

Board Characteristics and Green Innovation: A Study in Indian Context

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ABSTRACT:

Green innovation (GI) has proven vital for innovation practices in firms across countries. Nevertheless, the role of boards of directors (BODs) in green innovation practices is scarce. This study provides an empirical analysis using theoretical arguments of human and social capital theory (HSCT) and resource dependency theory (RDT) for the role of BODs in GI practices. Empirical evidence using regression techniques with publicly traded firms from emerging countries like India between 2013 and 2023 shows that board capital (Human and social capital) impacts GI. Further, outside board members (Independent and non-executives) improve the relationship. Moreover, the paper illustrates several implications and provides scope for future research.

Keywords: *Green Innovation, Human and Social Capital, Board of directors, Independent and Non-executive board*

1. INTRODUCTION:

According to corporate governance research, boards of directors (BODs) are crucial to directing firm strategy (Hillman et al., 2000; Klarner et al., 2020). Over the past

decade, sustainability awareness in the boardroom has evolved from a mere "nice to have" to an essential "must have" (Agnese et al., 2024). Sustainability driven by green innovation (GI) has become crucial to preserving environmental management for organizations (Chen et al., 2012; Yang et al., 2016). Nevertheless, many boards are contending with an expanding green skills gap, resulting in a lack of essential competence to manoeuvre in a landscape where sustainability and profitability are inherently connected (Thomson Reuters, 2024). Giovanna and Trojanowski (2018) determined that entrepreneurial boards possessing a specific level of green human capital and a prior history of being green (Cowden et al., 2015) can favour GI (Hillman & Dalziel, 2003) and encourage their firms to embrace pro-environmental practices (Yousaf et al., 2022; Zhang & Li, 2023). Moreover, according to the Companies Act (2013), every firm's board composition should have at least three non-executive and one-third independent directors. Also, non-executive members should comprise at least half of the board (Clause 49, SEBI).

The role of BODs characteristics like diversity (Galia et al., 2015), independence (Li et al., 2017), ownership concentration (Walls et al., 2012) and board structure (Yousaf et al., 2024) has been researched concerning GI, but these features are mainly structural and overlook the board's intrinsic functional ability (Fernandez et al., 2019; Yousaf et al., 2021). Boards' human capital (BHC) (Yousaf et al., 2022) considering experience owned by foreign directors (Hao et al., 2019; Quan et al., 2021) and board social capital (BSC) (Yousaf et al., 2022) are further studied, but how these characteristics impact GI is still understudied. Moreover, the outside board member (OBM) significance has garnered relatively less focus in previous studies. The Companies Act (2013) mandates that every firm's board composition should have at least three non-executives comprising at least half of the board (Clause 49, SEBI) and one-third of

independent directors. Thus, to fill the gap in the previous studies, we aim to understand the role of Green BHC and BSC on GI and how OBM might address significant deficiencies in the relationship.

Moreover, most studies considered developed nations like the US (Lu et al., 2022; Yousaf et al., 2022). Thus, current studies still need to concentrate on the BOD's impact on GI, particularly in emerging nations like India, which lack resource availability and where GI may be a relatively new occurrence. Moreover, environmentally concerned actors in India will likely harness GI mechanisms directly (Buhl et al., 2016).

Our study comprises panel data of publicly traded firms from emerging countries, such as India, from 2013 to 2023. By adopting the Hausman random-fixed effect regression model, we understand the linkages between the BHC and BSC on GI and the moderating effect of outside directors. The study found that specific backgrounds or skills and interlock networks of BODs improve GI. Moreover, the presence of outside directors influences the relationship. We enhance this research by concentrating on independent and non-executive BODs in India's publicly traded companies. Our study makes several contributions. First, human and social capital theory (HSCT) combined with resource dependence theory (RDT) is used in the study to investigate the connection between BODs and GI, which will nobly extend the literature. Second, the study demonstrates how the outside directors shape important characteristics of GI. Third, our study included rising nations, such as India, demonstrating how the results vary concerning developing countries where green patent filling is increasing. The study concludes with a discussion and provides scope for future research.

2. LITERATURE REVIEW

2.1 Green Innovation and Corporate Governance: Green innovation (GI) is now recognized as a crucial strategic tool for attaining ecological goals (Huang et al., 2021), which reduces environmental impacts and improves energy conservation (Xia et al., 2022). Studies examine the determinants of the efficacy of GI, which surpasses other sustainable methods (Arfi et al., 2018) and fosters a beneficial impact on the natural environment. GI results from its strategic actions (Walls et al., 2011) by filling green patents (Favot et al., 2023), which is driven by the board's strategic direction (Yousaf et al., 2023). These boards may effectively manage corporate strategies and provide vital resources, information, and guidance for the firm, enhancing corporate strategies, including initiatives such as GI (Yousaf et al., 2023). Studies further suggest that factors that affect corporate governance also impact GI (Walls et al., 2011), where board competence and GI are related (Yousaf et al., 2023).

2.2 Board Capital (Human and Social) and Green Innovation:

Intellectual capital is increasingly recognized as the primary resource for a firm's innovation (Swartz & Firer, 2005). Intellectual capital combines structural, human, and societal (Vitolla et al., 2020). Structural capital includes the governance structure of the board (Yousaf et al., 2022) and human capital, which is of two distinct forms -- educational knowledge and industry experience (Kor & Sundaramurthy, 2009), which combine the board members' education and skills, knowledge, and perspectives, while social capital pertains to BOD's affiliations with other firms (Chen, 2008; Tian et al., 2011). While structural changes limit flexibility, human and board capital enables the board for GI (Yousaf et al., 2022).

