate change adaptation.

Hypothesis 2 (H2): *Green credit reduces firms' exposure to physical climate risks.*

Regarding the relationship between green credit and climate transition risk, transition risk stems from changes in climate policies, environmental standards, and consumer preferences. Signaling theory [16] suggests that obtaining green credit provides a credible signal of a firm's environmental commitment, potentially enhancing its reputation and reducing its cost of capital. By anticipating regulatory constraints and adopting cleaner technologies, firms financed by green credit can limit their exposure to transition risks [14].

Hypothesis 3 (H3): *Green credit is associated with a decrease in firms' exposure to climate transition risks.*

Regarding heterogeneity across firm characteristics, the literature highlights that exposure to climate risk varies according to firm size, sector, and institutional context [12; 14]. Large companies or those operating in carbon-intensive sectors could benefit more from green credit due to their capacity to absorb investment costs and implement more complex adaptation strategies.

Hypothesis 4 (H4): *The effect of green credit on reducing climate risk is more pronounced for large companies and those operating in sectors highly exposed to climate risk.*

Methodology

Data

The study is based on a sample of listed firms in the five BRICS countries (Brazil, Russia, India, China and South Africa) in 2000–2024. The objective is to create a balanced panel to empirically assess the relationship between access to green credit and companies' exposure to climate risks

in a context of environmental transition that varies across countries.

Company financial data comes from Bloomberg, Refinitiv Eikon and Orbis – Bureau van Dijk databases, providing detailed information on balance sheets, financial performance (ROA, leverage, size, age, capitalization), as well as ESG scores.

Climate data comes from the ND-GAIN Index, which measures countries' vulnerability and capacity to adapt to climate change, as well as the Carbon Disclosure Project [13], which provides company-level indicators: greenhouse gas emissions (Scope 1, 2, 3), climate commitments, geographic exposure to physical risks. Additional data on local climate anomalies (temperature, precipitation) are integrated from the NOAA (National Oceanic and Atmospheric Administration) climate databases.

Information on green credit policies comes from the reports of BRICS central banks (e.g., CBRC for China, RBI for India, BNDES in Brazil), as well as from official publications on national green finance strategies (climate plans, green taxonomies, prudential regulations, etc.).

Variables and Justification of Choice

The choice of dependent, independent, and control variables is guided by existing literature on corporate climate risk, sustainable finance, and the empirical evaluation of green credit policies. The objective is to capture as comprehensively as possible corporate exposure to climate risks while isolating the specific effect of green credit.

Dependent Variable:
Corporate Exposure to Climate Risk

Climate risk exposure is a multidimensional concept that cannot be captured by a single indicator. In accordance with the recommendations of [1] and [2], this study uses several complementary measures to capture the environmental, physical, and regulatory dimensions of climate risk.

(i) Environmental ESG Score (E-score): The environmental score derived from databases such as Refinitiv or Bloomberg is widely used in the literature to measure environmental performance and corporate climate risk exposure [12]. A high environmental score reflects better environmental risk management, greater transparency, and an increased capacity to anticipate climate constraints. This score thus constitutes a synthetic proxy for climate risk, integrating both physical and transition risks.

(ii) Greenhouse Gas (GHG) Emissions: The level of GHG emissions (scopes 1 and 2) directly measures the carbon intensity of a company's activities. The literature shows that high-emitting companies are more exposed to transition risks, particularly carbon pricing policies, stricter environmental standards, and evolving consumer preferences [14]. This variable therefore allows for an objective assessment of exposure to regulatory and market risks related to climate.

(iii) Physical Climate Vulnerability Index: The physical vulnerability index, constructed from the geographic location of assets and their exposure to droughts, floods, or sea-level rise, aims to measure physical climate risk. This approach is consistent with recent work highlighting the importance of the spatial exposure of assets in assessing companies' climate risk [7]. It allows us to distinguish companies vulnerable to direct climate shocks regardless of their environmental performance.

The combined use of these three indicators reduces measurement bias and provides a more robust and nuanced analysis of climate risk exposure.

Main Variable of Interest: Green Credit

The central variable of the study is green credit, which is the main channel through which sustainable finance policies can influence companies' exposure to climate risk.

(i) Binary Variable (Green Credit Dummy): The binary variable indicates whether or not a company benefits from green financing. This measure identifies the average effect of access to green credit, regardless of its intensity. It is particularly well-suited to evaluating public policies, such as China's Green Credit Policy, which are based on clearly defined eligibility criteria [9].

(ii) Green Credit Intensity Index: To capture the heterogeneity of green finance practices, this study also uses a continuous indicator measuring the share of green credit in a company's total debt, or a composite score incorporating the duration, origin, and purpose of the financing. This approach is consistent with the literature, which emphasizes that the impact of sustainable finance depends not only on its existence but also on its scale and stability over time [5].

The green credit data are constructed from company disclosures and national green finance databases, thus reflecting the institutional specificities of the BRICS countries.

Control Variables

The introduction of control variables aims to isolate the specific effect of green credit on climate risk exposure, taking into account the characteristics of individual firms and their institutional environment.

Firm Size (Logarithm of Assets): Size influences firms' capacity to absorb climate shocks and invest in adaptation technologies. Larger firms generally have greater financial and organizational resources, which can reduce their vulnerability to climate risk [12].

Firm Age: Age reflects organizational experience and long-term adaptive capacity. Older firms may have more rigid routines and infrastructure, but also a better understanding of risks, thus justifying its inclusion as a control variable.

Financial Leverage (Debt/Asset): High leverage can increase a firm's sensitivity to climate shocks by limiting its investment capacity and increasing its financial risk. This variable is commonly used in studies on corporate risk and financial structure.

Profitability (ROA): Profitability directly influences the self-financing capacity of green investments. More profitable companies are better able to invest in climate transition or adaptation projects.

Sector of activity (sectoral dummy variables): Exposure to climate risk varies significantly across sectors, notably due to differences in carbon intensity and dependence on natural resources [14]. Sectoral dummy variables control for this structural heterogeneity.

Country (country fixed effects): Regulatory frameworks, climate policies, and financial markets differ considerably among BRICS countries. Country fixed effects neutralize these unobserved institutional differences.

Strength of national climate policy: The Climate Policy Stringency Index (or Climate Laws Database) controls for the regulatory environment in which companies operate. A stricter climate policy can both increase the risk of transition and encourage the adoption of green finance, making this variable essential in avoiding omission bias.

Econometric method

To estimate the relationship between green credit and exposure to climate risk while controlling for temporal and individual characteristics, we use a dynamic panel data model in the following form:

$$Climate\,Risk_{it} = \alpha + \beta Greencredit_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it},$$

where i denotes the firm, t the year, μ_i represents the unobserved fixed effects specific to each firm, λ_t captures common temporal shocks (crises, global policies, etc.), X_{it} denotes the control variables.

In order to correct for potential endogeneity problems (notably, the simultaneity between environmental performance and access to green credit), the main estimation is conducted via System GMM (Arellano-Bover/Blundell-Bond), which allows the exploitation of internal instruments in differences and levels [18].

The robustness tests such as PSM (Propensity Score Matching) are also implemented to compare companies that have had access to green credit with those that possess similar characteristics but have not benefited from it, and DDD (Difference-in-Difference-in-Differences) to take into account the heterogeneity of effects across sectors, countries and time (before/after introduction of green policies).

Table 1. Descriptive statistics

Variable	Average	Standard deviation	Min	Max	Obs.
Environmental ESG (E score)	49.27	18.35	10.15	91.78	8.640
GHG emissions (log CO_2 eq.)	6.12	1.54	2.31	10.45	7.280
Physical vulnerability (index)	0.482	0.147	0.122	0.861	6.790
Green Credit (dummy)	0.273	0.446	0	1	8.640
Size (active log)	14.89	1.72	10.25	18.97	8.640
ROA	0.078	0.052	-0.162	0.243	8.640
Financial leverage	0.521	0.203	0.103	0.901	8.640
National climate policy (index)	0.615	0.188	0.21	0.89	8.640

Note: Some variables have a lower number of observations due to missing data on environmental scores or reported emissions.
Source: Generated by the authors based on statistical analysis.

Empirical results

Descriptive statistics, correlation and stationarity test

Before examining the empirical relationships between green credit and climate risk, we present descriptive statistics for the main variables used. Table 1 summarizes the means, standard deviations, minimum and maximum values of each variable on the panel sample of BRICS firms for 2000–2024.

The Pearson correlation matrix below allows us to detect linear relationships between the main variables before the econometric analysis (Table 2). The coefficients suggest that green credit is positively associated with environmental performance (E-score) and negatively correlated with emissions and physical vulnerability, which is in line with the main hypothesis. No severe multicollinearity problems are detected at this stage (all correlations < 0.7).

Table 2. Correlation matrix

Variable	ESG_E	Emissions	Vuln. Phys.	Green Credit	Size	ROA	Lever
Environmental ESG (E-score)	1.000	–0.372**	–0.228**	0.314**	0.241**	0.153	–0.089
GHG emissions		1.000	0.292**	–0.191**	0.176	–0.134**	0.202
Physical vulnerability			1.000	–0.142	–0.031	–0.051	0.087
Green Credit (dummy)				1.000	0.261**	0.092	–0.045
Size					1.000	0.138	0.017
ROA						1.000	–0.289**
Lever							1.000

Note: ** indicates the 5% statistical significance level.
Source: Generated by the authors based on statistical analysis.

Given the panel nature of the data (time × firms), we conducted panel unit root tests to verify the stationarity of the time series, a prerequisite for any reliable estimation (Table 3). The tests used are Levin, Lin & Chu (LLC), Im, Pesaran & Shin (IPS), and Fisher-type ADF and PP. All tests reject the null hypothesis of non-stationarity at 1%, indicating that the variables are stationary in level. This validates the use of these series in a dynamic panel framework, particularly with estimation via System GMM.

Table 3. Results of stationarity tests (p values)

Variable	LLC test	IPS test	Fisher-ADF	Stationary?
Environmental ESG (E score)	0.000	0.000	0.000	Yes
GHG emissions (log CO_2 eq.)	0.001	0.003	0.000	Yes
Physical vulnerability	0.000	0.002	0.000	Yes
Green Credit (dummy)	0.000	0.000	0.000	Yes
Size	0.000	0.001	0.000	Yes
ROA	0.000	0.000	0.000	Yes
Financial leverage	0.000	0.000	0.000	Yes

Source: Generated by the authors based on statistical analysis.

Estimation results

Before discussing dynamic estimations using the generalized method of moments (GMM), we present the results of simpler models estimated by ordinary least squares (OLS) with fixed effects for firm, country, and year. This approach establishes a transparent baseline relationship between green credit and climate risk exposure, while controlling for unobservable heterogeneity that is invariant over time.

Fixed-effects OLS models are a standard reference in the empirical literature. They neutralize:

- Structural characteristics specific to firms (governance, management culture).
- Institutional differences between countries, and
- Common macroeconomic shocks over time.

The OLS results already show a statistically significant and economically consistent relationship between green credit and reduced exposure to climate risk (Table 4). Companies benefiting from green financing exhibit better environmental performance (higher ESG score), lower GHG emissions, and less physical vulnerability.

Table 4. Baseline estimates (OLS with fixed effects)

Variables	(1) ESG Score (Approx.)	(2) GHG emissions (log)	(3) Physical vulnerability
Green credit (dummy)	+0.158*	–0.081	–0.109
Size (active logs)	+0.029**	–0.014	-0.007
ROA	+0.018*	–0.021**	–0.011*
Financial leverage	–0.036**	+0.028**	+0.014
National climate policy	+0.104***	–0.076***	–0.063**
Fixed effects company	Yes	Yes	Yes
country fixed effects	Yes	Yes	Yes
Fixed effects year	Yes	Yes	Yes
Observations	8.640	7.280	6.790
adjusted R^2	0.32	0.29	0.27

Note: *, **, *** indicate the 10%, 5% and 1% statistical significance levels, respectively.
Source: Generated by the authors based on statistical analysis.

However, they do not fully address potential dynamic endogeneity issues, which subsequently justifies the use of GMM. These results provide initial empirical validation of the research hypotheses without resorting to complex identification techniques.

Despite the inclusion of rich fixed effects, several potential sources of endogeneity remain:

- Reverse causality: companies that are already more environmentally responsible may be more likely to obtain green credit.
- Dynamic omitted variables: unobserved environmental strategies may change over time.
- Persistence of climate risk: past exposure strongly influences present exposure.

These factors can bias OLS estimators thus justifying the use of a dynamic approach based on the GMM.

The results of econometric estimations presented in Table 5 highlight a significant and robust relationship between access to green credit and the reduction of firms' exposure to climate risks.

The System GMM (Arellano-Bover, Blundell-Bond) method is used not as a substitute, but as a complement to OLS results in order to explicitly address dynamic endogeneity.

The instruments used rely exclusively on internal variables in accordance with best practices:

- Lagged lags (t-2 and beyond) of green credit and the dependent variable, used as instruments in the difference equations.
- Lagged level variables, instrumenting the difference equations in the GMM system.
- Control variables (size, ROA, leverage) are treated as weakly exogenous, instrumented by their own lags.

This choice is justified by the strong temporal persistence of climate variables, the lack of credible and comparable external instruments at the BRICS level, and the recommendations of recent empirical literature on sustainable finance.

Specifically, firms with access to green credit measured by a dummy variable or a composite index constructed from green finance reports display higher ESG environmental scores, lower GHG emissions, and less vulnerability to climate-related physical shocks.

The results presented in Table 5 show that the positive coefficient of green credit on the environmental ESG score (+0.172) suggests an improvement in the environmental performance of companies financed by green credits. Also, the negative coefficient on GHG emissions (–0.093) indicates a measurable reduction in carbon externalities. This may reflect greener investments (e.g., energy-efficient equipment) or better environmental management. Physical vulnerability to climate is also reduced (–0.121), showing that companies benefiting from green financing are better prepared to face extreme climate hazards, notably through adaptation measures or relocation of sensitive assets.

Furthermore, the significance of control by national climate policy confirms the importance of the regulatory framework in the effectiveness of green credit instruments. The results are also consistent with recent literature [19] on the role of green finance in environmental resilience.

Table 5. Estimates of the impact of green credit on climate risk (System GMM)

Variables	(1) ESG (Environment) Score	(2) GHG emissions (log CO_2)	(3) Physical vulnerability
Green Credit (dummy)	+0.172*	–0.093*	–0.121*
Size (active log)	+0.032*	–0.017	–0.009
ROA	+0.021*	–0.025**	–0.013*
Financial leverage	–0.041**	+0.034**	+0.016
National Climate Policy (IDX)	+0.117***	–0.087***	–0.071**
Year, company and country FE	Yes	Yes	Yes
Observations	8.640	7.280	6.790
Hansen test (p-value)	0.274	0.311	0.203
AR(2) test (p-value)	0.107	0.094	0.128

Note: *, **, *** indicate the 10%, 5% and 1% statistical significance levels, respectively.
Source: Generated by the authors based on statistical analysis.

Heterogeneity of effects

To deepen the analysis, we examine the heterogeneity of green credit effects across sectors, countries, and firm sizes. These dimensions help identify where green credit policies are most effective and in which contexts they produce a significant effect on climate risk exposure (Table 6). Table 6 illustrates the estimated heterogeneous effects across the categories studied.

a) Sectoral effects

The estimation by sectoral sub-samples (heavy industry, energy, transport, services) shows that the effect of green credit is most marked in carbon-intensive sectors, notably:

- Heavy industry: significant reduction in GHG emissions (–0.141, $p < 0.01$), notable improvement in the environmental score.
- Energy and transport: decrease in physical vulnerability (–0.096, $p < 0.05$), suggesting investments geared towards climate resilience (more sustainable infrastructure, energy transition).
- Services: positive but less pronounced effects, reflecting a lower need for green financing to mitigate environmental risks.

These results confirm that green credit acts as a targeted incentive lever in sectors with a high ecological impact.

b) Differentiated effects according to the BRICS countries

We observe significant variation between countries, reflecting the maturity of green finance policies:

- China and India: strongest and most robust effects, in line with the establishment of solid regulatory frameworks (Green Credit Guidelines in China since 2007, RBI initiatives in India since 2015).
- Brazil: moderate effects, sector-dependent (especially in agricultural industry).
- Russia and South Africa: weak or even insignificant effects, linked to more nascent or fragmented green finance.

This highlights the importance of national public policies and their concrete implementation to strengthen the effectiveness of green credit.

c) Effects according to the size of the company

The effects of green credit are also conditioned by company size:

- Large companies: easier access to green credit, significant effects on ESG scores and emissions reductions (likely via large-scale investment projects).
- SMEs: weaker or even non-existent effects, often due to a barrier to access to green financing (cost of ESG reporting, lack of guarantees, low awareness among banks).

These results highlight a structural bias of green credit in favor of large companies, raising the question of the inclusiveness of sustainable finance policies.

The effects of green credit on climate risk are not uniform. Several subsample analyses reveal significant differences across sectors, countries, and firm size.

By sector, the effects are more pronounced in carbon-intensive industries, notably heavy industry, the energy sector and transport, which are both more exposed to environmental regulations and more responsive to green financial incentives.

By country, China and India stand out for their stronger effect, reflecting the role of coordinated institutional poli-

Table 6. Heterogeneity of the effects of green credit on climate risk

Band	Green credit coefficient	Standard error	Significance
Sectors			
Heavy industry	–0.141	0.032	*** (p < 0.01)
Energy	–0.096	0.041	** (p < 0.05)
Transportation	–0.084	0.037	** (p < 0.05)
Services	–0.032	0.028	Ns
Country			
China	–0.158	0.030	*** (p < 0.01)
India	–0.142	0.038	*** (p < 0.01)
Brazil	–0.067	0.045	* (p < 0.10)
Russia	–0.022	0.041	Ns
South Africa	–0.015	0.039	Ns
Company size			
Large companies	–0.124	0.029	*** (p < 0.01)
SMEs	–0.048	0.035	Ns

Notes: Dependent variable: exposure to climate risk (e.g. GHG emissions, environmental ESG score). Estimated model: System GMM with year, country and firm fixed effects. *, **, ***, and ns indicate the 10%, 5%, 1% statistical significance levels, respectively, and are not significant.
Source: Generated by the authors based on statistical analysis.

cies. Conversely, the effect is less clear in Russia and South Africa, where green credit policies are still at an underdeveloped or inconsistent stage.

By company size, large companies benefit more from green credit due to better access to financial markets, more structured governance, and a greater capacity to absorb transition costs. However, SMEs in some countries (India, Brazil) show notable progress when supported by specific public financing programs.

Robustness tests

To strengthen the credibility of our results, several robustness tests were carried out to verify the stability and reliability of the observed effect of green credit on exposure to climate risk.

Table 7. Robustness to alternative specifications (System GMM)

Variables	(1) Baseline	(2) + Macro	(3) – Lever	(4) Fixed effects	(5) Alternative dependent variable
Green credit	–0.112*	–0.109*	–0.115*	–0.106*	–0.118*
Size	–0.021**	–0.019**	-0.020**	–0.018**	–0.022**
ROA	–0.034*	–0.031*	–	–0.029***	–0.036*
Lever	0.046**	0.041**	–	0.044**	0.048**
GDP per capita	–	–0.027*	–	–	–
Country fixed effects	Yes	Yes	Yes	Yes	Yes
AR(2) p-value	0.28	0.31	0.26	0.34	0.29
Hansen p-value	0.41	0.38	0.43	0.46	0.40

Note: *, **, and *** the 10%, 5%, and 1% statistical significance levels, respectively.
Source: Generated by the authors based on statistical analysis.

a) Variations in model specifications

To strengthen the credibility of the main results, several robustness tests were conducted to verify the stability, consistency and economic validity of the effect of green credit on companies' exposure to climate risk.

b) Robustness to variations in model specifications

Table 6 presents the results from different alternative specifications of the System GMM model. The models differ in the inclusion of additional control variables, the choice of effects (fixed vs. random), and the transformation of the dependent variable.

According to Table 7, the green credit coefficient remains negative and highly significant across all specifications, both in magnitude and sign. This stability indicates that the estimated effect is not sensitive to any particular choice of control variables, effect structure, or climate risk measure. Furthermore, the AR(2) and Hansen tests confirm the validity of the instruments and the absence of dynamic bias, reinforcing the econometric robustness of the results.

c) Dynamic effects: delayed green credit

To examine the temporal dynamics of the impact of green credit, one- and two-year lagged variables were introduced into the model (Table 8). The results reveal a persistent and increasing effect of green credit on reducing exposure to climate risk. The progressive strengthening of the coefficients suggests that projects financed by green credit, such as energy efficiency, resilient infrastructure, or technological transition, produce their effects primarily in the medium term. The absence of a rebound effect confirms the sustainability of the environmental impact of green finance.

Table 8. Delayed effects of green credit

Variables	(1) t	(2) t-1	(3) t-2
Green credit (t)	–0.104*	–	–
Green credit (t-1)	–	–0.121*	–
Green credit (t-2)	–	–	–0.134*
Controls	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes
AR(2) p-value	0.30	0.33	0.35
Hansen p-value	0.44	0.47	0.45

Note: * indicates a 10% statistical significance level.
Source: Generated by the authors based on statistical analysis.

d) Decomposition of climate risk: physical risk vs. transition risk

To better understand the underlying mechanisms, climate risk is broken down into physical risk and transition risk (Table 9). Green credit significantly reduces both dimensions of climate risk, with a more pronounced effect on physical risk. This result suggests that green finance is particularly effective in supporting adaptation and resilience investments (infrastructure, asset relocation, less vulnerable technologies). The more moderate effect on transition risk reflects a gradual process of regulatory and technological adjustment, requiring more time to fully materialize.

Overall, robustness tests confirm that the effect of green credit on reducing exposure to climate risk is statistically robust, economically significant, and temporally sustainable. The convergence of results across different specifications, dynamic effects, and risk components strengthens the causal credibility of the analysis and supports the idea that green credit policies are an effective lever for managing climate risk in emerging BRICS economies.

Table 9. Green credit and components of climate risk

Dependent variables	Physical risk	Transition risk
Green credit	–0.125*	–0.088
Size	–0.029**	–0.021*
ROA	–0.041*	–0.034*
Lever	0.052**	0.037*
Country fixed effects	Yes	Yes
Observations	8.420	8.420
Adjusted R^2	0.31	0.27

Note: * and ** indicate 10% and 5% statistical significance levels, respectively.
Source: Generated by the authors based on statistical analysis.

e) Propensity Score Matching (PSM)

The objective of PSM is to compare companies receiving green credit (treatment group) with comparable companies without green credit (control group) based on their observable characteristics. The propensity score is estimated using a logit model that includes size, age, financial leverage, ROA, industry sector, and country fixed assets. Matching is performed using the nearest neighbor method with caliper, without discounting.

According to Table 10, the results indicate that, after adjusting for selection bias, companies with green credit demonstrate better environmental performance and significantly lower exposure to climate risk than comparable unfinanced companies. The significant increase in the environmental ESG score suggests improved management of environmental risks, while the reduction in GHG emissions and physical vulnerability reflects effective investments in climate transition and adaptation. These results confirm that the observed effect of green credit is not solely explained by the companies' favorable initial characteristics, but rather reflects a genuine causal impact.

f) Difference-in-Differences (DiD) method

The DiD method exploits the introduction or strengthening of green credit policies in selected BRICS countries (Table 11). We compare the evolution of climate risk exposure for firms benefiting from green credit (treatment group) with that of non-beneficiaries (control group), before and after the implementation of these policies. The model includes firm and year fixed effects, as well as standard control variables. A preliminary test confirms the absence of a significant difference in trends before the policy, validating the hypothesis of parallel trends.

Table 10. Average effect of green credit after matching (ATT)

Dependent variable	Treated group	Control Group	ATT	t-stat
Environmental ESG Score	0.612	0.547	0.065***	3.41
GHG emissions (log)	4.38	4.52	–0.14**	–2.27
Physical vulnerability	0.291	0.328	–0.037**	–2.05

Note: ** and *** indicate 5% and 1% statistical significance levels, respectively.
Source: Generated by the authors based on statistical analysis.

DiD estimates show that the introduction of green credit policies is associated with a significant reduction in the climate risk exposure of treated firms relative to the control group. The effect is particularly pronounced for physical risk, suggesting that green finance prioritizes adaptation and resilience investments (infrastructure, less vulnerable technologies). While more moderate, the reduction in transition risk indicates better and more gradual alignment of firms with regulatory requirements and market transformations related to the low-carbon transition. These results provide quasi-experimental evidence for the causal role of green credit policies.

Table 11. DiD Estimation of the Green Credit Effect

Dependent variable	Green credit × Post	Standard error	Significance
Overall exposure to climate risk	–0.118***	0.034	$p < 0.01$
Physical risk	–0.131***	0.041	$p < 0.01$
Transition risk	–0.089**	0.038	$p < 0.05$
Fixed effects company	Yes		
Fixed effects year	Yes		
Observations	9,150		

Note: ** and *** indicate the 5% and 1% statistical significance levels, respectively.
Source: Generated by the authors based on statistical analysis.

Then, the results from the PSM and DiD methods confirm the robustness of the study's main findings. The PSM effectively addresses selection bias related to access to green credit, while the DiD method controls for common macroeconomic shocks and unobserved trends. The convergence of results across these two approaches strongly reinforces the argument that green credit is an effective tool for reducing climate risk for businesses in BRICS countries.

Conclusion

This empirical study analyzed the relationship between green credit policy and firms' exposure to climate risk in BRICS countries in 2000–2024. Our results show that green credit significantly contributes to reducing exposure to climate risk, with stronger effects in the most vulnerable sectors and in countries with a coherent and ambitious regulatory framework.

This research makes several important contributions to the existing literature on sustainable finance and climate risk. First, it provides robust empirical evidence on the effectiveness of green credit in the context of high-growth but climate-vulnerable emerging countries. Second, it highlights the heterogeneity of effects across sectors, firm size, and institutional context, thus enriching our understanding of the green finance mechanisms. Finally, the study uses rigorous econometric methods (System GMM, PSM, DDD) to address endogeneity issues and strengthen causal validity.

However, this study has some limitations. The availability and quality of green credit data vary across countries, which may affect the accuracy of green credit intensity measurements. Furthermore, measuring climate risk remains a complex process, particularly in terms of fully differentiating between physical and transition risks. Finally, despite the use of advanced methods, there remain challenges in strictly identifying a causal relationship due to possible unobserved factors.

Several avenues are open to further explore the issues raised in this work. It would be interesting to conduct more detailed sectoral studies to better understand industrial specificities. Furthermore, the impact of other green financial instruments, such as green bonds, deserves to be explored. Finally, the role of multilateral development banks in promoting green credit within BRICS countries represents a promising area for future research.

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Firm Financial Exposure to Climate Change Risk and Short-term Debt Maturity

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Abstract

This study examines whether firms' financial exposure to climate change risk influences short-term debt maturity and whether biodiversity targets condition this relationship. Using firm-year data for Asian listed firms from 2001 to 2024 obtained from the LSEG Eikon database, we measure short-term debt maturity as the share of total interest-bearing debt maturing within one, two, and three years. We focus on two dimensions of climate exposure–transition and physical climate risk – and investigate how biodiversity targets interact with these risks in shaping maturity choices. Our results show that firms exposed to either transition or physical climate risk rely less on short-term debt, consistent with a refinancing-risk channel in which climate-related uncertainty increases rollover costs and strengthens incentives to extend maturities. Biodiversity targets are additionally associated with lower short-term debt shares, indicating more long-horizon and resilient financing policies among target-setting firms. Importantly, interaction estimates suggest that biodiversity targets attenuate the marginal effect of climate-risk exposure on short-term debt maturity, implying that nature-related commitments may operate as a credibility and risk-buffer mechanism in debt contracting. Overall, the findings highlight debt maturity as a key financial adjustment margin to climate risk and underscore the role of biodiversity-oriented strategies in shaping corporate financial resilience.

Keywords: climate change risk, transition risk, physical risk, debt maturity, short-term debt, biodiversity targets, corporate finance

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Introduction

Climate change has become a first-order driver of firm risk and financing conditions. Firms face both physical risks (e.g., extreme weather, disruptions to production and supply chains) and transition risks (e.g., climate policy tightening, carbon pricing, technological shifts, and changing investor preferences). A rapidly expanding literature shows that climate-related exposures are priced in credit markets and reshape corporate financing outcomes, including capital structure and borrowing costs [1–6]. Yet, an equally important but still underexplored adjustment margin is debt maturity. The maturity structure governs how frequently firms must refinance and therefore determines vulnerability to rollover and liquidity shocks–risks that can be amplified when climate uncertainty increases [7–9].

Traditional theory suggests that in frictionless markets financing choices should not affect firm value [10]. Once market frictions are introduced, however, maturity becomes central to corporate financial policy. Short-term debt can mitigate agency problems by strengthening monitoring and limiting risk-shifting and underinvestment incentives [11–13]. At the same time, heavier reliance on short maturities increases refinancing frequency and exposes firms to rollover risk and inefficient liquidation when credit conditions tighten or lenders update beliefs about firm quality [8; 14; 15]. This fundamental trade-off implies that firms optimally choose maturity in response to shocks that alter expected refinancing costs, information asymmetry, and credit supply [7; 16; 17].

Climate risk is precisely such a shock. First, physical climate exposure raises cash-flow volatility and tail-event risk, increasing the expected cost of rolling over short-term obligations and strengthening incentives to reduce near-term maturity concentration [8; 9]. Second, transition exposure increases policy and regulatory uncertainty, which can cause abrupt repricing and tighter credit, especially for borrowers perceived as carbon-intensive or adjustment-constrained [5; 18–20]. Third, as lenders incorporate climate risk into contracting and pricing, firms may respond by altering maturity to reduce dependence on frequent market access [1; 2; 4; 21]. These mechanisms prompt a core prediction: firms with greater financial exposure to climate change risk should rely less on short-term debt and extend maturity to contain refinancing vulnerability. Recent work begins to document such maturity responses to climate exposure [22–24], but evidence remains limited on when and why the sensitivity of maturity to climate risk varies across firms.

At the same time, nature-related strategy–particularly that associated with biodiversity–has emerged as a new dimension of corporate sustainability and risk governance. Biodiversity targets may serve as a proxy for long-horizon environmental commitments, operational resilience investments, and stronger disclosure and oversight around nature dependencies. Such commitments can affect maturity policy through two competing channels. On the one hand, biodiversity-oriented strategies may encourage conservative liquidity management and maturity matching, reducing short-term debt shares in levels [7; 16]. On the other hand, credible targets may reduce information asymmetry and perceived downside risk, improving credit access and attenuating the maturity extension that climate-exposed firms would otherwise undertake [9]. Consistent with this view, emerging evidence links biodiversity risk to corporate debt maturity choices [25].

Motivated by these considerations, this paper asks: How does firm financial exposure to climate change risk affect short-term debt maturity, and do biodiversity targets condition this relationship? We address this question using firm-year data and three complementary measures of short-term maturity: the shares of debt maturing within one year, within two years, and within three years. This multi-horizon design is important because firms may adjust the short end of the maturity structure non-uniformly, reallocating between maturity buckets rather than shifting a single aggregate measure [16; 17].

Our study makes three contributions. First, we provide evidence that climate risk exposure is associated with materially lower reliance on short-term debt, highlighting maturity structure as a key corporate adaptation margin to climate-related uncertainty. Second, we introduce biodiversity targets as a conditioning strategy variable and show that nature-related commitments not only correlate with maturity in levels but also moderate how strongly climate exposure maps into short-term refinancing dependence. Third, by distinguishing risk types and evaluating multiple short-term cutoffs, we clarify the horizon at which climate risk and biodiversity commitments matter most, helping reconcile heterogeneity documented in recent environmental finance research [4; 22; 23].

The remainder of the paper proceeds as follows. Second section develops hypotheses and reviews related literature. Third section describes the data, variable construction, and empirical design. Fourth section presents the main results and robustness analyses. Fifth section concludes with implications for corporate risk management and debt contracting under climate and nature-related uncertainty.

Theoretical Frameworks and Literature Review

The classical irrelevance proposition of Modigliani and Miller [10] establishes that in frictionless capital markets, firms are indifferent to financing choices, including leverage and debt maturity. In this benchmark setting, refinancing risk, agency conflicts, and information asymmetries are absent, rendering debt maturity irrelevant for firm value. However, extensive theoretical and empirical research demonstrates that once market imperfections are introduced, debt maturity becomes a central element of corporate financial policy [7; 12]. As firms operate in environments characterized by uncertainty, contractual frictions, and institutional constraints, the choice between short-term and long-term debt reflects a complex trade-off between monitoring benefits and refinancing risks.

A core insight from agency theory is that short-term debt can function as a disciplinary mechanism by enhancing creditor monitoring and limiting managerial discretion. Myers [12] argues that short-maturity debt mitigates the debt overhang problem by forcing managers to access capital markets more frequently, thereby reducing incentives for inefficient investment and risk-shifting. This view is reinforced by Barnea et al. [11] and Stulz [13], who emphasize that frequent refinancing strengthens creditor oversight and constrains opportunistic managerial behavior. Empirical evidence further suggests that firms with severe agency problems tend to rely more heavily on short-term debt to substitute for weak governance mechanisms [7].

