The power trio: leveraging ESG and R&D for breakthrough green innovation in ASX companies

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Yazan Almnadheh and Afzalur Rashid
School of Business, University of Southern Queensland, Toowoomba, Australia
Eltayyeb Al-Fakir Al Rabab'a
School of Business, Victoria University, Melbourne, Australia, and
Syed Shams
School of Business, University of Southern Queensland, Springfield, Australia

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Abstract

Purpose – This study aims to examine how environmental, social and governance scores (ESGSs) influence the relationship between research and development investment (RDI) and green innovation among Australian Securities Exchange-listed firms.

Design/methodology/approach – The study uses panel data from 1,097 firm-year observations covering the period 2010–2024. Ordinary least squares regression models are employed to test the relationships between RDI, ESGS and green innovation, measured by the environmental innovation score. Robustness checks include alternative model specifications, instrumental variable estimation using two-stage least squares, and exclusion of the COVID-19 period (2020–2021).

Findings – The results indicate that both RDI and ESGS are positively associated with green innovation. Furthermore, the interaction between RDI and ESGS is positive and significant, suggesting that firms with strong ESG performance achieve higher green innovation outcomes from their RDI. The findings support stakeholder theory and the resource-based view, highlighting the role of intangible assets such as reputational capital and stakeholder trust in enhancing sustainable innovation.

Research limitations/implications – The study is limited by its reliance on observational data, which constrains causal inference, and its focus on Australian firms, which may limit generalizability. Future research could adopt cross-country comparisons or dynamic panel approaches to extend these findings.

Originality/value – This study contributes to the literature by demonstrating the complementary role of ESG performance in enhancing the effectiveness of RDI in driving green innovation. It provides empirical evidence that sustainability and innovation are strategically aligned, offering practical insights for firms and policymakers to promote ESG integration and eco-friendly R&D initiatives.

Keywords R&D investment, GREEN innovation, ESG scores, REGRESSION models, ASX-listed enterprises

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1. Introduction

Environmental, social and governance (ESG) performance has emerged as a critical factor shaping corporate strategy and investment decisions in the context of global sustainability goals. Policymakers, investors and corporate leaders increasingly recognize that long-term economic growth must be aligned with ecological stewardship and social equity (Almnadheh *et al.*, 2025; Mohy-ud-Din, 2024). While ESG is often conflated with corporate social responsibility (CSR), it differs significantly in its emphasis on measurable, standardized indicators that assess firm-level performance across environmental impact, labor practices and governance structures (Chen *et al.*, 2023; Mukhtar *et al.*, 2024). These quantifiable ESG metrics – aggregated into composite ESG scores (ESGSs) – are now widely used by capital markets and regulatory bodies to evaluate risk exposure, guide investment decisions, and benchmark sustainable performance (Li and Li, 2024; Zhou *et al.*, 2024). At the same time, the ESG literature highlights ongoing debates regarding materiality, indicating that the relative importance of environmental (E), social (S) and governance (G) dimensions varies across sectors, with environmental factors often more directly related to innovation outcomes, while governance structures shape oversight and resource allocation, and social dimensions influence stakeholder engagement and legitimacy (Zhang *et al.*, 2024a; Zhou *et al.*, 2024).

Despite increasing scholarly attention on ESG's influence on financial and strategic outcomes, its role in driving innovation, particularly green innovation, remains insufficiently understood. Innovation, especially in environmentally beneficial technologies, is both resource-intensive and uncertain, yet it is vital for maintaining competitiveness in a transitioning, decarbonized economy (Lan *et al.*, 2025; Qian, 2024). While prior studies suggest that strong ESG performance is positively related to lower capital costs, enhanced reputational capital, and reduced regulatory risks (e.g. AlKhouri and Suwaidan, 2023; Bhuiyan and Nguyen, 2020; Cajias *et al.*, 2014), less is known about how ESG interacts with key innovation inputs – such as research and development (R&D) investment – to generate tangible green innovation output. Comparative evidence from the European Union and China indicates that ESG engagement is positively related to green innovation outputs, particularly under stringent environmental regulations and active capital market monitoring; however, these relationships appear context-dependent and may vary in settings such as Australia, where regulatory enforcement and market pressures follow a hybrid model (Zhang *et al.*, 2024a; Zhou *et al.*, 2025).

This constitutes a significant research gap. Specifically, we lack a clear understanding of whether and how ESG performance is associated with the effectiveness of R&D expenditure in producing breakthrough green innovations. Moreover, while recent conceptual work suggests that ESG may serve as an enabler or moderator of innovation processes (Wang and Chu, 2024; Zhang *et al.*, 2024a), these claims remain largely correlational or theoretical, with limited empirical validation of the underlying mechanisms.

To address this gap, we examine how ESG performance is related to the relationship between R&D investment and green innovation output. Drawing on the resource-based view (RBV) and stakeholder theory, we propose that firms with higher ESG performance tend to possess superior intangible resources – such as legitimacy, stakeholder trust and access to green financing – that are positively associated with an enhanced capacity to convert R&D expenditure into impactful green innovations. Furthermore, we introduce a novel conceptual framework that integrates institutional pressures, organizational capabilities and stakeholder expectations to explain how firms achieve innovation efficiency in sustainability contexts.

Our empirical focus on publicly listed firms in Australia offers a unique and timely setting for examining these relationships. Australia ranks relatively well in global environmental indices but remains economically dependent on carbon-intensive industries such as mining and fossil fuels (Sarkodie and Strezov, 2018). This juxtaposition creates a compelling tension between economic imperatives and environmental accountability, making firms in Australia a fertile ground for studying the drivers of green innovation.

Importantly, Australia's institutional environment provides a distinctive regulatory backdrop for ESG-related disclosures and corporate accountability. In 2007, the Australian Securities Exchange (ASX) mandated enhanced corporate governance and sustainability reporting under its Corporate Governance Council Principles (Wedari *et al.*, 2023). This regulatory evolution has created variation in ESG maturity across firms, enabling our study to explore how differing levels of ESG performance are associated with differences in the returns to R&D investment.

Furthermore, compared to more mature ESG markets such as the European Union (EU) and North America – where investor activism and stringent climate policies play a central role in shaping ESG integration – Australia's market reflects a hybrid model that combines voluntary initiatives with emerging mandatory frameworks. This institutional heterogeneity allows our study to examine how ESG performance operates within a middle-income, resource-dependent economy undergoing structural transformation, offering insights that extend beyond Western-centric narratives and complement existing evidence from China and the EU.

The ASX provides a particularly instructive setting for examining ESG–innovation relationships. Established on 1 April 1987 through the amalgamation of six independent state-based stock exchanges under the *Australian Stock Exchange and National Guarantee Fund Act 1987*, the ASX ranks among the top-20 exchanges globally by market capitalization and spans a broad cross-section of industries, from resource extraction and financials to healthcare and technology (ASX, 2024). Listed entities are subject to oversight by the Australian Securities and Investments Commission (ASIC) and must comply with the ASX Listing Rules, which govern continuous disclosure and corporate governance standards. A pivotal institutional development was the introduction of the ASX Corporate Governance Council's *Corporate Governance Principles and Recommendations* (now in its fourth edition, released in 2019), which operate on an "if not, why not" basis: listed entities must either adopt the recommendations or publicly explain noncompliance (ASX Corporate Governance Council, 2019; Wedari *et al.*, 2023). This comply-or-explain mechanism has progressively embedded ESG considerations into board-level governance and strategic decision-making. More recently, mandatory climate-related financial disclosures aligned with International Sustainability Standards Board (ISSB) standards commenced on 1 January 2025 under the *Treasury Laws Amendment (Financial Market Infrastructure and Other Measures) Act 2024*, signaling a decisive shift from voluntary to compulsory ESG transparency (Treasury Laws Amendment Act, 2024). This evolving regulatory landscape has generated substantial variation in ESG engagement across ASX firms – variation that our empirical design is well placed to exploit. At the same time, the ASX's concentration in carbon-intensive sectors such as mining, energy and materials (representing over 30% of sample observations in this study) creates a compelling context for examining whether ESG performance conditions the returns to R&D investment in green innovation.

Our contribution is threefold. First, we shift the focus of ESG research from predominantly financial outcomes to innovation efficiency, particularly in the green innovation domain where empirical evidence remains limited. Second, we develop and test a novel conceptual model that explicates how ESG performance is associated with variation in the R&D–green innovation link through institutional, resource-based and stakeholder mechanisms. Third, by centering our analysis on Australian firms, we contribute to a more geographically diverse understanding of ESG–innovation dynamics and underscore the importance of institutional context in shaping sustainable innovation strategies.

The remainder of the paper proceeds as follows: Section 2 reviews relevant literature and develops the study's conceptual framework. Section 3 outlines the methodology, data sources and definitions of variables, while Section 4 presents the study's empirical results and their interpretation. Section 5 concludes the paper with the study's theoretical and practical implications, as well as suggestions for future research.

2. Review of literature and formulation of hypotheses

2.1 Research and development and green innovation

Understanding how firms generate green innovation requires more than a descriptive account of R&D inputs and environmental outcomes – it necessitates a theoretical framework that explains why and how R&D is associated with sustainable innovation. Drawing on the RBV and absorptive capacity theory, in this section, R&D is conceptualized as a strategic resource that enables firms to assimilate external knowledge, develop new competencies, and reconfigure internal capabilities toward sustainability goals.