Knowledge and skills related to the environment are crucial for enabling individuals to

engage in practical environmental behaviours and constitute a vital aspect of entrepreneurs' green human capital (GHC) (Meng et al., 2023). GHC possesses environmentally sustainable skills (Shah & Soomro, 2023) that stimulate green technologies and green innovations, promote green industries, and ensure sustainable growth (Nureen et al., 2023; Luo et al., 2023; Qin et al., 2023). Employees with education and knowledge about environmental issues can effectively implement their green competencies and convert their green-related expertise into developing and augmentation skills (Gifford et al., 1982; Meng et al., 2023). The green human capital of the entrepreneurial board is cultivated through "green" experiences and life history, including job and educational experiences (Yousaf et al., 2023). Board Green human capital is central to absorbing, transferring, and interpreting green knowledge from the dynamic environment (Chen & Lin, 2015; Luo et al., 2023). Moreover, the values and characteristics of board members significantly influence firms' strategic decisions and performance (Meng et al., 2023). Environmental awareness among human capital enables the creation of green inventions. It helps advance green enterprises (Qin et al., 2023), while knowledge and skills connected to the environment are essential for enabling people to adopt realistic environmental behaviours (Meng et al., 2023). Research has examined average years of education (Zhao et al., 2024) and competencies for sustainable development (Ni et al., 2023). Innovation is significantly impacted by highly educated human capital (Lenihan et al., 2019), promoting the dissemination of cross-border knowledge for GI (Ma & He, 2024). Most people agree that education is a good indicator of a person's cognitive capacity. Thus, increasing entrepreneurs' environmental awareness and fostering their green human capital can inspire them to engage in more GI (Meng et al., 2023).

The external social capital assumes increased importance within the framework of

BODs (Barroso-Castro et al., 2016). Green relational capital within the board context refers to the interaction ties with network members and partners concerning firms GI (Chen, 2008). Most board members are affiliated with another organization and are frequently chosen for their external connections, as they enhance the board's capacity to fulfil its resource provision duty (Kim & Cannella, 2008). The external social capital of directors is transformed into a sought-after attribute by enterprises, and their function as boundary spanners becomes more significant than in other workgroups (Barroso-Castro et al., 2016). Companies with more affiliated outside directors, especially those with social ties to CEOs, demonstrate superior company value compared to their peers (Joh & Jung, 2018) and maintain extensive links to the corporation.

Boards are characterized by their balanced composition of members with exposure to various global markets, pertinent skills, education, experience, and network connections (Yousaf et al., 2023), who can oversee corporate strategies and furnish essential resources and information for the organization, enhancing corporate strategy, including initiatives such as GI (Yousaf et al., 2023). According to human and social capital theory, the more firm-level connections with prior green patent issuers, the higher the likelihood of issuing green patents in later years. BODs who acquire sustainability and environmental management expertise may enhance their contributions to GI (Spischke, 2023). Therefore, we hypothesize that an organization is more inclined to begin issuing green patents if its board of directors includes individuals who concurrently serve as directors or top executives of another organization during the year the organization initiates green patent issuance or at any time in the preceding five years (termed green interlock). The BOD's recognition of sustainable or unsustainable opportunities is contingent upon information gained from

experience, education, or prior exposure to sustainability methods (Ferreira & Ferreira, 2023). Social capital, such as networks, enables access to knowledge and resources (Ferreira & Ferreira, 2023). The board's social capital offers essential resources, interacts with other businesses (Powell et al., 1999), and encourages firm innovation (Dhanaraj & Parkhe, 2006). It is reasonable to believe that social capital provides essential resources and contributes significantly to enhancing the board's decision-making and advisory tasks, which results in improved GI performance. The current study, by considering literature, posits the association between green human capital and GI; thus, we can hypothesize that:

***Hypothesis 1:** A board with green human capital (specific skills, experience, and knowledge in green technology, R&D and sustainability) improves firms' GI.*

***Hypothesis 2:** A board with more Green social capital (Interlocks) improves firms' GI.*

2.3 Outside (Independent and Non-Executive) Board members:

Outside directors can bring diverse ideas and consolidate their expertise, networks, and endeavours to achieve superior results (Kor & Sundaramurthy, 2009). The current and prior professional experiences of outside directors as managers and board members serve as significant indicators of their human capital (Bailey & Helfat, 2003; Carpenter & Westphal, 2001), as these experiences influence directors' cognition, perspectives, and interpretations (Westphal & Frederickson, 2001). Thus, bringing board members outside the organization brings more green knowledge and experience. BSC provides the firm with resources, counsel, and assistance, which is typically linked to outside board members and other organizational "ties" that the directors of the corporation hold (Zhou et al., 2021a, 2021b). Non-executive directors can get critical information and strategic skills through their connections to the firm's

surroundings (Pettigrew, 1992). Board members are frequently chosen for their external connections, as they enhance the board's capacity to fulfil its resource provision duty (Kim & Cannella, 2008). Moreover, connections between management and prospective directors impact the selection of directors (Fracassi & Tate, 2012). Boards comprising outside directors frequently get advantages from their external viewpoints and act as a resource-rich, while boards lacking such members may not have access to these insights. Board members vote on implementing changes in corporate policy, allowing outside directors, who represent a more significant proportion of the board, to exert increased influence over board decisions (Joh & Jung, 2018). According to Carpenter and Westphal (2001), BODs affiliating with strategically relevant organizations possess enhanced capabilities to offer guidance and counsel that are positively associated with the firm's performance. Resource dependency theory places great importance on establishing and growing networks with factors such as legitimacy, reputation, trust, and mutual interdependence (Lynall et al., 2003). As a result, the board's capacity to act as a resource may depend on the presence of directors with significant extra-organizational connections (Filatotchev & Nakajima, 2010). Involving GI is a crucial management strategy for organizations, and firms outside board members significantly impact their GI. Various institutional contexts may attenuate the effect of board ties since well-connected board members are more engaged in implementing GI projects (Wu et al., 2018). To overcome internal resistance to green practices, environmentally concerned actors in India will likely directly harness outside board members' mechanisms (Buhl et al., 2016). The study concludes that more outside board members improve and strengthen the link between BHC, BSC and GI (Figure 1).