At the same time, the literature highlights the substantial costs associated with short-term borrowing. Diamond [8] shows that reliance on short-term debt exposes firms to rollover risk and the possibility of inefficient liquidation when creditors reassess firm quality or market conditions deteriorate. Froot et al. [9] demonstrate that refinancing risk can distort firms' investment and financing decisions, leading to underinvestment or precautionary liquidity hoarding. These costs are particularly severe when firms face heightened uncertainty, as even fundamentally sound firms may be denied refinancing during periods of market stress [14]. Consequently, the net benefits of short-term debt depend critically on the stability of the firm's operating and financial environment.

In contrast, long-term debt provides greater financing stability by locking in borrowing conditions and reducing exposure to short-term credit market fluctuations. Prior studies document that firms use longer debt maturities to better match the duration of their assets and investment projects, thereby mitigating refinancing risk [7; 16]. By reducing the frequency of renegotiation with lenders, long-term debt allows firms to sustain investment and operational activities during adverse economic conditions [8]. As a result, firms facing persistent or non-transitory risks may optimally substitute short-term debt for longer maturities.

Risk-based theories further extend this trade-off by emphasizing the role of uncertainty and volatility in shaping debt maturity decisions. A growing body of literature shows that firms actively adjust their maturity structures in response to macroeconomic, political, and policy uncertainty [19; 20]. While short-term debt may preserve flexibility under conditions of moderate uncertainty, excessive volatility amplifies refinancing and liquidity risks, prompting firms to extend debt maturities to avoid repeated exposure to stressed credit markets [14]. These findings underscore that uncertainty fundamentally alters the costs and benefits of short-term borrowing.

More recently, scholars have applied this framework to environmental and climate-related risks, which represent a distinct and increasingly salient source of uncertainty. Climate change exposes firms to physical risks, such as extreme weather events and supply chain disruptions, as well as transition risks arising from regulatory changes, technological shifts, and evolving investor preferences. Nguyen and Phan [5] show that carbon risk reduces corporate leverage, reflecting lenders' heightened risk aversion. Ginglinger and Moreau [2] further demonstrate that climate risk increases borrowing costs and significantly affects firms' capital structure choices. Building on this work, Choi [22] and Goodell et al. [23] provide direct evidence that firms exposed to climate change adjust their debt maturity profiles, highlighting maturity structure as a key margin of financial adjustment to environmental risk.

Environmental risk affects debt maturity through several interrelated channels. First, climate-related shocks increase cash-flow volatility and operational uncertainty, magnifying the refinancing risk associated with short-term debt [8; 9]. Second, environmental risk intensifies regulatory and policy uncertainty, making frequent access to external finance more costly and unpredictable [20]. Third, lenders and investors may reassess firms' long-term viability in response to environmental exposure, further reducing the attractiveness of short-maturity borrowing [2]. In such settings, the traditional monitoring benefits of short-term debt are likely to be dominated by its liquidity and rollover costs.

Institutional theory provides an additional layer of insight by emphasizing the role of legal systems and regulatory environments. Qian and Strahan [26] show that stronger creditor protection and legal enforcement are associated with longer debt maturities, whereas weaker institutional environments encourage reliance on short-term debt. Cross-country evidence confirms that differences in institutional quality explain substantial variation in corporate debt maturity structures [27]. Importantly, environmental regulation has emerged as a key institutional factor shaping corporate financial decisions. Governments worldwide have implemented stricter climate and environmental policies, including disclosure mandates, carbon pricing schemes, and sustainability standards. Compliance with these regulations often requires long-term investments and stable financing arrangements. Consistent with this view, Liang et al. [24] show that firms with stronger climate concerns and greater regulatory exposure tend to issue longer-maturity bonds.

Taken together, the theoretical and empirical literature suggests that environmental and climate-related risks fundamentally reshape the trade-off underlying firms' debt maturity choices. While short-term debt can mitigate agency problems in stable environments, heightened environmental risk amplifies refinancing, liquidity, and regulatory risks, reducing the attractiveness of short-maturity borrowing. As firms increasingly face persistent and non-diversifiable environmental risks, debt maturity emerges as a critical instrument for managing financial stability and sustaining long-term investment.

Integrating insights from agency theory, risk-based theory, and institutional theory, we argue that environmental and climate-related risks fundamentally alter the trade-off between the benefits and costs of short-term debt. While short-term debt can mitigate agency problems under normal conditions, heightened environmental risk in-

creases cash-flow volatility, refinancing uncertainty, and liquidation risk, thereby magnifying the disadvantages of short-maturity borrowing. At the same time, regulatory pressure and institutional constraints associated with environmental risk encourage firms to adopt more stable and long-term financing schemes.

Accordingly, we posit that firms facing higher exposure to environmental and climate-related risks strategically reduce their reliance on short-term debt and extend debt maturity in order to mitigate refinancing and liquidity risks.

Hypothesis 1. *Firms with greater exposure to environmental and climate-related risks rely less on short-term debt.*

Data Sample and Model Specification

Data Sample

We begin by collecting firm-level financial and accounting information for Asian listed firms from the LSEG Eikon database for the 2000-2024 period. Following standard practice in the corporate finance literature, we apply several screening criteria to construct the final sample. First, we exclude financial firms because their balance-sheet structure and regulatory environment imply accounting and financing patterns that are not comparable to those of non-financial firms. Second, we remove firm-year observations with missing or zero values for total assets. Third, we drop firm-year observations with missing values in the dependent variables (short-term debt maturity measures) and the key explanatory variables capturing firms' financial exposure to transition and physical climate risks. In our baseline regressions (Table 2), the final samples comprise 8,389 firm-year observations for the one-year debt maturity ratio, 6,009 observations for the two-year debt maturity ratio, and 4,816 observations for the three-year debt maturity ratio. Descriptive statistics for all variables used in the main analyses are presented in the next section. To mitigate the influence of extreme observations, we winsorize all continuous variables at the 1st and 99th percentiles. To clarify the geographic scope of Asian listed firms, we explicitly identify the countries represented in our data. Based on the baseline specification with the largest sample (Model 1), the dataset covers 1,486 listed firms headquartered in the following 25 Asian countries: Azerbaijan, Bahrain, China, Hong Kong, India, Indonesia, Israel, Japan, South Korea (Republic of Korea), Kuwait, Macau, Malaysia, Mongolia, Oman, Pakistan, the Philippines, Qatar, Saudi Arabia, Singapore, Sri Lanka, Taiwan, Thailand, Turkey, the United Arab Emirates, and Vietnam. Because the effective estimation sample varies across specifications due to data availability, the country composition may differ slightly in models with smaller samples.

Variables

Dependent Variables

Our dependent variables measure firms' reliance on short-term debt, capturing their exposure to refinancing and liquidity risk. Following recent literature on corporate debt maturity and financial risk exposure [7; 8; 22], we construct three alternative measures of short-term debt maturity based on the contractual maturity structure of firms' outstanding debt.

Specifically, One-year Debt is defined as the ratio of debt obligations maturing within one year to total interest-bearing debt. Two-year Debt and Three-year Debt are defined analogously as the ratios of debt maturing within two years and three years, respectively, to total debt. These measures are constructed using detailed maturity information from firms' balance sheet disclosures and capture different horizons of refinancing exposure.

Using multiple maturity cutoffs allows us to account for the possibility that firms adjust their debt maturity structure incrementally by shifting debt across adjacent maturity buckets rather than making discrete changes in overall maturity [16; 17]. Moreover, shorter maturity horizons reflect greater sensitivity to rollover risk, as firms with a higher proportion of debt maturing in the near term face the need to refinance more frequently and heightened vulnerability to adverse credit market conditions [8; 9].

Higher values of these short-term debt ratios indicate greater reliance on short-maturity borrowing and, consequently, higher exposure to refinancing and liquidity risk. These measures are widely used in the literature to assess firms' debt maturity structure and provide a suitable framework for examining how external risk exposures, such as climate change risk, affect corporate financing policies.

Explanatory Variables

The key explanatory variables measure firms' financial exposure to climate change risk. We distinguish between two conceptually distinct dimensions of climate risk: physical risk and transition risk. Physical Climate Risk is a binary indicator equal to one if a firm is financially exposed to physical climate-related events, such as extreme weather conditions, natural disasters, or climate-induced disruptions to production and supply chains, and zero otherwise. Transition Climate Risk is a binary indicator equal to one if a firm is exposed to risks arising from the transition toward a low-carbon economy, including changes in environmental regulation, carbon pricing mechanisms, technological shifts, and evolving market or investor preferences.

This distinction follows recent literature emphasizing that physical and transition risks affect firms through different economic channels and may have heterogeneous implications for corporate financial policies [2; 22; 23]. By employing separate indicators for physical and transition climate risk, we are able to disentangle their respective effects on firms' debt maturity choices.

Control Variables

We include a comprehensive set of firm-level control variables that prior studies identify as important determinants of corporate debt maturity. These controls account for differences in firms' investment opportunities, liquidity, profitability, asset structure, and operating characteristics that may independently influence debt maturity decisions [7; 12].

Capital expenditures, scaled by total assets, proxy for firms' investment intensity. Firms with higher investment needs may prefer shorter debt maturities to preserve financial flexibility, or longer maturities to better match the duration of assets and liabilities [16]. Operating cash flow, also scaled by total assets, captures internal liquidity and firms' ability to service debt from operating activities. Firms with stronger cash flows are generally less exposed to refinancing risk and may rely less on short-term debt [8; 15].

Profitability is measured by return on assets, reflecting firms' overall operating performance. More profitable firms typically face lower default risk and better access to long-term financing, which may reduce their reliance on short-maturity debt [28]. Growth opportunities are proxied by Tobin's Q, as firms with higher growth prospects may use shorter debt maturities to mitigate underinvestment and asset substitution problems [12].

We further control for inventory ratio, defined as inventories scaled by total assets, to capture differences in working capital structure and operating cycles that may influence financing needs. Finally, asset tangibility, measured as the ratio of tangible assets to total assets, acts as a proxy for the availability of collateral. Firms with more tangible assets typically have greater access to long-term debt markets and may rely less on short-term borrowing [7; 27].

Model Specification

To examine the relationship between climate risk exposure and debt maturity, we estimate the following baseline regression model:

$$Debt\ Maturity_{i,t} = \alpha + \beta_1 Climate\ Risk_{i,t} + \gamma X_{i,t} + + \delta_{industry \times year} + \varepsilon_{i,t,} \quad (1)$$

where $Debt\ Maturity_{i,t}$ denotes one of the short-term debt ratios for firm i in year t, $Climate\ Risk_{i,t}$ represents either physical or transition climate risk exposure, and $X_{i,t}$ is a vector of control variables. All specifications include industry-by-year fixed effects to control for unobserved heterogeneity across industries and time. Standard errors are clustered at the firm and year levels to account for cross-sectional and temporal dependence.

This empirical specification allows us to isolate the association between climate risk exposure and firms' reliance on short-term debt while controlling for firm characteristics and common industry-year shocks.

Empirical Results

Descriptive Statistics

Table 1 reports descriptive statistics for the main variables used in the analysis. On average, firms in the sample hold approximately 20.4% of their total debt maturing within one year, 13.7% within two years, and 12.3% within three years. These figures indicate that a substantial portion of corporate debt is subject to short-term refinancing risk, consistent with prior studies on debt maturity structure [7; 8].

Regarding climate risk exposure, approximately 16.2% of firm-year observations are classified as exposed to physical climate risk, while 16.3% are exposed to transition climate risk. This distribution suggests meaningful cross-sectional variation in firms' climate risk exposure, which is essential for identifying its association with debt maturity choices. The control variables exhibit substantial heterogeneity across firms and align well with summary statistics reported in related literature [27; 28].

Table 1. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	P25	Median	P75	Min	Max
One-year Debt	24.980	0.204	0.217	0.061	0.133	0.258	0.000	0.999
Two-year Debt	16.581	0.137	0.134	0.043	0.103	0.183	0.000	0.719
Three-year Debt	12.147	0.123	0.126	0.039	0.093	0.159	0.000	0.709
Physical Climate Risk	26.421	0.162	0.369	0.000	0.000	0.000	0.000	1.000
Transition Climate Risk	26.421	0.163	0.370	0.000	0.000	0.000	0.000	1.000
Capital Expenditures	80.295	0.056	0.054	0.018	0.040	0.075	0.000	0.279
Operating Cash Flow	80.634	0.075	0.088	0.026	0.069	0.120	-0.196	0.353
Return on Assets	76.823	0.058	0.082	0.019	0.050	0.094	-0.242	0.334
Tobin's Q	70.915	1.615	1.687	0.699	1.027	1.796	0.259	10.617
Inventory Ratio	76.816	0.135	0.127	0.040	0.107	0.186	0.000	0.652
Asset Tangibility	80.419	0.314	0.223	0.132	0.280	0.463	0.000	0.900

Notes: This table reports descriptive statistics for the main variables used in the analysis. Debt maturity ratios measure the proportion of total debt maturing within one, two, and three years, respectively. Climate risk exposure variables are binary indicators capturing firms' exposure to physical and transition climate risks. All continuous variables are winsorized at the 1st and 99th percentiles.

Baseline Regression

Table 2 reports the baseline regression results examining the relationship between firms' exposure to climate change risk and their reliance on short-term debt. Columns (1)–(3) present the results for physical climate risk, while Columns (4)–(6) focus on transition climate risk. Across all specifications, the estimated coefficients on both climate risk measures are negative and statistically significant, indicating that firms exposed to climate-related risks systematically rely less on short-term debt.

The negative association between physical climate risk and short-term debt maturity suggests that firms facing greater exposure to climate-related shocks reduce their reliance on debt that requires frequent refinancing. This finding is consistent with the classic rollover-risk mechanism: when cash flows become more volatile and downside tail events become more likely, short-maturity borrowing becomes costlier because it increases the probability of refinancing under stressed market conditions [8; 9]. Recent evidence further supports the claim that physical climate risk is priced in debt markets and is reflected in credit-relevant terms, including higher borrowing costs and weaker credit risk assessments [3; 6]. Such pricing dynamics strengthen the economic rationale for firms to limit near-term refinancing needs by extending maturity.

Similarly, the results for transition climate risk indicate that firms exposed to regulatory and transition-related uncertainties also hold a lower proportion of short-term debt. Transition risk arising from climate regulation, carbon pricing, and technology shifts can elevate regulatory uncertainty and increase the sensitivity of credit conditions to policy news [19; 20]. Consistent with this channel, recent work using shocks to expected climate regulation shows that climate regulatory risk causally affects bond credit ratings and yield spreads, especially for high-carbon issuers and in stricter regulatory environments [21]. This evidence supports our interpretation that firms respond to transition risk by reducing exposure to frequent refinancing and the associated repricing risk in debt markets.

Importantly, the results are economically meaningful and remain significant across alternative maturity horizons (within one, two, and three years). The stability of the association across cutoffs suggests that firms adjust debt maturity in a broad and persistent manner rather than by merely shifting debt across adjacent maturity buckets [16; 17]. Moreover, the negative relationship for both physical and transition risk is consistent with the view that firms increasingly recognize and measure these risks separately, as emphasized in recent firm-level climate-risk measurement research [4].

Among the controls, asset tangibility is negatively associated with short-term debt in several specifications, consistent with the collateral channel: firms with more pledgeable assets can more easily access longer-term financing [7; 27]. Overall, the baseline evidence supports Hypothesis 1 and highlights debt maturity as a key margin through which firms manage climate-related refinancing and repricing risks.

Table 2. Baseline Regression Results

	(1) One-year Debt	(2) One-year Debt	(3) Two-year Debt	(4) Two-year Debt	(5) Three-year Debt	(6) Three-year Debt
Physical Climate Risk	−0.042*** (−3.87)		−0.012** (−2.08)		−0.023* (−1.82)	
Transition Climate Risk		−0.033*** (−3.26)		−0.013** (−2.52)		−0.024** (−2.46)
Capital Expenditures	0.025 (0.20)	0.026 (0.21)	−0.025 (−0.41)	−0.025 (−0.40)	−0.086 (−1.46)	−0.087 (−1.46)
Operating Cash Flow	0.012 (0.20)	0.009 (0.14)	−0.067 (−1.16)	−0.067 (−1.15)	−0.040 (−0.68)	−0.041 (−0.71)
Return on Assets	−0.020 (−0.23)	−0.022 (−0.25)	0.037 (0.73)	0.036 (0.71)	−0.011 (−0.21)	−0.011 (−0.21)
Tobin's Q	−0.002 (−0.78)	−0.002 (−0.63)	0.005 (1.45)	0.005 (1.45)	0.010*** (4.23)	0.010*** (4.43)
Inventory Ratio	0.000 (0.01)	0.001 (0.02)	0.002 (0.08)	0.002 (0.09)	0.016 (0.41)	0.017 (0.41)

	(1) One-year Debt	(2) One-year Debt	(3) Two-year Debt	(4) Two-year Debt	(5) Three-year Debt	(6) Three-year Debt
Asset Tangibility	−0.100*** (−4.22)	−0.099*** (−4.18)	−0.016 (−1.12)	−0.016 (−1.12)	0.001 (0.05)	0.001 (0.07)
Constant	0.229*** (19.62)	0.227*** (19.84)	0.138*** (19.15)	0.138*** (19.60)	0.119*** (12.99)	0.119*** (13.20)
Industry × Year	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.026	0.025	0.041	0.041	0.048	0.048
Obs.	8.389	8.389	6.009	6.009	4.816	4.816

Notes: The dependent variables are debt maturity ratios (one-, two-, and three-year debt). All specifications include industry-by-year fixed effects. t-statistics are reported in parentheses. Standard errors are clustered at the firm and year levels. p < 0.10, p < 0.05, *p < 0.01.

Robustness tests

Propensity Score Matching Analysis

Although the baseline regressions control for a rich set of firm characteristics and include industry-by-year fixed effects, firms' exposure to climate change risk may still be non-random. Firms facing physical or transition climate risks can differ systematically from non-exposed firms along dimensions such as investment intensity, profitability, liquidity, growth opportunities, and collateral capacity, which may independently influence debt maturity choices. To further mitigate concerns related to selection on observables, we employ a propensity score matching (PSM) approach that constructs a matched sample of climate-risk-exposed and non-exposed firms with similar observable characteristics [29].

Specifically, we first estimate propensity score models in which the dependent variable is the indicator for physical or transition climate risk exposure, and the explanatory variables consist of the same firm-level controls used in the baseline regressions. The pre-matching estimates reveal that several firm characteristics significantly predict climate risk exposure, confirming that exposed firms are not randomly drawn from the population. We then match climate-risk-exposed firms to non-exposed firms within the same industry-year cells using nearest-neighbor matching with a strict caliper of 0.001. This matching design ensures that treated and control firms face comparable economic and institutional environments, thereby improving the comparability of the two groups.

The post-matching diagnostics indicate that the systematic differences in observable characteristics between climate-risk-exposed and non-exposed firms are substantially reduced. Variables that are significant predictors of climate risk exposure in the pre-match models lose their explanatory power in the post-match stage, suggesting that the matched samples exhibit satisfactory covariate balance. This evidence indicates that the matching procedure effectively aligns treated and control firms along key firm-level dimensions relevant for debt maturity decisions.

Using the matched samples, we re-estimate the outcome regressions for short-term debt maturity. The results show that the negative association between climate risk exposure and short-term debt remains economically and statistically significant after matching. Firms exposed to physical climate risk continue to hold a lower proportion of debt maturing in the near term, consistent with the baseline findings. A similar pattern emerges for transition climate risk, indicating that regulatory and transition-related uncertainties are also associated with a reduced reliance on short-maturity borrowing. Importantly, these effects persist across alternative maturity horizons, suggesting that firms adjust their debt maturity structure in a broad and systematic manner rather than merely shifting debt across adjacent maturity buckets.

The persistence of the climate risk effect in the matched samples strengthens the interpretation that the baseline results are not solely driven by observable firm characteristics. Instead, the PSM evidence supports a refinancing-risk mechanism: when firms face heightened exposure to physical or transition climate risks, the liquidity and rollover costs associated with short-term debt become more salient, incentivizing firms to extend debt maturity in order to secure more stable financing [8; 9]. Overall, the matching results provide additional support for the view that climate change risk represents an economically meaningful determinant of corporate debt maturity choices (Tables 3 and 4).

Table 3. Propensity Score Matching Results for Physical Climate Risk

	(1) Physical Climate Risk Pre-match	(2) Physical Climate Risk Post-match	(3) One-year Debt Matched sample	(4) Two-year Debt Matched sample	(5) Three-year Debt Matched sample
Physical Climate Risk			−0.032**	−0.011**	−0.020**
			(0.012)	(0.004)	(0.008)
Capital Expenditures	−2.184***	0.156	−0.151	0.018	−0.028
	(0.509)	(0.692)	(0.125)	(0.103)	(0.152)
Operating Cash Flow	1.483***	0.318	0.022	−0.100	−0.170**
	(0.311)	(0.428)	(0.072)	(0.091)	(0.068)
Return on Assets	−1.379***	−0.459	−0.197	0.037	0.150***
	(0.330)	(0.470)	(0.119)	(0.056)	(0.046)
Tobin's Q	−0.119***	0.008	0.005	0.006	0.011*
	(0.013)	(0.017)	(0.004)	(0.005)	(0.006)
Inventory Ratio	0.017	0.114	−0.014	0.020	−0.002
	(0.153)	(0.196)	(0.047)	(0.023)	(0.059)
Asset Tangibility	−0.041	-0.034	−0.096***	−0.015	0.022
	(0.099)	(0.132)	(0.024)	(0.015)	(0.015)
Constant	−1.370***	−0.024	0.238***	0.135***	0.118***
	(0.046)	(0.060)	(0.013)	(0.012)	(0.013)
Obs.	24.600	8.090	2.916	2.177	1.713
Pseudo R^2 / Adj. R^2	0.009	0.000	0.016	0.033	0.043

Notes: Columns (1)–(2) report propensity score (PS) models estimated before and after matching, respectively. Columns (3)–(5) report outcome regressions estimated on the matched sample for one-, two-, and three-year debt maturity ratios. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4. Propensity Score Matching Results for Transition Climate Risk

	(1) Transition Climate Risk Pre-match	(2) Transition Climate Risk Post-match	(3) One-year Debt Matched sample	(4) Two-year Debt Matched sample	(5) Three-year Debt Matched sample
Transition Climate Risk			−0.027	−0.016***	−0.026*
			(0.016)	(0.005)	(0.013)
Capital Expenditures	−1.963***	0.799	−0.112	0.008	−0.204*
	(0.505)	(0.689)	(0.110)	(0.085)	(0.113)
Operating Cash Flow	1.526***	0.480	0.020	−0.082	−0.030
	(0.310)	(0.428)	(0.089)	(0.076)	(0.143)
Return on Assets	−1.196***	−0.504	−0.023	0.089	0.068
	(0.331)	(0.475)	(0.152)	(0.053)	(0.121)
Tobin's Q	−0.132***	−0.001	−0.002	0.000	0.004
	(0.013)	(0.017)	(0.004)	(0.002)	(0.006)
Inventory Ratio	−0.022	0.050	0.016	0.017	0.034
	(0.153)	(0.195)	(0.043)	(0.026)	(0.053)

	(1) Transition Climate Risk Pre-match	(2) Transition Climate Risk Post-match	(3) One-year Debt Matched sample	(4) Two-year Debt Matched sample	(5) Three-year Debt Matched sample
Asset Tangibility	−0.038 (0.099)	0.043 (0.130)	−0.086*** (0.020)	−0.013 (0.012)	0.017 (0.023)
Constant	−1.362*** (0.046)	−0.065 (0.059)	0.224*** (0.012)	0.140*** (0.009)	0.126*** (0.016)
Obs.	24.569	8.134	2.916	2.175	1.737
Pseudo R^2 / Adj. R^2	0.009	0.000	0.025	0.030	0.028

Notes: Columns (1)–(2) report propensity score (PS) models estimated before and after matching, respectively. Columns (3)–(5) report outcome regressions estimated on the matched sample for one-, two-, and three-year debt maturity ratios. Standard errors are reported in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

Placebo Tests

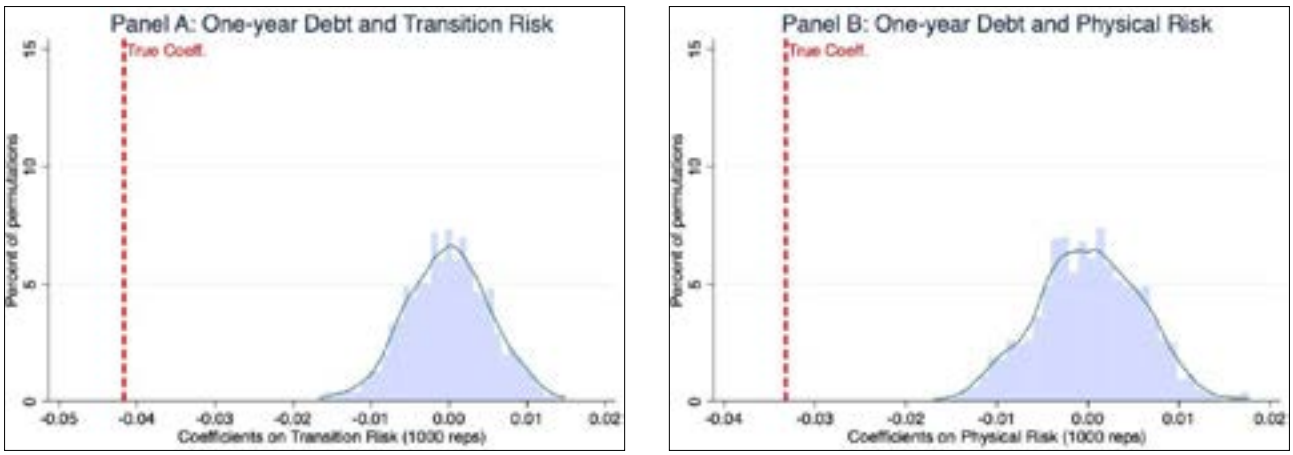
This section examines whether the estimated effects of climate change risk on short-term debt maturity could be driven by random assignment of climate risk exposure. To this end, we randomly assign the values of one or zero to firms as placebo indicators for transition risk and physical risk, drawn from a uniform distribution. We then re-estimate Equation (1) using these placebo variables and repeat the procedure 1,000 times for each debt maturity horizon.

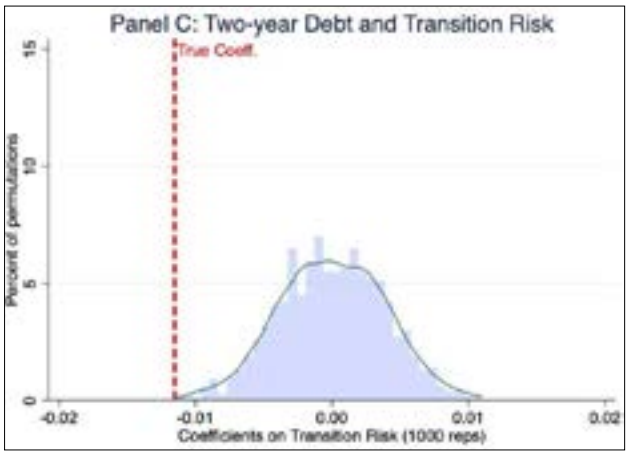
Figure 1 reports the distributions of the coefficient estimates obtained from the randomized placebo tests. Panels A, C, and E correspond to transition risk for debt maturing within one year, two years, and three years, respectively. Panels B, D, and F report the corresponding results for physical risk. In all panels, the distributions of placebo coefficients are centered around zero, indicating that randomly assigned climate risk does not systematically explain firms' short-term debt maturity.

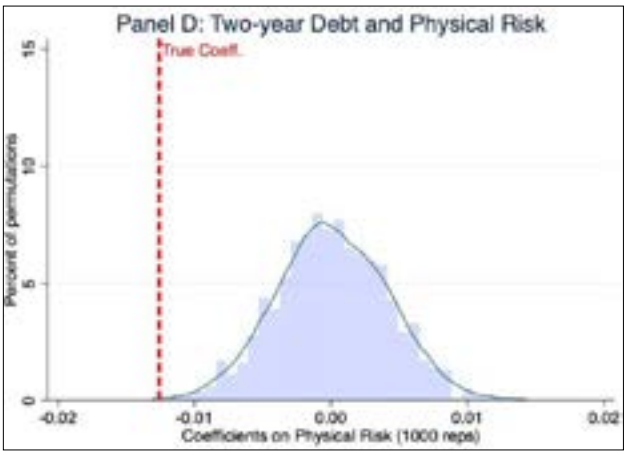
The vertical dashed red lines represent the coefficient estimates obtained using the actual climate risk measures. Across all panels, the true estimates are located far to the left of the placebo distributions and lie outside the range where the majority of randomized estimates are concentrated. This pattern is observed consistently across both transition and physical risk measures and across all debt maturity horizons.

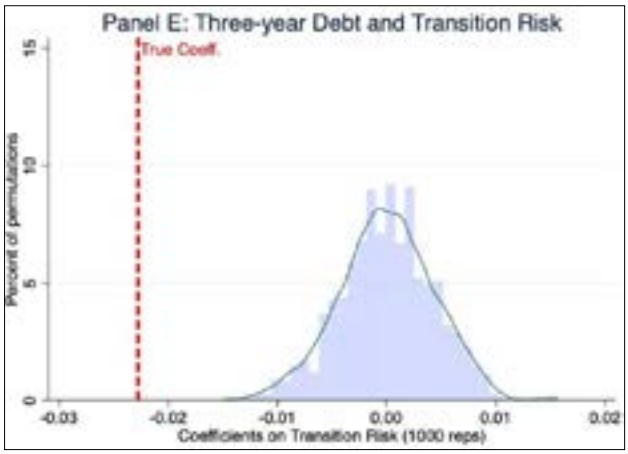
Overall, the randomization results suggest that the baseline findings are unlikely to be driven by random variation in climate risk assignment. Instead, the relationship between climate change risk exposure and short-term debt maturity reflects a systematic pattern in the data rather than a mechanical outcome of random measurement.

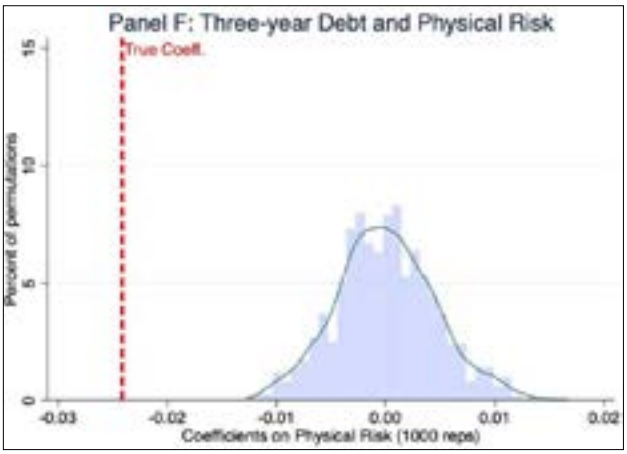
Figure 1. Estimates using Randomized Physical Risk and Transition Risk











Mechanism: The moderating role of biodiversity targets

Table 5 examines whether firms' financial exposure to climate change risk is associated with the maturity profile of short-term debt, and whether this association is moderated by firms' biodiversity targets. Across specifications, both transition and physical climate-risk exposure are negatively associated with short-term debt shares. The estimated coefficients are economically meaningful: for instance, higher transition (physical) exposure is linked with a lower one-year debt share, and the negative sign persists for the two-year and three-year maturity buckets. This pattern is consistent with a refinancing-risk channel: when climate risk raises uncertainty about future cash flows and collateral values, firms have incentives to reduce rollover vulnerability by decreasing reliance on short-maturity debt [8; 9]. In this view, climate risk functions as an external shock that amplifies liquidity risk and the probability of inefficient liquidation under short-term financing [8].

Importantly, our baseline results complement recent evidence that environmental risks reshape debt structure. For example, Goodell et al. [23] document that firm-level climate risk affects corporate debt maturity choices, while Ginglinger and Moreau [2] show that climate risk materially affects corporate financing decisions. Compared with settings where climate exposure may increase short-term borrowing for flexibility [22], our findings suggest that, when climate risk is financially salient, firms appear to term out debt to contain rollover exposure.

The coefficient on biodiversity targets is negative and statistically significant across all maturity buckets, suggesting that firms committing to biodiversity targets hold less short-term debt. One interpretation is that biodiversity-target setters follow a longer-horizon financial policy, aligning financing maturity with longer payback periods of environmental investments, and/or adopting more conservative liquidity management to stabilize stakeholder commitments. This is consistent with an emerging strand of literature emphasizing that nature- and biodiversity-related risks and commitments can influence corporate financial policies [25].

