

Climate Risk Disclosure, Green Finance, and Cost of Capital Among PSX Non-Financial Firms

Authors Details

Muhammad Ashraf^{1*}

Ph. D Scholar, Department of Business Administration [Gomal University, DI Khan],
Pakistan.

Dr. Amanullah Khattak²

Professor, Department of Business Administration [Gomal University, DI Khan], Pakistan.

Dr. Khalid Rehman³

Associate Professor, Department of Business Administration [Gomal University, DI Khan],
Pakistan.

Dr Muhammad Waseem Quershi⁴

Assistant Professor, Department of Business Administration [Gomal University, DI Khan],
Pakistan.

Corresponding Author: *Muhammad Ashraf*

ABSTRACT: Purpose: The purpose of this study is to examine correlations between climate risk disclosure quality (CRDI), green finance (GFI), and cost of capital (COC) among Pakistan Stock Exchange (PSX)-based non-financial companies for 2013-2023. The study is based on Information Asymmetry Theory, Stakeholder Theory and Legitimacy Theory to investigate whether superior climate risk disclosure leads to lower cost of equity, debt and WACC; whether green finance acts as a mediator in the context of the aforementioned relationship; and whether board environmental expertise acts as a moderator in the mediated pathway.

Design/Methodology/Approach: An unbalanced panel of 165 PSX-listed non-financial firms (maximum 1,815 firm-year observations) is analyzed. The Climate Risk Disclosure Index (CRDI) is a 24-item index based on structured content analysis (dual-coder, Cohen's Kappa = 0.83), which can be disaggregated to include the categories of transition risk disclosure (TRD), physical risk disclosure (PRD), and governance climate accountability (GCA). Cost of equity is calculated by using CAPM, cost of debt by using the interest expense ratio and WACC by using the market-value weighting. Green finance is expressed in a PCA-weighted combination of four instruments. Endogeneity is controlled for using System GMM (Blundell and Bond, 1998). Estimation of mediation (PROCESS Model 4) and moderated mediation (PROCESS Model 14) involves the use of BCa bootstrapped confidence intervals (5000 iterations).

Findings: CRDI is negatively and significantly associated with cost of equity (beta = -0.187, $p < 0.001$), cost of debt (beta = -0.142, $p < 0.001$), and WACC (beta = -0.168, $p < 0.001$). The CRDI-cost of equity relationship is partially mediated by green finance (indirect effect = -0.072; BCa 95% CI [-0.118, -0.031]), accounting for nearly 38.5% of the total. Highly-efficient boards (IMM = -0.024; BCa 95% CI [-0.041, -0.009]) provide significant moderation of this mediated pathway, reducing costs by 2.1x more. Other disclosure variables, including transition risk disclosure (beta = -0.214), have higher effects on capital costs than do physical risk disclosure (beta = -0.156). All results are robust to GMM endogeneity correction.

Research Limitations: Single-country PSX setting; GRI content-analysis-based CRDI is based on self-disclosed reports; limited data availability on green finance after 2023 for SECP-mandatory PE disclosures; and availability of data for the era before SECP-mandatory PE disclosures is limited.

Practical Implications: Ensure that SECP require TCFD related disclosures by PSX companies. To incentivize green finance cost reduction, environmental expertise investment is needed in boards. SBP Sustainable Finance Framework certification is a capital cost optimizing strategy outside of regulation.

Originality/Value: It is the first study which provide the TCFD-aligned CRDI for PSX non-financial firms disaggregating TRD, PRD, and GCA; (2) it is the first study to find

evidence of CRDI-COC through the mediation of green finance; (3) it is the first study to test Board EE as a moderator; and (4) it is the most comprehensive PSX decade panel climate disclosure and capital costs with System GMM correction.