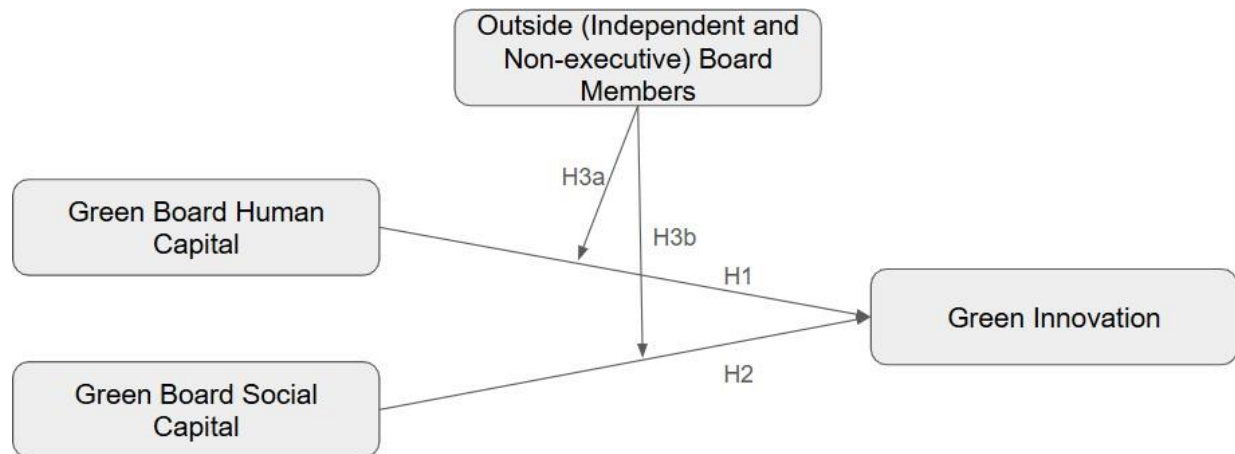
Hypothesis 3a: Including outside board members (Independent and non-executive)

impacts the relationship between green board human capital and GI.

Hypothesis 3b: *Including outside board members (Independent and non-executive)*

impacts the relationship between green board social capital and GI.

FRAMEWORK:



3. METHODOLOGY

3.1 Emerging country India as a context:

Emerging markets have some characteristics of developed markets and have the potential to become developed markets soon. Many researchers have studied in the context of emerging markets. Due to their recent rapid development rate, they are the most representative sample of emerging markets (Saeed & Sameer, 2017). According to Shao et al. (2021), these nations are anticipated to drive green innovation significantly. However, limited studies have examined social capital's role in environmentally friendly management. Companies with an established collaborative structure can better understand customers' requirements in the context of green management (Simpson et al., 2007; Geffen & Rothenberg, 2000). Although various studies have shown the trade-off between industrial competitiveness and environmental aspects, they have failed to address the role of rising nations in

spurring GI in the global market (Porter & Linde, 1995). There is growing interest in researching cooperative green innovation in emerging nations due to the lack of resources available in these regions. Thus, our study considers an emerging country like India as the context to explain our hypothesis as to how Green BHC and BSC, entrenched in environmental collaboration across organizational borders, affect GI.

3.2 Data Collection and Sample:

To test our assumptions, we conducted an empirical analysis within the context of the Indian firms, comprised of NSE-listed firms between 2013 and 2023. We have used publicly listed firms for our study since private enterprises generate fewer green patents than public entities (Vega Jurado et al., 2008). We considered only NSE-listed firms because they follow strict CG norms set by SEBI, India. Moreover, there is a detailed disclosure of the BOD profile. For several reasons, India might be seen as a sample of emerging nations. As the Companies Act 2013 mandates some changes in the board configurations, we decided to consider 2013 as the beginning year of our observation. India is a manufacturing hub for technological innovation and is ranked 40th in the world for innovation. The Indian government has chosen innovation-led growth and entrepreneurial development practices to boost employment and hasten economic growth (Abhyankar, 2014). According to Kumar and Russell (2002), India and other emerging economies are technologically behind developed economies. GI is crucial in helping Indian businesses build their technological and environmental capacities.

For board-level variables, we got 2084 Indian NSE listed firms and eliminated financial firms because of their differing regulatory and financial natures (He et al., 2021) and retained 1897 firms. Then, we matched the green patent data manually and for robustness, we used the Fuzzywuzzy package

(<https://pypi.org/project/fuzzywuzzy/>) in Python to match with a threshold value of 80, and again, it was supplemented by manual verification. Further, we matched the available data of board human capital and available board social capital, which retained 913 firms or 7084 firm-years. All variables were winsorized to eliminate the influence of outliers. Control variables encompass firm-level and individual characteristics, lagging all variables by one period. A list of variables and data sources is given in Table 1. Patent data is collected from PATSTAT and is coded as per the green technology codes IPC and CPC coded “Y02” are considered green patents (Hascic & Migotto, 2015), and board and control variable data are collected from CMIE Prowess and NSE prime Infobase.

3.3 VARIABLES:

Dependent Variable: Previous studies have frequently included green patent data to measure green innovation (Huang et al., 2021; Li et al., 2018; Qi et al., 2021). Following Huang et al. (2021), our dependent variable was green innovation, quantified as a log (1+green patents) according to Huang et al. (2021). We categorized the patent as green according to the CPC list “Y02%” and the tagging scheme established by the EPO (Favot et al., 2023; Block et al., 2025). Green innovation (GI) data are sourced from the PATSTAT database (Huang et al., 2021; Johnstone et al., 2012; Li et al., 2018; Qi et al., 2021; Yousaf et al., 2022).

Independent Variable: This study considers board capital, encompassing human and social capital, as the independent variable because structural characteristics typically do not indicate performance capability (Yousaf et al., 2022). BHC is calculated using a combination of two variables — educational level and expertise of board directors.

For educational level, we sum up the number of education types of board members and

divide it by board size (Chen, 2014; Yousaf, Ullah, Wang, et al., 2022). Board expertise is calculated using keywords like “Green” OR “Green Technology” OR “environment*” OR “tech*” OR “R&D” OR “research” OR “Energy” OR “sustain*” OR “Renew*” OR “climate” OR “carbon” OR “ESG” OR “Circular economy” OR “Recycling” OR “Waste” OR “Emission” by searching in the BODs Education, Skills/Competencies, occupation or their brief experience profiles (Lai et al., 2019; Ooi et al., 2015; Rossoni & Gonçalves, 2019; Lin, 2024; Castellani et al., 2022; Zarraga & Bonache, 2005; Ni et al., 2023; Khan et al., 2024). The above keywords then standardise by the size of the board (Zarraga & Bonache, 2005; Castellani et al., 2022; Ni et al., 2023; Khan et al., 2024). We employed principal component analysis (PCA) as our secondary technique to validate our BHC measure. Principal Component Analysis (PCA) generates eigenvectors—linear combinations of human capital dimensions—derived from the correlation matrix of the different components of board human capital. Following Black et al. (2017), we concentrate on components exhibiting loadings exceeding 0.4. We employed Varimax rotation, recognizing it as a prevalent technique for analyzing the sustained components (Black et al., 2017). The maximum eigenvalue is 1.51, and the minimum is 0.49. All BHC features possess at least one component with loading over 0.4; hence, we included all BHC facets in our regression analysis.