A key contribution of Table 5 is the interaction between climate-risk exposure and biodiversity targets. The interaction terms are positive and highly significant for the one-year debt share, and positive (though weaker) for the three-year bucket. This indicates that biodiversity targets attenuate the negative association between climate-risk exposure and short-term debt reliance. Put differently, for climate-exposed firms, setting biodiversity targets is associated with a smaller reduction in short-term debt shares.

This moderation effect is consistent with a credibility and risk-management mechanism. Biodiversity targets may serve as a verifiable signal of stronger environmental governance, improved disclosure quality, and more proactive risk mitigation, which can reduce lenders' concerns about downside tail risks and information asymmetry. As a result, creditors may be more willing to provide (or roll over) short-term funding even when climate exposure is high. Such an interpretation aligns with the broader corporate finance view that credible risk management reduces financing frictions and improves access to external capital [9]. It is also consistent with the evidence that environmental risks are priced differently across maturity segments in debt markets [21].

Table 5. Moderating Role of Biodiversity Targets

	(1) One-year Debt	(2) One-year Debt	(3) Two-year Debt	(4) Two-year Debt	(5) Three-year Debt	(6) Three-year Debt
Transition climate risk	−0.045** (−3.64)		−0.013* (−2.02)		−0.027 (−1.78)	
Physical climate risk		−0.036** (−3.12)		−0.014* (−2.23)		−0.028* (−2.36)
Biodiversity targets	−0.079*** (−6.07)	−0.076*** (−6.26)	−0.042*** (−3.86)	−0.037** (−3.10)	−0.042** (−3.59)	−0.045*** (−4.27)
Transition climate risk × Biodiversity targets	0.063*** (4.54)		0.014 (1.80)		0.034* (1.97)	
Physical climate risk × Biodiversity targets		0.058*** (4.48)		0.007 (0.73)		0.040* (2.39)
Capital Expenditures	0.038 (0.24)	0.040 (0.25)	0.029 (0.37)	0.030 (0.39)	−0.137 (−1.73)	−0.141 (−1.78)
Operating Cash Flow	0.033 (0.44)	0.027 (0.35)	−0.048 (−0.43)	−0.048 (−0.43)	0.027 (0.35)	0.024 (0.33)
Return on Assets	−0.102 (−1.03)	−0.104 (−1.05)	−0.023 (−0.59)	−0.026 (−0.65)	0.025 (0.37)	0.025 (0.37)
Tobin's Q	−0.005* (−2.03)	−0.005 (−1.80)	0.002 (0.66)	0.002 (0.66)	0.006* (2.23)	0.007* (2.44)
Inventory Ratio	−0.038 (−0.93)	−0.037 (−0.91)	0.028 (0.92)	0.028 (0.93)	0.056 (0.98)	0.056 (0.96)
Asset Tangibility	−0.117*** (−4.86)	−0.115*** (−4.77)	−0.032 (−1.58)	−0.032 (−1.60)	0.011 (0.55)	0.012 (0.56)
Constant	0.256*** (18.05)	0.250*** (18.62)	0.147*** (13.16)	0.148*** (14.05)	0.126*** (8.12)	0.126*** (9.02)
Industry × Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.025	0.021	0.012	0.012	0.024	0.025
Observations	3.685	3.685	2.468	2.468	1.981	1.981

Notes: This table examines the moderating role of biodiversity targets in the relation between firms' climate-risk exposure and short-term debt maturity. The dependent variables are the ratios of total interest-bearing debt maturing within one year (One-year Debt), within two years (Two-year Debt), and within three years (Three-year Debt). Transition climate risk and physical climate risk are indicator variables capturing firms' exposure to transition and physical climate risks, respectively. Biodiversity targets is an indicator equal to one if the firm commits to biodiversity targets and zero otherwise. Columns (1), (3), and (5) present specifications for transition climate risk and its interaction with biodiversity targets, while Columns (2), (4), and (6) present specifications for physical climate risk and its interaction with biodiversity targets. All regressions control for Capital Expenditures, Operating Cash Flow, Return on Assets, Tobin's Q, Inventory ratio, and Asset Tangibility. Industry × year fixed effects are included. t-statistics are reported in parentheses. Standard errors are two-way clustered at the firm and year levels. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Conclusion

This paper examines how firms' financial exposure to climate change risk shapes the maturity profile of corporate debt, with a focus on short-term refinancing dependence. Building on the canonical trade-off between monitoring benefits of short-term debt and its rollover costs [7; 8; 11; 12], we argue that climate risk increases refinancing frictions and tail-risk concerns, thereby strengthening firms' incentives to reduce short-term maturity concentration. We further investigate whether biodiversity targets – an increasingly salient dimension of nature-related strategy–directly relate to maturity choices and condition the maturity response to climate exposure.

Across baseline specifications and robustness designs, we document three main findings. First, higher climate-risk exposure (both physical and transition dimensions) is associated with a significantly lower share of short-term debt, consistent with firms actively managing rollover vulnerability when climate uncertainty intensifies [8; 9; 22; 23]. Second, biodiversity targets are strongly and negatively related to short-term debt shares, suggesting that target-setting firms adopt more long-horizon and resilient financing policies, consistent with maturity-matching considerations in debt design [7; 16; 17]. Third, the interaction evidence indicates that biodiversity targets mitigate the marginal sensitivity of short-term debt to climate risk exposure, implying that nature-related commitments may operate as a credibility and risk-buffer channel that relaxes refinancing pressure for climate-exposed firms [9; 25].

These results carry several implications. For corporate managers, the evidence highlights debt maturity as an important adaptation margin to climate-related uncertainty: reducing near-term refinancing reliance can lower liquidity fragility when climate risks trigger sudden repricing or credit tightening [14; 15]. For lenders and investors, our findings suggest that climate exposure and nature-related strategy jointly shape the risk profile of corporate debt. Transition and physical climate risks can translate into maturity restructuring, while biodiversity targets appear to contain the maturity adjustment required under high climate exposure, potentially reflecting stronger governance, disclosure, and adaptive capacity. This is consistent with evidence that climate risks are priced in debt markets and incorporated into credit contracting [1–3; 21]. For policymakers, the results underscore that corporate commitments, such as biodiversity targets, may interact with climate-risk exposure in shaping financial resilience, indicating a potential role for disclosure standards and incentive schemes that improve the credibility and comparability of nature-related commitments.

Our study is subject to several limitations that motivate future research. First, while we employ rich controls and identification strategies, causal interpretation may still be challenged by unobserved firm traits that jointly drive sustainability commitments and financing policies. Future work could extend quasi-experimental designs–e.g., exploiting regulatory shocks or disclosure mandates–and implement matching frameworks to sharpen causal inference [29]. Second, measurement of climate exposure and biodiversity targets can be refined as data availability improves; subsequent studies may examine whether alternative risk metrics, or more granular nature-related disclosures, yield differential maturity responses [4]. Third, an important extension is to investigate the pricing dimension jointly with maturity choice–how climate and nature-related factors influence not only maturity structure but also spreads, covenants, and loan/bond contract features [1; 3; 24]. Finally, future research may explore cross-country heterogeneity in institutions and creditor rights, which can condition the maturity channel through contractual enforcement and bank-loan design [26; 27].

Overall, our findings suggest that climate-risk exposure and biodiversity targets jointly shape corporate maturity policy in a non-additive manner. Debt maturity thus represents a key component of financial resilience in the transition to a low-carbon economy and in the broader shift toward managing nature-related risks.

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What Drives Green Bonds Returns and Valuation of the Safe-Assets Effect on Global, Russian and Chinese Markets?

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Abstract

This paper identifies the determinants of green bonds on global markets, China and Russia and evaluates the hedging effect of these instruments. We contribute to the existing literature by studying the emerging markets such as Russia and China, providing comparative analysis of the impact of identical factors on green bond yields on global, Russian ad Chinese markets, and implementing the methodology for time series analyses that involve studying several subperiods. Based on the sample of 2167, 1213 and 2167 observations for global, Russian and Chinese markets in 2017–2022, respectively, we analyzed the impact of various factors on green bond returns using two empirical methods: analyses of long- and short-term linkages between variables based on the VECM model and construction of the GARCH model. The obtained results revealed that green bonds act like a hedging asset on global, Chinese and Russian markets, which proves that investors can use them to hedge their portfolios during economic crises, policy uncertainties and other market fluctuations. However, the hedging effect of green bonds differs in global, Russia and Chinese markets. In case of China, green bonds have a significant short-term hedging effect for all considered factors, while for the global green bonds the short-term hedging effect is present for all variables except the common stock market index. Russian green bonds can be used for hedging against gold and gas prices both in the short- and long-run. These results show investors how to manage their portfolios more effectively by using green bonds as a hedge asset.

Keywords: green bonds, hedging effects, safe assets

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Introduction

The world faces environmental problems and moves towards sustainable growth. One of the examples is carbon-neutral growth, which is a goal for both developed [1] and emerging countries [2]. Green bonds have become a popular financial instrument of sustainable financing and an alternative opportunity for investors [3]. At the same time, investors are becoming more conscious of the need for sustainable investment, with a recent survey finding that nearly two-thirds of Asian investors are eager to make their investments more sustainable. As a result, the green bond market has been developing rapidly throughout the last decade. According to OECD estimates, the green bond market may grow to 4.7–5.6 trillion US dollars by 2035, and the volume of annual issuance will reach 620–720 billion dollars [4].

Moreover, modern financial and global economic uncertainty shows that there is a need for safe-haven assets. Based on historical experience, financial crises due to epidemics are expected to be deeper but shorter than the global financial crisis of 2009. For example, in the early stages of the 2020 pandemic, 30% of the worldwide stock market value evaporated within weeks, and that loss was recovered only in mid-2021. In such conditions, investors are forced to look for safe-haven investment opportunities. Financial crises usually lead to higher volatility, and the latter reduces the benefit of classic diversification methods across asset classes. Thus, gold and cryptocurrency fail to hedge risks during pandemic crisis [5], but green bonds seem to provide a promising solution to this issue.

The relevance and motivation of our research lie in several spheres. First, COVID-19 crisis has shown that there is always a possibility of unexpected disasters, to hedge against which investors need to find new safe-haven assets aside from traditional ones, such as gold. Secondly, the topic is important in the context of climate change and the transition to a low-carbon economy. It is essential to study the determinants of the green bond market to understand the motivation of investors to mobilize financial resources for eco-friendly projects.

In this study we identify the key determinants of green bond yields in the global, Chinese, and Russian markets and assess the hedging effect of these instruments. The contributions of this study to the literature stem from several key aspects. First, it focuses on emerging markets – namely Russia and China – in the context of the green bond market, thereby addressing a notable gap in detailed research on these countries. This selection of research objects aligns with contemporary calls in the literature, including Tang et al. (2023), which highlight the potential for novel findings from analyses of emerging economies [6]. Second, it examines the Russian, Chinese, and global green bond markets over the same period, facilitating a comparative analysis of how identical factors affect green bond yields. Our findings confirm the hedging effect of green bonds across all markets, regardless of maturity level. However, the influence of these factors varies significantly, highlighting the importance of incorporating country-specific characteristics when utilizing green bonds as hedging instruments. Third, the study delineates the directionality of factors influencing green bond yields and distinguishes short-run from long-run relationships using the VECM framework, thereby uncovering horizon-dependent hedging characteristics. Furthermore, we construct a green bond index for the Russian market.

The empirical results of this study have several implications for investors and policymakers. First, for private and institutional investors our results provide empirical evidence of the hedging capability of green bonds against uncertainty and other market fluctuations. Secondly, the results show the investors that it is vital to constantly monitor a green bond investment portfolio, as the relationship with market and policy uncertainty is time-varying and state-dependent. Also, understanding the relationships between green bonds and commodity markets, the stock market and the corporate bond market and defining other determinants of green bonds help investors to make more effective investment decisions.

Theoretical Framework and Hypotheses Development

Theoretical framework

The role of green bonds as hedging assets is investigated in the following papers. Cui et.al (2022) explores the impact of the COVID-19 pandemic on the global green bond and conventional assets, including commodity, treasury, stock and clean energy markets [7]. For green bonds, the authors use the S&P Green Bond Index to describe the global green bond price fluctuations. As to the conventional financial markets, S&P GSCI Commodity Index, Barclays Bloomberg Global Treasury Index, S&P 500 Composite Index and S&P Clean Energy Index are chosen to reflect the circumstances in commodity, treasury, stock and clean energy markets. According to the results, green bonds are most affected by the COVID-19 pandemic, followed by the treasuries, while other conventional assets are only slightly affected. Arif et al. (2021) examine the hedging potential of the S&P green bond index, with explanatory variables such as equity, bond, commodity, and currency indices [8]. The results demonstrated that in the short term there is a correlation between the green bond index and conventional investment returns, consequently, green bonds are ineffective as a "shelter" mechanism. More recent research provides a more nuanced view of the hedging role of green bonds. Arouri et al. (2025) examine the dynamic connectedness between green bonds, ESG indices and traditional financial assets using advanced econometric techniques [9]. Their findings suggest that green bonds can enhance portfolio diversification and provide hedging benefits, particularly during periods of market turbulence. However, they do not act as a standalone safe-haven asset, and their effectiveness depends on broader portfolio composition and market conditions.

To analyze the dynamics of green bond returns, we should define the determinants which influence the green bond markets. Determinants of global green bond market were investigated in the paper of Reboredo and Ugolini (2020), where the authors study price connectedness between the green bond and financial markets using a structural VAR model that captures direct and indirect transmission of financial shocks across markets [10]. Dependent variables are chosen at a global level and included indexes, representing fixed-income markets (Bloomberg Barclays Global Treasury Total Return Index Value), currency markets (Trade Weighted US Dollar Index), stock markets (MSCI World Index) and energy commodity markets (S&P GSCI Energy Spot CME Index). The authors conclude that green bonds are influenced by price shocks in all markets, except for energy. However, this influence differs among different markets. Green bond market is closely linked to the fixed-income and currency markets, receiving sizable price spillovers from those markets and transmitting negligible reverse effects. In contrast, the green bond market is weakly tied to the stock, energy and high-yield corporate bond markets. Jiang et al. (2022) study the relationship between green bonds and conventional financial markets for the global market [11].

Chi-Chuan Lee, Huayun Tang and Ding Li do the recent research dedicated to the linkages among oil shocks, geopolitical uncertainties, and Chinese green bond returns [12]. Authors focus on oil shocks and geopolitical uncertainties as main factors. They suggest two main hypotheses: significant effect of oil shocks on green bond returns and the significant effect of geopolitical risks on oil price dynamics. China green bond index is used as well as oil prices and as GPR index as the proxy for geopolitical turbulence. Authors conclude that geopolitical uncertainties have positive impact on green bonds' return while oil-specific demand shocks lead to the decrease in green bond index.

The Russian market of green financing is only at the formation stage. Popova T.A. and O.V. Mitrakova analyze green bond issuance on the Russian market in their recent research [13]. Authors note that green bonds demonstrate lower volatility compared to ordinary bonds, which makes it possible to characterize the green bond market as more stable and less risky. At the same time, since Russian green bonds are traded at an average discount of 6%, the authors argue that investors are not familiar enough with this financing tool. Frecautan I. examines the spillover effects of Russian green bonds on key capital market indices, both prior to and following the onset of the military conflict, while also identifying the directionality of these relationships. The author found low hedging effectiveness and hedging ratios between green bonds and sectoral indices, signaling no hedging need post-February 2022 events. It was also revealed that Russian green bonds as an exceptional tool for portfolio management amid geopolitical conflict [14]. In a paper from the same year, the authors Frecautan I. and Ivashkovskaya I. study the influence of corporate governance on the green bond yield spreads in emerging capital markets [15].

Hypotheses development

To identify the determinants of green bond yields and assess their hedging properties, – thereby aiding investors in navigating crisis conditions and exploring new portfolio diversification options to mitigate risks under normal market regimes, – we propose the following hypotheses for empirical testing across global, Chinese, and Russian markets.

Hypothesis 1: *Green bonds demonstrate a hedging effect in global, Chinese and Russian markets.*

By a hedging effect, we use the definition of a hedging asset as presented by Baur and Lucey (2010) and Baur and McDermott (2010) [16; 17]. To be specific, a hedge is an asset that displays a negative correlation with another asset or portfolio, while a weak hedge shows no correlation on average. The existence of a hedging effect of green bonds in an overall model (without checking each pair of variables separately) will be analyzed using DCC-MGARCH model. We will accept Hypothesis 1 if the DCC-MGARCH model reveals the significance of the hedging effect.

However, we expect different features and strength of the hedging effect and different determinants of green bond returns in the three markets considered. Therefore, we posed the hypothesis for each variable: stock market, bond market, oil price effect, gold price effect, gas price effect, economic policy uncertainty effect (EPU) and geopolitical risk index effect (GPR), as shown in Table 1.

Table 1. Expected determinants of green bonds and hedging effect for each factor on global, Russian and Chinese markets

	Global	China	Russia
H2: Stock market	No impact		
H3: Bond market	Positive impact		
H4: Oil	Negative impact	No impact	Positive mpact
H5: Gold	No impact		
H6: Gas	Positive impact		
H7: EPU	n/a	Negative impact	No impact
H8: GPR	Negative impact		

Hypothesis 2: *Stock market effect*

Since we expect green bonds to have a hedging role, there is also the hypothesis about the insignificant dependence between the stock market and green bonds. A similar hypothesis was tested in a research study by Reboredo and Ugolini (2022) [18]. One of the findings of their paper is that the green bonds are weakly connected with the stock and high-yield corporate bond markets. Similar results are concluded in the recent research by Jiang et el. (2022) [11].

One of the possible explanations is that stock market investors and green bond market investors have different goals. The goal of the former is to increase profitability, while the goal of the latter is to invest in the sustainable long-term development of companies. They want to receive returns from investing in green projects useful for the future. Accordingly, the behavior of these two groups of investors is weakly related to each other. In addition, it is different in times of crisis. After all, the people interested in the long-term progression towards a low-carbon economy will not change their behavior much in the event of economic or exogenous crises.

Hypothesis 3: *Conventional bonds effect*

Generally, green bonds are similar in most characteristics to standard bonds. The main difference is that the funds collected with their help are used to finance eco-friendly projects. Thus, prices of green bonds and conventional bonds move in the same direction. There is a negative premium in green bonds because investors accept a lower return due to the future benefits for the environment. However, in general, the direction of prices is the same and the influence is positive.

Hypothesis 4: *Oil price effect*

This conclusion was revealed in several recent studies, such as Reboredo and Ugolini (2020) and Elsayed et al. (2022) [18; 19]. In case of China, we assume this hypothesis because the Chinese economy doesn't crucially depend on the oil market and a significant share of green bonds are issued for energy-related projects. As for the global market, we presume a negative influence of oil prices. It can be explained by the following fact: when energy prices are low, investors will prefer to invest in them, while with expensive energy they will prefer green projects (Sohag et al., 2022) [20] For Russian market the hypothesis is the same as for the global market in terms of significance, since the Russian economy is strongly dependent on oil prices. However, we expect another direction of the determinant's impact: when oil prices are high, it is a positive signal for entire Russian financial market, including green bonds.

Hypothesis 5: *Gold price effect*

This hypothesis is based on the fact that gold is a robust and safe asset for many markets, especially during crisis periods. That is why we believe that gold will also be a hedging asset for green bonds.

Hypothesis 6: *Gas price effect*

Gas prices are rarely analyzed in existing literature in terms of their impact on the green bond market. However, we include this variable in the model since gas prices can be the cause of significant economic and political crises, and, moreover, it has an influence on the global economy overall. Therefore, we intend to test the linkages between gas prices and green bonds to reveal whether they are correlated, or green bonds can be a safe asset to use for hedging against gas price volatility.

We expect a positive impact of the gas price effect on green bonds for the Chinese market. That idea is based on the fact that one of five key projects in China financed by green bonds is related to the China-Russia East Route natural gas pipeline and focuses on energy efficiency. Taking this into consideration, as well as the fact that China is the world's top buyer of foreign gas, we expect that a decrease in gas prices will lead to a decrease in green bond returns. The same logic is applicable to Russia. The plans of the Russian government presented in St. Petersburg International Economic Forum includes further improvement of energy efficiency in the residential sector, heat supply systems, as well as the switch of public transport to gas, electricity, hybrid engines. (TASS, 2023) To this end, the government is starting to issue state-subsidized green bonds.

Hypothesis 7: *Economic policy uncertainty effect*

For the Chinese market, the argument for the hypothesis is as follows. Pham and Nguyen (2022) found that during times of high uncertainty, particularly at the beginning of the COVID-19 pandemic, financial and economic policy uncertainty had a significant impact on green bonds [21]. Zhang et al. (2021) noted that in 2016, Chinese government released guidelines for building a green financial system, including definitions, incentives, development goals, and risk monitoring measures [22]. Liu and Xiong (2022) discovered that as of the end of 2020, China had the world's second-largest stock of green bonds, valued at 813.2 billion yuan [23]. In summary, Pirtea et al. (2019) argue that external shocks to the economic policy uncertainty can worsen the decline in returns on green bonds, undermining corporate confidence in investing in green projects [24].

At the same time, for the Russian market we suggest no effect of EPU for green bonds returns. This idea is mainly based on the fact that the Russian market is only in the early stage of development, and the companies decide to issue this type of bonds to finance the specific non-scale projects which are not contingent on the economic policy changes

Hypothesis 8: *GPR index effect*

Geopolitical risks affect countries' development in the long-term period. Several recent studies have found that geopolitical risks can have a negative impact on asset prices, including in the green markets. This is due to frequent geopolitical shocks, such as terrorist attacks or military conflicts, which can lead to economic downturns and declining trade and global economic welfare. As a result, con-

sumers may postpone consumption and firms may postpone investments, leading to increased uncertainty in the overall economy. Ultimately, prolonged geopolitical turmoil and sluggish economic growth can result in a decline in equity returns. Therefore, we suggest negative influence of geopolitical uncertainty on green bonds returns.

Methodology

The main goal of this research is to reveal the determinants of the green bonds returns and the key features of the linkages between them, then based on the characteristics of the impact of the chosen explanatory factors we would make conclusions about the hedging effect of green bonds against those variables.

To achieve this goal, we implement two main approaches. The first is the development of the DCC – MGARCH model. The second one is building the VAR model and conducting cointegration and Granger causality tests based on the model. While the GARCH model allows to check whether there is hedging effect in terms of whole model, another gives the opportunity to reveal which chosen explanatory variables have significant impact on the green bonds returns and therefore to make conclusions about the hedging effect of green bonds index against those factors. However, at the same time both of the methods allow to make conclusion about the hedging effect of green bonds.

An important feature of our methodological approach is that we first implement the two above-mentioned methods for empirical analyses of the entire time period, and then we reveal breakpoint dates and conduct the empirical analyses for each subperiod. Iglesias-Casal et al. (2025) revealed that the hedging effects of green bonds can differ significantly during pre- and post-crisis periods [25]. Analyses of subperiods will be conducted for Chinese and global markets, however, the Russian case will be analyzed only based on the entire time series. This decision is justified by the early stage of development of the green bond market in Russia, which is why the number of bonds included in the index is limited. Moreover, the number of issued bonds changes throughout the period 2019 and 2020, and revealing the subperiods would give unreliable results sensitive to the issuance of each additional green bond. In other words, revealing subperiods would offer us several samples that can't be compared.

Data and Preliminary analysis

All variables for the markets were chosen with the same approach, which is described below. First, the green bond index was chosen as the dependent variable. For the Chinese market, we chose the SSE Green Corporate Bond Index as a dependent variable that is a proxy for green bond returns. This index included only corporate bonds, which allows us to eliminate the specific features of bonds issued by the government. For the global market, the S&P Green Bond Index is used as a dependent variable. For the Russian market we propose the construction of our own index due to its absence for the period under study . To construct the index we use information about effective daily returns of specific green bonds and then combining them into the index using the weights proportionally to the total volume of placed bonds. Table 2 below contains the references to literature that was the foundation for the variable choice.

The bond sample includes all corporate bonds issued in Russia in 2019–2022, the number of bonds is 11 with daily data provided, bringing the total number of observations in the index to 1213.

Table 2. Variable choice

Variable (Global)	Variable (China)	Variable (Russia)	Role	Literature foundation
S&P Global Green Bond Index	SSE China Corporate Green Bond Index	Green Bond Index	First difference in logarithms is proxy for Green Bonds return	Han et al. (2025) [26] Elsayed et al., (2022) [19]

As for the explanatory variable, we included the commodity market factors that are common for all three cases: oil, gold and natural gas indices (all calculated by Bloomberg) as well as uncertainty factors, such as economic policy uncertainty (EPU) or geopolitical risks (GPR). When geopolitical risk is high, it indicates lower investment, stock prices, and employment. Moreover, higher geopolitical risk is linked to a greater likelihood of economic disasters and larger downside risks to the global economy.

Preliminary preparation of the data is required because of the omitted values problem and the issue of asynchronous data. In this research, we observe the period from January 2017 to December 2022 for the Chinese and global market cases, and the period from July 2019 till December 2022 for the Russian market.

The choice of the time period is also based on the crisis dates since we want to reveal the differences in the determinants' impact on green bond returns during different crisis periods depending on the underlying cause of the crisis. The investigated time series include the following crises: China-US trade war in 2019-2020, COVID-19 pandemic in 2020, Russia-Ukraine conflict in 2022 (Table 3).

Also, we analyzed the subperiods for the Chinese and global markets since one of the research questions of this paper is whether green bonds can be effective as hedging financial instruments in crisis periods. In other words, we want to investigate how the determinants of green bond returns change before and after the crises. For defining the subperiods, the Bai-Perron test, as well as the analysis of significant economical and political events that affected the financial market, is implemented.

Table 3. Revealing the subperiods for the sample: crisis periods

Subperiod	China	Global
1	03/01/2017–05/07/2018	03.01.2017–30.05.2019
2	06/07/2018–16/12/2019	31.05.2019–19.06.2020
3	17/12/2019–30/01/2022	20.06.2020–18.01.2022
4	31/01/2022–09/12/2022	19.01.2022–09.12.2022

Empirical results

We conducted empirical research using two methods. Results demonstrate that these two approaches provide similar results.

1. **GARCH model**: overall hedging effect of green bonds was revealed.

The results show that our first hypothesis about the hedging effect of green bonds in all three markets against all considered types of factors is not rejected at 5% level (Appendix 1). This conclusion is made based on the results of the DCC-GARCH model that shows the existence of the hedging effect on the global, Russian and Chinese markets. DCC-MGARCH also showed that there is no dynamic constant conditional correlation over the time horizon in question, suggesting that the addition of green bonds to the portfolio can protect certain investments from economic policy shocks in Russia and China (according to the analysis).

2. **VECM model** and analysis of the determinants:

The revealed determinants for green bonds (variables with significant impact) are as follows:

- Global: gold prices (+), GPR (–), conventional bonds (+), common stocks (–)
- China: GPR index (–), EPU index (–), conventional bonds (+)
- Russia: oil prices (+), GPR index (–), EPU index (+)

The brief overall results of the empirical research are presented in Appendix 2 below.

The only explanatory variable that was revealed as a determinant for all three markets is the GPR index. Moreover, the direction of the influence was the same, the geopolitical risk and green bonds returns were negatively linked, therefore, it is concluded the increase in geopolitical uncertainty leads to a decrease in green bond returns. Such results show that the green bond market is vulnerable to geopolitical shocks in the long run and can't be used by investors to hedge this type of risks. Regarding country differences, we discovered that oil prices act as determinants for the green bond market only in Russia, which was expected because of the high overall dependency of the Russian economy on the oil market.

The short-term hedging effect was comparably stronger than the long-term effect because more variables were revealed as non-significant determinants. There were no short-term determinants revealed for the Chinese green bonds. The stock index has a significant short-term impact for predicting green bond returns for the global market, and for Russian market EPU, bonds and stock indices have a similar impact.

As a result, we can conclude that green bonds can be used as short-term hedging assets against the risks of the following factors:

1) Global: commodities (gas, oil and gold), geopolitical risk (GPR), economic policy uncertainties (EPU) and bond index
2) China: all explanatory variables (commodities, geopolitical risk (GPR) and economic policy uncertainties (EPU), stock and bonds indexes).
3) Russia: commodities and geopolitical risk (GPR).

We observe that green bonds can hedge geopolitical risks in all three cases in the short-run. Moreover, none of the commodities was a significant short-run determinant for green bonds in all three markets.

Now we proceed with the results for sub periods.

The results for the first and the second subperiods for the Chinese case coincides with the short-term results for the whole dataset: no variable is a determinant, therefore, green bonds are a strong hedging asset for all considered variables (Table 4). For the period 17/12/2019–30/01/2022, gold price has a significant impact on green bond returns, and for the last period (31/01/2022–09/12/2022), oil price and the S&P China Bond index are significant determinants with no hedging effect. The political and economic shock caused by the Russia–Ukraine conflict in 2022 led to oil price volatility. However, China was able to purchase oil from Russia at lower prices and consequently, the oil import increased, but at the same time such volatility led to an increased interest in alternative energy projects and a rise in the green bond index.

Overall, the weakest hedging effects of green bonds were observed during the last subperiod (both in the short and long run).

Table 4. The results of VECM model analyses for subperiods of the Chinese case

Subperiod	Date	Long-run determinants	Short-run determinants
1	03/01/2017–05/07/2018	EPU, GPR, S&P China Bond Index	None
2	06/07/2018–16/12/2019	EPU, GPR	None
3	17/12/2019–30/01/2022	EPU, GPR, S&P China Bond Index, SSE 100 Index	Gold prices
4	31/01/2022–09/12/2022	Gas prices, oil prices, EPU, GPR, S&P China Bond Index, SSE 100 Index	Oil prices, S&P China Bond Index

For the global market (Table 5), in the short run, the stock index was a significant determinant of the green bond index for each of the four revealed subperiods. It is an interesting result, because we previously noted that the stock market index was also revealed as a significant short-run factor for the whole period. Another important conclusion is that the GPR index was a determinant of green bonds in the first two subperiods, until June 2020. Hence, the hedging effect of green bonds for geopolitical risk is present only in the last year, after the COVID-19 pandemic and during one of the biggest political shocks of last years. Therefore, it can be inferred that during crisis periods caused by geopolitical reasons, green bonds can play the role of safe assets and hedge this type of risk.

For the global market there are also fewer variables against which green bonds can be used as a hedge asset in the long run. The results for the corporate Bond Index also coincided with the long-term results for the whole period since it has a significant influence on the green bonds' yield. Also, the GPR index was identified as a determinant of the green bonds' yields during the entire period and in each of the subperiods. This means that in the long run, green bonds also cannot be hedging assets for geopolitical risk in the global market.

Moreover, in comparison with the Chinese market, it is harder to use green bonds as a hedging asset.

Table 5. The results of VECM model analyses for subperiods of the global case

Subperiod	Date	Long-run determinants	Short-run determinants
1	03.01.2017–30.05.2019	Gas prices, MSCI Stock Price, GPR, S&P International Corporate Bond Index	MSCI Stock Price, GPR, Gold prices
2	31.05.2019–19.06.2020	All variables	MSCI Stock Price, GPR, Gold, Oil, S&P International Corporate Bond Index
3	20.06.2020–18.01.2022	Gold prices, GPR, S&P International Corporate Bond Index	MSCI Stock Price, Gold
4	19.01.2022–09.12.2022	GPR, oil prices, S&P International Corpo rate Bond Index	MSCI Stock Price

Finally, we compare the results that we obtained with the hypotheses. For the global market, the bond market, common stocks, gold and the GPR index are significant determinants in long-run, and a hedging effect is revealed only for oil prices. In the short run, the hedging effect is stronger: it was revealed for all variables except the common stock index. Thus, the variable for which the green bonds can be used as the hedging asset in both LR and SR is the oil prices. As for the hypotheses, all of them are rejected.

For the Chinese market, green bonds can be a strong hedging asset against all factors in short-run, while in long-run only oil prices and the stock market are insignificant for green bond returns. When we compare these results with prior hypotheses, we can conclude that Hypotheses 1 and 3 are confirmed, while all other hypotheses are only partially rejected since for other variables there are only long-term significant linkages.

For the Russian market, gas and gold prices are the variables for which the green bonds are a hedging asset in both short and long run. Thus, Hypothesis 5 about gold prices is confirmed, while Hypothesis 4 about gas prices is rejected. Hypothesis 7 about EPU is also rejected, because it was a significant determinant of green bond returns in both short and long run (therefore, no hedging effect). Common stocks and bonds have no significant impact on green bonds in the long run, but they are significant determinants in the short run, while for oil prices and the GPR index the results are contrary. That is why the hypotheses regarding these variables are rejected.

Conclusion

In this research, we analyzed the impact of various factors on green bond returns using two empirical methods: analyses of long- and short-term linkages between variables based on the VECM model and building the GARCH model. First, in the DCC-MGARCH model, green bonds act like a hedging asset on the global, Chinese and Russian markets, which proves that investors can use them to hedge their portfolios during economic crisis, policy uncertainties and other market fluctuations. In addition, hedging effects are visible on subperiods.

The VECM model broadens this idea and analyzes the determinants of green bonds and hedging effect for each factor. The GPR index is a long-term determinant of green bonds for all three markets, however, green bonds can hedge geopolitical risk in the short-term. Another important takeaway is that green bonds hedge the risks of commodity price volatility, again in short-term, in all three markets.