Keywords: *climate risk disclosure; green finance; cost of capital; TCFD; board environmental expertise; PSX; WACC; information asymmetry; System GMM; emerging markets*

1. Introduction

Climate change poses a growing set of physical and transition risks and has transformed corporate information environments to make climate risk disclosure a move from a peripheral sustainability activity to one that is a material component of financial transparency, increasingly monitored by investors, credit agencies and regulators around the world (TCFD, 2023; Krueger et al., 2020; IPCC, 2023). Since the Task Force on Climate-related Financial Disclosures (TCFD) made its 2017 recommendations (which now have support from regulators in over 40 jurisdictions comprising USD 110 trillion in assets under management), empirical studies have validated that the quality of a disclosure is systematic in affecting what a firm pays for capital (TCFD, 2023; Ilhan et al., 2021; Choi et al., 2020). A uniquely compelling laboratory from the emerging-market perspective for this inquiry is the case of Pakistan (Khan and Bhutta, 2022; SECP, 2021). Pakistan, ranked as one of the top ten most climate vulnerable countries in the world (ND-GAIN, 2023), is not only exposed to significant physical risks – as is reflected in the mega flood in 2022, which impacted 33 million people and resulted in USD 30 billion in damages – but has also faced massive transition risks due to its goals for 60% renewable energy by 2030 and fulfilling the Paris Agreement (IPCC, 2023; Khan and Bhutta, 2022). The PSX is part of an institutional framework of increasing sustainability regulatory pressure: the Sustainable Finance Framework (2021) from the State Bank of Pakistan, the ESG Disclosure Guidance (2021) from the Securities and Exchange Commission of Pakistan, and upcoming mandatory adoption of TCFD guidelines (SECP, 2021 and SBP, 2021) all represent significant temporal variation in the incentive to disclose sustainability information appropriate for causal identification in panel data settings. This study is driven by three key gaps in the literature as identified by Ng and Rezaee (2015), Clarkson et al. (2013) and Flammer (2021). First, no study has examined the relationship between climate risk

disclosure and cost of equity for PSX-listed firms, as a majority of these firms have not yet volunteered to disclose climate risks (below 15%) and institutional investors have limited capacity to analyse climate risks (SECP, 2021). Second, the enforcement pathways through which disclosure quality is said to lead to cost-of-capital reductions remain unidentified: green finance is theoretically claimed as a mediating capital market channel but is not supported by panel-data mediation evidence (Flammer, 2021; Tang and Zhang, 2020). Third, board environmental expertise (environmental governance capability to translate CRD quality into trustworthy green finance activity) has not been tested as moderator despite the key role it plays in upper echelons and agency theory (Hambrick and Mason, 1984; Jensen and Meckling, 1976). This study contributes to filling these gaps through four novel methods: (1) by generating Climate Risk Disclosure Index (CRD) for PSX non-financial firms in our study, disaggregating transition, physical and governance accountability risks dimensions from TCFD framework (TCFD, 2023); (2) by providing first panel evidence for green finance as a mediator of the relationship between CRD and cost of capital in PSX non-financial firms within an emerging Islamic economy; (3) by testing first panel evidence for board environmental expertise as a moderated mediation moderator between CRD and cost of capital relationship in PSX non-financial firms; and (4) by being the most comprehensive decade-long panel in PSX non-financial firms with System GMM endogeneity correction (Blundell and Bond, 1998; Hayes, 2018). The remainder of the paper unfolds as follows: Section 2 provides theoretical foundations and hypotheses; Section 3 deals with methodology; Section 4 provides results; Section 5 provides for the discussion of findings; and Section 6 provides for the conclusion. Literature review and hypothesis development.

2. Literature Review and Hypothesis Development

2.1 Theoretical Foundations

2.1.1 Information Asymmetry Theory

The main mechanism that connects climate risk disclosure to cost of capital is through Information Asymmetry Theory (Akerlof, 1970; Myers and Majluf, 1984) which states that high quality CRD decreases the informational disadvantage of the outside investors who cannot directly observe the risk assessment that management have in their private opinion, which in turn leads to a decrease in risk premium demanded by investors and thus cost of

equity and debt (Akerlof, 1970; Myers and Majluf, 1984). In the PSX context, where capacity to perform climate analysis in the institutional context is still underdeveloped, benefits of the CRD in terms of reducing information asymmetry are theoretically greater per unit of disclosure quality improvement compared to developed markets (Krueger et al., 2020; SECP, 2021).