Board Social Capital (BSC) is defined as the board members interlock with other firms. The quantity of simultaneous directorships in different firms is utilized to assess social capital. Data is sourced from Board Ex (Bruynseels & Cardinaels, 2014; Yusuf & Sherif, 2020) and Refinitiv Eikon (Adams et al., 2023).

Moderator Variable: We have outside board member (OBM) as our moderator variable influencing the connection between board capital and GI. Corporate boards

often consist of both executive and non-executive directors. Non-executive directors fulfil a supervisory and consultative function while overseeing the board's operations, particularly those of the executive directors (Mynhardt, 2013). A non-executive director is appointed to provide strategic, specific, and objective counsel at board meetings and is supposed to oversee the performance of the company's executive directors, management, and personnel. The presence of non-executive directors with prior experience in environmental matters and network connections can influence a firm's ethical and environmental conduct (Homroy & Slechten, 2019). Outside board members are the percentage of independent and non-executive directors (Baber et al., 2013; Gao & He, 2019). Data is collected from Refinitiv Eikon and CMIE prowess databases (Adams et al., 2023).

Control Variable: We implemented multiple controls considering the study relationships. The corporate governance control factors encompass board size, board gender diversity, and board duality. Organizations with larger board sizes (Gonzales-Bustos et al., 2020), improved gender diversity among board members (He and Jiang, 2019), and the lack of duality (Galia et al., 2015) demonstrate stronger performance in terms of GI. We employed firm size (Lin et al., 2019), leverage (Huang et al., 2021), return on assets (ROA) (Lin et al., 2019), state-owned enterprises (SOE) (Wang & Jiang, 2021), capital intensity (CI) (Huang et al., 2021), Board meeting and firm age (Quan et al., 2021) as controls at the company level. Additionally, we have incorporated industry, year, and country dummy variables. All data are sourced from the Refinitiv Eikon database (Adams et al., 2023) (Refer to Table 6: Appendix).

3.4 MODEL SPECIFICATIONS:

We have tested the hypothesis using the functional form: $Y_{it} = a_0 + a_1 * X_{it-1} + u_i + c_i$

+ ϵ_{it} ... (1) Where "i" is for the firm, "t" stands for the year, and "Y" stands for the dependent variable, in this case, the firm's green innovation. The variable "X" contains each of the control variables. "ui" stands for randomness at the company level, "ci" stands for randomness at the country level, "eit" for randomness across companies over time, and "a1" for estimated parameters. We are using Hausman fixed-random effect regression to determine the green innovation potential.

A model that examines the connections between GI practices and Board capital (BC) (Equation 2), as well as the connections between outside board members (OBM), board members experience and knowledge (BHC) (Equation 3), and board interlock (BSC) (Equation 4), is used to test the hypothesis. The board antecedents to GI are arranged appropriately in the equation, which can be used to represent the model as follows. The models also contain control variables $X_{i(t-1)}$.

We tested our empirical model using the econometric equation.

$$(GI)_{it} = \alpha_0 + \alpha_1 (BHC)_{it} + \alpha_2 (BSC)_{it} + \sum \alpha_3 Controls_{it} + \sum Year + \sum Industry + \sum Country + \epsilon_{it} \quad (2)$$

$$(GI)_{it} = \alpha_0 + \alpha_1 (BHC)_{it} + \alpha_2 (BHC)_{it} * (OBM)_{it} + \sum \alpha_3 Controls_{it} + \sum Year + \sum Industry + \sum Country + \epsilon_{it} \quad (3)$$

$$(GI)_{it} = \alpha_0 + \alpha_1 (BSC)_{it} + \alpha_2 (BSC)_{it} * (OBM)_{it} + \sum \alpha_3 Controls_{it} + \sum Year + \sum Industry + \sum Country + \epsilon_{it} \dots \dots (4)$$

BHC (board human capital) and BSC (board social capital) are the two independent variables, and control variables were added to the study. OBM (outside board member) is the moderator, and ϵ_{it} are the error terms, with time, industry and country fixed effects.

4. RESULTS:

4.1 Descriptive statistics and correlation analysis:

The descriptive statistics for several indicators encompass each variable's count of observations, mean, standard deviation, minimum, and maximum (as presented in Table 1). Table 2 displays Pearson's correlation coefficients for the examined variables and demonstrates that all values of the explanatory factors significantly fall short of the threshold of 0.8. It also indicates that outside board members influence GI BSC positively and significantly correlate, which validates our primary hypothesis.

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Green Innovation Board	7,082	0.02477	0.19063	0	2.550228
Human Capital Board	7,082	5.84E-10	1.2268	-3.49559	4.58445
Social Capital Outside Board	7,082	0.0000189	0.73913	-0.83407	8.1071
Member Board Size	7,082	-0.01054	0.068776	-0.18477	0.515233
Board Gender Diversity	7,082	24.99	6.0033	1	30
Board Duality	7,082	0.121	0.081155	0	0.545455
Firm Size	7,082	0.0525	0.2231	0	1
Return on Assets	7,082	9.9854	1.057224	2.304275	13.17599
Leverage	7,082	0.03981	0.1996	-4.314135	6.27051
State Owned	6,810	0.276449	0.23612	0	1.05
Enterprise Capital Intensity	7,082	0.0101666	0.1003	0	1
Board Meetings	5,566	0.809522	1.45978	0	10.5
Firm Age	7,040	8.7801	2.62485	1	28
	7,057	1.5303	0.2022	0	2.0792