However, the hedging effect of green bonds also differs among the global, Russian and Chinese markets. In case of China, green bonds have a significant short-term hedging effect for all considered factors, while for the global green bonds, the short-term hedging effect is present for all variables except the common stock market index. Russian green bonds can be used for hedging against gold and gas prices both in the short- and long-run. These results show investors how to manage their portfolios more effectively by using green bonds as a hedge asset.

Finally, our study expands preceding literature regarding the existence of a hedging effect and the determinants of green bonds in the global and Chinese markets and covers the literature gap regarding the determinants of the Russian green bonds. Also, we constructed a green bond index for the Russian market, and it can be used by researchers in future papers.

We have identified some limitations in our study, which can be covered in further research. First, we only used a limited period of data to study the hedging effect in the Russian market. Since the early stage of development of Russian green bond market led to certain study limitations, further research can conduct an analyses of the Russian market later, at a more mature stage. Additional research is required in the future if the Russian financial market continues to move towards sustainable growth and green financing. Secondly, we have analyzed macro parameters as the determinants of green bonds, and in our subsequent research we intend to broaden the analysis of determinants a on micro-level by using bond characteristics as explanatory variables. Thirdly, further research could focus on other emerging countries (e.g., India) to examine the impact of such contextual factors on the green bond markets.

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Appendices

Appendix 1. The results of DCC-MGARCH models

	GB Index	Russia EPU	China EPU	GB Index	SP International Corporate Bond	GPR Global
Const	4.921 **	5.105 **	4.197 **	4.935 **	4.885 **	4.227 **
ARCH	0.994 **	0.915 **	0.344 **	1.190 **	1.191 **	0.394 **
C1	0.187 **			0.250 **		
C2	0.763 **			0.701 **		
Wald	140.000.0 **			140.000.0 **		

*** - significant at 1% significance level, ** - significant at 5% significance level,

* - significant at 10% significance level.

Appendix 2. Generalized table on the influence of independent variables on the yield of green bonds

Variable	Result (Global market)	Result (Chinese market)	Result (Russian market)
Long-term linkages (cointegration)			
Whole period			
Gas prices	n/a	n/a	No significant impact -> hedging effect exists
Gold prices	Significant positive impact	n/a	No significant impact -> hedging effect exists
Oil prices	No significant impact -> hedging effect exists	No significant impact -> hedging effect exists	Significant positive impact
GPR	Significant negative impact	Significant negative impact	Significant negative impact
EPU (VIX for Russia)	n/a	Significant negative impact	Significant positive impact
Conventional bond index	Significant positive impact	Significant positive impact	No significant impact -> hedging effect exists
Common stock index	Significant negative impact	No significant impact -> hedging effect exists	No significant impact -> hedging effect exists
Short-term linkages (Granger causality)			
Whole period			
Gas prices	No significant impact -> hedging effect exists	No significant impact -> hedging effect exists	No significant impact -> hedging effect exists
Gold prices			
Oil prices			
GPR			
EPU			Significant impact
Conventional bond index			Significant impact
Common stock index	Significant impact		Significant impact

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The Impact of ESG Efficiency on the Cost of Equity Capital: Evidence from China

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Abstract

This paper presents an empirical analysis of the correlation between ESG performance and cost of equity capital of listed companies in mainland China and Hong Kong from 2018 to 2022. The final empirical results of the study show that there is a negative correlation between ESG performance and cost of equity capital in China. The study also finds that, among the three dimensions of ESG, the social dimension has the most significant impact on Chinese listed companies. The geographical location and property rights of companies also have an impact on the relationship between the two variables. Compared to companies in Hong Kong, the improvement in environmental, social, and corporate governance performance of mainland Chinese companies has a more pronounced effect on reducing the cost of equity capital. Similarly, compared to state-owned enterprises, the improvement in environmental, social, and corporate governance performance of non-state-owned enterprises has a more significant impact on reducing the cost of equity capital. These findings highlight the importance of incorporating ESG factors into business practices for the long-term success and sustainable growth of China's capital markets.

Keywords: ESG, cost of equity, Hong Kong, Mainland China, ownership structure

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Introduction

In 2006, the United Nations Environment Programme introduced the ESG (Environmental, Social, and Governance) principles, providing investors with a new framework for decision-making. That same year, Goldman Sachs published a comprehensive ESG report that systematically integrated the three core dimensions, effectively formalising the modern conception of ESG. Over time, ESG assessment has become a critical metric for evaluating a company's value and long-term prospects. Investors and stakeholders now routinely prioritise ESG performance, with ESG ratings playing a pivotal role in investment decisions.

In China, as one of the world's largest carbon dioxide emitters, significant environmental initiatives have been undertaken since 2020, with a national commitment to achieve carbon neutrality by 2060. These government-led efforts have spurred the adoption and implementation of ESG principles across Chinese enterprises. Although China entered the ESG investment sphere later than many developed economies, it has made remarkable strides in recent years through coordinated actions by the central government, stock exchanges, and listed companies. A major milestone came in 2022 with the release of two key regulatory documents: the Guidelines for Enterprise ESG Information Disclosure and the ESG Evaluation Agency Service Specification. These instruments have advanced China's ESG standardisation framework, establishing a systematic regulatory structure for ESG evaluation agencies, enhancing oversight of corporate behaviour, and providing clearer guidance for investment activities. Consequently, ESG investing has grown substantially in China.

Academically, interest in the relationship between ESG performance and corporate outcomes has intensified, particularly regarding the cost of equity capital – a central concern in corporate finance and investment strategy. However, research on the link between ESG factors and the cost of equity in China remains sparse, highlighting a need for further investigation. Most prior studies have concentrated on developed markets such as the US and Europe, yielding inconsistent results. For instance, a meta-analysis by Friede et al. [1] of over 2 000 studies found a positive correlation between ESG performance and financial outcomes. Similarly, Alareeni and Hamdan [2] observed that higher ESG ratings among S&P 500 companies were associated with improved returns on assets and equity, as well as higher Tobin's Q values. Conversely, Hillman and Keim [3] identified a negative relationship between social responsibility initiatives and market value in S&P 500 firms, while Brammer et al. [4] reported comparable negative associations for UK companies.

Several notable limitations characterise existing research on China's ESG landscape. First, China's unique institutional and regulatory environment may render findings from Western markets inapplicable. Second, most studies on the Chinese market exclude Hong Kong, despite its distinct historical trajectory, political framework, and economic structure. Given China's "one country, two systems" policy, Hong Kong often develops independently from mainland China, potentially leading to different dynamics in the relationship between ESG factors and the cost of equity. Third, Chinese scholars continue to debate about the influence of company ownership nature, yet comparative analyses rarely incorporate Hong Kong data, leaving a significant gap in understanding.

All in all, the study seeks to address these research gaps by conducting a comparative analysis of mainland Chinese and Hong Kong firms, aiming to clarify the unique role of ESG in China's dual-system market. By examining both regions, our research intends to provide actionable guidance for companies and investors, enhance the reliability and applicability of ESG research in China, and reveal how ESG performance operates within the country's distinctive context. Ultimately, the investigation contributes to both academic discourse and practical decision-making in ESG investing within China's evolving market landscape.

Literature Review

Western scholars were the first to engage in ESG performance research, progressing from basic descriptive studies to investigating the economic consequences of ESG performance and developing a relatively mature research system and methods. In contrast, ESG-related research in China is still in need of improvement. Overall, scholars' research perspectives vary significantly, leading to diverse conclusions. However, the theoretical mechanisms and empirical approaches used in their studies are of great reference value for this article.

Environmental performance is an important component of a firm's ESG performance. According to research conducted by Bui et al. [5] across 34 countries globally, firms with better environmental performance typically have lower costs of equity capital, and the intensity of greenhouse gas emissions is positively correlated with the cost of equity financing. Elmawazini et al. [6] observed that the use of green innovation to reduce the cost of equity capital is supported in the United States, while Hmiden et al. [7] found that when US firms are positioned away from the "toxic" ("green") industry's widely adopted worst (best) practices, their cost of equity financing is lower (higher). This highlights the dual importance of environmental corporate social responsibility practices in improving financial performance and reducing the cost of capital.

Regarding social responsibility, the research results are mixed. Wang et al. [8] found that in North America, Europe, and Africa, companies with higher social responsibility scores have lower costs of equity capital, but this result does not hold in Asian countries. This conclusion differs from the research of Matthiesen and Salzmann [9], who found that in countries with higher levels of collectivism, the relationship between corporate social responsibility and the cost of equity is stronger. Chen et al. [10], however, focused on the emerging market context and further showed that firm-level corporate governance has a signif-

icant negative impact on the cost of equity capital in these markets, an effect that is more pronounced in countries with relatively poorer legal protection.

At the governance level, Gupta et al. [11] explored the combined effect of financial development and legal institutions on the impact of firm-level governance on the cost of equity capital, finding that firm-level governance attributes primarily affect the cost of equity capital in common law countries with higher levels of financial development. Jang et al.'s [12] research in Korea showed that firms with stronger managerial capabilities tend to have lower equity costs, especially in situations of higher information asymmetry, lower institutional ownership, and higher capital intensity.

Beyond the separate assessment of these three dimensions, multiple studies have found that companies with higher overall ESG scores typically have lower costs of equity capital [13; 14]. This environmental, social, and governance performance effect has both a direct influence and an indirect effect (through reduced market risk and enhanced equity diversification) on lowering the cost of equity.

Existing research on the three dimensions of ESG and the cost of equity capital (COE) in the Chinese market is limited. While the environmental and governance aspects have relatively fewer available studies, the social responsibility dimension has benefited from the earlier establishment of CSR reporting practices in China, resulting in more related literature analysis.

Regarding environmental performance, Zhu's [15] empirical study found that in the Chinese market, environmental performance does not have a significant impact on firms' cost of equity capital, and the environmental performance of heavily polluting industries is also not significantly correlated with the cost of equity. In the area of corporate governance, scholars have showed that regulatory enforcement actions increase the cost of equity for companies [16]. However, government-controlled shareholders can mitigate the effect of these enforcement actions on the cost of capital. Additionally, Li et al. [17] found that in the global market, including China, board reforms lead to a significant increase in the cost of equity, although this effect is somewhat alleviated in emerging markets.

In terms of social responsibility, the research results for the Chinese market show some differences. Xu et al. [18] found that in China, the higher the social responsibility score of a company, the lower its cost of equity capital and that state-owned enterprises exhibit better corporate social responsibility and also have lower costs of equity. However, Yeh et al.'s [19] research revealed that the fulfilment of corporate social responsibility rapidly reduces the debt capital cost of Chinese firms without significantly lowering the cost of equity capital compared to developed countries.

When considering overall ESG performance, the Chinese market shows the same results as the international market (Table 1). Both Tang [20] and Chen et al. [10] reported a negative impact of ESG performance on the cost of equity capital (COE). Chen et al. [10] further found a mediating effect, indicating that ESG performance reduces the cost of equity capital both directly and indirectly (by lowering market risk and increasing equity diversification).

Table 1. ESG Performance and Cost of Equity Capital: A Research Overview

Dimension	International	China
E	Better environmental performance linked to lower cost of equity [5] Green innovation can reduce cost of equity [6] Distancing from "green" practices increases cost of equity [7]	Environmental performance does not significantly impact cost of equity [15]
S	Higher social responsibility associated with lower cost of equity in some regions, but not Asia [8] Stronger CSR–cost of equity link in more collectivist countries [9] Firm governance negatively impacts cost of equity, esp. in weaker legal protection [10]	Higher social responsibility linked to lower cost of equity [18] State-owned firms in China have better CSR and lower equity costs [18] CSR fulfilment reduces debt cost, but not equity cost vs. developed markets [19]
G	Firm governance affects cost of equity more in common law countries with higher financial development [10] Stronger managerial capabilities linked to lower equity costs in certain contexts [12]	Regulatory enforcement actions increase cost of equity, although government-controlled shareholders can mitigate this effect [16] Board reforms lead to higher cost of equity, less so in emerging markets [17]
ESG	Higher ESG scores typically linked to lower cost of equity [13; 14]	Higher ESG scores typically linked to lower cost of equity [20]

The existing literature on the relationship between environmental, social, and governance (ESG) performance and the cost of equity capital remains relatively limited within the Chinese market context. The majority of prior studies focus on examining the association between individual ESG dimensions or the overall ESG score and capital costs, while research that comprehensively considers the interactions between the various ESG facets and the cost of capital is scarce.

Notably, the existing literature primarily concentrates on the mainland Chinese market, with a dearth of empirical analyses covering the Hong Kong region of China. This oversight may have overlooked the potential impact of regional differences on the aforementioned relationships.

This study situates itself within a broader scholarly discourse on the relationship between ESG performance and the cost of equity capital (COE), acknowledging that while international research has advanced to a relatively mature stage – revealing nuanced and sometimes contradictory findings across environmental, social, and governance dimensions – China-specific inquiries remain underdeveloped. Although global evidence often points to a negative association between comprehensive ESG performance and COE (via direct effects and risk-mediated pathways), results vary by context: environmental performance tends to lower COE in many markets, social responsibility effects depend on cultural and regional factors, while governance impacts are shaped by legal and financial systems. In China, empirical results are mixed and fragmented: environmental performance shows limited influence on COE, governance effects are moderated by regulatory actions and state ownership, and social responsibility yields inconsistent outcomes across firm types. Nevertheless, studies of overall ESG performance in China largely align with international trends, indicating a negative impact on COE both directly and indirectly (through reduced market risk and enhanced equity diversification). This underscores the need for further integrated, context-sensitive research to clarify the mechanisms through which ESG dimensions influence COE in the Chinese market.

Therefore, the present study aims to address two aspects:

1. Examine the relationships between the three individual ESG dimensions (environmental, social, and governance) as well as the overall ESG performance and the cost of equity capital.
2. Conduct a comparative analysis of the ESG performance–cost of capital linkages between the mainland Chinese and Hong Kong markets, and compare the findings with international research results.

Methodology

To examine the impact of ESG performance on the cost of equity for firms in China, this section develops a rigorous empirical framework for hypothesis testing. The study adopts a quantitative research design, employing the ordinary least squares (OLS) regression as the primary analytical technique to estimate the baseline relationship between ESG performance and the cost of equity.

Subsequently, the analysis proceeds with stratified regression models, segmenting the sample according to two key dimensions: 1) geographic region (mainland China vs. Hong Kong) and 2) ownership structure (state-owned enterprises vs. private firms). This stratification allows for a nuanced assessment of how regional and institutional contexts moderate the ESG–cost-of-equity nexus. The stratification approach is informed by the methodology of Li et al. [17], who applied a similar grouping strategy to investigate the relationship between ESG performance and green innovation spillovers. By adapting this method, the present study enhances comparability across subsamples and reveals potential heterogeneity in the effect of ESG factors on the cost of equity across different types of Chinese firms.

Theory and hypotheses

Despite growing global attention to environmental, social, and governance (ESG) factors in corporate finance, the relationship between ESG performance and the cost of equity capital remains underexplored in the Chinese context. This lacuna raises critical questions regarding the mechanisms through which ESG practices influence firms' cost of capital in China – a market characterised by distinctive institutional features, including a prominent role of state institutions and a unique regulatory framework.

While existing literature has extensively examined the ESG–COE (cost of equity) linkage in developed economies (notably the United States and Europe), findings from these markets cannot be readily generalised to China. Geographic limitations in prior research have precluded analysis of how China's institutional environment shapes this relationship. Although recent contributions by Chen et al. [10] and Kong [24] have begun to address this gap, the field still lacks a comprehensive understanding of the ESG–cost of equity dynamic in China, necessitating further empirical inquiry.

From the perspective of signalling theory, firms' ESG activities function as strategic signals that convey information about their operational priorities and long-term sustainability commitments. Enhanced ESG performance can generate positive market signals, foster a favourable corporate reputation, and consequently attract a broader investor base – ultimately reducing the cost of equity financing [7].

A review of the literature reveals consistent evidence that ESG performance exerts a significant negative effect on the cost of equity capital for Chinese firms. This pattern has been documented across multiple studies, including Mio et al. [13], Ng and Rezaee, Tang [14], Chen et al. [10]. Building on this empirical foundation, the study posits:

Hypothesis 1 (H1). ESG performance has a significant negative impact on the cost of equity capital for Chinese firms.

Although Arrigo [21] identified the environmental dimension as having the strongest negative correlation with capital cost in China (followed by governance, with the social dimension showing statistically insignificant effects), the

present study advances an alternative perspective grounded in stakeholder theory. This framework emphasises that ESG practices reflect a firm's commitment to balancing the interests of diverse stakeholders through environmental stewardship, social responsibility, and robust governance.

Notably, strong corporate governance mechanisms have been empirically linked to reduced equity costs [22; 23]. By fostering a favourable stakeholder environment, enhancing market attractiveness, and facilitating access to external resources, ESG investments can alleviate financing constraints and lower the cost of equity [24]. Consequently, the study proposes:

Hypothesis 2 (H2). Among the three ESG dimensions (environmental, social, and governance), corporate governance has the greatest impact on the cost of equity capital for firms.

Prior research on China's ESG landscape has exhibited notable limitations in heterogeneity analysis, particularly concerning the relationship between ESG and the cost of equity. Most studies focus exclusively on mainland China, often subdividing it into central, eastern, and western regions [25], while neglecting Hong Kong, creating a significant research gap. Given the substantial political, economic, and social differences between mainland China and Hong Kong, these contextual variations may meaningfully influence the ESG–cost of equity relationship. This leads to:

Hypothesis 3 (H3). The impact of ESG on the cost of equity capital differs in mainland China and Hong Kong.

Furthermore, ownership structure constitutes a pivotal dimension in understanding China's economic dynamics. State-owned enterprises (SOEs) often align their ESG practices with policy mandates rather than voluntary initiatives, potentially limiting positive investor responses. In contrast, non-SOEs face distinct incentives and constraints in ESG implementation. Empirical evidence from Chen et al. [26] and Xu et al. [18] confirms differential motivations and outcomes in ESG practices between SOEs and non-SOEs. Accordingly, the study posits:

Hypothesis 4 (H4). The impact of ESG on the cost of equity capital varies between SOEs and non-SOEs.

Sample selection and data sources

Considering the availability of ESG performance data, the study selects listed companies in various industries in China as the sample from 2018 to 2022 to investigate the relationship between ESG efficiency and the cost of equity capital. The sample data are obtained from the Wind Financial Terminal database and processed as follows: (1) companies listed on multiple stock exchanges simultaneously are excluded; (2) cases with missing data for the variables are excluded; and (3) cases with a negative cost of equity capital are excluded based on the prediction requirements of the PEG model for equity capital. Additionally, to mitigate the effect of outliers, all continuous variables undergo tail trimming at 1% and 99%, resulting in a final sample size of 5,670 observations. For further heterogeneity analysis, the cases are categorized based on the geographic region of the firms and their ownership structure. The resulting sample contains 5,435 observations from mainland firms and 235 observations from Hong Kong firms. Furthermore, it has 2,430 observations from state-owned firms and 3,240 observations from non-state-owned firms.

Variable Description

Dependent variable

This paper focuses on the impact of ESG on firms' cost of equity capital, with the cost of equity capital serving as the explanatory variable, specifically referring to the cost of the firms' own equity capital.

Echterling et al. [27] conducted a review of various measures of the cost of equity capital developed over the years and synthesized findings from a wide range of scholars. The general research approach is categorized into two main groups: one is based on estimating the market risk premium (ex-post cost of equity capital approach), which primarily includes the Capital Asset Pricing Model (CAPM) and the Three-Factor Model (FFM). The other approach involves estimating asset prices by discounting the expected future rate of return to present value (ex-ante cost of equity capital approach), which encompasses the Dividend Discount Model (DDM) and the Discounted Residual Returns Model (GLS).

However, these models may not be entirely suitable for the Chinese market. Xu et al. [18] discovered that the PEG model aligns better with the Chinese national market environment compared to traditional cost of equity capital measurement studies. Consequently, drawing from Easton's [28] research, this paper adopts the PEG model to assess the cost of equity capital, which better reflects Chinese market practices. The model is grounded in the principle of residual income, where the price–earnings ratio is divided by the short-term earnings growth rate, assuming a zero long-term growth rate and implementation of a zero-dividend policy. The specific calculations are outlined below:

$$r_e = \sqrt{(eps_2 - eps_1) / P_{0,}}$$

where P_0 represents the closing price of the stock in the current period, and eps_1 and eps_2 stand for analyst-predicted EPS for the next two years. The calculation of the PEG model hinges on analysts' forecasted earnings per share (EPS). The year-end closing price data and analysts' EPS predictions utilized in this study are sourced from the Wind Financial Terminal database.

Independent variables

The explanatory variables in this paper consist of ESG scores, composite scores, and individual scores across three dimensions. Over the years, mature ESG evaluation systems have been established both in China and abroad. Since this paper focuses on the Chinese market, foreign rating agencies' systems are not entirely suitable for China's current capital market. As a result, this paper opts to utilize data from the Wind system, a highly authoritative independent ESG rating agency in China, for conducting the empirical study.

Table 2. Wind ESG indicators

Level 1 indicators	Level 2 indicators (27)	Level 3 indicators (300+)
E	Environmental Management	• Environmental Management Systems and Institutions
	Energy and Climate Change	• Energy Management Systems and Institutions
	Water Resources	• Scope 1, 2, 3 Greenhouse Gas Emissions
	Raw Materials and Waste	• Water Conservation Measures
	Air Emissions	• ...
	Wastewater	
	Biodiversity	
	Green Buildings	
	Green Finance	
S	Employment	• Employee Turnover Rate
	Occupational Health and Safety	• Average Training Hours per Employee
	Development and Training	• Intellectual Property Protection Community Welfare Contributions
	Research and Development	• ...
	Supply Chain	
	Product Quality	
	Sustainable Products	
	Customers	
	Privacy Protection	
	Community	
	Medical Accessibility	
G	ESG Governance	• ESG Performance Linked to Executive Compensation
	Board and Senior Management	• Turnover Rate of Board and Senior Management
	Equity and Shareholders	• Proportion of Independent Directors
	Auditing	• Whistleblowing Mechanism
	Business Continuity Management	• ...
	Corruption and Bribery	
	Antitrust and Fair Competition	

As shown in Table 2, the Wind ESG rating system comprises a three-tier indicator framework: the first-tier indicators encompass the three major themes of environment, social responsibility, and corporate governance; the second-tier indicators consist of 27 categorized topics under these three major themes, such as wastewater, raw materials, and air emissions; the third-tier indicators represent specific ESG metrics derived from over 300 data points, including water conservation measures, energy management systems, and protocols, among others, as detailed in Table 2. In addition to the overall ESG composite score, each company also receives individual environmental, social, and governance scores. The scores for the three dimensions are calculated proportionally to determine the ESG total score. The weights of environmental, social, and governance aspects within the ESG composite score vary by industry. Scores range from 0 to 10, with 0 representing the lowest performance and 10 representing the highest performance.

Control variables

This paper follows common practices in the research field by incorporating control variables into the regression model to account for other identified influences. Building upon the main factors influencing the cost of equity capital outlined earlier in the paper and drawing on empirical studies by Tang [20] in the field, this study includes indicators such as Return on Assets (ROA), Return on Equity (ROE), Total Asset Turnover Ratio (TR), Debt Ratio (DR), and Growth Rate (g) as control variables. In addition, time dummy variables (Year) and industry dummy variables (Ind) are employed to control for time effects and industry effects, respectively. Industry dummy variables are used to account for industry differences, while time dummy variables are used to consider period variations. Furthermore, to facilitate subsequent heterogeneity analysis, region (Region) and ownership structure (SOE) are chosen as grouping variables. Specific variable definitions are provided in Table 3.

Table 3. Variables

Variable type	Variable name	Variable symbol	Variable definition
Dependent variable	Cost of Equity	COE	Derived from the PEG model
Independent variables	ESG score	ESG	Wind ESG rating score
	E score	E	Wind Environmental score
	S score	S	Wind Social score
	G score	G	Wind Government score
Control variables	Return on Assets	ROA	Net Income to Total Assets
	Return on Equity	ROE	Net Income to Shareholder Equity
	Total Asset Turnover Ratio	TR	Total Sales to Average Total Assets
	Debt Ratio	DR	Total Debt to Total Assets
	Growth Rate	g	Year-on-Year Growth Rate of Operating Income
	Time	Year	Time dummy variable
	Industry	Ind	Industry dummy variable
Grouping variables	Region	Region	1 for Hong Kong enterprises, 0 for mainland enterprises
	Ownership Structure	SOE	1 for state-owned enterprises, 0 for non-state-owned enterprises

Model Specification

To test Hypothesis 1, empirical Model (1) is developed:

$$COE_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 Controls_{i,t} + \varepsilon_{i,t.}$$

To test Hypothesis 2, empirical Model (2) is developed:

$$COE_{i,t} = \beta_0 + \beta_1 E_{i,t} + \beta_2 S_{i,t} + \beta_3 G_{i,t} + \beta_4 Controls_{i,t} + \varepsilon_{i,t},$$

where β_0 is the constant term, β_i is the regression coefficient of the explanatory variables and each control variable, and $\varepsilon_{i,t}$ is the random error term. Meanwhile, in order to explore the variability of the impact of ESG performance on the cost of equity capital under different locations, this paper also classifies the research samples and conducts group testing on the basis of Model (1) for checking Hypotheses 3 and 4.

Empirical Results and Discussion

Summary statistics

Table 4 presents the results of the descriptive analysis of the variables. As shown in Table 6, the maximum value of the Cost of Equity (COE) is 0.131, the minimum value is 0.000181, and the standard deviation is 0.0214, indicating a relatively small difference in the Cost of Equity among the target companies and a narrow range of variation. The mean value of ESG is 6.255, suggesting room for improvement, with a standard deviation of 0.809, indicating significant variation in ESG performance among the sampled companies. Similar situations are observed for individual ESG scores, especially with the lowest mean score in the

Table 4. Summary statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
COE	5.670	0.0143	0.0214	0.000181	0.131
ESG	5.670	6.255	0.809	4.590	8.530
E	5.670	2.822	2.113	0.180	9.620
S	5.670	4.402	1.801	0.680	9
G	5.670	6.623	0.930	4.190	9.110
ROA	5.670	6.469	6.149	-11.37	27.13
ROE	5.670	9.226	9.850	-26.33	42.03
TR	5670	0.669	0.401	0.0348	2.362
DR	5.670	45.77	18.51	8.652	91.82
G	5.670	14.29	25.28	-42.29	123.1

Environmental (E) component, indicating substantial data volatility and significant differences in ESG practices among the target companies, with an overall low level.

In terms of control variables, the standard deviations of Return on Assets (ROA) and Return on Equity (ROE) are 6.149 and 9.850, respectively, pointing to significant differences in the profitability of the selected sample companies. The mean value of Total Asset Turnover Ratio (TR) is 66.9%, indicating that the majority of companies have high operating efficiency and can create value more effectively by utilizing assets. The maximum value of Debt Ratio (DR) is 91.82%, the minimum value is 8.652%, and the difference between the two values indicates significant differences in the debt structure and business risk among different companies. The maximum value of Growth (g) is 123.1, and the minimum value is negative, suggesting that some companies are experiencing rapid growth while others are experiencing a decline in business performance.

Correlation matrix and VIF

In this section, the relationship between variables is preliminarily examined through correlation analysis, with the test results presented in Table 5.

As Table 5 shows, the regression coefficient of the ESG score and the cost of equity capital for listed companies is equal to –0.056 and passes the 1% significance test. This indicates a significant negative correlation between the two, suggesting that companies can achieve a reduction in the cost of equity by enhancing their ESG performance. In terms of control variables, the Return on Assets (ROA), Return on Equity (ROE), and Growth (g) have a significantly negative impact on the cost of equity capital, while the Debt Ratio (DR) also has a significantly negative impact on the cost of equity capital. The above correlation analysis results indicate the practical significance of the empirical analysis in this study.

Table 5. Correlation matrix with ESG

	COE	ESG	ROA	ROE	TR	DR	g
COE	1						
ESG	–0.056***	1					
ROA	–0.160***	0.0150	1				
ROE	–0.149***	0.035***	0.885***	1			
TR	–0.0100	0.00700	0.226***	0.232***	1		
DR	0.210***	–0.00700	–0.387***	–0.126***	0.040***	1	
G	–0.069***	0.00700	0.307***	0.336***	0.158***	0.037***	1

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 6. VIF for variables

Variable	VIF	Tolerance, 1/VIF	Variable	VIF	Tolerance, 1/VIF
ESG	1.00	0.996977	E	1.24	0.805323
			S	1.21	0.828377
			G	1.12	0.891472
ROA	7.30	0.137002	ROA	7.33	0.136517
ROE	6.22	0.160892	ROE	6.23	0.160538
TR	1.08	0.925017	TR	1.08	0.923719
DR	1.62	0.616341	DR	1.65	0.607264
G	1.15	0.868668	g	1.16	0.864452
Mean VIF	3.06		Mean VIF	2.63	

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

In order to ensure the reliability and accuracy of the empirical results, this study further conducted a multicollinearity test on the empirical model using variance inflation factors (VIF), with the test results shown in Table 6. It can be observed that the maximum VIF of the model is 7.33, and all variables have VIF values below the critical threshold of 10, with average values not exceeding 3.1. Therefore, the empirical model constructed in this study does not exhibit multicollinearity.

Regression results and discussion

The regression results in Table 7 provide partial support for the study's hypotheses. Model (1) confirms Hypothesis 1: the aggregate ESG score exhibits a negative coefficient (–0.0007, $p < 0.10$), indicating that higher overall ESG performance is associated with a lower cost of equity capital (COE), albeit at the marginal 10% significance level. This aligns with the theoretical expectation that strong ESG performance signals reduced risk and enhances investor confidence, thereby lowering financing costs.

However, Model (2), which disaggregates the three ESG dimensions, yields a more nuanced picture regarding Hypothesis 2 (which posits governance as the most influential dimension). Contrary to this prediction, the governance (G) component shows a small, statistically insignificant coefficient (–0.0002, $p > 0.10$). Instead, the social (S) dimension emerges as the strongest predictor, with a large and highly significant negative effect (–0.0008, $p < 0.01$), while the environmental (E) dimension displays a positive and significant coefficient (0.0006, $p < 0.01$), suggesting that higher environmental performance is linked to a higher COE in this sample.

This result supports findings by Fedorova et al. [29] that underscore a notable shift in investor behaviour during 2021–2022, when social ESG factors began to exert a stronger influence on the investment appeal of Chinese firms. By employing panel regression analysis alongside

Table 7. Regression Results for Hypotheses 1 and 2

VARIABLES	(1) COE	(2) COE
ESG	–0.0007*	
	(–1.85)	
E		0.0006***
		(4.14)
S		–0.0008***
		(–4.70)
G		–0.0002
		(–0.53)
ROA	0.0005***	0.0005***
	(3.05)	(3.04)
ROE	–0.0005***	–0.0005***
	(–4.88)	(–4.92)
TR	–0.0006	–0.0007
	(–0.82)	(–0.92)
DR	0.0003***	0.0003***
	(10.50)	(10.01)
Growth (g)	–0.0000***	–0.0000**
	(–2.81)	(–2.50)
_cons	0.0060*	0.0051*
	(1.94)	(1.91)
Year effect	Yes	Yes
Industry effect	Yes	Yes
Observations	5.670	5,670
R-squared	0.113	0.118

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

textual assessment of corporate disclosures, Fedorova et al. [29] demonstrate that enhanced transparency in social performance metrics, such as labour practices, community engagement, and employee welfare, serve as credible signals that shape investor perceptions and decision-making.

This empirical confirmation of the heightened relevance of social factors lends further credence to signalling theory, suggesting that firms' transparent communication of social initiatives meaningfully influences market perceptions, ultimately contributing to lower equity financing costs. Meanwhile, the unexpected positive association between environmental performance (E) and COE underscores the complexity of ESG dynamics in the Chinese context, warranting deeper inquiry into the mechanisms through which different ESG pillars affect firm valuation.

When examining the three ESG dimensions (environment, social, and governance) separately, Model (2) regression results reveal a nuanced and somewhat counterintuitive pattern. Environmental factors exhibit a statistically significant positive coefficient (0.0006, $p < 0.01$), implying that higher environmental performance is associated with a higher cost of equity capital – a finding that runs counter to conventional expectations, although the value of this coefficient is very small. In contrast, the social dimension displays a strong negative and highly significant effect (−0.0008, $p < 0.01$), indicating that improved social performance meaningfully reduces firms' cost of equity. The governance dimension, while also negative (−0.0002), lacks statistical significance ($p > 0.10$), suggesting it does not exert a discernible influence on the cost of equity in this sample.