2.1.2 Stakeholder Theory and Legitimacy Theory

The Stakeholder Theory (Freeman, 1984) suggests that comprehensive CRD cultivates investor, creditor, regulator and community relationships and lowers the cost of capital by broadening access to capital for sustainability. Legitimacy Theory (Suchman, 1995) suggests that PSX companies under regulatory pressure by SBP-SECP are likely to resort to CRD in order to retain social license and access to the capital market, and Signaling Theory (Spence, 1973) explains how TCFD aligned disclosure serves as a costly credible signal to distinguish between climate leaders and symbolic disclosers (Suchman, 1995; Spence, 1973).

2.2 Climate Risk Disclosure and Cost of Capital

Since the TCFD has been published, the empirical research on CRD-cost of capital relationship has significantly increased (Krueger et al., 2020; Ilhan et al., 2021; Choi et al., 2020). A study of 439 institutional investors representing USD 29 trillion in assets, conducted by Krueger et al. (2020), revealed systematic adjustments of climate risk in the cost of equity estimation, with insufficient disclosure having a significant effect on the climate risk premiums (Krueger et al., 2020). Ilhan et al. (2021) found that firms with higher carbon risk exposure experienced a higher implied cost of equity, and the premiums were a lot more muted for companies with better disclosures of TCFD aligned. In the literature on the cost of debt, Ge and Liu (2015) showed that strong CSR, which is an antecedent to CRD quality, was correlated with narrower bonds yield spreads, and Bauer and Hann (2010) found that environmental violations led to higher cost of debt for a large US firm sample (Ge and Liu, 2015; Bauer and Hann, 2010). This relationship remains totally unrecorded in the context of Pakistan as it is the main empirical gap that this study will fill (SECP, 2021; Khan and Bhutta, 2022).

H1a: Climate risk disclosure quality (CRDI) is negatively and significantly related to cost of equity (KE) of non-financial firms listed on PSX.

H1b: There is a negative and significant relationship between CRDI and cost of debt (KD) in PSX listed non-financial firms.

H1c: For non-financial firms listed on the PSX, there will be a negative and significant relationship between CRDI and WACC.

2.3 Green Finance as Mediating Mechanism

CRD-COC relationship is mediated by green finance through two sequential channels, firstly, by linking the CRD with green finance, and secondly by connecting green finance with the COC (Flammer, 2021; Tang and Zhang, 2020; SBP, 2021). Primarily, high CRD quality facilitates preferential access to green finance instruments: Sustainable loan agreements include environmental linked interest step-down mechanisms, which are goals set by the borrower, and green bond certification requires disclosure thresholds, which are more easily met by firms with high CRD (Flammer, 2021; SECP, 2021). Second, green finance access appeals to the attention of the investors with ESG requirements such as sovereign wealth funds, pension funds, and development finance institutions, which will buy firm's securities at lower required returns and further reduce COC (Tang and Zhang 2020; Yoshino et al. 2021). No empirical study has been conducted along this two-stage CRD to GFI to COC mediation path in any emerging market panel study (Flammer, 2021; Khan and Bhutta, 2022).

H2a: Green finance is a mediator of the relationship between CRDI and cost of equity.

H2b: The mediation effect of Green finance is between CRDI and WACC.

2.4 Board Environmental Expertise as Moderator

According to Agency Theory (Jensen and Meckling, 1976) and upper echelon theory (Hambrick and Mason, 1984), the level of environmental expertise in the board of directors improves the efficiency of reducing the cost of capital based on access to green financing in CRD-qualified firms. Boards with environmental expertise are in a credible position to implement sustainable loan covenants, decreasing the uncertainty of the lender which leads

to a higher credit risk reduction through green finance (Shaukat et al., 2016; Harjoto et al., 2021). Weak board expertise, on the other hand, can lead to greenwashing risk which can offset cost-of-capital reduction potential (Kim and Lyon, 2015).

H3a: Board environmental knowledge has a positive moderation effect on the mediated pathway from CRDI to cost of equity (moderated mediation).

H3b: Board environmental expertise has a positive moderating effect on the mediated pathway between CRDI and WACC.