Table 1: Descriptive statistics of the Indian NSE firms

Greek Innovation	Board Human Capital (t-1)	Board Social Capital (t-1)	Outside Board Member	Board Size (t-1)	Board Gender Diversity	Board Duality (t-1)	Firm Size (t-1)	Return on Assets (t-1)	Leverage (t-1)	State Owned Enterprise	Capital Intensity	Board Meetings (t-1)	Firm Age (t-1)
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				1)	ber(t-1)	sity(t-1)			erp rise (t-1)	t-1)
Green Innovation	1									
Board Human Capital(t-1)	0.1070* (0.000)	1								
Board Social Capital(t-1)	0.0698* (0.000)	0.1813* (0.000)	1							
Outside Board Member (t-1)	0.0112 (0.3807)	- 0.0132 (0.2989)	0.2591* (0.000)	1						
Board Size(t-1)	0.0195* (0.1269)	0.1918* (0.000)	0.0376* (0.0032)	0.2099* (0.000)	1					
Board Gender Diversity(t-1)	- 0.0208 (0.1032)	0.0978* (0.000)	- 0.1631* (0.000)	- 0.1453* (0.000)	- 0.060 (0.6358)	1				
Board Duality(t-1)	0.1915* (0.000)	0.1516* (0.000)	- 0.0268* (0.0356)	- 0.0152 (0.2345)	0.0199 (0.1180)	0.0799* (0.000)	1			
Firm Size(t-1)	0.1277* (0.000)	0.3378* (0.000)	0.1387* (0.000)	0	0.2038* (0.000)	0.0090 (0.4822)	0.2158* (0.000)	1		
Return on Assets(t-1)	0.0175 (0.1710)	0.1030* (0.000)	0.0253* (0.0485)	0.0156 (0.2222)	0.0910* (0.000)	0.0078 (0.5413)	0.0599* (0.000)	0.0517* (0.0001)	1	

Leverage(t-1)	-	-	-	0.02	-	-	-	-	-	1		
	0.0104	0.1509*	0.0550*	0.0231	0.0795*	0.0881*	0.0918*	0.0170	0.2994*			
	(0.4252)	(0.0000)	(0.0000)	(0.0763)	(0.0000)	(0.0000)	(0.0000)	(0.1916)	(0.0000)			
State Owned Enterprise(t-1)	-	-	-	0.00	0.0	0.01	0.3801	0.1	0.00	-		
	0.0049*	0.0035*	0.0758*	0.0094	0.0447*	0.0178	0.3801*	0.1394	0.0068	0.0605*	1	
	(0.6993)	(0.7815)	(0.0000)	(0.4613)	(0.0004)	(0.1622)	(0.0000)	(0.0000)	(0.5947)	(0.0000)		
Capital Intensity(t-1)	0.01	-	0.043	-	-	0.06	-	0.0	-	0.22	0.0	
	0.0168	0.0791*	0.0435*	0.0180*	0.1094*	0.0628*	0.0100	0.469*	0.2596*	0.32*	0.114	1
	(0.2422)	(0.0000)	(0.0025)	(0.2094)	(0.0000)	(0.0000)	(0.4852)	(0.0011)	(0.0000)	(0.0000)	(0.4286)	
Board Meetings(t-1)	-	-	-	0.01	0.0	-	0.0205	0.0	-	0.06	0.0	-
	0.0009	0.0198	0.0019	0.0173	0.0807*	0.0560*	0.0205	0.0913*	0.0225	0.0604*	0.464*	0.0
	(0.9466)	(0.1209)	(0.8803)	(0.1743)	(0.0000)	(0.0000)	(0.1085)	(0.0000)	(0.0799)	(0.0000)	(0.0003)	(0.6908)
Firm Age(t-1)	0.06	0.0382	0.041	0.13	0.1	-	0.0454	0.1	0.03	-	0.0	-
	0.061*	0.0382*	0.0412*	0.1364*	0.1860*	0.0570*	0.0454*	0.1159*	0.0331*	0.1199*	0.706*	0.0
	(0.0000)	(0.0007)	(0.0012)	(0.0000)	(0.0000)	(0.0000)	(0.0004)	(0.0000)	(0.0099)	(0.0000)	(0.0000)	(0.0000)
												0.02
												53*
												(0.0480)
												1

Table 2 shows the pairwise correlation between the study variables. Where * <0.01, **<0.05 and ***<0.1 significance level.

Main Effect:

We used panel regressions to estimate the models since we converted the count variable to a continuous variable using log transformation. We checked for time-fixed effects, heteroscedasticity and auto-correlation and were found to be present. Thus, we took the remedial measures and used fixed and random effect regression. Since the Hausman fixed-random test shows (prob>chi2 = 0.000 is less than 0.05), the fixed effect is preferred for regression with BHC. For regression with BSC, the Hausman fixed-random test shows (prob>chi2 = 0.000 is less than 0.05); thus, the fixed effect is preferred, and for the whole model (prob>chi2 = 0.000 is less than 0.05), the fixed effect is preferred. For our model, we have

considered the results of random model regression for the overall model. We have checked for correlation among the variables; the results show that BHC and BSC are significant and correlated with the dependent variable GI. Moreover, the correlation coefficient for all the variables is less than 0.7; multicollinearity is not a concern. Further, we checked that the maximum value of Vif is 1.52 (Vif <10), which means there is no multicollinearity. Moreover, the BP-LM test shows (Prob > chi2 = 0.0000) that heteroscedasticity is present. Since our model can have endogeneity problems, we use an instrument variable. We have considered a lag of 1-year for all the explanatory and control variables. Second, we analyzed the moderation effect with OBM (Outside board member) through the interaction effect analysis. We created an interaction term between the IV and the moderator and tested it for statistical significance. Smaller firms with low assets and constrained sales might belong to the "always zero" group, which may not participate in GI activities (Table 3).

Partial Model BHC -> GI (Model 1)					Partial Model BSC -> GI (Model 2)				Full Model BHC & BSC -> GI (Model 3)			
Random effect model		Fixed effect model			Random effect model		Fixed effect model		Random effect model		Fixed effect model	
Panel Regression	With moderator	Without moderator	With moderator	Without moderator	With moderator	Without moderator	With moderator	Without moderator	With moderator	Without moderator	With moderator	Without moderator
Board Human Capital _(t-1)	.011956* (0.002)	.01111* (0.002)	-.0085 (0.392)	- .00913 (0.355)					.0122* (0.002)	.01095* (0.003)	-.00741 (0.458)	-.00899 (0.364)
Board Social Capital _(t-1)					0.00557 (0.221)	.0032 (0.462)	0.0025 (0.658)	-.001524 (0.776)	.00365 (0.426)	.00153 (0.726)	0.00285 (0.616)	.00122 (0.821)