These results directly challenge Hypothesis 2, which posits governance as the most impactful ESG dimension. Instead, the data underscore the predominant role of social factors in lowering the cost of equity, thereby corroborating the theoretical insights from Fedorova et al. [29] on the growing importance of social signals in the Chinese market. While the findings diverge from Kong [24] and Ramirez et al. [22], who emphasised governance effects, and also contrast with Wang et al. [16]'s observation of weaker social-COE linkages in Asian markets, they align closely with Xu et al. [18]'s evidence of a negative CSR–COE relationship in China. Moreover, the strong social effect resonates with Matthiesen and Salzmann [9], who argued that in collectivist societies, corporate social responsibility carries greater weight in investor valuations.

Table 8. Regression Results for Hypothesis 3

	(1) Hong Kong	(2) Mainland
ESG	0.0014 (0.43)	−0.0014*** (−3.69)
ROA	0.0014 (1.20)	0.0003* (1.86)
ROE	−0.0026*** (−4.40)	−0.0004*** (−3.48)
TR	0.0114** (2.12)	−0.0006 (−0.85)
DR	−0.0000 (−0.17)	0.0002*** (10.24)
Growth (g)	0.0000 (0.38)	−0.0000** (−2.45)
_cons	0.0104 (0.43)	0.0117*** (3.96)
Year effect	Yes	Yes
Industry effect	Yes	Yes
Observations R-squared	235 0.398	5435 0.108

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

To probe deeper into contextual heterogeneity, the study proceeds with sub-sample regressions, stratifying the data by geographical region and ownership structure. The following section presents the results of this heterogeneity analysis, shedding light on how regional and institutional factors moderate the ESG–cost of equity relationship in the Chinese market.

The regional heterogeneity analysis, presented in Table 8, examines how the relationship between ESG performance and the cost of equity capital (COE) varies between Hong Kong and mainland China. The sample is stratified by geographic location, with Regression (1) covering Hong Kong firms (N = 235) and Regression (2) focusing on mainland Chinese enterprises (N = 5435). Key findings reveal a striking divergence between the two regions. For Hong Kong listed companies, the ESG coefficient is positive (0.0014) but statistically insignificant (t = 0.43), indicating no discernible effect of ESG performance on COE in this subsample. In contrast, mainland Chinese firms exhibit a strong negative and highly significant relationship: the ESG coefficient stands at −0.0014 ($p < 0.01$; t = −3.69), suggesting that improved ESG performance meaningfully reduces the cost of equity capital.

This pronounced regional disparity supports Hypothesis 3: the impact of ESG on COE differs significantly between mainland China and Hong Kong. Several factors may explain this divergence such as distinct regulatory environments (mainland China's stronger policy push for

ESG adoption as Hong Kong is using a market-driven approach), differences in investor expectations and market maturity or varying degrees of state influence on corporate behaviour in the mainland.

The control variables further illuminate regional nuances:

- ROE shows a robust negative effect in both subsamples, consistent with profitability reducing financing costs;
- DR (debt ratio) is highly significant ($p < 0.01$) in the mainland model but insignificant in Hong Kong, reflecting different capital structure dynamics;
- TR (total revenue) is significant only in Hong Kong ($p < 0.05$), possibly capturing scale effects in a smaller, more concentrated market.

Notably, the model fit differs substantially: the Hong Kong regression explains 39.8% of the variance ($R^2 = 0.398$), while the mainland model has a lower R^2 (0.108), likely due to greater heterogeneity in the larger mainland sample.

In sum, the results confirm that ESG's influence on COE is context-dependent within China. While mainland firms benefit from ESG improvements through lower equity costs, Hong Kong companies do not exhibit this linkage, underscoring the importance of regional institutional factors in shaping ESG–finance relationships. Therefore, Hypothesis 3 is confirmed.

Table 9. Regression Results for Hypothesis 4

	(1) SOE	(2) Non-SOE
ESG	−0.0002 (−0.24)	−0.0014*** (−3.30)
ROA	0.0006** (2.23)	0.0002 (1.35)
ROE	−0.0007*** (−4.06)	−0.0003*** (−2.82)
TR	−0.0032*** (−2.83)	0.0010 (0.87)
DR	0.0003*** (8.19)	0.0002*** (6.77)
Growth (g)	−0.0001** (−2.48)	−0.0000 (−0.98)
_cons	−0.0000 (−0.01)	0.0143*** (4.22)
Year effect	Yes	Yes
Industry effect	Yes	Yes
Observations R-squared	2430 0.147	3240 0.082

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

The sub-sample regression analysis presented in Table 9 reveals a pronounced divergence in the relationship between ESG performance and the cost of equity capital (COE) across firms with different ownership structures in China. For state-owned enterprises (SOEs), the ESG coefficient is negative (−0.0002) but statistically insignificant ($t = -0.24$, $p > 0.10$), indicating that ESG initiatives do not translate into measurable reductions in equity financing costs. This finding suggests that investors may perceive ESG activities in SOEs primarily as compliance-driven rather than value-enhancing, potentially discounting their strategic significance given the implicit state backing these firms enjoy. In contrast, non-state-owned enterprises (non-SOEs) demonstrate a robust negative and highly significant relationship: the ESG coefficient reaches −0.0014 ($t = -3.30$, $p < 0.01$), implying that improved ESG performance meaningfully lowers the cost of equity. This pronounced effect likely reflects non-SOEs' greater reliance on market signals to attract capital; their ESG disclosures may effectively mitigate information asymmetry and signal long-term viability, thereby reducing perceived risk and required returns. Control variables further corroborate these patterns: while ROA and ROE exhibit expected significant effects in both subsamples, the debt ratio (DR) remains consistently significant ($p < 0.01$) across ownership types, underscoring the universal relevance of leverage in capital pricing. Notably, the model fit differs between groups, with SOEs explaining 14.7 % of the variance ($R^2 = 0.147$) versus 8.2 % for non-SOEs ($R^2 = 0.082$), possibly reflecting greater heterogeneity in the latter group. Collectively, these results strongly support Hypothesis 4, confirming that ownership structure critically moderates the ESG–COE nexus in China: non-SOEs derive substantial financial benefits from ESG investments, whereas SOEs do not exhibit this linkage, highlighting the importance of institutional context in evaluating ESG's capital market implications. Thus, Hypothesis 4 is confirmed.

The post-estimated heterogeneity analysis reveals that the impact of the social factor on the cost of equity capital varies significantly across different regions and ownership types of firms. This result suggests that the role of the social factor in Chinese firms' ESG practices is not uniform, exhibiting considerable heterogeneity.

The robustness check results indicate that the research conclusions remained relatively stable despite changes in model specifications, reflecting the high reliability of the aforementioned model results.

The analysis yields four key conclusions regarding ESG's impact on the cost of equity capital (COE) in China. Hypothesis 1 receives partial support: aggregate ESG performance negatively correlates with COE, though marginally ($p < 0.10$). Hypothesis 2 is rejected: governance (G) shows no significant effect, while social (S) emerges as the strongest predictor ($\beta = -0.0008$, $p < 0.01$). Hypothesis 3 is confirmed: mainland firms exhibit a significant ESG–COE linkage ($\beta = -0.0014$, $p < 0.01$), unlike Hong Kong firms ($\beta = 0.0014$, $p > 0.10$), highlighting regional institutional differences. Hypothesis 4 is also upheld: non-SOEs show

a strong negative ESG–COE relationship ($\beta = -0.0014$, $p < 0.01$), whereas SOEs display no significant effect ($\beta = -0.0002$, $p > 0.10$), underscoring ownership structure as a critical moderator.

Conclusions and Implications

Conclusions

This study employs an empirical model grounded in prior literature and drawing on five-year ESG data from the Wind database to examine the relationship between corporate ESG performance and the cost of equity capital (COE) among Chinese listed firms, controlling for ROA, ROE, TR, DR, and Growth. The findings reveal a significant negative correlation between overall ESG performance and COE, confirming that enhanced ESG practices reduce equity financing costs. However, results diverge from initial hypotheses in key respects. Contrary to the expectation that governance (G) would exert the strongest influence (Hypothesis 2), the social (S) dimension emerges as the most impactful, a finding at odds with Arrigo [21], Ramirez et al. [22], and Ashbaugh et al. [23] but consistent with Matthiesen and Salzmann [9]. This alignment may reflect China's collectivist context, where investor valuations prioritise social responsibility (e.g., employee welfare, community engagement) over environmental or governance metrics. Regional analysis (Hypothesis 3) further shows that mainland firms experience a more pronounced COE reduction from ESG improvement than Hong Kong counterparts, challenging assumptions that high marketisation (as in Hong Kong) strengthen this linkage. Instead, Hong Kong's robust regulatory framework and market orientation may constrain ESG's financial impact, as suggested by Zhu et al. [15] regarding marketisation's complex role in agency cost dynamics. Finally, ownership structure (Hypothesis 4) proves critical: non-SOEs exhibit a significant ESG–COE nexus (at $p < 0.01$), whereas SOEs show no such effect, likely due to differing incentives and investor perceptions of ESG as compliance-driven rather than value-creating.

Recommendations

For Chinese companies, the improvement of ESG performance can lead to a reduction in the cost of equity capital, particularly for non-state-owned enterprises and companies in mainland China, where this impact is more pronounced. Therefore, companies should actively enhance their ESG performance and integrate the improvement of the three dimensions of environmental protection, social responsibility, and corporate governance into their business strategies to achieve positive economic benefits. In line with the findings of this study, companies should proactively assume social responsibility, respond to national policies, and conduct activities in accordance with the Chinese government's social responsibility guidelines. Additionally, companies should genuinely focus on and maintain relationships with stakeholders, as well as strengthening communication with investors by enhancing the quality of information disclosure.

During China's past economic development, there have been long-standing issues such as excessive resource consumption and environmental pollution. The Chinese government has recognized the need to explore more sustainable and environmentally friendly development approaches as the economy enters a phase of high-quality development. This study shows that companies are linking higher E-pillar score with the COE values.

However, ESG-related systems in China still require further improvement. This study found that many ESG indicators are difficult to collect, and uniform, comprehensive standards are lacking. Therefore, the Chinese government should play a supervisory role, improve the ESG information disclosure system, establish corresponding guidelines and standards, and urge companies to regularly publish ESG reports. Encouraging support from various sectors of society for companies and projects with good ESG performance and providing technical or financial assistance to companies that fulfil social responsibilities can further guide the market, promote the concept of responsible investment and green finance, and build a green and sustainable financial system.

ESG rating agencies have played an important role in this field. Their ESG rating reports provide a comprehensive assessment of the ESG performance of listed companies and are an important means for various sectors of society to evaluate the non-financial performance of listed companies. Over the years, several rating agencies in China have introduced their own distinctive rating systems. While most rating agencies describe the indicators they use, the basis for selecting these indicators and their weights are not disclosed. In optimizing indicators to better align with China's national conditions, it is important to seek common ground while preserving differences and to consider incorporating rating comparisons with foreign companies. Rating agencies can also consider collaborating with government departments to increase data acquisition channels as well as utilizing big data and other technological means for tracking data more comprehensively from companies worldwide. This should not only cover ESG rating data for well-performing companies in the stock market and those with strong overall capabilities, but also consider more small and medium-sized enterprises, continually expanding the number of companies being evaluated to meet the needs of more investors, and provide more objective and accurate references.

Limitations & prospects

This paper discusses the relation between corporate ESG performance and cost of equity capital from a theoretical perspective, putting forward research hypotheses and then testing these hypotheses through panel regression models in the empirical process. However, due to the limitations of research level and objective conditions, this paper still has some limitations.

The research sample in this study only includes data from Chinese listed companies from 2018 to 2022. Despite the short time period, there are still many cases of missing data,

resulting in a relatively limited sample size. Additionally, the research sample is focused solely on listed companies in China. Therefore, further exploration would be necessary to understand the situation of non-listed companies. Furthermore, since the ESG ratings from the Wind Financial Terminal are specific to Chinese listed companies, it is not possible to compare them with companies from other countries, potentially limiting the generalizability of the results to other countries or regions.

Although this study examines the three dimensions of ESG, it places less emphasis on the sub-elements of ESG and does not adjust the weights of corresponding indicators based on industry differences. Many institutions adjust the weights of indicators based on industry differences to more accurately reflect a company's ESG performance. Considering that setting weights for industries often requires more comprehensive information disclosure, this study did not adjust indicator weights for different industries. Future research is encouraged to further investigate the sub-elements of each standard to determine if any one standard plays a predominant role in reducing the cost of equity capital for companies in different industries. Regional differences emerged: mainland firms benefit more from ESG improvements than Hong Kong counterparts, likely due to regulatory and marketisation disparities. The research also highlights systemic challenges including inconsistent ESG data disclosure and a lack of uniform standards, underscoring the need for stronger government oversight, clearer guidelines, and enhanced corporate transparency. Ultimately, the findings advocate for strategic ESG integration to lower financing costs and advance sustainable finance in China.

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ESG Disclosure and Firm Value: Dynamic Threshold Effects of Corporate Governance and Financial Flexibility

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Abstract

This study investigates the dynamic panel threshold effect of Environmental, Social, and Governance (ESG) disclosure on firm value, while examining the critical role of corporate governance effectiveness and financial flexibility as threshold determinants in the relationship between ESG disclosure and firm value creation. The primary objective is to ascertain the extent to which ESG disclosure contributes to firm value creation, as well as to explore the variability of this impact across different levels of corporate governance and financial flexibility. The study is based on secondary data from audited annual and sustainability reports of 94 sampled companies listed on the Nigerian Exchange Group (NGX) from 2016 to 2022. The results from the differential Generalized Method of Moments (GMM) regression revealed a positive significant relationship between ESG disclosure and firm value creation, which indicates that companies that prioritize ESG disclosure can achieve superior financial performance and market valuation. The dynamic threshold model results indicate non-linear positive effects of ESG disclosure on firm value in organizations with lower governance practices, however, the effect is significantly amplified in firms demonstrating higher governance effectiveness. Also, as financial flexibility increases, the threshold effect of *ESG* disclosure becomes more pronounced. In firms characterized by low financial flexibility, the contribution of *ESG* to firm value is minimal. However, as firms enhance their financial flexibility, the positive effects of *ESG* disclosure become increasingly significant, suggesting that the capacity to invest in *ESG* initiatives is critical to realizing their value-generating potential. This study offers important insights into the complex interplay between *ESG* disclosure, corporate governance, and financial flexibility in the context of firm value creation. It is recommended for firms to not only engage in ESG disclosure but to also ensure the alignment of their corporate governance and financial strategy in order to maximize the resultant value.

Keywords: ESG, firm value, sustainability, value relevance, corporate governance, financial flexibility

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Introduction

In recent times, pressing problems such as climate change, global warming, and environmental degradation have contributed to the occurrence of numerous natural disasters, societal and economic catastrophes [1–3]. The paradox that companies face in today's modern day is that while the reporting companies disclose their financial performance to stakeholders, they often neglect to reveal how their actions impact society and the environment in the pursuit of profit [4]. This creates a disconnect, as stakeholders, including investors, consumers, and the public, are increasingly interested in understanding not just a firm's results in terms of the financial aspect, but also their footprint as it relates to social and environmental impact. The paradox lies in the fact that companies may present positive financial outcomes without being transparent about the potentially harmful effects their operations have on people and the planet, raising concerns about the long-term sustainability of their practices [5].

Inherent in sustainability practices are the environmental and social issues that have created growing pressure on companies to address and disclose their sustainability actions, social accountability, and governance practices. However, there is a current debate regarding the role environmental, social, and governance (ESG) disclosures play in improving company value [6–8]. Despite increasing demands for transparency in how companies manage and report on these issues, the ESG disclosure impact on the valuation of firms remains uncertain and unresolved in academic literature. ESG reporting is an extension of sustainability and integrated reporting frameworks, which aims to broaden the scope of corporate reporting beyond traditional financial data. ESG includes non-financial information, focusing on the role of entities on their environment and society at large [9; 10]. This shift reflects a growing recognition among companies that success is not solely defined by financial performance, but also by how their operations affect stakeholders and the world at large. Companies are now increasingly developing sustainability strategies and providing non-financial reports to offer a more comprehensive picture of their activities [11; 12].

ESG disclosure has thus gained significant attention within the corporate world, as firms face increasing pressure to be not only profitable but also responsible in their social and environmental practices [13]. Companies are now focusing on sustainability in order to demonstrate stronger governance and commitment to eco-friendly practices [6]. Firms tend to prioritize ethical behaviour, social well-being, and responsible practices which is believed to lead to improved performance and increased firm value. When companies disclose ESG information with the aim of strengthening their competitive edge, it not only boosts investor confidence but also enhances their reputation in the market. This, in turn, positions them for superior future performance and a more sustainable path forward [14].

In the context of the Nigerian economy, the phenomenon of ESG disclosure has gained significant traction in the developing economies like Nigeria, where corporate governance and financial practices remain under scrutiny [15]. More so, peculiar corporate reporting challenges within Nigeria including rampant governance noncompliance, weak regulatory frameworks, and limited accountability have intensified the need for transparency and value relevance in corporate operations [16]. On this note, companies operating in Nigeria are increasingly being called upon to disclose their ESG practices to build stakeholder trust, mitigate potential reputational risks, and enhance firm value [17; 18]. Despite these pressures, many firms in the Nigerian corporate sector struggle with effective ESG reporting, highlighting a significant gap between corporate aspirations and actual practices.

Therefore, this study investigates the interplay between ESG disclosure, corporate governance effectiveness, and financial flexibility, as these factors are pivotal in determining a firm's value in Nigeria's unique economic landscape. Corporate governance effectiveness serves as a vital mechanism that not only promotes ethical behaviour but also enhances accountability among management, thereby leading to improved ESG disclosures [19; 20]. Financial flexibility, on the other hand, allows firms to adapt their capital structure in response to new ESG-related initiatives, demonstrating resilience and sustainability [21; 22]. Together, the investigation into all these will offer a comprehensive context in understanding the multidimensional connection between ESG disclosure and firm value. Furthermore, in consideration of the increasing literature on ESG practices and firm value, limited studies have adequately researched the complex roles of the effectiveness of corporate governance and the effect of financial flexibility within the Nigerian context. Existing studies often overlook the unique socio-economic and cultural dynamics that influence governance structures and capital management strategies in Nigeria. This paper therefore intends to bridge this lacuna by investigating how these concepts are related, offering a more comprehensive perspective on corporate behaviour in transitional markets like Nigeria [23; 24].

This study is structured into five sections. The next part, which is the second section, presents an extensive literature review, including hypothesis development grounded in existing studies and evidence. The third segment delineates the methodology employed, outlining the data collection and analytical techniques utilized in the paper. Section four offers empirical results and a discussion of the findings, integrating insights from the data to elucidate the relationships explored. Finally, the conclusion summarizes the key findings, contributions and present policy recommendations aimed at fostering improved ESG disclosures among Nigerian firms, thereby enhancing their overall value in the marketplace.

Literature review and hypotheses development

The connectedness between ESG disclosure and firm value creation has gathered substantial consideration in recent research. As global environmental and economic issues intensify, the inclusion of ESG factors in corporate reporting has become a critical focus for various stakeholders. Several studies have highlighted the influence of ESG disclosure on the value of the firm, emphasizing their role in signalling sustainable practices to investors. Similarly, prior research conducted across different countries and regions has employed diverse datasets and models to perform extensive theoretical analyses and empirical investigations to reveal that the value of firms is affected by various factors such as sustainability performance [5; 6; 8] earnings quality [23; 25–28] corporate governance mechanisms [24; 29–33], and firm characteristics [7; 34; 35]. Of these factors, financial variables and corporate governance attributes revealed a pivotal impact on the creation of firm value.

With respect to the growing emphasis on integrating non-financial information with traditional financial reporting, the study by Constantinescu et al. [36] disclosed the association between ESG factors disclosure and firm value, particularly in the energy sector. The study confirmed the association between ESG disclosure and firm value, suggesting that incorporating ESG factors into corporate reporting could positively influence a firm's ability to attract capital. Similarly, Yoon et al. [8] and Wang et al. [9] found that ESG disclosure enhances firms' attractiveness to investors by presenting a holistic view of value creation that integrates long-term sustainability with short-term profitability. This notion aligns closely with the findings of Abdulqadir [37], who reported that firms demonstrating robust ESG practices experience improved market valuation, particularly through environmental and governance disclosures. Similarly, Fu and Zhou [38] identified a significant positive association between ESG disclosures and firm value in China, particularly when firms emphasize environmental and social dimensions. These studies collectively emphasize the growing investor preference for companies that balance financial performance with sustainability objectives. This implies that firms can better leverage ESG initiatives to attract investors. However, while ESG disclosure has been generally found to positively influence firm value, the individual dimensions, i.e., environmental, social, and governance, exert varied effects. Alabi and Issa [5] and Ortas et al. [39] demonstrated that environmental disclosure significantly enhances firm value, reflecting investors' prioritization of sustainable practices and reduced environmental risks. In contrast, social disclosure often yield mixed results. For example, in Nigeria, Ibrahim and Tahir [4] revealed that sustainability disclosure contributes to firm valuation and enhances market performance.

Furthermore, the role of ESG disclosure and firm-specific characteristics in shaping firm value in emerging markets was examined in the study conducted by Suretno et al. [3]. The study investigated the relationship between ESG disclosure and firm value, focusing on companies listed on the Indonesia Stock Exchange. The study analysed a sample of 27 companies over a five-year period and found a positive and significant effect of environmental and social disclosures on firm value. This indicates that companies emphasizing these aspects can enhance their market valuation. In addition, the study also revealed that governance disclosure, in contrast, had a negative and significant impact on firm value, suggesting potential concerns over governance practices or misalignment with investor expectations. In a similar vein, Yordudom and Suttipun [40] examined the extent and impact of ESG disclosure on firm value, focusing on 60 listed Thai companies. The study found a positive relationship between environmental and social disclosures and firm value, indicating their potential to enhance investor perceptions and market performance. Conversely, governance disclosures were found to negatively influence firm value, suggesting that certain governance practices or reporting approaches might not align with shareholder expectations. Likewise, with a focus on China's listed companies, Zhang et al. [14] explored the interaction between corporate social responsibility on firm value and revealed that the environmental and social disclosures have a positive effect on firm value.

In the Nigerian context, drawing inspiration from the crisis of credibility that emerged in the investment sector after the collapse of several companies, Ebimobowei [30] examined the impact of corporate governance mechanisms on the valuation of Nigerian banks. The findings demonstrated that corporate governance mechanisms have a positive and significant effect on the value of these banks. This study implies that adopting robust corporate governance practices can enhance the overall value of firms operating within Nigeria's deposit money banking sector. Igbinovia and Agbadua [15] explored the impact of ESG reporting on value-based performance and the results indicate that stand-alone ESG reporting does not have a significant direct impact on firm value. However, when moderated by firm advantage, the effect becomes both significant and positive. This suggest that ESG disclosure exclusively enhances firm value when it is strategically leveraged to improve profitability, such as by boosting sales through an enhanced public image or lowering financing costs. Likewise, Terkuma and Aga [18] investigated the impact of ESG disclosure on the market value of listed manufacturing firms in Nigeria, specifically analyzing its effects on share prices. The study indicated that environmental disclosure positively and significantly affects market value, suggesting its importance in attracting environmentally conscious investors. Social disclosure also positively influences market value but the effect is insignificant, highlighting their limited direct impact on investor decisions. In contrast, governance disclosure shows a significant but negative effect on market value, implying potential misalignment between governance practices and market expectations.

While the literature consistently highlights the positive role of ESG disclosure, several gaps remain, particularly from a conceptual and methodological perspective. Methodolog-

ical rigor has been critical in advancing the understanding of ESG's effect on firm value. Quantile regression, as employed by Buallay et al. [41] and Wu and Chang [42], reveals that the positive impact of ESG disclosure and green innovation is more pronounced in firms with medium to high market value. Similarly, Alsulami [43] and Meng et al. [44] utilized dynamic panel threshold regression models to capture non-linear effects, providing insights into the varying influence of ESG factors across different thresholds of firm performance and economic development. Thus, it is presented that ESG disclosures are critical drivers of firm value, particularly in emerging markets like Nigeria. Environmental and governance disclosure tends to exert stronger positive effects, while social disclosure requires further refinement to deliver measurable financial benefits. Therefore, the study proposes the first hypothesis:

Hypothesis 1 (H_1): *ESG disclosure significantly contributes to firm value creation.*

The study further considered the connection between ESG disclosure and firm value, in consideration of the possible threshold effect of corporate governance effectiveness, with recent studies highlighting the significant role that effective governance effectiveness plays in enhancing sustainability performance and mitigating risks. Importantly, it is crucial to align governance mechanisms with legal frameworks in order to improve the importance of voluntary disclosure for attracting investors and then improve the overall firm performance. For instance, Assidi [1] investigated the impact of voluntary disclosure and corporate governance on firm value, in consideration of the moderating effect of legal changes in the French context. Using data from 1001 observations of firms included in the SBF 120 index, the results demonstrate that voluntary disclosure influences firm value in a positive manner. The study found that regulatory changes, such as the EU Directive 2013/34, amplified the positive effects of ESG disclosure by promoting transparency and aligning corporate governance practices with investor expectations. Moreover, the presence of legal reforms enhances this relationship by fostering improved governance practices, indicating that the interaction between voluntary disclosure and corporate governance creates value under favourable legal conditions.

Moreover, Wu et al. [45] suggest that efficient corporate governance can moderate the relationship between ESG initiatives and firm value, especially when governance is strong, with internal factors like board gender diversity and independence being particularly important. Similarly, Bukari et al. [46] emphasize that corporate governance attributes, such as board diversity, independent boards, and regular meetings, positively influence firm value, while the integration of ESG performance further strengthens this relationship. Mishra et al. [47] extend this by demonstrating that effective governance structures that incorporate climate considerations reduce risks and improve long-term sustainability, thereby contributing to higher financial performance. These studies also highlight a threshold effect where the effectiveness of corporate governance may influence the extent to which ESG factors affect firm value. In line with Shrivastava and Addas [48], the evidence suggests that disciplined governance tends to translate to better and higher ESG disclosure scores, which in turn can enhance firm value. Moreover, Fahad and Rahman [49] identify a more precise relationship, where certain board characteristics, like board age and employee CSR training, can weaken the disclosure of CSR activities. Also, Bello and Abdullahi [50] noted that governance disclosure sometimes negatively influences firm value in developing economies like Nigeria. This could stem from misalignment between governance practices and investor expectations or the excessive cost of compliance in less-developed regulatory environments. However, Mishra et al. [47] and Sharma et al. [2] revealed that while ESG disclosure can negatively impact firm value in some contexts, particularly when governance structures are weak, strong governance can mitigate these effects. This suggests that the effectiveness of corporate governance may have a threshold effect on the relationship between ESG practices and firm value, potentially influencing how firms respond to stakeholder expectations and environmental challenges. Given this, the study formulated the second hypothesis:

Hypothesis 2 (H_2): *The impact of ESG disclosure on the value of a firm varies by the effectiveness of corporate governance and is greater in firms with higher corporate governance effectiveness.*

Furthermore, this study likewise considered the threshold effect of financial flexibility on the relationship between ESG disclosure and firm value creation. The literature on the relationship between financial flexibility, ESG performance, and firm value highlights the fundamental role of financial flexibility in enhancing the positive impact of ESG performance on firm value. Naseer et al. [51] find that financial flexibility moderates the effects of climate change risks on firm value and ESG performance, which implies that firms with higher level of financial flexibility can mitigate risks and capitalize on ESG opportunities. Similarly, Akbar and Setiana [52] confirm that financial flexibility reinforces the positive effect of ESG performance on firm value, although they argue that financial flexibility does not mediate this relationship. Zhang and Liu [53] further support this by revealing that ESG performance enhances financial flexibility, especially in high-uncertainty environments. These studies collectively emphasize that companies with robust ESG practices are better positioned to improve their financial stability and adaptability, especially when facing external challenges. Conversely, Yunica and Rokhim [10] suggest that while ESG performance enhances financial flexibility, financing constraints do not significantly mediate this relationship, highlighting that the direct effect of ESG on financial flexibility remains robust.

The findings across these studies suggest that financial flexibility is crucial for firms to leverage ESG disclosure and effectively improve firm value. The threshold effect of financial flexibility appears particularly significant, as revealed by Sheng and Ann [54], who argue that excessive financial flexibility could lead to diminishing returns in sustainable performance, depending on external factors like environ-

mental uncertainty and government grants. Istan [55] further asserts that financial flexibility, alongside asset structure and income volatility, plays a critical role in enhancing corporate performance and capital structure, reinforcing the notion that financial flexibility is a key driver of firm success. Based on these insights, the third hypothesis for this study is formulated:

Hypothesis 3 (H_3). *The influence of ESG disclosure on the value of a firm varies by level of financial flexibility and is greater in firms with higher levels of financial flexibility.*

Methodology

Sample and Data Source

Relying on the positivist approach, the study investigated the role of ESG disclosure of listed Nigerian firms in their value creation, in consideration of their financial flexibility and the effectiveness of adopted corporate governance. The study utilizes secondary data obtained from the audited annual reports and sustainability reports of companies listed on the Nigerian Exchange Group (NGX) between 2016 and 2022. A total of 94 quoted companies were included in the sample, representing a diverse range of sectors. The study considered the listed companies across all sectors to improve its generalizability and relevance. This broad coverage ensures that the findings apply to a wide variety of businesses, industries, and corporate environments.

Variables definition and measurement

Dependent variable: The study employed the Tobin's Q (TQ) ratio, which is a market-based performance indicator as a measure of a firm's value. Tobin's Q is calculated by dividing the sum of a firm's market capitalization, its liabilities, equity, and minority interest by its total assets [56]. The reason for choosing this metric is that it reflects the expectations of shareholders regarding the firm's future performance, taking into account its past or current performance [17; 56]. Tobin's Q is a metric commonly used to assess companies' performance in meeting or exceeding stakeholder expectations, as well as to evaluate how well a company maximizes shareholder returns by increasing the firm's equity value [57]. Unlike traditional accounting measures of performance, which overlook systematic risks, Tobin's Q incorporates these risks, providing a more comprehensive valuation of firm performance and value creation [20].

Main explanatory variable: ESG disclosure (ESG) is the core explanatory variable of this study. In order to assess the extent of ESG disclosure across the sampled firms, the study developed a checklist of twenty-six (26) items. The full 26-item ESG checklist is provided in Appendix A. Items were selected based on Ortas et al. [39] and cross-checked against global reporting frameworks (GRI Standards) and relevant Nigerian reporting guidance to ensure contextual relevance. The study utilized a dichotomous (0/1) coding approach primarily due to data availability and to ensure consistent scoring across firms and years. The dichotomous scoring was conducted as follows: companies were awarded a score of "1" if they provided either full or partial disclosure of an item and "0" if they made no disclosure. The total ESG information disclosed is then divided by the total number of possible ESG disclosures.. Utilizing this approach, an overall ESG disclosure score was calculated for each company to quantify their level of ESG disclosure.

Control variables: The study incorporates several control variables that can influence a firm's value creation. Using a two-step process, the study developed a corporate governance (CGE) index based on the 2018 Nigerian Code of Corporate Governance. In the first step, following the methods of Dembo [58] and Nsour and Al-Rjoub [19], five key corporate governance components were identified: board structure, board procedure, disclosure, ownership structure, and minority shareholder rights. A sub-index was constructed for each component, specifying governance requirements based on Nigerian best practices, governance guidelines, and existing literature. The detailed breakdown of items composing each of the five CGE sub-indices is provided in Appendix B. In the second step, a binary scoring system was applied, where companies received a score of "1" if they complied with and disclosed a specific governance provision and "0" if they did not. Each element within a sub-index was equally weighted, and the scores were averaged to determine the overall score for that dimension. The choice for equal weights was driven by (a) comparability to previous studies in similar contexts, (b) interpretability for policy audiences, and (c) data limitations preventing reliable estimation of differential weights across certain sparse items.

Financial flexibility (FINFL) is assessed using a combination of two key financial indicators: cash holdings and debt levels, consistent with previous studies [51; 59]. While cash flexibility represents a firm's ability to use its internal funds and is calculated by dividing cash and cash equivalents by total assets, debt flexibility reflects the firm's ability to access external financial resources and is measured as 1 minus the corporate debt ratio. The overall financial flexibility is then determined by adding cash flexibility and debt flexibility [21; 22]. The final index score was calculated by averaging the scores across all sub-indices, ensuring a systematic and balanced evaluation of corporate governance practices. The study acknowledges that this FINFL measure used (cash/assets + (1 – debt ratio)) is a simplified composite that conflates different forms of flexibility. Alternative approaches, such as constructing separate indices for liquidity and debt capacity, or using scaled z-scores and principal component analysis to combine them, may better capture the trade-offs between cash holdings and debt headroom. Due to data availability and to follow precedent in similar emerging-market studies, the study presents the additive index in the baseline analysis. The study further controlled for firm-specific variables; financial leverage (FLEV) is a proportion of total liabilities to the total assets. Growth (GRW) was measured by the percentage change in total assets, while the value of the total assets was used as a proxy for firm size (FSIZ) [9; 17].