From an RBV perspective, R&D functions as a critical organizational capability that underpins competitive advantage by enabling firms to create unique products, processes, or systems (Barney, 1991). In the context of green innovation, R&D investment enables firms to develop proprietary technologies that reduce environmental harm while enhancing operational efficiency. However, not all R&D is associated with green innovation. Absorptive capacity, that is, the ability to recognize, assimilate and apply new knowledge, mediates this process (Cohen and Levinthal, 1990). Firms with sustained R&D efforts tend to be better positioned to absorb external scientific and technological developments, which may facilitate the development of novel green solutions.

Innovation theory further refines this understanding. Schumpeterian dynamics distinguish between incremental and radical innovation, emphasizing the role of entrepreneurial activity in disrupting existing production paradigms (Schumpeter, 1959). In the case of green innovation, radical shifts often require substantial R&D investment to overcome path dependencies in carbon-intensive industries. This is particularly relevant for Australian firms, many of which operate in sectors such as mining, energy and heavy manufacturing, where technological lock-in poses barriers to sustainability transitions (Sarkodie and Strezov, 2018). Beyond Schumpeterian dynamics, systems-of-innovation theory highlights that firm-level R&D does not generate innovation in isolation; rather, innovation emerges from the interaction between firms, institutions and the broader knowledge environment (Lundvall, 2010). From this perspective, a firm's ESG performance can be understood as a systemic enabler – it signals embeddedness within networks of stakeholders, regulators and knowledge partners that collectively enhance the absorptive and generative capacity required for green technological advance. This insight connects directly to the findings of the present study: the positive and significant ESG × RDI interaction effect suggests that R&D investment translates more effectively into green innovation when firms are institutionally and socially embedded through strong ESG performance. Furthermore, socio-technical transition theory (Geels, 2002) posits that green innovation is shaped by multilevel interactions between technological niches, socio-technical regimes and broader landscape pressures. Firms with high ESG performance may be better positioned to align their R&D activities with the niche-level experiments and regime-level expectations that drive sustainability transitions – an interpretation consistent with the moderating role of ESGS documented in this study. Together, innovation theory's emphasis on systemic embeddedness, knowledge networks and regime alignment provides an additional theoretical lens through which the ESG–R&D–green innovation nexus can be understood, complementing the resource-based and stakeholder perspectives developed in the following section.

Empirical studies confirm that R&D intensity is positively related to green innovation output, especially when firms engage in internal R&D rather than relying on external technology acquisition (Zhang *et al.*, 2024b). Internal R&D fosters deeper learning and customization, allowing firms to tailor innovations to their specific environmental and operational contexts. For example, Chen *et al.* (2024) find that firms investing in process innovation are more likely to be associated with cleaner production technologies, while those focusing on product innovation are more likely to be associated with greener offerings. However, these effects are not uniform across industries or institutional settings. In developing economies, green innovation is often constrained by weak regulatory enforcement and limited access to green financing (Li *et al.*, 2023b), whereas in developed economies, like Australia, stronger ESG disclosure requirements and stakeholder pressures are associated with greater returns to R&D investment. Similarly, evidence from the European Union suggests that stricter environmental regulations and policy incentives are positively related to green innovation outcomes, while studies from China highlight the role of government intervention and ESG-related policies in shaping the effectiveness of R&D investment (Zhang *et al.*, 2024a; Zhou *et al.*, 2025). In contrast, emerging markets often exhibit weaker or more heterogeneous relationships due to institutional gaps and financing constraints, underscoring regional differences in how R&D translates into green innovation.

Importantly, recent research challenges the assumption of a linear relationship between R&D and green innovation. Wang *et al.* (2024a) suggest that the effectiveness of R&D is associated with firm-level governance structures, leadership commitment, and the presence of cross-functional teams focused on sustainability. Similarly, collaborative R&D initiatives – particularly those involving universities or government agencies – are associated with enhanced innovation performance by pooling complementary resources and reducing uncertainty (Li *et al.*, 2023a). These findings underscore the importance of contextualizing R&D–green innovation linkages within broader organizational and institutional frameworks.

Despite the growing body of evidence, significant gaps remain. First, most studies treat R&D as a homogeneous input, neglecting distinctions between exploratory and exploitative R&D or between product-oriented and process-oriented innovation. Second, few studies examine how institutional environments *are associated with differences in* the R&D–green innovation relationship. Finally, while green patents are often used as proxies for innovation output, they may not fully capture the complexity of implementation, diffusion or impact across different sectors. Addressing these limitations is essential for advancing both theory and practice.

Building on this analysis, we refine our hypothesis to reflect a contextualized and conditional view of R&D's role in green innovation:

H1. A positive relationship exists between research and development (R&D) and green innovation.

2.2 High environmental, social and governance scores strengthen the relationship between research and development and green innovation

This section argues that environmental, social and governance scores (ESGSs) moderate the relationship between firms' R&D investment and their capacity to generate green innovation. Drawing on stakeholder theory and the RBV, we propose that a high ESGS is associated with stronger internal capabilities and external legitimacy, thereby being positively related to higher returns on R&D in the form of sustainable technological advances. This moderate effect is particularly relevant in industries where environmental performance is increasingly scrutinized by regulators, investors and consumers (Ji *et al.*, 2025; Zhou *et al.*, 2025).

Stakeholder theory suggests that firms with strong ESG performance tend to be better aligned with societal expectations, especially regarding environmental responsibility (Freeman and Phillips, 2002). By proactively addressing stakeholder concerns – such as climate change, labor rights or governance transparency – firms are more likely to secure broader support from key constituencies. This legitimacy is associated with reduced reputational risk and facilitates access to critical resources such as capital, talent and regulatory approval (Farooq *et al.*, 2024; Qian, 2024). In turn, this is positively related to a firm's ability to pursue long-term innovation goals, including green technologies.

Complementing this, the RBV emphasizes that competitive advantage arises from resources that are valuable, rare, inimitable and non-substitutable (Barney, 1991). A high ESGS can be interpreted as reflecting the presence of such strategic resources – such as reputational capital, organizational culture and stakeholder relationships – that are not easily replicated by competitors. For instance, firms with superior environmental practices are more likely to develop unique capabilities in clean production, supply chain transparency or energy efficiency (Chang and Wang, 2024), which become embedded in their operational DNA and are associated with ongoing innovation efforts (Wang *et al.*, 2024b).

Together, these theories suggest that the ESGS does more than reflect compliance – it appears to shape the conditions under which R&D investment translates into green innovation outcomes. Firms with a high ESGS tend to benefit from both favorable external perceptions and enhanced internal capabilities, creating an environment where innovation is more likely to occur.

We define the ESGS as a composite indicator reflecting a firm's performance across environmental stewardship, labor practices and corporate governance. These scores are typically sourced from third-party ratings agencies, such as Morgan Stanley Capital International (MSCI) or Sustainalytics, although some studies use custom-built indices based on publicly disclosed sustainability metrics (Dai and Zhu, 2024; Zhang *et al.*, 2024a). Importantly, unlike general CSR initiatives – which may be project-specific or *ad hoc* – the ESGS provides a quantifiable, time-series measure of a firm's commitment to sustainable practices.

Building on Guerrero-Villegas *et al.* (2018) who find that CSR mediates the relationship between innovation and performance, we extend this insight by proposing that the ESGS operates as a moderator rather than simply as a mediator. While mediation explains how CSR influences outcomes through intermediate variables, moderation explains under what conditions R&D leads to green innovation. Specifically, we argue that the ESGS is associated with altering the strength and direction of the R&D–green innovation link by shaping the institutional and resource environments in which firms operate.

Three interrelated mechanisms explain how the ESGS strengthens the relationship between R&D investment and green innovation. First, firms with high ESGSs are generally perceived as more trustworthy, responsible and forward-thinking, which is positively related to their ability to attract funding for green innovation projects (Li *et al.*, 2023a; Mohy-ud-Din, 2024). Investors and financial institutions tend to view these firms as lower risk, especially in industries that require significant upfront investment in sustainable technologies (Qian, 2024; Zhou *et al.*, 2023). As Zhang *et al.* (2024a) highlight, improved access to capital enables firms to allocate more resources to R&D, thereby accelerating the development and commercialization of green patents – an important indicator of green innovation output. In this way, ESG performance serves as a credible signal to the market, reinforcing investor confidence and facilitating financial support for sustainability-driven innovation.

Second, strong ESG performance is positively related to cleaner production methods and enhanced operational efficiency (Wang *et al.*, 2024b). Firms with high ESGSs often implement energy-efficient processes and invest in renewable energy sources (Chang and Wang, 2024). These practices not only reduce operating costs and improve resource utilization but also are associated with creating internal capacity for further innovation. Moreover, such firms typically foster a culture of continuous improvement and environmental stewardship, which is positively related to the development of green innovation (Dai and Zhu, 2024). By embedding sustainability into core operations, firms are better positioned to innovate in environmentally conscious ways.

Third, firms with strong ESG performance tend to be better equipped to anticipate and adapt to evolving environmental regulations (Lan *et al.*, 2025). They are also more responsive to shifting consumer preferences toward eco-friendly products (Ji *et al.*, 2025). This dual responsiveness appears to help firms take advantage of policy incentives, such as tax breaks or subsidies for green technologies, while also capturing emerging market opportunities. As Luan and Wang (2023) observe, ESG-driven firms are associated with reduced capital costs due to lower perceived risks, enabling them to scale green innovations more quickly and effectively. Thus, high ESG performance not only is linked to mitigating regulatory risk but also enhances strategic agility in pursuing green innovation.