Board Human Capital *Outside Board Member _{t-1}	.03124 (0.379)		.0221 (0.624)							.0371 (0.302)		.0376 (0.409)	
Board Social Capital *Outside Board Member _{t-1}					- 0.0838 8*** (0.081)		- 0.107 95** (0.033)			- .0932 55*** (0.053)		- .1132 4** (0.027)	
Board Size _{t-1}	.00024 1 (0.678)	.00039 (0.492)	0.0008 8 (0.270)	0.0009 (0.264)	0.0002 6 (0.652)	.00045 6 (0.429)	0.000 7** (0.398)	0.0008 3 (0.320)		.0000 098 (0.987)	0.000 41 (0.477)	0.000 698 (0.403)	0.000 853 (0.305)
Board Gender Diversity _{t-1}	- .03111 (0.494)	-.0305 (0.503)	-.0656 (0.266)	-.0648 (0.272)	- 0.0266 6 (0.559)	- .02826 (0.535)	-.061 (0.305)	- .06567 8 (0.273)		- .0295 6 (0.516)	- .0305 8 (0.502)	- .0613 55 (0.299)	- .0643 (0.277)
Board Duality _{t-1}	.1062* (0.001)	.10651 * (0.000)	.07497 7* (0.000)	.0754 (0.000)	0.1099 * (0.000)	.10946 * (0.000)	.0751 * (0.000)	.07497 * (0.000)		.1066 4* (0.000)	.1066 * (0.000)	.0747 1* (0.000)	0.075 3* (0.000)
Firm Size _{t-1}	.00756 * (0.008)	.0075* (0.009)	.00252 (0.444)	.00251 (0.446)	0.0088 * (0.002)	.00882 * (0.002)	.0024 4 (0.458)	.00251 8 (0.446)		.0074 8* (0.009)	.0074 5* (0.009)	.0024 9 (0.450)	.0025 4 (0.441)
Return On Assets _{t-1}	0.005 (0.761)	0.0062 3 (0.769)	.0192 (0.394)	.0192 (0.395)	0.0089 9 (0.672)	.00852 93 (0.688)	.0202 (0.370)	.01976 (0.381)		0.007 237 (0.733)	0.006 045 (0.776)	.0199 6 (0.376)	.0193 3 (0.391)
Levera ge _{t-1}	0.0053 1 (0.761)	0.0048 5 (0.781)	.00046 (0.849)	.0044 (0.855)	0.0023 (0.897)	0.0021 (0.905)	.0056 (0.818)	.00424 (0.861)		0.005 4 (0.757)	0.004 54 (0.795)	.0061 6 (0.800)	.0044 4 (0.855)

State Owned Enterprise _(t-1)	- .151354* (0.000)	- .15261* (0.000)	- .10198** (0.025)	- 0.1025** (0.024)	- 0.1538* (0.000)	- .15422* (0.000)	- 0.10143** (0.026)	- 0.10104** (0.026)	- .15031* (0.000)	- .15225* (0.000)	- .10163** (0.026)	- 0.10223** (0.025)
Capital Intensity _(t-1)	- .00143 (0.543)	- .00135 (0.564)	.000125 (0.965)	.00017 (0.953)	-.0017 (0.468)	.00174* (0.458)	.00037 (0.896)	0.00020 (0.945)	.00141 (0.549)	.00137 (0.560)	.000256 (0.930)	0.000145 (0.960)
Board Meeting _(t-1)	- .00261** (0.016)	- .00262** (0.016)	- .00326* (0.005)	- .00325* (0.005)	- 0.0026** (0.015)	- .00264** (0.015)	- .00324* (0.005)	- .0033* (0.005)	- .0026044* (0.016)	- .0026** (0.016)	- .00325* (0.005)	- .00324* (0.005)
Firm Age _(t-1)	.0704* (0.001)	.07188* (0.001)	0.2156 (0.105)	0.21781 (0.101)	0.06913* (0.001)	.06913* (0.001)	0.2427*** (0.068)	0.2267*** (0.088)	.0698* (0.001)	.0713* (0.001)	0.23367** (0.080)	.2199*** (0.098)
Model Significance	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000

Table 3: Shows fixed and Random effect results for Indian firms. Where * <0.01, **<0.05 and ***<0.1 significance level.

The test results of the random and fixed effect regression, by taking a 1-year lag for all the explanatory and control variables, show that considering the random effect model, BHC has a significant effect on the GI of the firm (Coeff = .01111, p-value = 0.002). While OBM is included in the board, BHC positively impacts GI (Coeff = .01196, p-value = 0.002), and the interaction effect of BHC with OBM shows that it strengthens the relationship by shifting (coeff. = .01111 to .01196). Thus, an outside board member is essential for the board's human capital to influence the firm's green innovation. Results show an insignificant effect of BSC on GI; even in the presence of the moderator, it shows no effect.

In the case of the entire model random-fixed effect regression, while considering the

random effect regression – in the absence of the outside board member, BHC positively GI (Coeff = .01095, p-value = 0.003), while there is no effect of BHC on GI. When the outside board members are included, the effect of BHC on GI increases (Coeff = .0122, p-value = 0.002), and BSC has no effect. Thus, in the full model, the presence of an outside board member increases the impact of BHC on GI. This concludes that including outside non-executive board members is necessary for GI in the firm, and there is a positive effect on GI activities.

	Partial Model BHC -> GI (Model 1)		Partial Model BSC -> GI (Model 2)		Full Model BHC & BSC -> GI (Model 3)	
Feasible Generalized Least squares effect model						
Panel Regression	Moderator included	Moderator Excluded	Moderator included	Moderator or Excluded	With moderator	Without moderator
Board Human Capital _(t-1)	.0147* (0.000)	.01392* (0.000)			0.01439* (0.000)	.013278* (0.000)
Board Social Capital _(t-1)			.0105* (0.009)	.00904** (0.018)	.000696*** (0.086)	.00565 (0.145)
Board Human Capital*Outside Board Member _(t-1)	.0435* (0.203)				.0429 (0.214)	
Board Social Capital*Outside Board Member _(t-1)			- 0.06781 (0.204)		- 0.08919*** (0.095)	
Board Size _(t-1)	-.00053 (0.345)	- .0002232 (0.661)	- .000245 (0.642)	- 0.00007 (0.885)	-.000789 (0.177)	-.0002587 (0.612)
Board Gender Diversity _(t-1)	-.01597 (0.690)	.01807 (0.651)	0.02817 (0.482)	0.02784 (0.487)	0.0166 (0.678)	0.01847 (0.644)
Board Duality _(t-1)	.18978* (0.000)	.1903* (0.000)	.19779* (0.000)	.19661* (0.000)	.1914* (0.000)	.190549* (0.000)
Firm Size _(t-1)	.014487* (0.000)	.01437* (0.000)	.01768* (0.000)	.01758* (0.000)	.0142* (0.000)	.014022* (0.000)