Model Construction

At the initial stage of this study, the direct impact of ESG disclosure on firm value was considered. Due to the inertia inherent in firm value (Tobin's Q), which is not easily changed or redefined because of its dependence on historical decisions, strategies, and investments, hence, the study further included a one-period lag of firm value proxied with Tobin's Q as one of the explanatory variables in the dynamic panel model. The study specified the first model in consideration of the direct effect in the absence of the selected control variables of the study, while the second model included the effects of the control variables. Thus, these baseline models are constructed as follows:

$$TQ_{it} = \alpha_0 + \alpha_1 ESG_{it} + \alpha_2 TQ_{it-1} + \varepsilon_{it}; \quad (1)$$

$$TQ_{it} = \alpha_0 + \alpha_1 ESG_{it} + \alpha_2 TQ_{it-1} + \beta X_{it} + \varepsilon_{it}, \quad (2)$$

where *TQ* refers to Tobin's Q; *ESG* is the constructed *ESG* disclosure index score, while *X* represents the control variables; *i* signifies the selected sampled listed firms on the *NGX* across all sectors ($i = 1, 2, \ldots 20$); *t* represents the year in question; ε refers to the random disturbance terms in the model.

Subsequently, with reference to the prime validation of the impact of *ESG* disclosure on firm value, the models of the dynamic threshold regression are intended to investigate the likely threshold effects between *ESG* and firm value. The level of corporate governance effectiveness (*CGE*) and the sampled firms' financial flexibility (*FINFL*) were selected as the two variable thresholds. In order to examine whether there is any distinction in the level of *ESG* impact on firm value at different levels of corporate governance effectiveness and the intervals of financial flexibility, the process further involved testing the variables threshold's significant effects, and the next step was to estimate the precise threshold number and values corresponding to the variable thresholds.

The dynamic threshold regression models have been extensively employed in prior literature [37; 38; 60]. Hansen [61] initially introduced a stationary panel threshold model based on fixed effects, but it required strong exogeneity of the explanatory variables, which limited its applicability. In order to address this limitation and adapt the model for dynamic contexts, Kremer et al. [62] further developed a dynamic threshold model. Building on this foundation, this study constructs two single-threshold dynamic models, utilizing both CGE and FINFL as thresholds correspondingly:

$$TQ_{it} = \alpha_0 + \alpha_1 ESG_{it} \cdot I(CGE_{it} \le \lambda) + \alpha_2 ESG_{it} \cdot I(CGE_{it} > \lambda) \alpha_3 TQ_{it-1} + \beta X_{it} + \varepsilon_{it}; \quad (3)$$

$$TQ_{\text{it}} = \alpha_0 + \alpha_1 ESG_{it} \cdot I(FINFL_{it} \le \lambda) + \alpha_2 ESG_{it} \cdot I(FINFL_{it} > \lambda) \alpha_3 TQ_{it-1} + \beta X_{it} + \varepsilon_{it}. \quad (4)$$

In Models (3) and (4), the threshold value to be estimated is denoted by λ, while $I(\cdot)$ characterises the threshold indicator function. If the condition inside the brackets is true, then $I(\cdot)$ equals 1; else, it equals 0. The coefficients estimating the impact of *ESG* on firm value are represented by α when the level of *CGI* or *FINFL* (as the case may be) is beneath the threshold value (CGE_{it} or $FINFL_{it} \le \lambda$), and α_1 when the level of *CGI* or *FINFL* exceeds the threshold value (CGE_{it} or $FINFL_{it} > \lambda$). The significance of the threshold effect in these models is tested by evaluating the hypothesis H_1: $\alpha_1 = \alpha_2$. If this hypothesis is rejected, it indicates significant differences in how *ESG* impacts the firm value of companies listed on the *NGX*. All other symbols in Models (3) and (4) retain the same meanings as in Model (1).

As specified earlier, Models (3) and (4) incorporate only a single threshold, however, it is essential and practical to extend the framework to include two thresholds, denoted as λ_1 and λ_2. This leads to the development of double-threshold dynamic panels as presented in Models (5) and (6), which respectively utilized corporate governance effectiveness and financial flexibility as threshold variables. Specifically, the estimated coefficients in Model (5) that reflect the impact of *ESG* on firm value are represented as α_1, α_2, and α_3, corresponding to the three intervals of corporate governance effectiveness: $CGE_{it} \le \lambda_1$, $\lambda_2 < CGE_{it} \le \lambda_3$, and $CGE_{it} > \lambda_4$. Similarly, Model (6) is also constructed by substituting financial flexibility as the threshold variable, resulting in three financial flexibility intervals: ln $FINFL_{it} \le \lambda_1$, $\lambda_2 <$ ln $FINFL_{it} \le \lambda_3$, and ln *FINFLit* $> \lambda_4$. The equations for Models (5) and (6) are expressed as follows:

$$TQ_{it} = \alpha_0 + \alpha_1 ESG_{it} \cdot I(CGE_{it} \le \lambda_1) + \alpha_2 ESG_{it} \cdot I(CGE_{it} \le \lambda_2) + \alpha_3 ESG_{it} \cdot I(CGE_{it} > \lambda_2) + \alpha_4 TQ_{it-1} + \beta X_{it} + \varepsilon_{it}; \quad (5)$$

$$TQ_{it} = \alpha_0 + \alpha_1 ESG_{it} \cdot I(FINFL_{it} \le \lambda_1) + \alpha_2 ESG_{it} \cdot I(FINFL_{it} \le \lambda_2) + \alpha_3 ESG_{it} \cdot I(FINFL_{it} > \lambda_2) + \alpha_4 TQ_{it-1} + \beta X_{it} + \varepsilon_{it}. \quad (6)$$

All the symbols in both Models (5) and (6) retain the same meanings as in Models (3) and (4).

Results and discussions

Summary statistics

Table 1 illustrates the relationships in the form of correlations, variance inflation factors (VIF), and descriptive statistics for the variables involved in this study. The first seven columns (1)–(7) present the pairwise correlations between the variables, suggesting that all the independent variables do not exhibit any indication of multicollinearity, which is essential for reliable regression analysis. In order to provide a deeper understanding, Columns (10)–(11) present the VIF values, confirming that they fall within the range deemed acceptable in statistical analysis. Typically, a VIF value above 10 indicates potential multicollinearity, but in this case, all the values suggest that multicollinearity is not a concern. This confirms the independent variables' robustness against multicollinearity.

Further, columns (8) and (9) offer descriptive statistics, focusing mainly on the crucial elements of the means and standard deviations, which provides insights into the central tendency and variability of the study variables. From the results on Table 1, the mean value of *TQ* (4.663) sug-

Table 1. Correlations, descriptive statistics and VIF results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Variables	*TQ*	*ESG*	*CGE*	*FINFL*	*FSIZ*	*GRW*	*FLEV*	*Mean*	*Std Dev*	*VIF*	*1/VIF*
(1) TQ	1							4.663	9.129		
(2) ESG	0.568	1						1.161	0.984	2.08	0.480
(3) CGE	0.18	0.34	1					10.63	0.95	2.10	0.476
(4) FINFL	–0.02	–0.08	0.563	1				1.245	1.742	4.89	0.205
(5) FLEV	0.032	0.02	0.053	–0.02	1			0.50	0.23	1.01	0.991
(6) GRW	0.22	0.3	0.445	0.76	–0.03	1		1.137	1.87	4.13	0.242
(7) FSIZ	0.432	0.29	0.143	0.25	0.016	0.47	1	29.03	149.385	1.36	0.737
Mean VIF										2.6	

gests a moderate level of firm value creation within the studied entities. The substantial standard deviation (9.129) indicates a wide variation in value creation across firms, signalling that while some firms create significant value, others lag considerably behind. The mean for *ESG* disclosure is relatively low at 1.161, with a standard deviation of 0.984, implying that most firms have limited *ESG* disclosures. This limited disclosure may correlate with lower overall firm value, indicating that firms with stronger *ESG* practices potentially exhibit higher firm valuation. Further examining the other variables, corporate governance effectiveness shows a mean of 10.63 with minimal variability (0.95), suggesting a relatively uniform level of governance across firms. In contrast, financial flexibility and financial leverage have means of 1.245 and 0.50, respectively, which, in tandem with their higher standard deviations, indicate variations in financial strategies among firms. The mean firm size of 29.03, accompanied by a notably high standard deviation (149.385), suggests that the sample includes a diverse group of firms ranging among all sectors from small startups to large corporations. This diversity is essential for analysing how different contextual factors, such as financial flexibility and governance effectiveness, interact with ESG disclosure to affect overall value creation.

Regression Result

A structured approach was employed in testing the hypothesis regarding the relationship between *ESG* disclosure and firm value among listed firms in Nigeria. First, the study employed the differential generalized method of moments (*DF-GMM*) to address the issue of endogeneity, which is a common challenge in panel data analysis. This method ensures the reliability of the results while allowing for a theoretical exploration of how *ESG* disclosure influences firm value. Second, in order to account for the inertia or path dependence of firm value over time, the study incorporates a dynamic perspective by including lagged firm value as an explanatory variable. Furthermore, the dynamic threshold regression models were examined to investigate whether the effects of ESG disclosure on firm value vary depending on the effectiveness of corporate governance and the sampled firms' financial flexibility. These thresholds allowed the study to identify specific conditions under which the impact of *ESG* disclosure might change.

DF-GMM Estimation Results

The effect of *ESG* disclosure on firm value was evaluated using the *DF-GMM* technique. The study estimated two models: Model 1 (M1) includes only the independent variable (*ESG* disclosure), and Model 2 (M2) adds the control variables to test the robustness of the findings. As illustrated in Table 2, the examination of the first-order serial autocorrelation (AR (1)) revealed a significant p-value at the 5% threshold for the residuals in models (1) and (2). In contrast, the second-order serial autocorrelation (AR (2)) did not show significance, suggesting that the series is free from autocorrelation issues and also implies that once the first-order dynamics are accounted for, no further dependence exists, which reinforces the robustness of the model. This result thus validates the appropriateness of employing the differential *GMM* technique in this analysis. However, the Hansen test for instrument validity in M1 reports a statistically significant statistic, indicating potential issues with instrument validity. In contrast, M2, which

Table 2. Differential GMM (DF-GMM) regression results

	(M1)		(M2)	
	Dep. Var. TQ			
ESG	0.563***	(0.0919)	0.694***	(0.0673)
TQ with a one-period lag	0.445***	(0.111)	0.177**	(0.0759)
CGE			0.794**	(0.382)
FINFL			-0.0264	(0.0384)
FLEV			0.112	(0.0722)
GRW			-0.121	(0.0832)
FSIZ			-0.0140	(0.0244)
Individual effects	Yes		Yes	
Year effects	Yes		Yes	
Industry effects	Yes		Yes	
Constant Term	–25.63	(16.43)	–16.05	(17.87)
AR (1)	–2.47 **	(0.014)	–2.87**	0.004
AR (2)	0.16	0.872	–1.32	0.186
Hansen	20.69**	0.023	8.83	0.116

Standard errors in parentheses *** p<0.01, ** p<0.05/

captures control variables, does not exhibit this issue. This suggests that the inclusion of control variables helps to address concerns about instrument validity. The consistency of findings across both models and improved instrument validity in M2 lend support to the robustness of the *DF-GMM* regression results presented in Table 2.

Specifically, the findings indicate a statistically significant positive relationship between *ESG* disclosure and firm value creation, as represented by the Tobin's Q (*TQ*). In order to conduct a thorough examination of the value relevance of *ESG* disclosure, the study disaggregated the model. While the first model (M1) conducts a clear examination of the direct effect of ESG on firm value without the potential confounding effect of control variables, the second model (M2) includes the control variables to account for other factors that might influence firm value. This approach helps confirm whether the relationship observed in the first model holds true when these additional factors are considered.

Table 2 revealed significant coefficients of ESG disclosure (0.563 and 0.694) in both models, indicating a strong positive relationship with firm value at the 1% significance level. This portrays the compelling importance of ESG reporting as a strategic tool for improving firm performance in the Nigerian market. Numerous studies have established that robust ESG practices are increasingly viewed as indicators of a firm's resilience and long-term profitability [9; 38; 39]. In the context of emerging markets like Nigeria, the significance of ESG disclosures becomes even more pronounced. For instance, the studies of Alabi and Issa [5] and Terkuma and Aga [18] suggest that firms engaging in comprehensive *ESG* reporting tend to attract a more diverse investor base, which can enhance their capital access and ultimately drive firm value. This correlation is particularly vital within developing markets, where governance and sustainability practices can differentiate firms in a crowded marketplace. The Nigerian market presents unique challenges and opportunities, as highlighted by the work of Terkuma and

Table 3. Threshold value and threshold effect test of corporate governance effectiveness

Threshold Variable	No. of Thresholds	Threshold Value	F Value	p Value	95% Confidence Intervals		1%	5%	10%
CGE	Single**	9.683	70.73	0.0333	[7.146	11.420]	116.2683	62.7897	47.9071
	Double	9.831	8.52	0.8267	[4.092	6.651]	159.8779	86.2378	56.4183

The bootstrap value is 300. ** Represents a 5% significance level.

Aga [18], who note that strong *ESG* disclosure can help mitigate risks associated with regulatory changes and volatility. As companies navigate a rapidly evolving landscape, the proactive communication of *ESG* efforts appears to correlate with enhanced investor confidence and firm value. Therefore, the proposed first hypothesis (H_1) of this study is proven in the sense that ESG disclosure plays a significant and crucial role in promoting firms value of listed Nigerian firms.

Additionally, the significant positive coefficient of the one-period lag firm value are 0.445 in Model 1 and 0.177 in Model 2, both of which pass significance tests at the 1% and 5% levels. This finding implies that the current firm value in both models is significantly influenced by the *ESG* disclosures from the previous period. This indicates a robust path-dependence effect, implying that previous performance metrics, such as total quality (*TQ*), have a lasting impact on a company's current value creation, reaffirming the need for consistent *ESG* engagement over time.

Threshold Effects of Corporate Governance Effectiveness

In order to test the threshold effect of corporate governance effectiveness, Model 3 and Model 5 were estimated with corporate governance effectiveness as the threshold variable, with the threshold value and confidence intervals of 95%. The threshold effect significance tests are presented in Table 3. The results of the threshold regression analysis clearly indicate a significant non-linear relationship between the effectiveness of corporate governance (CGE) and the impact of ESG disclosure on firm value.

In Model (3), the analysis revealed that the threshold effect is significant at the 5% level, highlighting the notion that the effectiveness of corporate governance plays a critical role in mediating the relationship between *ESG* and firm value. This suggests that strong corporate governance mechanisms can enhance the positive effects of *ESG* performance on firm valuation, as good governance not only mitigates risks but also improves stakeholder confidence and long-term strategic alignment. However, Model (5) fails to exhibit significant threshold effects, suggesting that adding complexity does not necessarily enhance the explanatory power regarding the *ESG*-firm value relationship when considering governance effectiveness. This reinforces the idea that a single-threshold model from Model (3) provides a clearer, more interpretable framework for policymakers and corporate leaders, guiding strategic decisions regarding ESG investments and governance practices.

The specific threshold value identified at 9.683 is particularly noteworthy, as it identifies two distinct regimes in regard to *CGE*'s impact on firm value: the low effectiveness of corporate governance interval ($CGE \leq 9.683$) and the high effectiveness of corporate governance interval ($CGE > 9.683$). Firms with a CGE score lower than this threshold exhibit a negligible or even negative response to *ESG* initiatives, implying that weak governance structures may hinder the potential benefits that *ESG* considerations could otherwise yield. In contrast, however, firms surpassing this threshold experience a markedly positive relationship between *ESG* and firm value, supporting the hypothesis that effective governance amplifies the advantages associated with responsible corporate practices.

Table 4. Threshold effects of corporate governance effectiveness in the relationship between ESG disclosure and firm value creation

	TQ		
Variables	**Coefficient**	**Standard Error**	**p value**
ESG (CGE ≤ 9.683)	5.372***	0.652	0.000
ESG (CGE > 9.683)	9.283***	1.088	0.000
Constant Term	–19.533	18.655	0.296
Other Controlled Variables	Controlled		
F value		21.65***	

*** Denotes significance at 1%.

The results of the dynamic panel single threshold model in Table 4 revealed non-linear effects of *ESG* disclosure on firm value with the effectiveness of corporate governance (*CGE*) as the threshold variable. The correlation between *ESG* disclosure and firm value was observed to be positive at both low and high levels of corporate governance effectiveness with a significant impact of ESG disclosure on firm value creation (*TQ*). The results show two distinct threshold effects based on *CGE*. For firms with a corporate governance effectiveness score of 9.683 or lower, the coefficient of *ESG* disclosure is 5.372, which is statistically significant at the 1% level. This suggests that among firms with lower governance practices, *ESG* disclosures positively contribute to firm value creation, although the marginal impact is comparatively less than that observed in firms with higher governance scores.

Furthermore, at higher levels, where *CGE* exceeds the threshold value of 9.683, the effect of *ESG* disclosure on firm value becomes even more pronounced, with a coefficient of 9.283, also significant at the 1% level. This indicates that firms with effective corporate governance not only gain a higher value from their *ESG* activities, but their value creation is more substantial compared to those with lower governance effectiveness. This threshold effect emphasizes the importance of an effective corporate governance as a facilitator that enhances the positive implications of *ESG* initiatives. Therefore, firms operating in environments with robust governance frameworks appear better positioned to leverage *ESG* disclosure for maximizing their firm value [1; 45]. The second hypothesis (H_2) is thus confirmed by the findings that suggest that the effectiveness of corporate governance amplifies the value relevance benefits associated with *ESG* disclosure. For firms below the governance effectiveness threshold, it may be essential to bolster governance practices to fully capture the advantages of *ESG* initiatives. Conversely, firms with higher governance standards are already harnessing substantial value from their *ESG* disclosures, indicating that investing in effective governance structures can yield significant returns in terms of firm value. The significant *F* value of 21.65 further supports the overall validity of the regression, reinforcing the robustness of these threshold effects.

Threshold Effects Using Financial Flexibility as a Threshold

In order to test the threshold impact of the financial flexibility level, Model 4 and Model 6 were estimated with financial flexibility as the threshold variable, with the threshold value and 95% confidence intervals. The threshold effect significance tests are thus shown in Table 5. The results of the threshold regression analysis clearly indicate a significant non-linear relationship between the level of financial flexibility (FINFL) and the impact of ESG disclosure on firm value, especially at specific threshold levels

In both Model (3) and Model (5), the results revealed that the threshold effects are both significant at the 5% level, highlighting the notion that financial flexibility plays a critical role in mediating the relationship between *ESG* and firm value. The study, however, opted for the double threshold model as this choice lies in the statistical significance and robustness of the results presented. The double threshold shows a lower p-value (0.007) compared to the single threshold (0.040), indicating stronger evidence against the null hypothesis. Moreover, the *F*-value of 57.47 suggests a more pronounced effect of financial flexibility on the relationship between *ESG* disclosures and firm value across two distinct thresholds, signifying potentially effective interactions that a single threshold may not capture.

Having identified the thresholds, the results indicate that when financial flexibility is low (below 0.20), the impact of *ESG* disclosure on creating firm value is minimal. Conversely, as financial flexibility increases (beyond the first threshold of 0.20), the effect becomes more substantial. This implies that financially flexible firms seem to be better positioned to leverage *ESG* disclosures for value creation, supporting the idea that the ability to allocate resources effectively plays a crucial role in maximizing returns on sustainability initiatives.

Specifically, the threshold regression results in Table 6 illustrate significant insights into the relationship between *ESG* disclosure and firm value creation, particularly through the lens of financial flexibility (*FINFL*). The results indicate that firms with lower financial flexibility (*FINFL* ≤ 0.20)

Table 5. Threshold value and threshold effect test of financial flexibility

Threshold Variable	No. of Thresholds	Threshold Value	F Value	p Value	95% Confidence Intervals		1%	5%	10%
FINFL	Single **	2.51	47.05	0.040	[0.942	3.709]	62.354	44.0045	35.8697
	Double**	0.20	57.47	0.007	[0.565	3.659]	54.304	44.3028	34.1679

The bootstrap value is 300. ** Represents a 5% significance level.

Table 6. Threshold effects of financial flexibility in the relationship between ESG disclosure and firm value creation

		TQ	
Variables	**Coefficient**	**Standard Error**	**p value**
ESG (FINFL ≤ 0.20)	2.325***	3.30	0.001
ESG (FINFL > 0.20)	2.112***	0.788	0.008
Constant Term	-4.285***	0.887	0.000
Other Controlled Variables		Controlled	
F value		38.08***	

*** Denotes significance at 1%.

experience a coefficient of 2.325 for *ESG* disclosure, which is statistically significant at the 1% level. This suggests that firms with lower financial flexibility derive substantial benefits from *ESG* disclosure, potentially due to enhanced reputational advantages or improved stakeholder relations [15; 20]. In times of financial constraints, robust *ESG* practices may serve as a differentiator that attracts investment and loyalty, indicating that both investors and stakeholders place a high value on firms' sustainability efforts in challenging economic contexts.

Conversely, the impact of *ESG* disclosure is slightly attenuated for firms with higher financial flexibility (*FINFL* > 0.20). When financial flexibility exceeds 0.20, the coefficient for ESG disclosure on firm value creation slightly decreases to 2.112 yet remains significant at the 1% level. This decline indicates that while firms with high financial flexibility still reap rewards from their *ESG* initiatives, the marginal benefit is not as pronounced as in lower-flexibility scenarios. This aligns with the findings of Yunica and Rokhim [10] and Akbar and Setiana [52], who argue that firms with greater financial resources may use those resources more effectively in other areas than their *ESG* initiatives, leading to a decreased incremental value effect derived from *ESG* disclosures. This phenomenon could likewise imply that financially flexible firms often prioritize other value-creating strategies that directly enhance profitability (or might not feel as pressed to enhance their image through robust ESG practices) over *ESG* [54]. The diminishing returns observed in the upper threshold may suggest that as firms become less financially constrained, they ultimately divert their investment strategies from *ESG*-focused initiatives. This result thus fails to confirm the third hypothesis of the study (H_3), as the finding reveals that in the higher thresholds, firms with higher financial capabilities could potentially face diminishing returns on *ESG* investments, while in lower thresholds of financial flexibility, stringent *ESG* practices may serve as a vital mechanism for added value.

Conclusion

This study investigated the dynamic panel threshold effects of *ESG* disclosure on firm value, considering the threshold roles of corporate governance effectiveness and financial flexibility within the context of firms listed on the Nigerian Exchange Group (NGX) from 2016 to 2022. The empirical findings robustly indicate a significant positive relationship between *ESG* disclosure and firm value creation. This finding emphasizes the increasing importance of *ESG* practices in shaping a firm's competitive advantage and long-term sustainability. Further analysis using a threshold model elucidated the contingent nature of *ESG* impacts. Specifically, while firms with lower corporate governance effectiveness experience positive contributions from *ESG* disclosure, the marginal impact is significantly lower than that of firms with higher governance scores. This finding substantiates the essential role of corporate governance as a facilitator of effective *ESG* implementation. Consequently, this reveals that corporate governance practices not only influence firm operations but also modulate the benefits derived from *ESG* engagement. Moreover, the study demonstrated that the impact of ESG disclosure is contingent on the level of financial flexibility. While lower levels of financial flexibility translate to minimal value creation from *ESG* efforts, a notable enhancement in firm value is observed as financial flexibility increases. This highlights the importance of financial health as a critical enabler for firms to leverage *ESG* disclosures effectively.

The findings of this research provide actionable insights for corporate leaders and policymakers like the NGX, and the Financial Reporting Council of Nigeria (FRCN), suggesting that enhancing corporate governance mechanisms and improving financial flexibility are essential for maximizing the benefits of *ESG* disclosure. Firms should prioritize investments in governance structures to ensure they can fully capture the positive impacts of *ESG* initiatives. Additionally, strategies aimed at strengthen-

ing financial positions can empower firms to undertake better *ESG* practices, thus enhancing overall firm value. Theoretically, this study enriches the literature on *ESG* disclosure by illustrating the in-depth relationships between corporate governance, financial flexibility, and firm value. It adds to existing frameworks by demonstrating that *ESG* practices do not uniformly impact firm value, thus necessitating a contextual analysis that examines governance and financial dynamics. The integration of dynamic panel threshold models introduces a sophisticated methodological approach, offering a robust avenue for future research in this domain. It is important to acknowledge the study's limitations, starting from the *ESG* measurement 0/1 coding, which reduces granularity and may introduce measurement error by equating partial and full disclosures. This was necessitated by the heterogeneous reporting formats across firms and years. Future work should implement graded scoring or automated text analysis. In addition, the additive measurement of *FINFL* is pragmatic, and the equal CGE weighting, while adopted for transparency and comparability; index creation using the principal component analysis or factor analysis are recommended in future studies. Lastly, this study is limited by its focus on firms listed solely on the NGX, which may limit the generalizability of the findings to other geopolitical contexts. Future research could explore similar dynamics in different markets to validate and extend these results.

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Appendix

Appendix A: 26-item ESG Disclosure Checklist

S/N	Aspect	Indicators
		Environment
1	Environment	Existence of environmental policy
2	Environment	Quantified emissions (Co2, other GHGs)
3	Environment	Energy consumption and energy efficiency measures
4	Environment	Water usage and water management
5	Environment	Waste management and recycling practices
6	Environment	Pollution control measures and compliance
7	Environment	Environmental impacts in the supply chain and actions taken
8	Environment	Biodiversity and land-use disclosures
		Social
9	Social	Labour practices and workforce composition
10	Social	Employee health and safety statistics/policies
11	Social	Training and development programs
12	Social	Diversity and equal opportunity policies
13	Social	Community engagement and social investment
14	Social	Freedom of Association and Collective Bargaining
15	Social	Human rights policies
		Governance
16	Governance	Board composition and independence
17	Governance	Board committees (audit, remuneration, nomination)
18	Governance	Executive remuneration disclosure
19	Governance	Ownership structure and major shareholders
20	Governance	Minority shareholder rights/protections
21	Governance	Minority shareholder rights/protections
22	Governance	Risk management framework disclosure
23	Governance	Audit quality and external auditor disclosures
24	Governance	Internal control disclosures
25	Governance	Disclosure on related-party transactions
26	Governance	Sustainability/ESG governance (committee or oversight)

Appendix B: Elements of Corporate Governance Effectiveness Index

S/N	Dimension	Elements
		Board structure
1	Board structure	Chair/CEO separation
2	Board structure	Proportion of independent directors
3	Board structure	Board size within recommended range
4	Board structure	Presence of non-executive directors
		Board procedure
5	Board procedure	Board meeting frequency disclosed
6	Board procedure	Existence of board evaluation process
7	Board procedure	Board committees in place and terms of reference
		Disclosure
8	Disclosure	Timely publication of annual reports
9	Disclosure	Sustainability/ESG report publication
10	Disclosure	Disclosure of related-party transactions
		Ownership structure
11	Ownership structure	Concentration of ownership disclosed
12	Ownership structure	Existence of institutional shareholders
13	Ownership structure	Disclosure of significant shareholdings
		Shareholder Rights
14	Shareholder Rights	Mechanisms for minority shareholder protection
15	Shareholder Rights	Policies for equitable treatment of shareholders
16	Shareholder Rights	Shareholders having access to the meeting minutes of the general assembly
17	Shareholder Rights	Existing shareholders have a priority to subscribe to any new share issuance
18	Shareholder Rights	Specific provisions for shareholders to effectively vote and participate in the general meetings

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Investment Incentives and Corporate Sustainability: Evidence from China[1]

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Abstract

This research studies the effect of the Accelerated Depreciation Policy (ADP) on the corporate sustainability of Chinese A-share firms between 2012 and 2017. We employ difference-in-differences estimation and reveal that ADP has a significant positive effect on corporate sustainability, particularly regarding employment, remuneration, and stakeholder rights. The effect is mostly attributed to increases in total factor productivity and short-term leverage, with a lesser role played by workforce skill structure upgrades. This effect is consistent and particularly prominent in firms with higher visibility and labor intensity, lower probability of obtaining long-term bank loans, and firms that are not state-controlled or politically connected. Our findings demonstrate that tax policy is vital in sustainability-related corporate decision-making.

Keywords: investment incentives, accelerated depreciation policy, corporate sustainability

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Introduction

Investment incentives, such as grants, tax credits, accelerated depreciation allowances, and tax holidays, are commonly used by governments to stimulate industrial growth and technological advancement. Research has shown that these incentives positively impact various economic indicators, including fixed capital investments [1–3], innovation [4], employment [5], productivity [6; 7], foreign direct investments [8], and exports [9; 10].

However, the current international agenda, guided by the United Nations' Sustainable Development Goals (SDGs), calls for economies to prioritize sustainable development beyond economic objectives, considering social and environmental performance [11]. In line with this trend, researchers have begun exploring the impact of investment incentives on corporate social responsibility (CSR) engagement [12–15]. Nevertheless, there is a lack of research on the influence of these incentives on overall corporate sustainability, which encompasses economic, social, and environmental indicators with a longer-term orientation and less focus on corporate governance quality, thus going beyond CSR's assessment of meeting current stakeholder interests [16; 17]. Our study addresses this gap by investigating the influence of investment incentives on corporate sustainability in Chinese firms, as measured by the novel Common Prosperity Index.

We investigate the sustainability effect of investment incentives using China's Accelerated Depreciation Policy (ADP) pilots implemented in 2014–2015 as a quasi-natural experiment. ADP pilots, introduced by the Ministry of Finance and the State Administration of Taxation, enabled firms from targeted industries to take advantage of an accelerated depreciation schedule for newly acquired fixed assets.

Our conceptual framework for the relationship between ADP and corporate sustainability is based on resource-based view [18], stakeholder theory [19; 20], and legitimacy theory [21]. We view the ADP effect as consisting of three complementary mechanisms: increased total factor productivity (TFP), an upgrade in workforce skill structure, and a rise in short-term leverage, as documented in prior ADP literature in China [22–26]. We build upon this research by exploring the link between these ADP consequences and corporate sustainability.

We construct a comprehensive panel dataset of Chinese A-share non-financial listed firms from 2012 to 2017 and estimate the ADP effect on corporate sustainability using the multiple period difference-in-differences (DID) approach [27]. Our results indicate that ADP positively impacts the sustainability performance of Chinese firms in terms of employment, remuneration, and sharing with shareholders, debtholders, and distributors, contributing to at least 4 of the 17 SDGs. Robustness checks strengthen our baseline results. Our investigation into TFP channels, short-term leverage, and skill structure upgrades reveals that all three significantly mediate the relationship between ADP and corporate sustainability, with TFP and short-term leverage having the highest mediation power. Further analyses examine the heterogeneity of the ADP effect, the value relevance of corporate sustainability, and ADP's effect on environmental engagement. Cross-sectional analyses indicate that the ADP effect is more prevalent in labor-intensive firms with higher visibility, a lower probability of obtaining long-term bank loans, and firms that are not state-controlled or politically connected.

Our investigation into value relevance reveals that corporate sustainability in China contributes to a favorable corporate profile, higher Economic Value Added (EVA) per share, and higher stock liquidity. Finally, we extend our baseline results in the environmental direction, revealing that ADP has a significant positive effect on environmental performance and environmental disclosure of eligible firms.

Our research makes significant contributions to multiple strands of literature. First, we expand the existing knowledge on investment incentives and sustainability-related engagement [12–15, 28]). Unlike Tang and Wang [14] and Zhao and Peng [28], who focus on ADP's effect on CSR performance in China, our study investigates corporate sustainability using the more comprehensive Common Prosperity Index, which is less skewed towards corporate governance quality. We also develop innovative channels and connect the results to SDGs. Second, we contribute to research on corporate sustainability drivers [29–32] by demonstrating that corporate tax policy can effectively influence corporate sustainability in its holistic definition. Third, our work adds to studies on corporate tax policy efficacy [33–35], showing that tax policy can have effects beyond its intended target.

The paper is structured as follows. Second section reviews the literature and formulates the research hypothesis. Third section presents the data and empirical strategy. Fourth section provided an analysis of ADP's effect on corporate sustainability, examining its impact on specific indicators and potential mediating roles of TFP, short-term leverage, and workforce skill structure. Fifth ection displays the results of performed robustness checks. Six sectionoffers a deeper exploration of heterogeneous effects, value-related consequences, and environmental engagement. Finally, seven section concludes this study.

Literature Review and Hypotheses Development

Tax Incentives in China

Policymakers worldwide implement corporate tax incentives to stimulate economic growth, as neoclassical investment models suggest firms adjust investments in response to fiscal instruments [36]. Accelerated depreciation, by permitting greater tax savings at earlier stages of a company's life cycle, creates cash inflows and alleviates financial constraints [37]. Previous research focused on its impact on fixed asset investments [1–3], productivity [7], and R&D [4].

China's government uses tax incentives to drive innovation and growth, including R&D [38] and FDI [39]. Key permanent reforms include the 2004 VAT reform, the 2012 business tax (BT)-to-VAT reform, and the 2014 ADP. The 2004 VAT reform allowed VAT taxpayers to deduct fixed asset costs, increasing investment, capital intensity, free cash flow, and productivity [7; 40; 41]. It also increased exporting likelihood [10] and skilled labor share, while decreasing employment and average wages [41]. The 2012 BT-to- VAT reform targeted the service industry, reducing tax burdens and positively impacting free cash flow, capital investment, R&D, specialization, and productivity in services [42–44]. It also improved manufacturing firm productivity via value chain linkages [45].