It is important to distinguish between the ESGS and broader CSR initiatives. While CSR initiatives often reflect voluntary actions or philanthropy, the ESGS represents a structured, measurable approach to sustainability performance. Unlike CSR, which can serve as a mediator (Guerrero-Villegas *et al.*, 2018), the ESGS functions as a moderator as it influences the conditions under which R&D leads to green innovation. This distinction is crucial for hypothesis formulation and empirical testing. Based on the above arguments, we propose the following testable hypothesis:

H2. The relationship between research and development (R&D) and green innovation is stronger for firms with high environmental, social and governance scores (ESGSs).

3. Data and research methods

3.1 Selection of the sample

Our final sample comprises 1,097 firm-year observations from ASX-listed firms included in the London Stock Exchange Group (LSEG) database, following the exclusion of 1,938 observations due to insufficient or inconsistent financial data. We selected ASX-listed firms for their high-quality governance and transparent reporting, both of which support rigorous empirical analysis (Qian, 2024; Zhou *et al.*, 2023). The sample spans 11 industries, with strong representation in resource-intensive sectors such as materials (23.61%) and financials (13.31%), reflecting Australia's economic structure. This distribution indicates a degree of sectoral imbalance, as resource-intensive industries are overrepresented relative to less capital-intensive sectors, which may influence the generalizability of the findings across industries. Underrepresented sectors, such as utilities (0.46%) and information technology (4.38%), may introduce sectoral bias; however, they are aligned with local market realities. Data concentration in 2022–2024 (36.88%) reflects improved ESG disclosure practices in recent years (Dai and Zhu, 2024; Zhang *et al.*, 2024a) but also indicates a temporal concentration in more recent periods, which may limit the ability to fully capture long-term trends and introduce recency bias. While the national focus may not capture global corporate dynamics, the ASX provides a relevant context for studying ESG and green innovation, particularly in environmentally scrutinized sectors (Ji *et al.*, 2025; Lan *et al.*, 2025), despite potential limitations in statistical power for smaller industries. Table 1 provides the details of sample selection and distribution.

3.2 Definitions of variables

This study investigates how sustainable practices influence both green innovation and capital investment efficiency. The primary dependent variable is the environmental innovation score (EIS), which captures a firm's capacity to develop environmentally beneficial technologies

Table 1. Sample selection and distribution

Details		Observations
Panel A – Sample selection		
Firm-year observations available in the database		3,035
Less: Firm-year observations with insufficient financial data		(1,938)
Firm-year observations in final sample		1,097
Industry	Obs.	% of sample
Panel B – sample breakdown by industry		
Communication services	37	3.37
Consumer discretionary	151	13.76
Consumer staples	58	5.29
Energy	68	6.20
Financials	146	13.31
Health care	91	8.30
Industrials	135	12.31
Information technology	48	4.38
Materials	259	23.61
Real estate	99	9.02
Utilities	5	0.46
Total	*1,097*	*100%*
Year	Obs.	% of sample
Panel C sample breakdown by year		
2010	6	0.55
2011	20	1.82
2012	21	1.91
2013	29	2.64
2014	53	4.83
2015	58	5.29
2016	57	5.20
2017	65	5.93
2018	68	6.20
2019	74	6.75
2020	80	7.29
2021	79	7.20
2022	183	16.68
2023	222	20.24
2024	82	7.47
Total	*1,097*	*100.00*

Note(s): Panel A presents the sample selection process. Panel B presents the sample distribution by industry based on the Industrial Classification Benchmark (ICB). Panel C presents the sample distribution by year and products. The *EIS* variable is constructed using data from the LSEG database, incorporating metrics such as environmental patents, eco-product development and sustainability-linked R&D output. This allows our study to distinguish between general innovation and innovations specifically aimed at environmental improvement. The dual use of *EIS* enables a more comprehensive understanding of how sustainability efforts influence both innovation outcomes and capital efficiency.

The independent variables in this study include measures of innovation input and sustainability performance. The R&D intensity (*RDI*) variable is defined as the ratio of R&D expenditure to total revenue, reflecting the proportion of resources allocated to innovation relative to firm size:

$$RDI_i = \frac{R\&D\,Expenditure_i}{Total\,Revenue_i}$$

This study captures sustainability performance using multiple indicators to reflect the multidimensional nature of corporate responsibility. The *ESGS* variable reflects a firm's performance across ESG dimensions, based on Refinitiv's proprietary scoring methodology, which aligns with widely accepted industry standards used by providers such as Bloomberg and Sustainalytics. The ESG combined score (*ESGC*) extends *ESGS* by incorporating adjustments for ESG-related controversies – such as environmental violations or governance scandals – thereby offering a more risk-adjusted assessment of sustainability performance (Zhou *et al.*, 2024; Zhou *et al.*, 2023). In addition, the CSR strategy score (*CSRS*) evaluates how effectively firms integrate economic, social and environmental considerations into strategic decision-making. The *CSRS* is sourced from Sustainalytics, which assesses corporate behavior against global sustainability benchmarks (AlKhouri and Suwaidan, 2023; Mukhtar *et al.*, 2024).

A central focus of this study is the moderating role of ESG performance in shaping innovation and investment outcomes. Specifically, we propose that the ESGS moderates the relationship between R&D investment and green innovation (EIS). Importantly, although green innovation is directly aligned with the environmental (E) dimension of ESG, we use the aggregate ESGS as the moderating variable for both theoretical and empirical reasons. First, firms do not operate environmental innovation activities in isolation from their broader ESG framework. Instead, environmental innovation is typically shaped by an integrated set of organizational practices that span environmental commitment, stakeholder management and governance quality. The aggregate ESGS therefore captures this broader institutional environment within which R&D decisions are made and translated into innovation outcomes.

Second, the social (S) and governance (G) components can indirectly facilitate environmental innovation even if they are not directly environmental in nature. Social factors such as employee engagement, human capital development and stakeholder pressure can enhance knowledge sharing and innovation capacity, while governance mechanisms improve oversight, resource allocation efficiency and long-term strategic orientation toward sustainable investment. As such, ESGS reflects the overall capability of firms to convert R&D inputs into effective innovation outputs.

Finally, the use of the composite ESG measure is consistent with prior empirical studies that adopt ESG as an integrated indicator of corporate sustainability performance, particularly when examining innovation outcomes. This approach recognizes that the three pillars are interdependent and jointly shape firms' strategic orientation toward sustainability and innovation.

To account for structural and temporal variations across firms, control variables are used. These comprise firm size (*FS*), measured as the natural logarithm of total assets; leverage (*LVG*), calculated as total debt over total assets; profitability (*PO*), measured as net income divided by total assets; cash holdings (*CH*), measured as cash and equivalents over total assets; asset turnover (*AT*), measured as sales over total assets; and asset growth (*AG*), measured as annual change in total assets. Industry and year fixed effects are included via dummy variables *INDUSTRY* and *YEAR*.

All continuous variables are winsorized at the 1% and 99% levels to reduce the influence of extreme outliers. We assume that publicly available disclosures accurately reflect firm behavior and that third-party ESG ratings serve as reliable proxies for overall sustainability performance. However, we acknowledge that methodological differences across ESG rating providers may introduce some subjectivity into the measurement construct. Table 2 provides detailed definitions of all variables used in the analysis, ensuring clarity, consistency and replicability of our empirical framework.

3.3 Model specification

To examine the relationship between R&D investment and green innovation, we estimate two baseline models using panel data. The dependent variable is the EIS, a composite metric sourced from the LSEG database that captures a firm's capacity to develop environmentally beneficial technologies and products. The EIS variable incorporates indicators such as environmental patents, eco-product development and sustainability-linked R&D output, thereby distinguishing green innovation from general innovation activity (Sajwan and Chetty, 2018). Because EIS contains many zero observations, the variable reflects both whether firms engage in measurable green innovation and, conditional on engagement, the intensity of such innovation. This distributional feature is explicitly considered in the robustness analysis.

The first model examines the baseline association between R&D intensity (RDI) – defined as R&D expenditure divided by total revenue – and green innovation:

$$\begin{aligned}\mathrm{EIS}_{it} = \beta_0 + \beta_1 \mathrm{RDI}_{it} + \beta_2 \mathrm{FS}_{it} + \beta_3 \mathrm{LVG}_{it} + \beta_4 \mathrm{PO}_{it} + \beta_5 \mathrm{CH}_{it} \\ + \beta_6 \mathrm{AT}_{it} + \beta_7 \mathrm{AG}_{it} + \gamma \mathrm{INDUSTRY}_i + \delta \mathrm{YEAR}_t + \varepsilon_{it}\end{aligned} \tag{1}$$

where:

- FS_{it} = firm size, measured as the natural logarithm of total assets.
- LVG_{it} = leverage, calculated as total debt divided by total assets.
- PO_{it} = profitability, measured as net income divided by total assets.
- CH_{it} = cash holdings, defined as cash and equivalents over total assets.
- AT_{it} = asset turnover, measured as sales over total assets.
- AG_{it} = asset growth, calculated as the change in total assets relative to the prior year's total assets.
- $INDUSTRY_i$ = industry fixed effects to control sector-specific heterogeneity.
- $YEAR_t$ = year fixed effects to account for macroeconomic and temporal trends.
- ε_{it} = error term.

These control variables are selected based on empirical precedents in studies examining innovation performance and capital structure (D'Amato *et al.*, 2024; Drempetic *et al.*, 2020; Tran and Nguyen, 2025). They are included to account for observable firm-level characteristics that may be associated with both R&D investment and green innovation.