Return On Assets _(t-1)	-.03075 (0.202)	-.03218 (0.181)	-.0247 (0.304)	-.2450233 (0.170)	-.0312 (0.196)	-.0329 (0.171)
Leverage _(t-1)	0.00597 (0.682)	0.00474 (0.745)	-.00093 (0.949)	-.00101 (0.945)	.0049 (0.736)	0.0034 (0.817)
State Owned Enterprise _(t-1)	-.26002* (0.000)	-.26271* (0.000)	.26792* (0.000)	.26726* (0.000)	-.25745* (0.000)	-.259* (0.000)
Capital Intensity _(t-1)	-.00407*** (0.055)	-.00394*** (0.063)	.00498* (0.019)	-.00495** (0.020)	-.004289** (0.043)	-.00415*** (0.050)
Board Meeting _(t-1)	-.001427 (0.232)	.00145** (0.224)	.001536 (0.200)	-.00153 (0.202)	-.001369 (0.251)	-.00138 (0.248)
Firm Age _(t-1)	.08485* (0.000)	.0856* (0.000)	.0839 * (0.000)	.0833* (0.000)	.08458* (0.000)	.0844* (0.011)
Model Significance	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000	Prob > chi2 = 0.0000

Table 4: Shows Negative binomial regression results for Indian firms. Where * <0.01, **<0.05 and ***<0.1 significance level.

Moreover, since heteroskedasticity and autocorrelation exist, we have used feasible generalized least square regression. The test results of the Feasible Generalized Least Squares regression of Indian NSE-listed firms show that for the partial model, considering board human capital (BHC) -- BHC positively impacts the GI of the firm (Coeff = .01392, p-value = 0.000). While Outside board members (OBM) are included, the impact of BHC on GI increases and positively impacts GI (Coeff = .0147, p-value = 0.000). While considering board social capital (BSC) -- BSC positively impacts the GI of the firm (Coeff = .0091, p-value = 0.018), considering the Outside board members (OBM) interaction effect, BSC positively impacts GI (Coeff = .0105, p-value = 0.009). Again, considering the entire model without the interaction term, BHC positively impacts GI (Coeff. = .013278, p-value = 0.000), and BSC impacts GI positively (Coeff. = .00565, insignificant). While the whole model

considering both BHC and BSC and the interaction effect of OBM shows that BHC has a positive impact on GI (Coeff. = 0.01439, p-value = 0.000), while BSC also impacts GI (Coeff. = .000696, p-value = 0.086). However, an interaction effect exists for both BHC and OBM (Coeff. = .0429, p-value = .214) and BSC with OBM (Coeff. = -.008919, p-value = 0.095) (Table 4). This concludes that including independent and non-executive members on the board will improve green innovation in the firm and positively affect green innovation activities. The results show positive outcomes and contribute to the existing literature.

Robustness check:

Our analysis demonstrates that augmented board capital improves the efficacy of green innovation. Our methodology may demonstrate an inverse causal relationship between board capital and green innovation. This analysis asserts that board capital is exogenous. It is likely endogenous and may depend on the firm's need to hire individuals with superior board capital to address endogeneity (Cenciarelli et al., 2018). We additionally employed lagged values of independent variables.

This research tests endogeneity using the Durbin-Wu-Hausman test using the instrument variable environmental social and governance (ESG score) (Mehedi et al., 2024; Lv et al., 2024). We failed to reject the null hypothesis (p-value = 0.4705). This means there is no strong evidence of endogeneity, and OLS regression is acceptable. Further, for robustness check, we used 2sls measure with different possible instruments like the CSR reporting (1 indicated if the company reported, else 0), ESG score, which is a combined measure of environmental, social and governance measures of the firm and environmental score as instrumental variables using two-stage least squares (2SLS) (Chen, 2014). Human and social capital enhance corporate social responsibility and improve ESG scores, particularly in environmental

performance, and are related (Yousaf et al., 2022). Over-identification and weak instrumental variable tests are conducted before the regression with panel instrumental variables. In our case, we found that the ESG score acts as a strong instrument. Model 1 – BHC measure shows that using the instrument variable ESG score with a 1-year lag, the first stage result shows an F value = $96 > 10$, which means the instrument used is strong; further test of endogeneity shows that $p = 0.2112 > 0.05$ thus, X is exogenous and there is no endogeneity concern using ESG score with 1-year lag as instrument variable. Similarly, Model 2 – BSC measure shows that using the instrument variable ESG score with a 1-year lag, the first stage result shows an F value = $17.855 > 10$, which means the instrument used is strong; further test of endogeneity shows that $p = 0.78 > 0.05$ thus, X is exogenous and there is no endogeneity concern using ESG score with 1-year lag as instrument variable.

5. CONCLUSION:

Our study, employing the panel regression, analyzes that BODs having BHC related to green knowledge and experiences positively impacts firm GI, and outside board members, positively enhances the connection between BHC and BSC with GI. Measuring Green Innovation empirically proved difficult due to numerous influencing factors and limited data availability (Kor, 2006). Our research expands upon previous studies (Huang et al., 2021; Johnstone et al., 2012; Li et al., 2018; Qi et al., 2021; Yousaf et al., 2022) by providing a comprehensive analysis of the positive moderating influence of OBM on the relationship between board capital (BHC and BSC) and Green Innovation. Our study employed panel data from the top emerging nations (India). Based on earlier research on intellectual capital, this paper offered a fresh construct-- green intellectual capital. Our paper contributes to the literature by analyzing the impact of BHC and BSC on GI. Moreover, our study depicts green human

capital and social capital constructs in the context of green innovation, which previous studies have lagged (Meng et al., 2023; Luo et al., 2023). We also extend the literature by employing human and social capital theory and resource Dependency theory in the context of CG and GI. Since our study is done in the context of emerging nations like India, which have not been widely researched in previous studies, this study gathers information from Indian NSE-listed firms. It compares how India has embraced new technologies, procedures, and goods to address environmental issues and advance sustainability. Results show a positive impact of having outside board members onboard the board team, and by having green human capital, a firm can engage more in green innovation practices. Moreover, having good connections and networks influences the firm's adoption of GI practices.