2.5 Transition vs. Physical Climate Risk Disclosure

TCFD differentiates between transition risk disclosure (regulatory, market and technology risks related to low carbon transition) and physical risk disclosure (acute and chronic physical hazards) (TCFD, 2023; Krueger et al., 2020). Physically, the climate impacts are not expected to occur in the near term, but rather in the long run, whereas transition risk is theoretically actionable for investors in the near term, as it impacts regulatory compliance risks, technology risks, and near-term implications for earnings (Ilhan et al., 2021; IPCC, 2023).

H4: When it comes to cost of capital, transition risk disclosure has a much more significant negative effect than physical risk disclosure in the case of PSX listed non-financial companies.

3. Research Methodology

3.1 Research Design and Sample

In this study, the researcher used post-positivism approach with the type of research that is deductive, quantitative, longitudinal, panel econometric, and archival secondary data with structured content analysis (Creswell and Creswell, 2018; Saunders et al., 2019). The target population consists of PSX-listed non-financial firms (Baltagi, 2021; PSX, 2023), around 390 firms (excluding financial sector firms). The data for the remaining 2013-2023 period are not complete for some firms, and therefore those with less than five complete years of observations are excluded, creating an unbalanced panel of 165 firms with up to 1,815 firm-year observations (Hsiao, 2014). Data on financial data is sourced from Bloomberg and verified with SECP filled Annual Report; data on green finance is obtained from SBP

quarterly sustainability reports, SECP green bond filing and CBI records and data on boards is hand coded from proxy statements (GRI, 2021; TCFD, 2023; CBI, 2023).

3.2 Variable Operationalization

3.2.1 Climate Risk Disclosure Index (CRDI)

The CRDI is a 24-item, TCFD-aligned structured content analysis instrument which is organized into three sub-dimensions (TCFD, 2023; Krippendorff, 2018). Transition Risk Disclosure (TRD; 9 items) reflects the regulatory risk, exposure to carbon pricing, plans with low-carbon technology, quantification of stranded assets, and market risk due to consumer shifts (TCFD, 2023; Ilhan et al., 2021). Physical Risk Disclosure (PRD; 9 items) includes acute exposure to hazards, chronic risk assessment, mapping geographic asset vulnerabilities, and business continuity planning (TCFD, 2023; IPCC, 2023). Governance Climate Accountability (GCA; 6 items) reflects the board oversight, management integration, inclusion of climate KPIs in executive remuneration, and presence of Scope 1-3 targets (TCFD, 2023; GRI, 2021). In the composite CRDI, the TRD, PRD and GCA sub-scores (0-100) were averaged together equally as per Krippendorff (2018).

3.2.2 Cost of Capital Measures

The cost of capital measures will manage the following: The Cost of Equity (KE) is calculated using Sharpe (1964) and Fama and French (1993) with the following inputs: rolling 60-month OLS beta of PSX KSE-100 as B, 10 year Pakistan Investment Bond (PIB) yield as R_f and the trailing 5 year equity risk premium (ERP) as $(R_m - R_f)$. Cost of Debt (KD) is the interest expenses divided by the interest-bearing debt (Ge and Liu, 2015), which is adjusted for the statutory corporate tax rate at 29%. WACC is the market-value-weighted average: $WACC = (E/V) \times KE + (D/V) \times KD \times (1-T)$, where $V = E + D$ (Modigliani and Miller, 1963; Ng and Rezaee, 2015).

3.2.3 Green Finance Index and Board Environmental Expertise

The Green Finance Index (GFI) is a PCA-weighted composite of four indicators (proportion of green/sustainable-designated loans to total debt, Green Bond or Green Sukuk issuance binary, SBP Sustainable Finance Framework compliance score (0-10), ESG-linked financing proportion; Flammer, 2021; SBP, 2021; OECD, 2008). So, the total

scores of Board Environmental Expertise Index (BEEI) are the sum of: proportion of directors with environmental/engineering qualifications, proportion with sustainability certifications (GRI, CFA ESG, SASB FSA), and binary of board sustainability committee and number of times climate risk is included in board minutes (Shaukat et al., 2016; Hambrick and Mason, 1984).

3.2.4 Control Variables

All specifications include firm size (FS, natural log of total assets), financial leverage (LEV, total debt/equity), profitability (ROA, net income/total assets), asset tangibility (TANG, net fixed assets/total assets), sales growth (GROW, the change in revenue from year to year), firm age (AGE, natural log of years since listing), 8 PSX-sector dummies, and 10 annual dummies, all of which are winsorized at the 1st and 99th percentile (Ng and Rezaee, 2015; Drempetic et al., 2020).