Table 2. Definitions of variables

Variables	Abbreviation	Definition
Environmental innovation score	*EIS*	Environmental innovation score, showing a firm's ability to minimize environmental costs and customer burden by creating new markets through new technologies and eco-products
ESG score	*ESGS*	ESG score, reflecting a firm's performance in environmental, social, and governance (ESG) dimensions
ESG combined score	*ESGC*	ESG combined scores, reflecting a firm's overall score based on reported information on the environmental, social, and governance pillars, with an overlay of ESG controversies
CSR strategy score	*CSRS*	CSR strategy score, reflecting a firm's integration of economic, social, and environmental dimensions into its daily decision-making processes
R&D intensity	*RDI*	Research and development (R&D) expenditure is divided by total revenue, indicating innovation investment relative to firm size
Firm size	*FS*	Firm size, measured by total assets or market capitalization
Leverage	*LVG*	Leverage, calculated as the ratio of debt to equity
Profitability	*PO*	Profitability, measured as earnings before interest and taxes (EBIT) divided by total assets
Cash holdings	*CH*	Cash holdings, calculated as cash and equivalents divided by total assets
Asset turnover	*AT*	Asset turnover, calculated as net sales as a percentage of total assets
Asset growth	*AG*	Assets growth, measured as annual change in total assets
Industry dummy	*INDUSTRY*	A dummy variable that takes a value of 1 if a firm belongs to a specific industry, 0 otherwise
Year dummy	*YEAR*	A dummy variable for the years included in the study (except the benchmark year)

Note(s): The *INDUSTRY* classification includes sectors such as manufacturing; processing of food from agricultural products; manufacturing of textiles, chemicals, machinery, automobiles, and electronics; and other related industries. These sectors are selected to capture a broad representation of economic activities across various domains. Regarding the temporal dimension, *YEAR* serves as a dummy variable in the study, spanning multiple years. One year is designated as the benchmark for comparison, allowing for the analysis of trends and variations over time while controlling annual fluctuations

We extend the analysis by testing whether ESG performance conditions the R&D–green innovation relationship. This is operationalized through an interaction term between RDI and ESGS (RDI × ESGS), where ESGS reflects firm-level performance across ESG dimensions based on Refinitiv's proprietary scoring methodology (Zhang *et al.*, 2024a; Zhou *et al.*, 2023):

$$\begin{aligned}\mathrm{EIS}_{it} = {} & \beta_0 + \beta_1\mathrm{RDI}_{it} + \beta_2\mathrm{ESGS}_{it} + \beta_3(\mathrm{RDI}_{it} \times \mathrm{ESGS}_{it}) + \beta_4\mathrm{FS}_{it} + \beta_5\mathrm{LVG}_{it} \\ & + \beta_6\mathrm{PO}_{it} + \beta_7\mathrm{CH}_{it} + \beta_8\mathrm{AT}_{it} + \beta_9\mathrm{AG}_{it} + \gamma\mathrm{INDUSTRY}_i + \delta\mathrm{YEAR}_t + \varepsilon_{it}\end{aligned}$$

Before estimating the interaction model, we center the continuous predictors, RDI and ESGS, to reduce multicollinearity between the main effects and the interaction term (Aiken and West, 1991). A positive and statistically significant coefficient on the interaction term, β_3, would indicate that ESG performance is positively associated with the strength of the relationship between R&D investment and green innovation.

The distribution of EIS also requires careful econometric treatment. Since many firms report zero values for EIS, the dependent variable is zero-inflated and potentially censored at the lower bound. In this setting, standard OLS estimates may be influenced by the large mass of non-innovating observations. Therefore, in addition to the baseline OLS models, we conduct robustness checks using Tobit and hurdle specifications. The Tobit model accounts for the censored nature of EIS, while the hurdle model distinguishes between the likelihood of engaging in green innovation and the level of green innovation among firms with positive EIS values. This approach allows us to assess whether the main findings are robust to the non-normal and zero-heavy distribution of the dependent variable.

We cluster standard errors at the firm level to account for serial correlation and heteroskedasticity within firms over time (Petersen, 2008). We also conduct additional robustness checks using alternative measurements of R&D and ESG performance, random-effects estimation, OLS with clustered standard errors, and instrumental variable estimation to address potential endogeneity concerns, including reverse causality between ESG performance and innovation outcomes.

For the instrumental variable analysis, we use two-stage least squares (2SLS) estimation and report first-stage diagnostics to assess instrument relevance. In addition, we include overidentification tests, particularly the Hansen J-test, to evaluate whether the instruments are jointly valid and plausibly satisfy the exclusion restriction. This addition strengthens the credibility of the IV strategy by examining whether the instruments affect EIS only through the endogenous regressors.

Given the relatively modest sample size and the number of observations per firm, we are cautious about overfitting and ensure that the number of parameters estimated remains proportionate to the available degrees of freedom. In addition, we assess variance inflation factor (VIF) values to confirm that multicollinearity does not distort our estimates. Overall, the empirical strategy is designed to identify robust associations among R&D, ESG performance and green innovation, while explicitly recognizing the limitations associated with observational data, zero-inflated outcomes and potential unobserved heterogeneity.

4. Results

4.1 Summary of descriptive statistics

Table 3 presents descriptive statistics for the full sample of 1,097 firm-year observations, summarizing key variables used in the analysis. The EIS variable averages 17.646 (standard deviation [SD] = 27.900), indicating substantial variation in green innovation across firms, with a median of 0.000, highlighting that more than half of the observations report no measurable green innovation activity each year, and a maximum of 95.270. The RDI variable has a mean of 17.153 but is highly skewed, ranging from 0.000–549.648, with a median of 0.000, suggesting that a large proportion of firms do not report R&D investment, which reinforces the presence of a zero-inflated distribution.

The ESGS variable averages 45.918 (SD = 20.935), with scores spanning from 5.708–93.009, reflecting heterogeneous sustainability performance. The FS variable, measured as the natural logarithm of total assets, averages 9.297 (SD = 0.916), indicating typical mid- to large-capitalization ASX-listed firms. The LVG variable averages 0.452, showing moderate debt levels overall, although some firms approach full debt financing (max = 0.963). The POV variable, defined as net income over total assets, has a mean of 0.073 (SD = 0.213), with minimums indicating financial distress. The CH, AT and AG variables reveal variability in liquidity, efficiency and growth dynamics.

The presence of a substantial proportion of zero values in EIS and RDI variables has important implications for model specification. To address this concern, we implement

Table 3. Descriptive statistics for full sample

Variables	Mean	SD	Min	P25	Median	P75	Max
ESGS	45.918	20.935	5.708	29.458	44.420	61.274	93.009
RDI	17.153	73.685	0.000	0.000	0.000	1.200	16.648
EIS	17.646	27.900	0.000	0.000	0.000	26.217	95.270
FS	9.297	0.916	5.726	8.737	9.222	9.809	12.228
LVG	0.452	0.239	−0.002	0.283	0.447	0.608	0.963
POV	0.073	0.213	−0.784	0.008	0.068	0.136	0.872
CH	0.104	0.162	−0.043	0.008	0.043	0.133	1.243
AT	0.599	0.579	−0.341	0.171	0.506	0.796	2.920
AG	0.192	0.719	−1.202	−0.034	0.062	0.259	4.516
ESGCS	43.447	18.552	5.708	29.424	43.509	56.954	89.315
CSRS	41.128	34.368	0.000	3.079	37.727	71.622	99.724

Note(s): This table presents descriptive statistics for the firm-level variables for the full sample of 1,097 firm-year observations. Std. Dev. = standard deviation. Table 2 presents the definitions of variables

robustness checks using alternative estimation approaches. Specifically, we estimate a Tobit model to account for the left-censoring of EIS at zero, and we further reestimate the models using a subsample of firms with positive EIS values. These complementary approaches help ensure that the main results are not driven by the mass of zero observations and provide additional confidence in the validity of the findings. Given skewness and outliers, we apply winsorization at the 1% and 99% levels for all continues variables. These statistics confirm sufficient variation to support regression modeling while also highlighting the need for careful econometric treatment and cautious interpretation of results.

4.2 Correlation analysis results

Table 4 presents Pearson's correlation matrix and VIF values for all study variables. The analysis reveals a strong positive correlation between *EIS* and *ESGS* (r = 0.589), suggesting that firms with higher sustainability performance also demonstrate greater green innovation capacity. This supports the theoretical expectation that ESG engagement facilitates environmentally oriented innovation. Notably, *ESGS* also correlates moderately with firm size (*FS*) (r = 0.714), indicating that larger firms may have greater capacity to invest in sustainability initiatives.

All VIF values remain well below the conventional threshold of 5, ranging from 1.17 (*CH*) to 3.22 (*FS*), confirming the absence of severe multicollinearity. Specifically, VIF values for key predictors – *ESGS* (2.76), *RDI* (1.85) and *EIS* (2.96) – suggest stable estimation conditions for regression modeling. Diagnostic tests for autocorrelation using the Durbin–Watson and Breusch–Godfrey procedures confirm no significant serial correlation in the residuals, thus ensuring valid inferences. These results support the robustness of our model specification and provide confidence in proceeding with regression analysis to test the hypothesized relationships.