5.1 THEORETICAL AND MANAGERIAL IMPLICATIONS:

Theoretical Implications: We employ human and social capital (HSC) and resource dependency (RDT) theories to analyze the influence of extensive green expertise and a good network on a firm's innovation outcomes. The social capital at the board level influences the board's overall effectiveness. Pfeffer and Salancik's (1978) foundational research on BODs and establishing networks within and beyond companies constitutes a critical responsibility of directors. The social capital of directors serves as a mechanism through which firms develop communication networks and exert influence over essential decision-making processes of GI practices. The articles used HSC theory, which posits that the board possesses the human and social capital necessary for GI practices. With board expertise and networks, firms can improve their green patenting activities.

Further, the article used RDT (Pfeffer, 1972), which posits that cohesive leadership

with external affiliations and specialized knowledge influences innovation decisions. Resource dependence theory is related to the membership and attributes of a firm's BODs (Aggarwal et al., 2019; Zahra & Pearce, 1989). Hillman and Dalziel (2003) assert that board capital encompasses both the monitoring and resource-providing roles of the board (Pfeffer & Salancik, 1978). In comparison, the facts on board capital substantiate the theoretical assertions concerning the board's resource-provisioning (resource dependency) functions. The resource dependence view is thorough and enhances the overall understanding of board functions (Hillman & Dalziel, 2003; Maere et al., 2014).

Combining both theories necessitates understanding the impact of Board characteristics on GI. Board capital helps bring in non-inherited resources through their expertise and networks, which allows for patent creation. Moreover, with their knowledge and expertise in sustainability and networking with firms possessing sustainable practices, boards can act as resource providers, which helps generate more green patents for the firm.

Policymakers and Managerial Implications: This study recommends that the upper echelons of executives play an important role in firms' GI practices and help collaborate strongly with external resources, generating an inflow of resources. Secondly, if the board is renewed with external members recruited from outside the organization, they will help bring more external resources to the organization to help with green patenting. Thus, practitioners need to follow all the practices suitable for their firm. The management team can bring more board members with high human and social capital for more green patent filling. Progress in green technology and broad human capital significantly influences the reduction of energy consumption and resource management in the production sector. GI and board human capital

substantially enhance product quality and optimize energy use, increasing energy efficiency and mitigating pollution emissions. Consequently, the economy may attain the objective of sustainable development since these measures diminish production expenses and previously mentioned environmental concerns.

6. LIMITATIONS AND FUTURE DIRECTIONS:

We encountered various challenges while studying BHC and BSC and their impact on GI. One of the reasons is the context of the study. Our study is done in the context of the emerging nation India, which has not been widely researched in previous studies. We face various challenges for several reasons. First, board-related data is difficult to extract because of the lack of proper board and governance-related databases. Second, it is tough to integrate all the data from all the variables we are studying; all the data may not be available in a single database, which often reduces the number of final observations. The study is not free of limitation; we have only considered the firms available in all used databases, reducing the number of observations in our study. Moreover, we have considered only NSE-listed Indian firms. Future researchers can look for a more robust study by considering more firms for their study sample. Further studies can consider the context of developed nations like the US and can consider the multi-country level context. Further study can be done using a cross-country analysis, which gives a holistic view of emerging nations, including India, versus developed nations like the US. Moreover, studies can consider the impact of other board-level variables like the age of BODs and characteristics of CEOs and other TMTs, which can be further studied. Moreover, we have investigated the GI but have not tested its impact on environmental performance, which warrants further studies.

APPENDIX:

Variables	Variable Name	Measure	Data Source	Citation
DV	Green innovation (GI)	Green Patents = log (green patents +1)	PATSTAT database filter with CPC code “Y02%”	(Huang et al., 2021; Li et al., 2018; Qi et al., 2021, Yousaf et al.,2022).
IV	Board Human Capital with specific experience	Green BHC = Principal component analysis of the Ratio of the board members with the number of educations to the board size, and specific skills/occupations related to green innovation in their brief profile to the board size.	NSE Prime Infobase	(Tian et al., 2011; Yousaf et al.,2022)
	Board Social Capital	BSC = Board member interlocks (total number of other org. directors standardized to the board size.	CMIE Prowess database	(Yousaf et al.,2022)
Moderator	Outside board members	The ratio of outside or independent and non-executive directors to the board members’ size.	CMIE Prowess database	(Baber et al., 2013; Gao & He, 2019)
Control	Board size (BSIZE)	Total number of directors on the board.	CMIE Prowess database	(Gonzales Bustos et al., 2020; Yousaf et al.,2022)
	Board Meetings	The total number of board meetings held in that particular year	Thomson Eikon (Adams et al., 2023)	(Galia et al., 2015; Yousaf et al.,2022)
	Board gender diversity (BGD)	The ratio of women sitting on the board of directors to the board size.	Thomson Eikon (Adams et al., 2023)	(He and Jiang, 2019; Yousaf et al.,2022)
	Board Duality	A dummy variable, 1 if the CEO and chairman of the board are the same person and 0 otherwise	Thomson Eikon (Adams et al., 2023)	(Galia et al., 2015; Yousaf et al.,2022)
	Firm size (FSIZE)	Natural logarithm of total assets.	Thomson Eikon (Adams et al., 2023)	(Lin et al.,2019; Yousaf et al.,2022)
	Return on assets (ROA)	The ratio of net income to average total assets after each fiscal year.	Thomson Eikon (Adams et al., 2023)	(Lin et al., 2019; Yousaf et al.,2022)
	Leverage (LEV)	The ratio of total debt to total assets.	Thomson Eikon (Adams et al., 2023)	(Huang et al., 2021; Yousaf et al.,2022)
	State	A dummy that equals one if a	Thomson	(Wang and Jiang,

	Owned Enterprises (SOE)	firm is an SOE and zero otherwise	Eikon (Adams et al., 2023)	2021; Yousaf et al.,2022)
	Capital intensity (CI)	Measured by dividing fixed assets by sales	Thomson Eikon (Adams et al., 2023)	(Huang et al., 2021; Yousaf et al.,2022)
	Firms Age	Years from the date of incorporation	CMIE Prowess database	(Huang et al., 2021; Yousaf et al.,2022)
Instrument	ESG Score	A combined score of Environment, Social and Governance	Thomson Eikon (Adams et al., 2023)	(Mehedi et al., 2024; Lv et al., 2024)

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