In October 2014, ADP was introduced in China to stimulate manufacturing equipment expansion and innovation by reducing the industrial sector's tax burden. Initially, six industries were eligible for accelerated depreciation rules starting on January 1st, 2014[1].

In September 2015, four more industries were added[2]. Eligible firms could reduce the useful life of new assets by 60% or use methods like double-declining balance to accrue higher depreciation earlier. Small firms in targeted industries could immediately expense capital expenditures for R&D. These changes were permanent for all fixed asset purchases. Additional incentives, regardless of industry, included immediate expensing for assets under RMB 5,000 or RMB 1 million for R&D, and accelerated depreciation for innovation assets over RMB 1 million [46]. In April 2019, ADP expanded to the entire manufacturing sector.[3] Research demonstrates that ADP positively affects investments, productivity, skilled labor demand, free cash flow, employment, and internationalization [22; 23; 26; 47; 48].

Another strand of literature on Chinese ADP is related to its impact on firm financial leverage, financialization, and cash holdings. ADP-induced investments are largely financed by short-term debt, increasing short-term leverage and creating a mismatch between investment and financing [26; 25]. ADP also lowers corporate financialization by incentivizing fixed asset investments over financial assets [49; 50]. Consequently, reduced financial constraints and financialization lead firms to decrease cash holdings [48].

Hypothesis Development

Empirical research shows China's ADP pilots (2014-2015) positively affected firm-level investment, productivity, and demand for skilled labor. Fan and Liu [47] found ADP significantly impacted firm investment, especially in equipment, more so for firms with higher tax compliance and fewer financial constraints. Zhao and Fang [23]; Zhao et al. [24] also showed ADP boosted cash flow, investment, and demand for skilled labor, with a stronger effect under higher tax compliance. However, Zhao and Fang [23] also found the sensitivity of skilled labor demand to ADP was more pronounced for financially constrained firms, aligning with prior research on investment and productivity elasticity to tax changes [7; 44]. Increased investments, R&D, and alleviated financial constraints from ADP favorably impact firm TFP and employment [22; 51]. Furthermore, market expansion post-ADP favors corporate internationalization [52].

Based on this evidence, we consider three mechanisms through which ADP can stimulate corporate sustainability: increased TFP, a boost in short-term leverage, and an upgrade in skill structure. Theoretically, ADP increases TFP by boosting investments and R&D [53; 54]. The rise in short-term leverage is due to the banking system's inability to meet industry-wide demand for long-term loans and banks' preference for short-term loans to manage risk and information asymmetry [55–58]. Finally, ADP can upgrade skill structure due to capital-skill complementarity: fixed investments boost demand for skilled labor [59; 60]. Our theoretical framework is outlined in Figure 1.

Various theories explain how changes in productivity, debt maturity, and labor skill structure affect corporate sustainability. The resource-based view [18] posits that firms with superior resources (e.g., higher TFP, skilled labor) can allocate available to sustainability initiatives, gaining competitive advantage [61–64]. Stakeholder theory [19; 20] suggests that short-term lenders, as key stakeholders, demand transparency and responsible behavior [65, 66]. Qualified employees, as vital internal stakeholders, also have higher sustainability expectations [67]. Firms with higher TFP often experience positive stakeholder perceptions and greater returns from sustainability [68; 69].

Legitimacy theory [21] argues that prominent, highly productive firms are pressured to legitimize their market position through sustainability initiatives, ensuring societal acceptance and avoiding backlash [70]. Firms increasing the amount of short-term loans may also use sustainability to enhance societal legitimacy and long-term viability [71; 72].

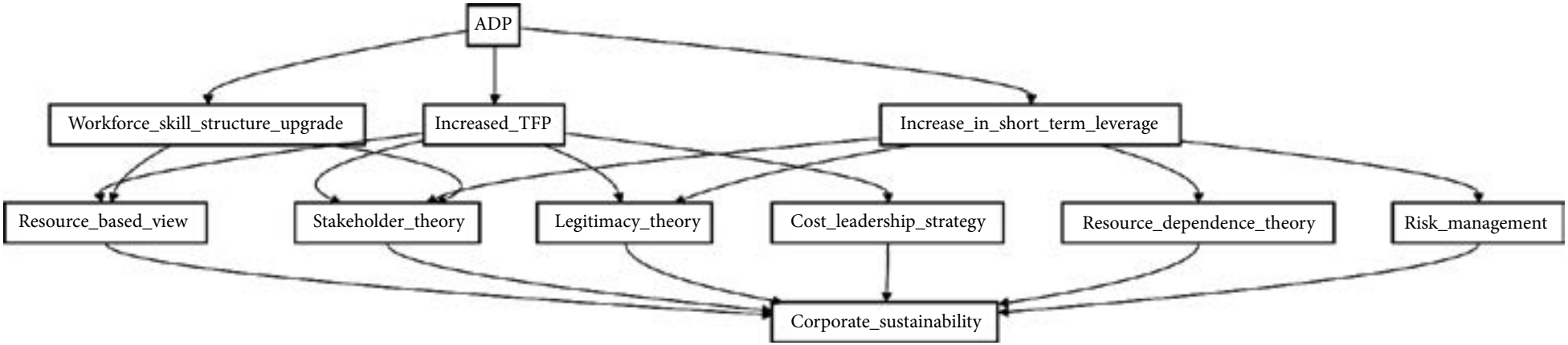
Based on this, we expect ADP's effects on firm productivity, labor, and capital structures to improve sustainability performance. This aligns with prior evidence from China

[1] Notice of the Ministry of Finance and the State Administration of Taxation on Improving the Enterprise Inco/.me Tax Policy for Accelerated Depreciation of Fixed Assets (Finance and Taxation [2014] No. 75) is available at https://www.shui5.cn/article/d6/74674.html.

[2] Notice of the Ministry of Finance and the State Administration of Taxation on Further Improving the Enterprise Income Tax Policy for Accelerated Depreciation of Fixed Assets (Finance and Taxation [2015] No. 106) is available at https://www.shui5.cn/article/d1/82145.html.

[3] Announcement No. 66 of 2019 by the Ministry of Finance and the State Administration of Taxation on Expanding the Scope of Application of the Accelerated Depreciation Preferential Policy for Fixed Assets is available at https://www.shui5.cn/article/5d/126952.html.

Figure 1. Theoretical Framework



showing that investment incentives foster CSR engagement [13; 14; 28]. Given that ADP affects long-term firm strategy, our main hypothesis is:

H1: ADP significantly promotes corporate sustainability.

Data and Methodology

Data and Sample

Our sample comprises Chinese A-share non-financial listed firms from 2012 to 2017, covering two years before the 2014 ADP pilot and two years after the 2015 pilot. We obtain general, financial, governance, and ownership data from the China Stock Market and Accounting Research (CSMAR) database. Corporate sustainability data come from the "Enterprises' Contribution to Common Prosperity Research" database, contributing to the Common Prosperity Index.

We exclude firms with special treatment (ST) status[4] and observations with missing data. The final sample contains 2,665 firms and 13,386 firm-year observations. We winsorize continuous variables at their 1st and 99th percentiles to mitigate outliers.

Corporate Sustainability Measurement

Originating from the Brundtland Report [16], sustainable development balances current needs with future generations' well- being. In a corporate context, the Triple Bottom Line framework [73] holistically merges economic, societal, and environmental perspectives, a cornerstone in sustainability studies [17; 74; 75].

We use the Common Prosperity Index to measure corporate sustainability due to its comprehensive nature within the Chinese business landscape. Table A3 details this index and its relationship to SDGs. It covers economic and institutional sustainabil- ity (shareholder returns, tax contribution, healthy competition, public welfare), social sustainability (employment, wages, employee safety, customer/partner engagement), and environmental sustainability (environmental violations as part of Other Partner Sharing sub- score) [76], consistent with the Triple Bottom Line [73].

The Common Prosperity Index serves as a strong measure of corporate sustainability, meeting criteria for long-term orientation and holistic definition [74; 77; 78]. It emphasizes stakeholder engagement, delves into employment dynamics and compensation, and covers a broad spectrum of societal challenges like social inclusion, disability rights, poverty, and healthy competition. Its balanced methodology, which grants equal weight to all components, ensures a holistic sustainability capture.

Empirical Strategy

We investigate ADP's influence on corporate sustainability using a staggered DID approach [27]:

$$CS_{i,t} = \beta ADP_{i,t} + \gamma Controls_{i,t} + \delta_i + \theta_{j,t} + \epsilon_{i,t}, \quad (1)$$

where i, j, and t denote firm, industry, and year, respectively. $CS_{i,t}$ is corporate sustainability (Common Prosperity Index transformed to a score). $ADP_{i,t}$ is an interaction between $TREAT_{i,t}$ (dummy for eligible primary industry) and $POST_{i,t}$ (dummy for post-eligibility year). $Controls_{i,t}$ are control variables, δ_i is a firm fixed effect, $\theta_{j,t}$ is an industry-year fixed effect, and $\epsilon_{i,t}$ is white noise. Industry-year fixed effects account for varying sustainability norms across industries, as the index is not industry-adjusted.

Our analysis includes the Common Prosperity Index and its individual sub-scores: firm- level employment (*HIRE*), remuneration (*PAY*), employee protection (*SAFE*), customer sharing (*QUAL*), other partner sharing (*OBLIG*), shareholder sharing (*SHARE*), contribu- tion to healthy competition (*COMP*), tax contribution (*TAX*), and contribution to public welfare and charity (*CHAR*).

Following prior literature on sustainability drivers, we include firm-level controls: profitability (*ROA*), valuation (*TQ*), size (*SIZE*), cash holdings (*CASH*), leverage (*LEV*), capital expenditures (*CAPEX*), firm age (*AGE*), sales growth (*GR*), and R&D expenses (*RD*) [79–83]. To account for managerial long- termism, we include institutional ownership (*INST*) and insider ownership (*MGT*) [84; 85]. Detailed variable measurements are in Table A2.

Summary Statistics

Panel A of Table 1 presents summary statistics. The mean CS is 5.3, reflecting the balanced nature of the Common Prosperity index compared to other China-based CSR indices (e.g., Zhong et al. [86]; Li et al. [87]). The treatment group (TREAT) accounts for 53.4% of observations, and the post-intervention period (POST) for 32.4%. Average firm size is 22.1, ROA is 3.6%, leverage is 43.0%, Tobin's Q is 2.3, and sales growth is 19.6%. Cash balance averages 18.1% of total assets, capital investments 4.8%, and R&D 3.3% of sales. Institutional and managerial ownership average 6.5% and 9.5%, respectively. These statistics align with prior literature. Panel B of Table 1 shows the Spearman correlation matrix. ADP positively correlates with CS, supporting H1. Firm size, profitability, sales growth, age, institutional ownership, cash ratio, and R&D correlate positively with CS. Managerial ownership and firm valuation correlate negatively. Most correlation coefficients are below 0.3, indicating minimal multicollinearity.

[4] In China, ST status is used to refer to firms that are experiencing financial distress.

Table 1. Descriptive Statistics

This table presents the descriptive statistics and Spearman correlation matrix for a sample of Chinese A-share listed firms from 2012 to 2017. Variable definitions are shown in Table A2. ***. **. and * denote the significance at the 1%. 5%. and 10% levels. respectively.

Panel A. Summary Statistics

	Mean	S.D.	Min	Q25	Median	Q75	Max	N
CS	5.329	2.410	1.000	4.000	5.000	7.000	9.000	13.386
ADP	0.324	0.468	0.000	0.000	0.000	1.000	1.000	13.386
TREAT	0.534	0.499	0.000	0.000	1.000	1.000	1.000	13.386
POST	0.324	0.468	0.000	0.000	0.000	1.000	1.000	13.386
SIZE	22.137	1.246	19.593	21.260	21.989	22.857	25.847	13.386
ROA	0.036	0.051	-0.164	0.012	0.033	0.061	0.187	13.386
AGE	2.272	0.688	0.693	1.792	2.398	2.890	3.219	13.386
LEV	0.430	0.210	0.050	0.257	0.421	0.593	0.840	13.386
TQ	2.256	1.527	0.936	1.319	1.753	2.587	9.748	13.386
CASH	0.181	0.128	0.017	0.091	0.146	0.236	0.650	13.386
CAPEX	0.048	0.046	0.000	0.014	0.034	0.067	0.222	13.386
RD	0.033	0.041	0.000	0.001	0.027	0.044	0.237	13.386
GR	0.196	0.502	-0.575	-0.030	0.102	0.273	3.348	13.386
INST	0.065	0.068	0.000	0.013	0.044	0.096	0.313	13.386
MGT	0.095	0.165	0.000	0.000	0.000	0.131	0.672	13.386

Panel B. Spearman Correlation Matrix

	CS	ADP	SIZE	ROA	AGE	LEV	TQ	CASH	CAPEX	RD	GR	INST	MGT
CS	1.00												
ADP	0.07***	1.00											
SIZE	0.46***	-0.08***	1.00										
ROA	0.26***	0.06***	-0.00	1.00									
AGE	0.08***	-0.08***	0.34***	-0.20***	1.00								
LEV	0.15***	-0.18***	0.52***	-0.39***	0.39***	1.00							
TQ	-0.14***	0.24***	-0.47***	0.06***	0.02**	-0.26***	1.00						
CASH	0.04***	0.02**	-0.21***	0.25***	-0.23***	-0.36***	0.13***	1.00					
CAPEX	-0.01	-0.06***	-0.06***	0.12***	-0.26***	-0.10***	-0.06***	-0.04***	1.00				
RD	0.02**	0.35***	-0.25***	0.06***	-0.32***	-0.35***	0.20***	0.25***	0.08***	1.00			
GR	0.09***	0.04***	0.05***	0.17***	-0.02**	0.02**	-0.01	-0.01	0.00	-0.02**	1.00		
INST	0.23***	0.06***	0.18***	0.21***	0.04***	0.02**	0.11***	0.06***	0.08***	0.07***	0.08***	1.00	
MGT	-0.06***	0.10***	-0.32***	0.17***	-0.59***	-0.33***	-0.01	0.21***	0.13***	0.30***	0.04***	-0.03***	1.00

Empirical Results

Accelerated Depreciation and Corporate Sustainability

Before presenting baseline results, we evaluate alternative model specifications. Table 2 shows OLS without fixed effects (Column (1)) had the strongest ADP effect but lowest adjusted R^2. Including firm-level fixed effects (Column (2)) significantly improved R^2 but halved the ADP effect. ADP's positive effect on CS remained significant with firm and industry-year effects (Column (3)), though smaller than the full baseline model (Column (4)).

Our baseline results show that ADP has a statistically and economically significant positive effect on corporate sustainability, increasing firm-level sustainability performance by 0.23 points (4% of its mean value). This supports Hypothesis H1.

These results align with the resource-based view [18] (increased sustainability capability from resource allocation efficiency); stakeholder theory [19] (boost in sustainability efforts from increased stakeholder awareness); legitimacy theory and risk management [21; 88] ((sustainability as a tool for legitimacy or risk hedging); and cost leadership [89] (sustainability boosted by cost advantages). Our findings expand the findings of Tang and Wang [14] and Zhao and Peng [28], showing that Chinese ADP drives contributions to overall sustainability, a broader definition than short-term CSR.

Controls, size, profitability, sales growth, and institutional ownership showed a significant positive effect, while capital expenditures had a negative effect, consistent with prior literature. Age's negative effect may stem from larger firms' greater exposure to societal issues [80]. The positive impact of leverage could be due to increased pressure on debtors. The loss of significance for cash holdings, Tobin's Q, and insider shareholding with fixed effects may be due to their correlation with time-invariant firm characteristics or industry characteristics.

Table 2. Accelerated Depreciation Policy and Corporate Sustainability

This table presents the effect of ADP on corporate sustainability for a sample of Chinese A-share firms from 2012 to 2017. The dependent variable is CS in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the industry are reported in parentheses. ***. **. and * denote the significance at the 1%. 5%. and 10% levels. respectively.

	(1) CS	(2) CS	(3) CS	(4) CS
ADP	0.2965***	0.1581**	0.1756**	0.2268***
	(4.61)	(2.17)	(2.56)	(2.98)
SIZE	0.9113***	0.9156***		0.6665***
	(15.67)	(11.41)		(11.48)
ROA	11.6958***	3.3924***		3.9056***
	(10.02)	(9.16)		(8.97)
AGE	-0.0433	-0.1416		-0.7368***
	(-0.64)	(-1.37)		(-7.17)
LEV	1.0853***	0.6202***		1.1810***
	(4.08)	(4.51)		(10.53)
TQ	0.0616***	0.1010***		0.0111
	(2.88)	(5.03)		(0.70)
CASH	1.3210***	0.3848		0.3292
	(3.02)	(1.68)		(1.71)
CAPEX	-0.8513	-1.4662***		-0.6100*
	(-0.89)	(-2.93)		(-1.74)
RD	5.4768***	2.0092**		1.4292
	(3.70)	(2.49)		(1.61)
GR	0.0662	0.2702***		0.2954***
	(0.95)	(4.40)		(4.70)
INST	2.5342***	0.9568***		0.6531**
	(7.70)	(4.05)		(2.38)
MGT	0.4639***	0.8420*		0.2377
	(3.86)	(1.88)		(0.72)

	(1) CS	(2) CS	(3) CS	(4) CS
Firm FE	No	Yes	Yes	Yes
Industry-Year FE	No	No	Yes	Yes
Observations	13.386	13.386	13.386	13.386
Adjusted R^2	0.31	0.74	0.74	0.76

Performance of Corporate Sustainability Indicators

We investigate the sustainability components prioritized by firms. Given ADP's effect through TFP, skilled employees, and short-term debt, we expect a significant impact on stakeholders directly affected by these mechanisms. Employees and debtholders are prime examples. Investments may also benefit customers, shareholders, and the environment. We hypothesize that Healthy Competition, Public Welfare and Charity sub-scores are unaffected due to their irrelevance to ADP's orientation, and Tax Contribution is ambiguous.

Table 3 shows that ADP significantly affects employment, remuneration, shareholder sharing, and other partner sharing (Columns (1)–(2) and (5)–(6)). Table A1 further reveals that among "other partners", ADP favors distributors and debtholders, leading to a decreased turnover of accounts receivable, reduced debt violations, and increased interest on debt per share. This suggests that investment incentives promote SDG 8 "Decent Work and Economic Growth", SDG 10 "Reduced Inequalities", SDG 5 "Gender Equality", and SDG 16 "Peace, Justice and Strong Institutions" (Table A3).

The positive impact on Employment and Remuneration sub-scores (employee number, diversity, training, compensation) aligns with ADP's effect on workforce skill structure upgrades [23; 24]. Skilled employees command higher wages and higher demands for employee responsibility [90]. However, ADP does not affect Employee Protection (safety, security, rights) (Column (3)), suggesting firms prioritize workforce structure and competitiveness over working conditions.

The rise in the Shareholder Sharing sub-index, driven by profitability and dividends, is consistent with evidence of reduced financial constraints, increased investment, innovation, and TFP [22; 47]. The Other Partner Sharing sub-score also rises, largely due to Debtholder Sharing (Columns (3)–(4) of Table A1), aligning with increased short-term debt post-ADP [25; 26] and pressure from short-term lenders [58]. Increased distributor sharing (lower accounts receivable turnover) suggests firms, with added cash flow from accelerated depreciation, offer more relaxed credit terms. The insignificant effect on Supplier Sharing is likely due to ADP's irrelevance to supplier interests.

The lack of significant effect on Healthy Competition, Tax Contribution, and Public Welfare and Charity (Columns (7)–(9) of Table 3) aligns with our prediction. The policy's capital investment focus provides no direct incentive for competitive or philanthropic changes. Ambiguous tax base effects (depreciation allowances vs. increased profitability) may explain the lack of impact on tax contribution. The absence of ADP's effect on Customer Sharing (product quality, Column (4)) may be due to a focus on process rather than product innovation, and no direct customer pressure from ADP.

Plausible Channels

Our baseline analysis suggests ADP incentivizes sustainability in employment, remuneration, shareholder, and debtholder sharing. We formally analyze TFP, short-term financial leverage, and employee skill structure as potential mediators.

Firm Productivity

Rising firm TFP naturally results from ADP, driven by innovation and resource allocation efficiency [53; 54]. ADP effectively stimulated TFP growth in China [22]. TFP's positive impact on sustainability is explained by stakeholder theory (positive stakeholder perceptions, higher returns from initiatives for high-TFP firms) [68; 69], legitimacy theory (need to legitimize market position) [21; 70; 90], resource-based view (efficient resource allocation to sustainability) [63], and cost leadership (sustainability effect of cost advantages) [89]. ADP encourages long-term investment, leading to reinvestment of cost savings into sustainability [92]. Sustainability also boosts corporate reputation, competitiveness, sales, market value, and lowers capital cost [93–99].

To test TFP's mediation, we estimate:

$$TFP_{i,t} = \beta ADP_{i,t} + \gamma Controls_{i,t} + \delta_i + \theta_{j,t} + \epsilon_{i,t}, \quad (2)$$

$$CS_{i,t} = \beta TFP_{i,t} + \gamma Controls_{i,t} + \delta_i + \theta_{j,t} + \epsilon_{i,t}, \quad (3)$$

where TFP is measured using the LP method [100].

Table 3. Accelerated Depreciation Policy and Performance of Corporate Sustainability Indicators

This table presents the effect of ADP on corporate sustainability indicators' performance for a sample of Chinese A-share firms from 2012 to 2017. The dependent variables are HIRE, PAY, SAFE, QUAL, SHARE, OBLIG, COMP, TAX, and CHAR in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the firm are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

	(1) HIRE	(2) PAY	(3) SAFE	(4) QUAL	(5) SHARE	(6) OBLIG	(7) COMP	(8) TAX	(9) CHAR
ADP	0.7430**	0.4382*	-0.0753	-0.2241	1.7256**	0.5377**	-0.1315	-0.5613	-0.0377
	(2.14)	(1.81)	(-0.80)	(-1.20)	(2.22)	(2.82)	(-0.56)	(-0.66)	(-0.21)
SIZE	3.4921***	0.3885	-0.1632	-0.0910*	0.2056	0.0713	-0.4803***	4.5368***	0.2036
	(10.59)	(1.29)	(-1.63)	(-1.98)	(0.53)	(0.48)	(-3.22)	(10.21)	(1.37)
ROA	-4.0790**	1.6178	0.6913*	0.2594	28.2018***	-0.1800	1.4478	70.5550***	-0.9816
	(-2.32)	(0.71)	(2.00)	(0.74)	(18.58)	(-0.14)	(0.90)	(14.78)	(-1.02)
AGE	-0.1297	-2.5198***	-0.1398	0.2205	-1.9242	-0.5144	0.4839	-8.3581***	-0.2452
	(-0.23)	(-3.35)	(-0.57)	(1.63)	(-1.64)	(-1.26)	(0.64)	(-7.31)	(-0.61)
LEV	1.5919	4.2872***	0.0262	0.0663	-5.3673***	4.1162***	0.8089*	13.4721***	-1.1503***
	(1.61)	(4.93)	(0.11)	(0.41)	(-3.62)	(4.76)	(1.84)	(9.88)	(-2.89)
TQ	0.1285	-0.0476	-0.0329	-0.0063	-0.0191	-0.1035	-0.0443	-0.2611	0.0415
	(1.71)	(-0.55)	(-1.28)	(-0.40)	(-0.12)	(-1.11)	(-0.77)	(-1.44)	(0.47)
CASH	-1.5037*	1.4573	-0.0012	0.0911	6.2391***	1.2431**	-0.3824	1.1953	0.1060
	(-1.76)	(1.32)	(-0.01)	(0.42)	(5.37)	(2.09)	(-0.73)	(1.02)	(0.41)
CAPEX	5.2167**	-1.8855	-0.1590	-0.1709	-3.3535	-4.6834***	-0.5802	-17.8898***	3.8532**
	(2.26)	(-1.27)	(-0.35)	(-0.50)	(-0.92)	(-3.30)	(-0.27)	(-5.31)	(2.83)
RD	7.7256***	12.2727***	0.4388	0.9900	-6.5918***	-7.6433**	0.2162	-19.2450*	7.0780***
	(2.94)	(4.54)	(0.58)	(1.57)	(-3.05)	(-2.22)	(0.09)	(-2.07)	(6.17)
GR	0.9973***	1.0730***	-0.0581	0.0095	-0.9022***	0.6784***	0.1924*	1.3789***	-0.1871***
	(5.13)	(3.91)	(-1.67)	(0.47)	(-4.64)	(4.22)	(1.86)	(4.54)	(-4.29)
INST	1.0940	1.0797	-0.7938	0.1819	-2.3605	-0.0272	-0.1953	8.3712***	-0.9815*
	(0.89)	(1.41)	(-1.32)	(0.74)	(-1.58)	(-0.03)	(-0.26)	(3.36)	(-2.05)
MGT	0.2126	1.2326	-0.3266	0.2218	2.6801*	0.9131	-1.0220	-1.7875	1.5342***
	(0.20)	(0.97)	(-1.42)	(1.52)	(1.87)	(1.14)	(-0.51)	(-1.05)	(3.63)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13.386	13.386	13.386	13.386	13.386	13.386	13.386	13.386	13.386
Adjusted R^2	0.77	0.68	0.61	0.92	0.55	0.67	0.32	0.68	0.98

Columns (1) and (4) of Table 4 confirm ADP positively affects TFP at 1% significance [22], and TFP is positively associated with CS. Thus, TFP mediates the relationship, increasing firms' productivity and sustainability. Shareholder Sharing and Distributor Sharing are TFP-mediated sustainability indicators (Section "Performance of Corporate Sustainability Indicators").

Table 4. Plausible Channels

This table presents the potential mediation of TFP, short-term leverage, and skill structure in the effect of ADP on corporate sustainability for a sample of Chinese A-share firms from 2012 to 2017. The dependent variables are CS, TFP, STDEBT, and SKILL in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the firm are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

	(1) TFP	(2) STLEV	(3) SKILL	(4) CS	(5) CS	(6) CS
ADP	0.0512*** (4.71)	0.0117** (2.19)	0.0124*** (2.72)			
TFP				0.2498*** (4.83)		
STLEV					1.2478*** (8.95)	
SKILL						0.4010** (2.23)
SIZE	0.4079*** (16.26)	0.0537*** (13.83)	0.0048 (1.48)	0.5617*** (10.66)	0.6662*** (10.85)	0.6626*** (13.67)
ROA	1.9638*** (13.33)	-1.1411*** (-21.39)	0.0548** (2.35)	3.4417*** (8.27)	3.8453*** (8.65)	3.8839*** (9.49)
AGE	-0.0359 (-1.05)	0.0255*** (6.17)	-0.0313*** (-4.34)	-0.7186*** (-6.40)	-0.7255*** (-5.67)	-0.7190*** (-6.39)
LEV	0.3226*** (5.31)		-0.0139 (-1.26)	1.0933*** (6.73)		1.1816*** (7.25)
LTLEV		-0.4488*** (-7.11)			0.6840* (1.89)	
TQ	0.0172*** (3.85)	0.0050** (2.80)	-0.0008 (-0.67)	0.0058 (0.35)	0.0059 (0.36)	0.0110 (0.68)
CASH	0.1223*** (3.22)	-0.1797*** (-8.02)	0.0067 (0.63)	0.3079* (1.83)	0.2399 (1.19)	0.3301* (1.96)
CAPEX	-0.3663* (-1.78)	-0.1241*** (-3.50)	0.0387 (1.55)	-0.5117 (-1.32)	-0.6806* (-1.97)	-0.6368 (-1.64)
RD	-2.9293*** (-26.47)	-0.8921*** (-12.22)	0.3905*** (5.25)	2.0768*** (2.60)	1.7348* (1.85)	1.2520 (1.54)
GR	0.1901*** (13.15)	0.0186*** (2.92)	0.0034 (1.50)	0.2485*** (7.48)	0.2784*** (4.58)	0.2942*** (9.33)
INST	-0.0949* (-1.77)	0.0408 (1.51)	0.0204 (1.31)	0.6975*** (2.78)	0.6497** (2.58)	0.6515*** (2.60)
MGT	-0.0632 (-0.96)	-0.0210 (-1.46)	-0.0179 (-1.06)	0.2717 (1.16)	0.0773 (0.22)	0.2521 (1.07)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13.060	12.530	13.386	13.380	12.581	13.386
Adjusted R^2	0.93	0.43	0.84	0.77	0.77	0.76

Short-Term Leverage

Short-term leverage is another mediator positively affected by ADP [25; 26]. ADP incentivizes fixed asset investment, increasing demand for long-term loans. With underdeveloped bond/equity markets in China [101] and limited bank supply, firms turn to short-term debt. Banks also prefer short-term loans to manage risk and moral hazard due to information asymmetry [56–58].

The effect of short-term leverage on sustainability stems from stakeholder theory [19; 20], where increased short-term debt leads to greater lender pressure [65; 66], motivating firms to engage with debtholders. Legitimacy theory [21] suggests firms with large short-term debt use sustainability to address lender pressure [71]. Risk management and resource dependence perspectives [88; 102; 103] imply frequent short-term debt needs prompt sustainability practices to secure favorable funding terms and potentially lower loan costs [104].

We test short-term leverage (STLEV, current liabilities to total assets) mediation using a model analogous to Eqs. 2 and 3, replacing total leverage (LEV) with long-term leverage (LTLEV) in controls to avoid multicollinearity.

Columns (2) and (5) of Table 4 show that ADP leads to increased short-term leverage, consistent with Feng et al. [26] and Du et al. [25]. Short-term leverage, in turn, positively affects CS. This, combined with ADP's favorable effect on debtholder interests (Table A1), suggests that short-term debt financing strongly mediates ADP's effect on sustainability. The mediation effect of short-term leverage (0.015) is slightly higher than that of TFP (0.013).

Workforce Skill Structure

The third mediator is workforce skill structure upgrade. China's ADP led to increased demand for skilled labor and corresponding skill structure upgrades [23; 24] due to capital-skill complementarity [59; 60]. Stakeholder theory suggests that this amplifies sustainability pressure from skilled employees, who are more aware and have greater bargaining power [67; 105]. Resource-based view supporters [64] suggest skilled workers' efficiency and strategic insights improve sustainability.

To assess the mediating role of workforce skill composition, we use a model similar to Eqs. 2 and 3, with skilled labor proportion (SKILL, ratio of technician employees to total workforce, as perZhao and Fang [23]) as the mediator.

Our results confirm the capital-skill complementarity hypothesis [23; 24]: ADP significantly influences the proportion of skilled employees (Column (3) of Table 4). An elevated share of skilled employees positively affects CS (Column (6) of Table 4). This mediating role aligns with ADP's significant effect on Employment and Remuneration sub-scores. However, its magnitude (0.005) is weaker than short-term leverage and TFP.

Robustness Checks

We conduct multiple robustness checks to assess potential selection and omitted-variable biases.

Propensity Score Matching

To address potential sample selection bias from observable pre-intervention differences, we use propensity score

Table 5. Propensity Score Matching

This table presents the effect of ADP on corporate sustainability for a matched sample of Chinese A-share firms from 2012 to 2017. The dependent variable is CS in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the firm are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

Panel A. Matched Sample

	(1) CS	(2) CS	(3) CS	(4) CS
ADP	0.1736*** (5.96)	0.3312*** (7.88)	0.2216** (2.88)	0.2237** (3.04)
SIZE	0.8986*** (13.26)	0.7817*** (15.29)		0.6735*** (12.94)
ROA	12.3777*** (34.45)	3.5450*** (7.92)		4.0368*** (7.42)
AGE	0.0215 (0.12)	-0.4368*** (-7.88)		-0.9804*** (-7.88)
LEV	1.6863*** (8.14)	0.7421*** (3.30)		1.1085*** (5.25)
TQ	0.0384** (2.55)	0.0401*** (6.08)		-0.0137 (-1.11)

	(1) CS	(2) CS	(3) CS	(4) CS
CASH	1.2622** (2.69)	0.2023 (1.50)		0.2929* (1.94)
CAPEX	-2.2261*** (-5.94)	-1.6567** (-3.05)		-0.9479** (-3.03)
RD	6.4366*** (3.54)	1.5762 (1.60)		1.4929 (1.10)
GR	0.0486 (0.43)	0.3750*** (5.85)		0.3623*** (6.92)
INST	3.3301*** (26.15)	1.1821** (2.77)		0.7083 (1.65)
MGT	0.6348** (2.62)	-0.2336 (-0.82)		-0.6210* (-2.25)
Firm FE	No	Yes	Yes	Yes
Industry-Year FE	No	No	Yes	Yes
Observations	5.785	5.785	5.785	5.785
Adjusted R^2	0.33	0.74	0.74	0.77

Panel B. Covariate Balance

Sample	Control	Treatment	Diff	T-stats
SIZE	22.37 21.99	21.75 21.98	0.62 0.01	30.82 0.01
ROA	0.03 0.03	0.05 0.04	-0.01 -0.00	-16.46 -0.17
AGE	2.33 2.44	1.92 2.25	0.41 0.19	30.29 0.51
LEV	0.48 0.42	0.37 0.39	0.11 0.03	34.27 0.28
TQ	2.01 1.96	2.41 2.38	-0.39 -0.42	-16.39 -0.69
CASH	0.17 0.18	0.20 0.19	-0.04 -0.01	-18.11 -0.12
CAPEX	0.05 0.04	0.05 0.05	-0.01 -0.01	-7.09 -0.24
RD	0.02 0.02	0.05 0.05	-0.03 -0.03	-59.94 -1.72
GR	0.20 0.20	0.19 0.18	0.00 0.02	0.28 0.06
INST	0.06 0.06	0.06 0.07	-0.00 -0.01	-2.96 -0.22
MGT	0.07 0.07	0.15 0.11	-0.07 -0.04	-25.73 -0.49

matching (PSM) [106]. After excluding observations that did not meet the common support condition for 1:1 nearest-neighbor PSM, we obtained 2,893 matched pairs. Panel A of Table 5 presents PSM-DID estimation results, which largely replicate baseline findings.