4.3 Regression analysis results

Table 5 presents the results from a series of ordinary least squares (OLS) regression models examining the relationship between R&D intensity (RDI) and EIS, with the ESGS as a moderate variable. All models use clustered robust standard errors at the firm level, ensuring more reliable inferences in the presence of heteroskedasticity and within-firm correlation. In addition, Models 3 and 4 include year and industry fixed effects, which serve to account for

Table 4. Correlation matrix

Variables	*ESGS*	*RDI*	*EIS*	*FS*	*LVG*	*POV*	*CH*	*AT*	VIF
ESGS	1.000								2.76
RDI	−0.064	1.000							1.85
EIS	0.589	0.002	1.000						2.96
FS	0.714	−0.215	0.501	1.000					3.22
LVG	0.304	−0.056	0.078	0.278	1.000				1.55
POV	−0.020	−0.098	−0.007	−0.002	−0.027	1.000			1.18
CH	−0.140	0.076	−0.071	−0.155	−0.142	0.092	1.000		1.17
AT	0.111	−0.130	0.024	−0.055	0.196	0.176	0.013	1.000	2.15
AG	−0.055	−0.045	−0.066	0.011	0.015	−0.063	−0.047	−0.091	1.09

Note(s): Table 4 presents Pearson's correlations between the variables. The variance inflation factor (VIF) values are reported in the last column, with this calculated for independent variables in the baseline models in this table. Table 2 presents the definitions of variables

Table 5. Ordinary least squares (OLS) regression results of association between *RDI* and *EIS*

DV=	*EIS* (1)	*EIS* (2)	*EIS* (3)	*EIS* (4)
RDI	*0.001 (0.03)*	*0.047*** (4.25)*	*0.058*** (3.60)*	0.015 (1.07)
ESGS				0.673*** (13.54)
RDI × *ESGS*				*0.011** (2.25)*
FS		16.943*** (8.24)	16.924*** (6.47)	5.242*** (4.23)
LVG		−10.202 (−1.55)	−9.598 (−1.55)	−13.330*** (−4.40)
POV		−1.789 (−0.46)	−5.496** (−2.25)	−3.704** (−2.23)
CH		−1.559 (−0.24)	4.382*** (3.82)	6.882** (1.97)
AT		4.083* (1.77)	8.370*** (3.55)	3.342** (2.48)
AG		−2.282*** (−2.62)	−1.800* (−1.94)	−0.691** (−2.01)
Intercept	17.633*** (8.61)	−137.781*** (−7.85)	−148.521*** (−5.73)	−51.518*** (−4.17)
Year fixed effects	No	No	Yes	Yes
Industry fixed effects	No	No	Yes	Yes
R^2	0.000	0.279	0.481	0.574
Obs.	1097	1097	1097	1097

Note(s): This table presents the main results of the association between *RDI* and *EIS* and the moderating effect of *ESGS* on this association. All models are estimated using ordinary least squares (OLS) regressions with clustered robust standard errors by firm, with *t*-statistics reported in parentheses. DV = dependent variable. Superscript *, ** and *** indicate significance at 10, 5 and 1% levels, respectively. Table 2 presents the definitions of variables

temporal and sectoral heterogeneity, thereby improving model specification and reducing potential omitted variable bias.

Model 2 assesses the baseline RDI–EIS relationship. The coefficient for RDI is positive and statistically significant ($\beta = 0.047$, $p < 0.01$), suggesting that firms with greater R&D investment intensity are more likely to be associated with green innovation. This finding aligns well with prior literature that positions R&D as a key input in the innovation process, especially in the context of sustainable and environmentally focused technological development (Farooq *et al.*, 2024; Qian, 2024). In other words, consistent financial commitment to research is positively related to environmental innovation.

Building upon this foundation, Model 3 incorporates a broader set of control variables, significantly improving the model's explanatory power (R^2 = 0.481). Notably, the positive and significant coefficient for RDI remains largely unchanged ($\beta = 0.058$, $p < 0.01$), indicating that R&D intensity remains positively associated with EIS even after controlling firm-specific characteristics.

Among the control variables, firm size (FS) shows a strong positive association with EIS, indicating that larger firms – presumably with greater access to resources – are better positioned to invest in sustainability initiatives (Garcia *et al.*, 2017). Leverage (LVG), in contrast, exhibits a negative and significant association ($\beta = -13.33$, $p < 0.01$), implying that high debt levels may constrain a firm's capacity to fund long-term innovation projects. Furthermore, asset turnover (AT) is positively associated with EIS, suggesting that operational efficiency may support green innovation activity. Asset growth (AG), however, shows a negative and significant coefficient in Model 4, suggesting that rapid expansion may be associated with resource constraints or competing investment priorities. Profitability (POV) also shows a negative association with EIS, which may indicate that more profitable firms in the sample do not necessarily allocate resources toward green innovation, or that short-term profitability priorities may differ from longer-term sustainability-oriented investment. These findings illustrate how both strategic and structural factors are associated with environmental innovation outcomes.

Moving beyond the main effects, Model 4 introduces the interaction term (RDI × ESGS) to test *H2*, which posits that ESG performance moderates the relationship between R&D investment and green innovation. The interaction term is positive and statistically significant ($\beta = 0.011$, $p < 0.05$), offering support for the view that firms with stronger ESG performance are associated with greater green innovation returns from their R&D investment.

This result suggests that the ESGS functions not solely as a compliance or disclosure metric, but rather as a strategic asset positively related to the effectiveness of innovation-related investment. In line with stakeholder theory and the RBV, superior ESG performance is likely to be associated with reputational legitimacy, stakeholder trust and internal alignment – all of which may strengthen the relationship between R&D expenditure and environmental innovation (Li *et al.*, 2023b; Luan and Wang, 2023).

Despite the overall robustness of the study's models, several limitations should be acknowledged. First, due to the observational nature of the data, causal inferences must be drawn cautiously. For instance, reverse causality cannot be ruled out, as successful innovation in green technologies may subsequently improve a firm's ESG disclosures, rather than ESG performance preceding innovation.

Second, while multicollinearity diagnostics indicate acceptable levels of independence between predictors (VIF values < 5 across all models), the relatively modest *t*-values observed for some key coefficients – particularly in the interaction model, such as RDI in Model 4 – suggest caution against overinterpreting marginal effects. Finally, the very low R^2 values in earlier models, such as Model 1 with $R^2 \approx 0.000$, highlight the importance of including relevant controls and year and industry fixed effects to capture meaningful variation attributable to firm-level and time- and industry-specific factors.

The control variables in Table 5 provide additional context. The FS variable positively correlates with green innovation performance, consistent with Garcia *et al.* (2017), as larger firms have greater resources to invest in sustainability initiatives. The LVG variable is negatively associated with green innovation, in alignment with Bhuiyan and Nguyen (2020), suggesting that financial constraints may limit sustainability-oriented investment. The POV variable, reflecting profitability, shows a negative association with EIS, suggesting that higher profitability is not necessarily linked to greater environmental innovation in this sample. In contrast, the CH and AT variables, through their positive associations, emphasize the role of liquidity and efficient resource management in supporting green innovation (Wang and Chu, 2024). Due to regulatory pressures and stakeholder expectations (Zhang *et al.*, 2024a), firms in environmentally sensitive sectors may place greater emphasis on green innovation, while regional evidence from China indicates that ecological policy priorities can also shape environmental innovation patterns (Deng and Cheng, 2019).

To interpret the moderating role of the ESGS, Figure 1 presents a heatmap of predicted EIS values across different combinations of RDI and ESGS, rather than simple slopes. The graph illustrates how EIS varies across joint levels of ESGS and RDI. As ESGS increases, the colors transition to warmer shades, indicating higher predicted EIS values associated with stronger ESG performance. Vertically, higher RDI is similarly associated with higher predicted EIS values. The top-right corner, where both ESGS and RDI are high, shows the warmest colors, highlighting a positive interaction between these two variables. Conversely, the bottom-left corner reflects the lowest predicted EIS values, where both ESGS and RDI are low.

4.4 Robustness analysis

To ensure the robustness of our findings, we conducted a series of additional tests, using alternative methodologies and specifications. These tests comprised addressing sample selection bias, controlling for endogeneity, employing alternative measurements for key variables, and addressing potential confounding effects, such as the COVID-19 pandemic and simultaneous causality. The results of these robustness checks are presented in Tables 6–9.

To address potential sample selection bias arising from missing ESG data, we applied Heckman's (1979) two-stage correction procedure. In the first stage, a probit model was estimated to predict the likelihood that a firm disclosed its ESG data (disclosure [*DIS*] = 1 if

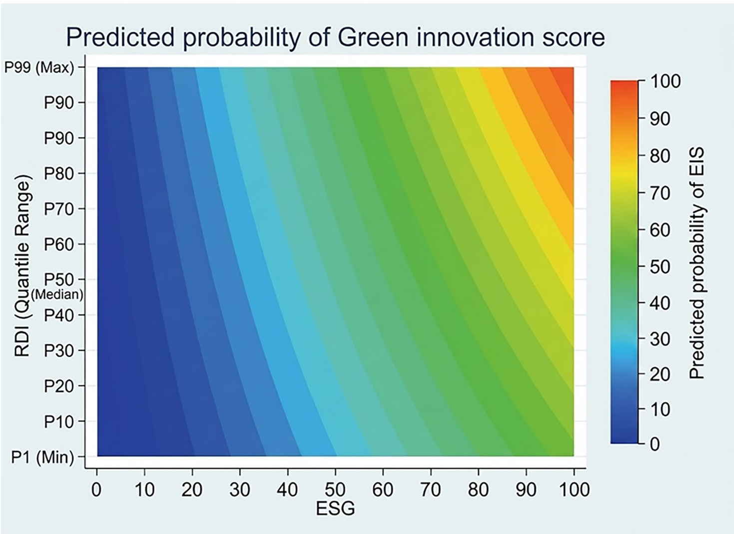

Figure 1. Predicted probability of green innovation score (GIS)

Table 6. Robustness test: Sample selection bias – Heckman's (1979) Two-stage model

	First stage	Second stage	
	DIS	*EIS*	*EIS*
DV=	(1)	(2)	(3)
RDI		*42.795*** (4.01)*	−0.015 (−0.80)
ESGS			0.644*** (6.83)
ESGS × *RDI*			*0.013** (2.18)*
FS	1.066*** [5.98]	47.431*** (5.85)	29.672*** (3.91)
LVG	−0.608 [−1.51]	−27.760*** (−3.69)	−27.438*** (−3.99)
POV	−0.446 [−1.47]	−21.918*** (−4.25)	−16.817*** (−3.34)
CH	0.763** [2.26]	25.229*** (3.50)	23.755*** (3.78)
AT	0.601*** [3.89]	24.480*** (4.94)	16.322*** (3.80)
AG	−0.103 [−1.38]	−4.554*** (−3.80)	−2.905** (−2.50)
IMR		42.795*** (4.01)	34.110*** (3.76)
Intercept	−10.581*** [−5.86]	−475.150*** (−5.51)	−313.468*** (−4.00)
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Pseudo R^2/R^2	0.315	0.490	0.577
Obs.	3,035	1049	1049

Note(s): Model 1 reports the first stage of Heckman's (1979) Two-stage model, a probit regression model with the dependent variable (disclosure [*DIS*]) equal to 1 for firms that have ESG data, and 0 otherwise. Models 2 and 3 present the second-stage regressions, a baseline model regression including the inverse Mills ratio (*IMR*) which is calculated from the first stage. All regressions are estimated with clustered robust standard errors by firm and include year and industry fixed effects. DV = dependent variable. *EIS* = environmental innovation score. The *t*-statistics (*z*-statistics) are reported in parentheses (brackets). Superscript *, **, and *** indicate significance at 10, 5, and 1% levels, respectively. Table 2 presents the definitions of variables

ESG data were available, 0 otherwise). Based on this estimation, we derived the inverse Mills ratio (*IMR*), which was then included as a correction term in the second-stage regression models.

The second-stage results, presented in Table 6, Models 2 and 3, confirm the robustness of our primary findings. The coefficient for *ESGS* remains positive and statistically significant, indicating that firms with stronger ESG performance are more likely to engage in green innovation. Model 3 shows that *ESGS* maintains a substantial effect ($\beta = 0.644$, $p < 0.01$), reinforcing its role as a core driver of environmental innovation even after correcting for potential sample selection bias. Notably, the interaction term between *RDI* and *ESGS* retains its positive sign and remains marginally significant ($\beta = 0.013$, $p < 0.10$). This result lends further support to the argument that ESG performance enhances the effectiveness of R&D investment in generating environmental innovation (Mohy-ud-Din, 2024; Zheng *et al.*, 2023). These results are consistent with stakeholder and resource-based theories, which view ESG capabilities as amplifiers of innovation outcomes.

The inclusion of the *IMR* does not alter the direction, significance or magnitude of the key coefficients, increasing confidence that the results are not biased by the nonrandom exclusion of firms lacking ESG data. Control variables behave as expected, with *FS*, *CH* and *AT* positively associated with environmental innovation, suggesting that scale, liquidity and operational efficiency support sustainability-oriented initiatives. In contrast, *LVG* and *AG* exhibit negative associations, indicating that financial constraints and aggressive expansion may impede green R&D efforts.

Table 7. Robustness test: Control for endogeneity (2SLS model)

DV=	*ESGC* (1)	*RDI* (2)
Panel A: First stage		
MEAN_IY_ESGS (IV1)	0.426*** (12.76)	
FIRST_ESGS (IV2)	0.611*** (24.28)	
MEAN_IY_RDI (IV1)		0.836*** (16.93)
FIRST_RDI (IV2)		0.347*** (14.67)
Intercept	−58.031*** (−8.24)	96.209** (2.42)
Other controls	Yes	Yes
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
Corr. of (*IV1*)	0.66	0.74
Corr. of (*IV2*)	0.86	0.65
Under-identification test: Kleibergen–paap rk LM statistic (*p* -value)	0.000	0.000
Weak identification test: Cragg–donald wald *F*-statistic	573.30	290.42
Stock–Yogo (2005) critical value	19.93	19.93
Hansen J statistic (overidentification test)	0.327	0.113
Obs.	1097	1097
DV=	*EIS* (1)	*EIS* (2)
Panel B: Second stage		
RDI	*0.082*** (3.95)*	0.025 (0.79)
ESGS		0.675*** (13.52)
ESGS × *RDI*		*0.017*** (2.68)*
Intercept	−155.429*** (−10.84)	−51.897*** (−4.17)
Other controls	Yes	Yes
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
R^2	0.479	0.574
Obs.	1097	1097

Note(s): This table presents the results of the association between *RDI* and *EIS* and the moderating effect of *ESGS* on this association using the Two-stage least squares (2SLS) model. The instrumental variables are: (1) *IV1*, which is the industry–year mean of *ESGS* and *RDI* and (2) *IV2*, which is the *ESGS* and *RDI* values recorded when the firm enters the sample. The under-identification test tests whether the instruments are relevant enough to identify the endogenous variables in our 2SLS model under the null hypothesis that the model is under-identified (instruments are not relevant). The Cragg–Donald Wald *F*-statistic is used to test for weak instruments in our regression models. A higher *F*-statistic indicates stronger instruments. According to Stock and Yogo (2005), an *F*-statistic above the critical value (19.93 in this case) suggests that the instruments are not weak. The Hansen overidentification test is conducted to assess instrument validity. All regressions are estimated with clustered robust standard errors by firm. DV = dependent variable. The *t*-statistics are reported in parentheses. Superscript *, ** and *** indicate significance at 10, 5 and 1% levels, respectively. Table 2 presents the definitions of variables

While Heckman's (1979) correction mitigates selection bias, we acknowledge that broader endogeneity concerns remain. Observational design limits causal inferences, with unobserved confounders still possibly influencing the estimated relationships. Future research could benefit from additional robustness checks, such as lagged variable models, instrumental variable (IV) strategies or matched sample comparisons. Nonetheless, the Heckman (1979)-adjusted results lend further validity to our central conclusion: ESG

Table 8. Robustness test: Alternative measurements

DV=	*EIS* (1)	*EIS* (2)
Panel A		
RDA	*3.526** (2.23)*	−2.673 (−1.07)
ESGS		0.711*** (13.52)
ESGS × *RDA*		*0.108* (1.94)*
Intercept	−143.696*** (−4.57)	−40.624*** (−3.10)
Other controls	Yes	Yes
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
R^2	0.457	0.556
Obs.	1097	1097
Panel B		
RDCAP	*2.619** (2.49)*	−1.670 (−1.05)
ESGS		0.724*** (13.74)
ESGS × *RDCAP*		*0.084** (2.30)*
Intercept	−144.297*** (−4.63)	−40.329*** (−3.11)
Other controls	Yes	Yes
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
R^2	0.455	0.559
Obs.	1097	1097
Panel C		
RDLOG	*1.379*** (2.92)*	0.076 (0.16)
ESGS		0.698*** (13.10)
ESGS × *RDLOG*		*0.020* (1.69)*
Intercept	−143.415*** (−4.64)	−40.090*** (−3.07)
Other controls	Yes	Yes
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
R^2	0.462	0.559
Obs.	1097	1097
Panel D		
RDI	0.024** (2.10)	0.034* (1.77)
CSRS	0.328*** (11.27)	
CSRS × *RDI*	*0.028** (2.40)*	
ESGCS		0.598*** (6.77)
ESGCS × *RDI*		*0.022* (1.71)*
Intercept	−71.072*** (−5.28)	−86.657*** (−3.72)
Other controls	Yes	Yes
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes
R^2	0.543	0.559
Obs.	1097	1097

Note(s): This table presents the results of the association between *RDI* and *EIS* and the moderating effect of *ESGS* on this association using alternative measurements. We use *RDA*, *RDCAP*, and *RDLOG* as alternative measurements of *RDI* in Panels A, B, and C, respectively. Alternative measures of *ESGS* are employed in Panel D, including the CSR strategy score (*CSRS*) and the ESG combined score (*ESGCS*). All models are estimated using ordinary least squares (OLS) regressions with clustered robust standard errors by firm and include year fixed effects and industry fixed effects, with *t*-statistics reported in parentheses. DV = dependent variable. Superscript *, **, and *** indicate significance at 10, 5 and 1% levels, respectively. Table 2 presents the definitions of variables

Table 9. Additional analyses

	Addressing COVID-19 pandemic		Addressing simultaneous causality (IND-Vs at *t – 1*)	
	EIS	*EIS*	*EIS*	*EIS*
DV=	(1)	(2)	(3)	(4)
RDI	0.059*** (3.50)	0.012 (0.71)	0.061*** (4.19)	0.032* (1.85)
ESGS		0.632*** (11.81)		0.619*** (5.52)
ESGS × *RDI*		0.021*** (3.66)		*0.018** (2.49)*
Intercept	−146.276*** (−5.60)	−55.070*** (−4.12)	−147.642*** (−5.30)	−57.163** (−2.51)
Other controls	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
R^2	0.49	0.57	0.50	0.58
Obs.	938	938	813	813

Note(s): This table presents the main results of the association between *RDI* and *EIS* after addressing the COVID-19 pandemic years (Models 1 and 2) and simultaneous causality (Models 3 and 4). All models are estimated with clustered robust standard errors by firm and include year and industry fixed effects. IND-Vs = independent variables. DV = dependent variable. The *t*-statistics are reported in parentheses. Superscript *, ** and *** indicate significance at 10, 5 and 1% levels, respectively. Table 2 presents the definitions of variables

performance functions not solely as a reporting metric but as a strategic asset that enhances the innovation payoff from R&D investment.