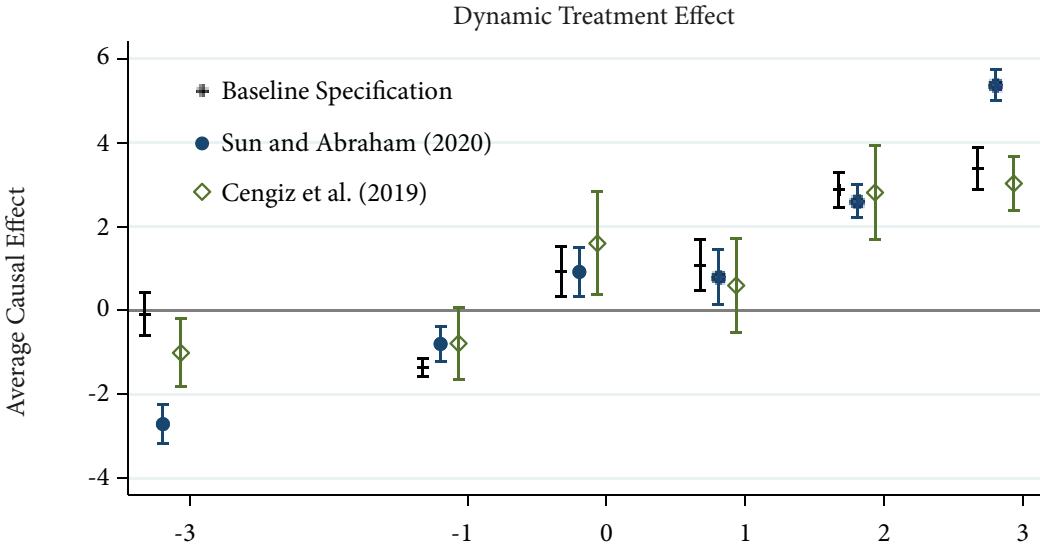
Parallel Trend Test

A key DID assumption is parallel trends in the pre-intervention period. We assess this by estimating dynamic treatment effects, replacing ADP with interactions between TREAT and period dummies for three years before and after ADP.

Given the staggered treatment, standard DID results could be biased [107]. Solutions include interaction-weighted estimation [108] and "stacked" regression [109].

Figure 2 shows pre-intervention interactions are non-positive and insignificant. Post- ADP, the effect becomes significantly positive and increases, satisfying the parallel trend assumption. Results remain consistent with alternative DID specifications.

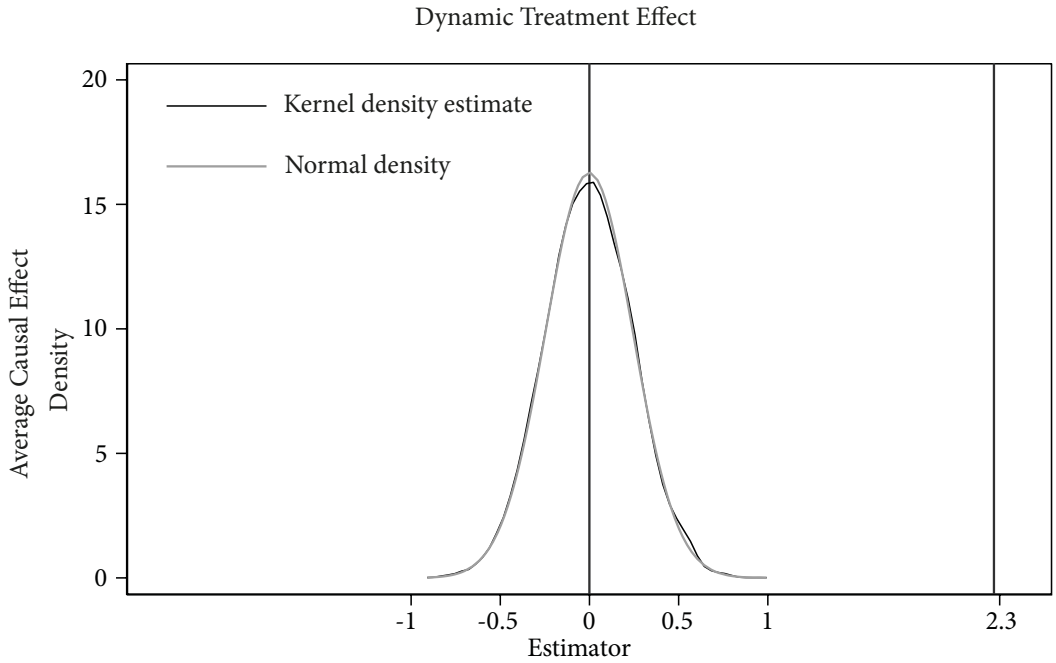
Figure 2. Parallel Trend Test



Placebo Test

We conduct a placebo test to rule out other events or shocks. We randomly assign ADP values via 5,000 Monte Carlo permutations [110] and re-estimate pseudo- intervention effects. Figure 3 shows the baseline estimate is outside the random distribution, suggesting that our effect is unlikely to be driven by other factors.

Figure 3: Placebo Test



Additional Robustness Checks

We conduct additional robustness checks for omitted-variable, functional-form, and sample- selection biases. We control for the 2012–016 BT-to-VAT reform [45], corporate effective tax rate, and depreciation expense scaled to fixed assets [41].

Panel A of Table 6 shows that accounting for BT-to-VAT reform does not materially alter the ADP effect. Controlling for effective tax rate and depreciation leads to a minor decrease in magnitude but remains significant at the 5% level.

We then test alternative model specifications: ordered regression (as CS is an ordinal score), dynamic panel models (for pre-ADP sustainability), and instrumental variable regression (for unobservable factors). We also add province-level fixed effects for provincial differences. For instrumental variable regression, we use the province's dependence on secondary industry (manufacturing sector's GDP share) as an instrument, assuming higher manufacturing concentration encourages ADP participation but industry composition doesn't directly impact sustainability. Panel B of Table 6 shows baseline statistical significance is unaffected by model specification changes.

Regarding alternative sampling criteria, we consider the factors influencing CSR investment after tax incentives [23; 41; 47]. First, we exclude treatment group observations during ADP's first year, as implementation occurred in the second half, limiting immediate firm response. Second, we remove firms in western provinces due to the additional tax benefits available there.[5] Third, we ex-

Table 6. Additional Robustness Checks

This table presents additional robustness checks for the ADP effect on corporate sustainability for a sample of Chinese A-share firms from 2012 to 2017. The dependent variable is CS in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the firm are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

Panel A. Additional controls

	(1) Incl. BT-to-VAT reform	(2) Incl. tax rate and depreciation
ADP	0.2298*** (3.02)	0.2209** (2.70)
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes
Observations	13.386	13.352
Adjusted R^2	0.76	0.76

Panel B. Alternative model specifications

	(1) Ordered Logit	(2) Ordered Probit	(3) Dynamic Panel	(4) Static Panel
ADP	0.2624*** (4.27)	0.1562*** (4.27)	0.2610*** (3.51)	0.2311*** (2.92)
L1.CS		0.1578*** (15.03)		
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Province FE	No	No	No	Yes
Observations	13.740	13.740	13.334	13.386
Adjusted R^2 / Pseudo R^2	0.09	0.09	0.77	0.76

[5] Western provinces of China include Chongqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Tibet, Xinjiang, and Yunnan.

	Instrumental variable regression	
	(5) ADP	(6) CS
SECONDRATIO	0.9670** (2.43)	
ADP		0.8811** (3.58)
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes
Observations	13.386	13.386
Adjusted R^2	0.66	0.05

Panel C. Alternative sampling criteria

	(1) Excl. policy starting year	(2) Excl. western provinces	(3) Excl. exporting firms	(4) Excl. high-tech firms
ADP	0.2454*** (3.19)	0.2353*** (3.15)	0.4694** (2.42)	0.2094** (2.36)
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Observations	12.223	11.467	5.804	11.329
Adjusted R^2	0.76	0.76	0.77	0.76

clude exporting firms due to export-specific tax benefits. Finally, we exclude high-tech firms, which have an *ex-ante* lower tax rate (15% vs. standard 25%) [47]. Panel C of Table 6 shows the ADP effect magnitude slightly decreases only when high-tech firms are excluded. For other subsamples, the effect magnitude increases at the 5% significance level.

Further Discussion

Firm Heterogeneity

We hypothesize that the sustainability response to ADP depends on labor intensity, firm visibility, likelihood of long-term bank credit, and ownership structure.

Corporate labor intensity is a key moderator. Labor-intensive firms have a lower initial capital-to-labor ratio. When ADP is introduced, marginal returns on new capital investments might be higher for these firms, making ADP more attractive [111]. They can also adjust production processes more easily [112]. Evidence from China shows ADP's TFP effect is stronger for labor-intensive firms [22]. We divide the sample by labor intensity (and indirectly, capital intensity) to differentiate.

Firm visibility is another strong moderator. Highly visible firms face greater stakeholder pressure, motivating sustainability initiatives to enhance legitimacy and reputation [70; 90].

Increased visibility also heightens the risk of negative attention during failures, necessitating legitimacy maintenance [113; 114]. We hypothesize ADP's positive effect is stronger in firms with greater visibility, measured by media and analyst coverage [115; 116].

The probability of obtaining long-term bank credit moderates short-term leverage. Smaller firms with fewer financial guarantees typically face disadvantages in obtaining long-term credit [117; 118]. Chinese evidence shows ADP's increasing effect on short-term debt is more pronounced in firms with weak long-term financing capacity [26], smaller size, and lower asset tangibility [25]. Thus, we hypothesize ADP's sustainability effect concentrates in smaller firms and those with lower asset tangibility.

Finally, state control and political connections are crucial in China. State-controlled firms often have soft budget constraints [119], potentially leading to weaker ADP responses. Politically connected firms receive preferential external financing, reducing financial constraints [120; 121].

Stronger financial constraints lead to a stronger response to tax savings from ADP and thus greater fixed investment [3]. Literature on Chinese ADP confirms this [22; 26]. State-owned enterprises (SOEs) also prioritize public welfare [122], making their sustainability efforts less ADP-dependent. We hypothesize ADP's positive effect is significant only among non-state-controlled or politically connected firms. SOEs are firms with significant state control, while political connections are indicated by a firm-level China Communist Party branch (Party branch), which exists in both SOEs and non-SOEs to communicate Party agenda and monitor compliance [123].

We test moderating roles by forming subsamples based on median moderator proxies and comparing baseline estimates, as well as performing coefficient equality tests. Panel A of Table 7 shows ADP's effect is positive and significant only in firms with higher labor and lower capital intensity (p-value of equality test near zero), confirming labor intensity is critical. This aligns with theory: flexible, labor-intensive firms benefit more from new capital investments.

Panel B of Table 7 reveals ADP's positive effect on CSR performance is significant only among firms with higher visibility (media and analyst coverage). The coefficient equality hypothesis is rejected at 1% significance. This supports our prediction that more visible firms have a greater need to meet stakeholder demands and boost legitimacy/reputation, lending credibility to our conceptual framework based on stakeholder and legitimacy theories.

The sensitivity of the ADP effect to long-term bank loan probability is in Panel C of Table 7. As predicted, only firms with relatively lower asset tangibility and size show a significant sustainability response. ADP coefficients differ at 5% significance. This confirms the short-term leverage channel (Section 4.3): firms less likely to obtain long-term debt rely on short-term debt, facing increased lender pressure, which benefits debtholders and other stakeholders.

Panel D of Table 7 highlights the difference in ADP response based on state control or political connections. Only firms without state control and political connections, facing greater financial constraints, increase corporate sustainability in response to ADP. This aligns with Zhao and Fang [23] and Zeng and Chan [48], emphasizing financial constraints in ADP response.

Value Relevance behind Corporate Sustainability

Our framework suggests that sustainability initiatives confer competitive advantage, positive image, and recognition. To support this, we posit that increased sustainability performance has value-relevant consequences: corporate profile, economic value added (EVA), and stock liquidity.

Table 7. Cross-Sectional Heterogeneity

This table presents the heterogeneity of the ADP effect on the corporate sustainability for a sample of Chinese A-share firms from 2012 to 2017. The sample is divided into two parts based on the median value of moderators in year t. Labor intensity is workforce headcount over total assets. Capital intensity is the natural logarithm of fixed assets over workforce headcount. Media coverage is the number of web articles whose titles mention the firm. Analyst coverage is the number of analysts following a firm. Tangibility is the ratio of fixed assets to total assets. Size is the natural logarithm of total assets. SOE is a dummy indicator of significant state control. Political connections is a dummy indicator of whether a firm has established a Party branch. The dependent variable is CS in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the firm are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

Panel A. Labor intensity

	Labor intensity		Capital intensity	
	(1)	(2)	(3)	(4)
	Low	High	Low	High
ADP	-0.0863 (-0.28)	0.1669*** (2.98)	0.3675** (2.61)	-0.3138 (-1.03)
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Observations	6.143	6.159	5.792	6.424
Adjusted R^2	0.75	0.80	0.78	0.76
Coefficient equality	0.00		0.01	

Panel B. Firm visibility

	Media coverage		Analyst coverage	
	(1)	(2)	(3)	(4)
	Low	High	Low	High
ADP	0.1780 (1.15)	0.3440** (2.35)	0.1211 (1.13)	0.2510* (1.69)
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Observations	5.772	6.600	6.345	6.260
Adjusted R^2	0.76	0.77	0.72	0.76
Coefficient equality	0.00		0.00	

Panel C. Probability of long-term bank credit

	Tangibility		Size	
	(1)	(2)	(3)	(4)
	Low	High	Low	High
ADP	0.4803*** (4.99)	0.0903 (0.60)	0.2733** (2.85)	0.1037 (0.77)
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Observations	6.159	6.696	6.058	6.958
Adjusted R^2	0.77	0.78	0.71	0.77
Coefficient equality	0.03		0.04	

Panel D. State control and political connections

	State control		Political connections	
	(1)	(2)	(3)	(4)
	SOE	Non-SOE	Yes	No
ADP	-0.0724 (-0.42)	0.2952** (2.42)	0.1140 (0.86)	0.3016** (2.28)
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Observations	4.965	8.290	7.638	5.309
Adjusted R^2	0.79	0.74	0.78	0.75
Coefficient equality	0.01		0.03	

Sustainable practices positively affect corporate legitimacy, attracting consumers, in- vestors, and employees, leading to a favorable corporate profile. They can also reduce costs, mitigate risks, and identify new revenue streams, increasing EVA. Firms engaged in sustainability may be perceived as less risky and more transparent, boosting investor confidence, trading volumes, and stock liquidity [124–126].

To investigate value-relevant consequences, we employ:

$$VAL_{i,t} = \beta CS_{i,t} + \gamma Controls_{i,t} + \delta_i + \theta_{j,t} + \epsilon_{i,t}, \quad (4)$$

where $VAL_{i,t}$ denotes PROFILE (difference in positive/negative web media news scaled by total news), EVA (per-share net operating after-tax profit adjusted by capital and WACC), and LIQUID (negative logarithm of Amihud ratio).

Table 8 shows corporate sustainability has a highly significant positive effect on corporate profile, EVA per share, and stock liquidity, confirming our conceptual arguments regarding its value-relevant nature.

ADP and Environmental Engagement

The Common Prosperity Index, our primary sustainability proxy, has limited environmental coverage, mainly through environmental violations in the Other Partner Sharing sub- score. Given the importance of environmental protection, and the lack of variance in the Ecosystem Conservation and Environmental Protection sub-score (Section "Performance of Corporate Sustainability Indica-

Table 8. Value Relevance of Corporate Sustainability

This table illustrates the effect of corporate sustainability on value-relevant outcomes for a sample of Chinese A-share firms from 2012 to 2017. The dependent variables are PROFILE, EVA, and LIQUID in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the firm are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

	(1) PROFILE	(2) EVA	(3) LIQUID
CS	0.0065*** (4.71)	0.0040*** (4.33)	0.0108** (2.27)
SIZE	0.0148** (2.51)	0.0021 (0.36)	0.3998*** (16.81)
ROA	1.0967*** (7.75)	1.4596*** (38.25)	1.4416*** (7.64)
AGE	-0.0644*** (-5.02)	-0.0363*** (-3.34)	0.3060*** (5.49)
LEV	0.0434** (2.49)	0.0931*** (6.30)	-0.2933*** (-3.53)
TQ	0.0016 (0.57)	0.0005 (0.69)	0.0829*** (8.22)
CASH	0.0038 (0.12)	-0.0634*** (-3.04)	0.0882 (1.10)
CAPEX	0.1569*** (3.57)	-0.0775** (-2.18)	0.7441*** (4.34)
RD	0.0198 (0.15)	0.2248*** (6.36)	0.7380* (1.91)
GR	0.0156* (1.78)	0.0188*** (3.73)	-0.0580*** (-3.80)
INST	0.3496*** (7.72)	0.0888*** (3.38)	-0.7431*** (-6.38)
MGT	0.1191*** (4.84)	-0.0174 (-0.80)	0.0202 (0.19)
Firm FE	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes
Observations	13.375	11.335	13.386
Adjusted R^2	0.42	0.58	0.71

tors"), we explore ADP's effect on environmental engagement using other data.

We evaluate equation 1 with environmental engagement proxies as the dependent variable. We use environmental sub-scores from the Sino-Securities ESG Index (SSI) and the Hexun CSR score (HEXUN) for environmental performance. For environmental disclosure, we use CSMAR (environmental protection and sustainable development disclosure indicator) and BLOOMBERG (environmental sub-score of Bloomberg ESG disclosure), recognized sources for corporate data [127; 128].

Columns (1) and (2) of Table 9 show ADP's positive and significant effect on environmental performance, consistent with Tang and Wang [14] and Zhao and Peng [28]. Columns (3) and (4) provide evidence that ADP implementation increases environmental disclosure, aligning with signaling theory.

Conclusion

Investment incentives are crucial for global economic growth, but sustainable development demands balancing

Table 9. Accelerated Depreciation Policy and Environmental Engagement
This table presents the effect of ADP on environmental performance and disclosure for a sample of Chinese A-share firms from 2012 to 2017. The dependent variables are SSI, HEXUN, CSMAR, and BLOOMBERG in year t. Variable definitions are shown in Table A2. The robust *t*-statistics clustered by the firm are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

	Environmental performance		Environmental disclosure	
	(1) SSI	(2) HEXUN	(3) CSMAR	(4) BLOOMBERG
ADP	0.0320*	0.0585**	0.0318**	0.0673***
	(2.32)	(2.77)	(2.42)	(3.70)
SIZE	0.2472***	0.0826***	0.0773***	0.0316
	(8.56)	(6.15)	(12.15)	(1.37)
ROA	0.7283**	0.2084**	0.3741***	0.4496***
	(3.10)	(2.51)	(3.44)	(2.88)
AGE	-0.0389	0.1541	0.0219**	0.1497
	(-1.52)	(1.73)	(2.03)	(1.27)
LEV	-0.0551	-0.0778	-0.0646*	0.1716**
	(-0.81)	(-1.69)	(-1.70)	(2.59)
TQ	-0.0045	0.0096**	-0.0035	-0.0036
	(-0.62)	(2.70)	(-0.81)	(-0.41)
CASH	-0.2189**	-0.1057**	-0.2415***	0.2407***
	(-2.80)	(-2.78)	(-5.21)	(2.96)
CAPEX	0.0549	0.0751	0.2215**	-0.0860
	(0.40)	(0.71)	(1.97)	(-0.44)
RD	-1.1609	0.1494	-0.6234***	-0.0279
	(-1.96)	(1.04)	(-3.38)	(-0.13)
GR	-0.0997**	-0.0011	-0.0584***	-0.0117
	(-4.26)	(-0.17)	(-7.35)	(-0.70)
INST	0.1748	0.2155***	-0.1391*	0.0821
	(0.95)	(3.09)	(-1.84)	(0.58)
MGT	0.0960**	-0.1492**	-0.0916**	0.5377*
	(2.80)	(-2.41)	(-2.14)	(2.00)
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Observations	13.448	13.369	13.717	4.301
Adjusted R^2	0.16	0.46	0.14	0.73

economic objectives with social and environmental issues. This study investigates the impact of China's Accelerated Depreciation Policy (ADP), implemented from 2014-2015, on corporate sustainability using a DID approach.

Our research finds that investment incentives promote corporate sustainability, par- ticularly in employment, remuneration, and sharing with shareholders, debtholders, and distributors. The DID model is validated by various robustness checks. This effect is primarily channeled through increased total factor productivity (TFP) and short-term leverage, with a lesser role for workforce skill structure upgrades. Heterogeneity analysis confirms this mechanism, showing the effect is concentrated in labor-intensive firms with a lower probability of obtaining long-term bank credit. It also reveals a prevalence of effects among more visible, non-state-controlled, and non-politically connected firms, aligning with our conceptual framework. Corporate sustainability performance also has value-relevant effects, leading to a more favorable corporate profile, higher Economic Value Added (EVA), and higher stock liquidity. Finally, we demonstrate ADP's positive effect on environmental performance and disclosure.

Our findings have important implications for sustainable development in emerging markets. ADP is ineffective in capital-intensive, state-controlled firms, suggesting investment incentives need tailoring for these entities. Fostering public visibility for firms is crucial for successful government interventions in sustainability. Banks' monitoring role should also be leveraged by incorporating social and environmental indicators, which could significantly impact sustainable development in developing countries.

A limitation of our research is the lack of firm-level responsiveness data for ADP, and its focus on the Chinese market and listed firms. We call for further research comparing sustainability outcomes across developed and developing countries to inform policy recommendations in diverse institutional contexts. Future research should also explore ADP's sustainability outcomes in unlisted small and medium enterprises, which constitute a large market segment and are often government tax incentive targets. Their tight financial constraints, profit-driven mentality, and low visibility create an environment distinct from listed firms, warranting specific investigation.

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Investment Incentives and Corporate Sustainability: Evidence from China Online Appendix

Table A1. Accelerated Depreciation Policy and Other Partner Sharing

This table presents the effect of ADP on other partner sharing sub-score constituents for a sample of Chinese A-share firms from 2012 to 2017. SUPPLIER is a standardized Protection of Supplier's Rights and Interests score. DISTRIBUTOR is a reversed standardized Distributor's Rights and Interests score. DEBTINTEREST is a standardized Contribution of Interest on Debt per Share score, DEBTDEFAULT is a reversed standardized Protection of Debtor's Rights and Interests score. The results on the ADP effect on Ecosystem Conservation and Environmental Protection score are skipped due to the lack of variation in this score value. All dependent variables are measured in year t. Details on corresponding scores' measurements are presented in Table A3. Control variable definitions are shown in Table A2. The robust *t*-statistics clustered by the industry are reported in parentheses. ***, **, and * denote the significance at the 1%, 5%, and 10% levels, respectively.

	(1) SUPPLIER	(2) DISTRIBUTOR	(3) DEBTINTEREST	(4) DEBTDEFAULT
ADP	0.1858 (0.26)	-0.5312*** (-2.84)	1.5647** (2.22)	-0.0920* (-2.02)
SIZE	-3.2427*** (-5.08)	-0.1501 (-0.74)	3.8426*** (10.09)	-0.0070 (-0.30)
ROA	3.8866 (0.95)	0.0076 (0.00)	-8.0993*** (-4.18)	-0.1246 (-1.08)
AGE	1.4060* (1.99)	-0.7340** (-1.97)	-1.5140 (-1.30)	-0.0331 (-0.44)
LEV	-8.2809*** (-4.13)	-0.6137 (-0.88)	31.6616*** (13.86)	0.1323* (2.07)
TQ	-0.1574 (-1.10)	-0.1395** (-2.12)	-0.1764 (-1.48)	0.0216** (3.51)
CASH	5.3448** (2.57)	-1.8863*** (-2.66)	2.3670*** (4.42)	-0.0859* (-2.47)
CAPEX	-14.9331*** (-2.97)	-3.1569** (-2.36)	1.8259 (0.65)	0.0881 (0.36)
RD	-47.7716*** (-5.53)	4.785*** (2.84)	7.2770** (2.84)	-1.2217** (-3.61)
GR	3.5135*** (10.01)	-0.4402*** (-2.99)	-0.2462 (-0.83)	-0.0073 (-0.48)
INST	0.6567 (0.26)	-0.0016 (-0.00)	0.9832 (0.42)	0.0473 (0.36)
MGT	2.6696 (1.61)	1.2610** (2.37)	0.6501 (0.16)	-0.0778 (-0.63)
Firm FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Observations	13.386	13.386	13.065	13.386
Adjusted R^2	0.82	0.74	0.73	0.34

Table A2. Variable Definitions

Variable	Definitions
CS	Corporate Sustainability Performance: Common Prosperity rating from Enterprises' Contribution to Common Prosperity Research Database. This rating is a weighted average of HIRE, PAY, SAFE, QUAL, SHARE, OBLIG, COMP, TAX, and CHAR. The Common Prosperity rating is transformed into a score from 9 (AAA rating, the highest) to 1 (C rating, the lowest).
HIRE	Standardized Employment sub-score (out of 10).
PAY	Standardized Remuneration sub-score (out of 10).
SAFE	Standardized Employee Protection sub-score (out of 10).
QUAL	Standardized Customer Sharing sub-score (out of 10). SHARE Standardized Shareholder Sharing sub-score (out of 10). OBLIG Standardized Other Partner Sharing sub-score (out of 10). COMP Standardized Healthy Competition sub-score (out of 10). TAX Standardized Tax Contribution sub-score (out of 10).
CHAR	Standardized Public Welfare and Charity sub-score (out of 10).
TREAT	A dummy variable that equals one for firms operating in industries subject to ADP rules.
POST	A dummy variable that equals one from the year of firm industry eligibility to the ADP rules (2014 or 2015).
ADP	TREAT × POST.
SIZE	Firm Size: The natural logarithm of total assets.
ROA	Return on Assets: Net income divided by total assets.
AGE	Firm Age: The natural logarithm of listed years plus one.
LEV	Leverage: Total liabilities divided by total assets.
LTLEV	Long-Term Leverage: Long-term liabilities divided by total assets.
TQ	Tobin's Q: the sum of equity market value and liabilities book value over total assets CASH Cash Ratio: The sum of cash and cash equivalents divided by total assets.
CAPEX	Capital Expenditures Ratio: Capital expenditures over the total assets. RD R&D Expenditures Ratio: R&D expenditures over sales.
GR	Growth Rate: The growth rate of sales from year t-1 to year t.
INST	Institutional Shareholding: The proportion of shares held by institutional investors. MGT Managerial Shareholding: The proportion of shares held by the management team. TFP TFP: LP method (Levinsohn and Petrin, 2003).
STLEV	Short-Term Leverage: current liabilities over total assets.
SKILL	Skilled Labor: number of technician employees over total workforce count.
SECONDRATIO	Province Dependence on Secondary Industry: the share of province GDP contributed by secondary industry.
PROFILE	Corporate Profile: The difference in the number of positive and negative web media news about a firm, scaled by the total number of firm-related web news.
EVA	EVA per Share: EVA is calculated as after-tax net operating profit less the product of total capital and weighted average cost of capital.
LIQUID	Stock Liquidity: the negative logarithm of Amihud illiquidity measure (Amihud, 2002).
SSI	Environmental Sub-score of Sino-Securities ESG Index: a rank is transformed to a score from 9 for AAA level (the highest) to 1 for C level (the lowest).
HEXUN	Environmental Sub-score of Hexun CSR Score: the total score is 10; a higher score corresponds to a higher environmental performance.
CSMAR	Environment and Sustainable Development Disclosure Indicator from CSMAR: equals 1 in case of sufficient disclosure, 0 otherwise.
BLOOMBERG	Environmental Sub-score of Bloomberg ESG Disclosure Score: the total score is 10; a higher score corresponds to a higher environmental disclosure.

Table A3. Common Prosperity Index Methodology

Sub-Score / Determinant	Definition	Related SDG
Employment sub-score		
Number of Employees	n/a	SDG 8 “Decent Work and Economic Growth”; SDG 10 “Reduced inequalities”; SDG 5 “Gender Equality”
New Positions	Employment growth	
Gender Diversity of the Management Team	Percentage of women in management personnel	
Career Competitiveness and Career Management	Labor union and employee education expenses scaled by operating revenue	
Vulnerable Groups Care	Hiring the disabled (yes/no)	
Remuneration sub-score		
Remuneration Contribution per Share	Total employee remuneration over total number of shares	SDG 8 “Decent Work and Economic Growth”; SDG 10 “Reduced Inequalities”
Profit Sharing with Employees	Employee shareholding proportion	
Average Remuneration	n/a	
Remuneration Growth	n/a	
Average Remuneration Ratio	Senior management remuneration over remuneration of other employees	
Employee Protection sub-score		
Legal Employment	Policy or published promise preventing child labor (yes/no)	SDG 3 “Good Health and Well-Being”; SDG 8 “Decent Work and Economic Growth”; SDG 11 “Sustainable Cities and Communities”
Investment in Safe Production	Safe production investment over operating revenue	
Safe Production Level	Production accidents number	
Occupational Health Protection	Offering occupational health examination, occupational disease fund, conducting occupational health invest- ments, or occupational safety training (yes/no)	
Social Security Payment Proportion	Social Security payments over total employee remuneration	
Commercial Insurance	Commercial insurance investments over operating revenue	
Protection of Employee Rights and Interests	Number of disputes over employee’ rights and interests over total number of employees	

Sub-Score / Determinant	Definition	Related SDG
Customer Sharing Sub-Score		
Product and Service Quality	Qualified products ratio	SDG 12 "Responsible Consumption and Production"
Product Recall	Product recalls number	
Protection of Consumer Rights and Interests	Customer complaints number	
Shareholder Sharing Sub-Score		
Return on Equity	Net profit over net assets	SDG 16 "Peace, Justice and Strong Institutions"
Cash Dividend per Share	Total cash dividends over the total number of shares	
Independent Director System	Proportion of independent directors in the Board	
Other Partner Sharing Sub-Score		
Protection of Supplier's Rights and Interests	Accounts payable turnover ratio	SDG 16 "Peace, Justice and Strong Institutions"; SDG 3 "Good Health and Well-Being"; SDG 6 "Clean Water and Sanitation"; SDG 7 "Affordable and Clean Energy"; SDG 8 "Decent Work and Economic Growth"; SDG 9 "Industry, Innovation, and Infrastructure"; SDG 11 "Sustainable Cities and Communities"; SDG 13 "Climate Action"; SDG 14 "Life Below Water"; SDG 15 "Life on Land"
Protection of Distributor's Rights and Interests	Accounts receivable turnover ratio	
Contribution of Interests on Debts per Share	Interests on debt scaled by total number of shares	
Protection of Debtor's Rights and Interests	Number of debt violations for which the company is accountable	
Ecosystem Conservation and Environmental Protection	Number of environmental violations for which the company has been sanctioned	
Healthy Competition sub-score		
Competitor Cooperation or Alliance	Number of lawsuits among competitors over unfair competition, dumping, and anti-dumping	SDG 16 "Peace, Justice and Strong Institutions"
Fair Competition	Involved in disputes over unfair com- petition, dumping, and anti-dumping (yes/no)	
Tax Contribution sub-score		
Tax Contribution per Share	Annual taxes and surcharges scaled by the total number of shares	Goal 17 "Partnership for the Goals"

Sub-Score / Determinant	Definition	Related SDG
Public Welfare and Charity sub-score		
Donation	The total amount of public and private welfare donations over operating revenue.	SDG 1 "No Poverty"; SDG 2 "No Hunger"; SDG 4 "Quality Education"; SDG 6 "Clean Water and Sanitation"; SDG 7 "Affordable and Clean Energy"; SDG 11 "Sustainable Cities and Communities"
Investment in Poverty Alleviation	Poverty alleviation investments scaled by operating revenue	
Number of Disadvantaged Students Funded by the Company	n/a	
Investment in Poverty Alleviation and Rural Revitalization	Poverty alleviation and rural revitalization investments scaled by operating revenue	

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