To mitigate potential endogeneity between *ESGS*, *RDI* and *EIS* – arising from reverse causality or omitted variable bias – we employed a two-stage least squares (2SLS) instrumental variables approach, following Stock and Yogo (2005).

In the first stage (Table 7, Panel A), we utilized two sets of instruments:

(1) Industry–year means RDI and ESGS (IV1), capturing sector-level sustainability and innovation trends.

(2) Initial firm-level RDI and ESGS values upon a firm's entry into the sample (IV2), serving as lagged, exogenous predictors.

These instruments are selected based on relevance and theoretical plausibility (Dal Maso *et al.*, 2020; Al Rabab'a *et al.*, 2024). The industry–year mean instruments are motivated by the idea that firms operating within the same industry and year are exposed to similar regulatory pressures, technological opportunities, competitive dynamics and sustainability norms, which are likely to influence firm-level ESG engagement and R&D investment decisions. These common external conditions generate strong correlations with the endogenous regressors, satisfying the relevance condition. At the same time, after controlling for firm characteristics, industry fixed effects and year fixed effects, the industry-year averages are unlikely to directly affect an individual firm's environmental innovation except through their influence on the firm's own ESGS and RDI decisions. Accordingly, their effect on EIS is expected to operate indirectly through the endogenous variables rather than through a direct causal channel.

The second set of instruments consists of firms' initial ESGS and RDI values observed at the beginning of the sample period. These variables capture relatively persistent organizational capabilities, governance structures and strategic orientations that shape subsequent ESG and R&D behavior over time. Because these initial values are predetermined and temporally distant from current innovation outcomes, they are less likely to be directly associated with contemporaneous shocks to environmental innovation. Their role is therefore to provide exogenous variation in current ESGS and RDI while reducing concerns that current EIS simultaneously influences the explanatory variables.

To further assess the validity of the instruments, we report Hansen's J test (overidentification test) in Table 7. The test results fail to reject the null hypothesis that the instruments are exogenous (p-values of 0.327 for Model 1 and 0.113 for Model 2), providing empirical support for the exclusion restrictions underlying the 2SLS specification. These findings provide empirical support for the appropriateness of the selected instruments and suggest that the instruments do not exert a direct effect on EIS beyond their association with the endogenous regressors.

In the second stage (Table 7, Panel B), the coefficients of RDI, ESGS, and their interaction closely mirror our baseline OLS results, underscoring the robustness of our findings. The ESGS variable shows a strong positive effect on EIS ($\beta = 0.675$, $p < 0.01$), indicating that firms with superior ESG performance are positively associated with higher levels of green innovation. Moreover, the RDI × ESGS interaction remains positive and statistically significant ($\beta = 0.017$, $p < 0.01$), suggesting that a higher ESGS is associated with a stronger relationship between R&D investment and environmental innovation outcomes.

These results corroborate prior literature highlighting the synergistic relationship between sustainability efforts and innovation (Li *et al.*, 2023a; Zhou *et al.*, 2024). They imply that ESG performance not only signals organizational legitimacy but also is positively related to internal capabilities and stakeholder alignment, facilitating more effective translation of R&D into green innovation. Nevertheless, we acknowledge our study's limitations. Although endogeneity concerns are reduced by the 2SLS approach, it does not establish causality. The validity of the instruments depends on exclusion restrictions, which are inherently untestable. Furthermore, we did not perform alternative specifications or sensitivity analyses to assess robustness across model variations. Future research could employ complementary identification strategies – such as lagged generalized method of moments (GMM), difference-in-differences (DiD) designs or natural experiments – to strengthen causal inferences and further validate this study's findings.

To enhance the validity and reliability of our findings, we conducted a series of robustness checks using alternative *RDI* and *ESGS* measurements. These alternative specifications are summarized in Table 8, Panels A–D, in which each panel tests whether our core results hold under different operationalizations of key variables. This approach helps to address concerns about construct validity, measurement sensitivity and potential model misspecification.

In Panel A, we reestimated our baseline models using R&D to total assets (*RDA*) as an alternative measure of innovation input. This specification adjusts firm size and capital structure, offering a normalized view of R&D investment. The results show that *RDI* remains positively associated with *EIS*, although the magnitude and significance vary slightly from those in the main model. Specifically, the coefficient of *RDA* is positive but not statistically significant in the base model. However, it becomes more meaningful when interacting with *ESGS*, suggesting that capital-intensive firms gain more benefit from ESG alignment in driving green innovation. In Panel B, we employed capitalized R&D expenditure (*RDCAP*) as a proxy for R&D investment (*RDI)*. This adjustment accounts for firms that capitalize their R&D investment rather than incurring R&D expenditure, a practice that can affect financial reporting and innovation measurement. Results indicate that *RDCAP* maintains a positive association with *EIS*, reinforcing the role of R&D in promoting environmental innovation. Notably, the moderating effect of *ESGS* remains significant, suggesting that firms with stronger sustainability performance derive greater innovation value from capitalized R&D, possibly due to longer-term strategic planning or improved stakeholder support.

To address potential skewness in the *RDI* distribution, particularly given its wide range (0–549.648) – we applied a log transformation (*RDLOG*) in Table 8, Panel C. This specification improves normality and reduces the influence of extreme values. The results confirm that *RDI*'s relationship with *EIS* remains directionally consistent, with a marginal positive effect before moderation. Importantly, the interaction term between *RDLOG* and *ESGS* remains statistically significant at the 10% level, indicating that, even after adjusting for scale effects, *ESGS* continues to condition the effectiveness of R&D expenditure on green innovation outcomes. In Panel D, we tested the robustness of our findings using *ESGCS* and *CSRS* as alternative metrics. Both measures capture different dimensions of sustainability engagement:

- *ESGCS* incorporates risk-adjusted adjustments for controversies such as environmental violations or governance scandals.
- *CSRS* reflects the integration of economic, social and environmental considerations into corporate strategy.

Results show that both *ESGCS* and *CSRS* exhibit significant positive associations with *EIS*, supporting the conclusion that broader constructs of sustainability consistently drive green innovation. In addition, the interaction terms involving these alternative ESG indicators remain statistically significant, further validating the moderating role of ESG in amplifying the returns on R&D investment.

To further assess the reliability of our findings, we conducted two additional robustness checks using alternative sample specifications and lagged variable models. These tests aim to mitigate potential bias introduced by unusual economic conditions during the COVID-19 pandemic (2020–2021) and to address concerns regarding simultaneous causality – that is, the possibility that green innovation may influence ESG performance or R&D investment rather than vice versa.

In the first test, we excluded firm-year observations from the pandemic years (2020–2021) to reduce the risk of confounding effects caused by disruptions in operations, supply chains and financial markets. Table 9, Models 1 and 2 present the regression results based on this reduced sample ($n = 938$). Model 1 shows that *RDI* remains positively associated with *EIS* ($\beta = 0.059$, $p < 0.01$), while Model 2 confirms that *ESGS* continues to exhibit a strong positive relationship with *EIS* ($\beta = 0.632$, $p < 0.01$). Moreover, the interaction term (*RDI* × *ESGS*) remains statistically significant ($\beta = 0.021$, $p < 0.01$), indicating that the moderating role of ESG performance persists even after removing the volatile pandemic period.

To examine the issue of simultaneous causality, we reestimated the models using lagged independent variables (Table 9, Models 3 and 4), which helps to reduce the risk of reverse causation, for example, where green innovation influences ESG performance rather than the other way around. In Model 3, *RDI* retains its positive and significant effect on *EIS* ($\beta = 0.061$, $p < 0.01$), while in Model 4, *ESGS* remains significantly associated with *EIS* ($\beta = 0.619$, $p < 0.01$). The interaction term also remains positive and statistically significant at the 5% level ($\beta = 0.018$, $p < 0.05$), reinforcing the conclusion that firms with stronger ESG performance derive greater returns on R&D investment in terms of green innovation outcomes.

To further assess the robustness of our findings, we conduct additional analyses addressing the zero-inflated nature of EIS. As shown in Table 10, EIS exhibits a large proportion of zero values, which may raise concerns regarding the suitability of a standard

Table 10. Robustness test: Tobit and nonzero EIS samples

	Tobit models		Nonzero EIS samples	
	EIS	*EIS*	*EIS*	*EIS*
DV=	(1)	(2)	(3)	(4)
RDI	*0.056* (1.83)*	−0.116 (−1.42)	*0.032** (2.19)*	−0.159** (−2.58)
ESGS		1.534*** (12.98)		1.106*** (8.22)
ESGS × RDI		*0.002** (2.31)*		*0.002*** (2.86)*
Intercept	−416.445*** (−11.98)	−147.282*** (−5.20)	−174.607*** (−6.01)	−32.263 (−1.12)
Other controls	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Pseudo R^2 / R^2	0.114	0.149	0.446	0.564
Obs.	1097	1097	461	461

Note(s): This table reports robustness tests addressing the high concentration of zero observations in EIS. Models (1) and (2) employ Tobit regression with left-censoring at zero, while Models (3) and (4) are estimated using only observations with positive EIS values (non-zero EIS subsample). All models include clustered robust standard errors at the firm level, as well as year and industry fixed effects. DV = dependent variable. The t-statistics are reported in parentheses. Superscripts *, **, and *** indicate statistical significance at the 10, 5 and 1% levels, respectively. Table 2 provides variable definitions

linear specification. To account for this issue, we estimate a Tobit model that accommodates left-censoring at zero, as well as a subsample analysis restricted to firms with positive EIS values.

The results reported in Table 10 reveal a more nuanced picture than the baseline findings alone. An interesting finding emerging from Table 10 is the change in the coefficient of RDI once the interaction term is introduced and the distributional characteristics of EIS are explicitly addressed. In the baseline OLS analysis (Table 5), the coefficient on RDI becomes statistically insignificant after including the interaction term, whereas in the Tobit and nonzero EIS specifications it turns negative, with the coefficient reaching statistical significance in the nonzero EIS subsample. This difference suggests that the role of R&D intensity may differ depending on whether it influences firms' decision to engage in green innovation at all (the extensive margin) or the amount of green innovation produced by firms that are already engaged in such activities (the intensive margin).

In the full-sample OLS models, the estimated effect of RDI captures both firms that do not engage in green innovation and those that do, implying that R&D investment may facilitate firms' initial participation in green innovation activities. However, after accounting for the censoring of EIS at zero or restricting the analysis to firms with positive EIS values, the coefficient reflects the association between R&D intensity and the level of green innovation among firms that already engage in such activities. The negative coefficient on RDI in these specifications suggests that, at average levels of ESG performance, additional R&D investment may not necessarily be directed toward environmental innovation and may instead support broader innovation objectives. Importantly, the positive and significant ESGS × RDI coefficient across all specifications indicates that ESG performance plays a critical role in shaping how R&D resources are deployed. Overall, the results confirm that the baseline findings are not driven by the presence of excess zero observations and are robust to alternative model specifications.

The consistency of these results across both robustness checks provides further confidence in the validity of our estimated relationships, particularly regarding the moderating role of ESG performance in enhancing the effectiveness of R&D expenditure. Despite these encouraging results, we acknowledge that these checks do not fully resolve endogeneity concerns. While lagging the independent variables reduces the likelihood of simultaneity bias, it does not eliminate all sources of endogeneity, such as omitted time-varying factors or measurement errors. In addition, no sensitivity analyses were performed using alternative model specifications, instrumental variables or dynamic panel estimators, which would offer stronger identification strategies. Furthermore, excluding the COVID-19 pandemic years improves internal validity but may reduce external applicability, especially for firms operating in sectors disproportionately affected by public health and economic shocks.

5. Conclusion

This study investigates the relationship between R&D investment, ESG performance and green innovation within the Australian capital market, using a sample of 1,097 firm-year observations spanning 2010–2024. Our findings provide robust empirical evidence that both RDI and the ESGS are significantly associated with green innovation, as measured by the EIS. Moreover, we find that the ESGS moderates the relationship between R&D investment and green innovation, with a positive association observed in the interaction effect. These findings should be interpreted as associational rather than causal, suggesting that ESG performance functions not solely as a compliance mechanism but as a strategic factor associated with organizational capacity for sustainable innovation.

From a theoretical standpoint, our work contributes to the growing body of literature at the intersection of sustainability, innovation and corporate strategy. First, we extend the RBV by identifying the ESGS as a strategic intangible asset associated with stronger internal capabilities and environmentally oriented innovation. Second, drawing on stakeholder theory, we show how firms with strong ESG performance are associated with reputational legitimacy, stakeholder trust, and access to funding and partnerships, all of which are positively related to innovation outcomes. Third, we introduce a novel conceptual framework centered on R&D, ESG and green innovation acting synergistically to be associated with sustainable value creation. This framework provides a lens through which firms can understand how aligning these three dimensions **is** positively related to environmental progress and competitive advantage.

Our findings offer actionable insights for corporate managers seeking to improve innovation outcomes in alignment with sustainability goals. Firms aiming to improve their green innovation performance should not only maintain or increase investment in R&D but also ensure that such investment is aligned with high ESG standards. This dual focus is associated with a higher likelihood of developing environmentally beneficial technologies while simultaneously strengthening stakeholder confidence and reputational capital. Managers are advised to prioritize cross-functional collaboration between R&D teams and sustainability officers, use ESG reporting as a strategic signaling tool, and embed green metrics into innovation key indicators (KPIs) to ensure that sustainability objectives are integrated with technological development. These strategies are particularly relevant for firms operating in carbon-intensive sectors, such as mining and energy, where firms with stronger ESG performance tend to scale their R&D efforts toward cleaner technologies while also exhibiting greater operational resilience, regulatory alignment and market differentiation.

At the institutional level, Australia's regulatory environment offers a compelling context for examining the interplay between ESG and innovation. The country's increasing emphasis on climate accountability and governance transparency presents an appropriate setting for assessing policy incentives and investor expectations are associated with sustainable innovation. Based on our analysis, we propose several policy actions to further this agenda. First, regulators, such as the Australian Securities and Investments Commission (ASIC), should continue to strengthen climate-related financial disclosures, bringing them into line with global frameworks, such as the Task Force on Climate-related Financial Disclosures (TCFD). Second, institutions, like the Clean Energy Finance Corporation (CEFC), should direct public funds toward firms with proven ESG credentials and demonstrate R&D capability, thus optimizing national investment in sustainable innovation. Third, policymakers should consider sector-specific tax incentives for firms investing in green R&D, particularly in industries facing structural transition risks under net-zero targets. Finally, ESG reporting practices urgently need to be standardized across the ASX to improve transparency, reduce the risk of greenwashing, and enable more informed investment decisions. Importantly, achieving these goals will require collaboration between government agencies, industry groups and private enterprises to promote ESG integration into innovation pipelines and accelerate decarbonization efforts.

Despite these meaningful contributions, our study has several limitations that suggest opportunities for future research. First, our sample is limited to publicly listed firms on the ASX; this may constrain the generalizability of our findings in other markets, particularly emerging economies with different regulatory and institutional environments. Future studies could expand the scope by conducting comparative analyses across multiple jurisdictions to assess how regional differences influence ESG–innovation dynamics. Second, while we control firm characteristics and time effects, endogeneity remains a concern due to the observational nature of the data, reinforcing that the reported relationships are associational. Subsequent research employing dynamic panel models (e.g. system GMM) or quasi-experimental designs would help to establish stronger causal relationships. Third, we call for deeper exploration of firm-level moderators, such as board diversity, governance structures and systematic risk, which may significantly influence the effectiveness of ESG performance in relation to innovation. Longitudinal studies tracking changes in ESG ratings and innovation output over time could further illuminate the evolving nature of these relationships under shifting policy landscapes.

In conclusion, this study underscores the complementary role of R&D investment and ESG performance in being positively associated with green innovation and long-term value creation. We highlight how firms can strategically integrate ESG principles into innovative processes to be associated with improved sustainability and competitive outcomes. We encourage both managers and policymakers to move beyond viewing ESG as a cost center, instead recognizing it as a factor linked to technological transformation and resilience. Green innovation, after all, is not solely about new technologies; it is about cultivating the right organizational cultures, systems and incentives that reward sustainability-aligned R&D investment. In doing so, firms and institutions alike can better navigate the path toward a low-carbon, innovation-driven economy.

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Futher reading

ASX Limited (2024), "ASX story", available at: www.asx.com.au/about/asx-story

About the authors

Yazan Almnadheh is a PhD Student in the School of Business at the University of Southern Queensland. He published papers in peer reviewed journals and presented papers at some international conferences.

Afzalur Rashid, PhD, CPA is a Senior Lecturer in Accounting in the School of Business at the University of Southern Queensland. In the last quarter century, he taught at universities in Australia and overseas. The major areas of his research interest are in Carbon Emission and Disclosure, Corporate Governance, Corporate Social and Environmental Disclosures and Earnings Management. He is the author/coauthor of 45 research papers published in international peer-reviewed journals including papers in many top ranked journals, such as *Asia Pacific Journal of Management, International Review of Economics and Finance*, *International Review of Finance*, *International Review of Financial Analysis*, *Journal of Business Ethics (FT50)*, *Journal of Contemporary Accounting and Economics*, *Journal of Financial Research and Managerial Auditing Journal*. He is (was) the editor and guest editor of many international journals. Afzalur Rashid is the corresponding author and can be contacted at: afzalur.rashid@usq.edu.au

Eltayyeb Al-Fakir Al Rabab'a, PhD is a Senior Lecturer in Finance and Business data Analytics at Victoria University, Brisbane, Australia. He completed his PhD studies at University of Southern

Queensland in 2022. His broad research interests include corporate finance, corporate governance, corporate sustainability, and corporate disclosure. His publications have appeared in reputable journals including *International Review of Financial Analysis*, *Journal of Contemporary Accounting and Economics* and *International Journal of Finance and Economics*. He is actively involved in the supervision of PhD students.

Dr Syed Shams is an Associate Professor in Finance at the University of Southern Queensland, Australia. He has published more than 60 research articles in a range of highly respected journals and a book chapter. His publications have appeared in reputable journals, including in the *Journal of Corporate Finance*; *Journal of Business*, *Finance and Accounting*; *British Accounting Review*; *Journal of Business Research*; *Journal of Financial Markets*, *Institutions and Money*; *Journal of Financial Research*; *European Financial Management*; *Journal of Accounting Literature*; *International Review of Finance*; *International Review of Economics and Finance*; *International Review of Financial Analysis*; *China Accounting and Finance Review*; *Journal of Behavioural and Experimental Finance*; *Corporate Governance: An International Review*; *Accounting and Finance*; *Australian Journal of Management*, *Managerial Auditing Journal*; *Journal of Contemporary Accounting and Economics*; *Finance Research Letters*; *Emerging Market Review*; *International Journal of Managerial Finance*; *Global Finance Journal*, and *Pacific-Basin Finance Journal*. His broad research interests include corporate finance, corporate governance, mergers and acquisitions, corporate sustainability, and corporate disclosure. He is actively involved in the supervision of PhD students and support earlier career researchers.