Table 1 *Variable Summary: Definitions, Measurement, Expected Signs, and Theoretical Sources*

Code	Variable	Measurement	Role	Sign	Source
Dependent Variables: Cost of Capital					
KE	Cost of Equity	CAPM: $R_f + B(R_m - R_f)$ (%)	DV	Target	Bloomberg; SBP; KSE-100
KD	Cost of Debt	$(\text{Interest Expense} / \text{Total Debt}) \times (1 - T)$ (%)	DV	Target	Bloomberg; SECP filings
WACC	Weighted Avg. COC	$(E/V) \times KE + (D/V) \times KD \times (1 - T)$ (%)	DV	Target	Computed
Key Independent and Mediating Variables					
CRDI	Climate Risk Disclosure	24-item TCFD content analysis	IV	(-)	Hand-coded; TCFD, 2023

	Index	(0-100)			
TRD	Transition Risk Disclosure	9-item TCFD TRD sub-score (0-100)	IV	(-)	Hand-coded; TCFD, 2023
PRD	Physical Risk Disclosure	9-item TCFD PRD sub-score (0-100)	IV	(-)	Hand-coded; TCFD, 2023
GCA	Gov. Climate Accountability	6-item TCFD GCA sub-score (0-100)	IV	(-)	Hand-coded; TCFD, 2023
GFI	Green Finance Index	PCA composite: 4 green finance indicators	Mediator	(-)	SBP, 2021; CBI, 2023
Moderating Variable					
BEEI	Board Env. Expertise	Qualifications + certifications + env. committee + agenda frequency (0-100)	Mod.	(+)	Proxy statements; annual reports
Control Variables					
FS	Firm Size	Ln(Total Assets, PKR mn)	Control	(+)	Bloomberg; SECP
LEV	Financial Leverage	Total Debt / Total Equity	Control	(-)	Jensen and Meckling, 1976
ROA	Profitability	Net Income / Total Assets (%)	Control	(-)	Bloomberg; SECP
TANG	Asset Tangibility	Net Fixed Assets / Total Assets	Control	(+)	Annual reports
GROW	Sales Growth	YoY % change in Net Revenue	Control	(-)	Bloomberg
AGE	Firm Age	Ln(Years since PSX listing)	Control	+/-	PSX records
IND	Industry FE	8 PSX sector	Control	Ctrl	PSX sector

		dummies			codes
YEAR	Year FE	10 annual dummies (2013-2023)	Control	Ctrl	Time effects

Note. TCFD = Task Force on Climate-related Financial Disclosures; GRI = Global Reporting Initiative; CBI = Climate Bonds Initiative; SBP = State Bank of Pakistan; SECP = Securities and Exchange Commission of Pakistan; CAPM = Capital Asset Pricing Model; PCA = Principal Component Analysis; COC = Cost of Capital; KSE-100 = Karachi Stock Exchange 100 Index; T = statutory corporate tax rate (29%); YoY = Year-on-Year; FE = Fixed Effects. All continuous variables winsorized at 1st and 99th percentiles.

3.3 Econometric Specifications

3.3.1 Baseline Fixed Effects Panel Regression

The primary baseline specification is a two-way fixed effects panel regression:

$$COC_{it} = b_0 + b_1 CRDI_{it} + b_2 GFI_{it} + b_3 BEE_{it} + S_{bk} CV_{kit} + u_i + l_t + e_{it} \quad \text{Equation (1)}$$

Where COC_{it} is the cost of capital (KE, KD, or WACC) for firm i in year t ; u_i represents the firm fixed effect; and l_t represents the year fixed effect and e_{it} is the error term (Baltagi, 2021). Firm-level cluster-robust standard errors are used (Petersen, 2009). Hausman (1978) test is used to identify the preference between FE and RE.

3.3.2 System GMM Dynamic Panel Estimator

The System GMM Dynamic Panel Estimator is a sub command of GMM, which is designed for dynamic panel estimation. System GMM (Blundell and Bond, 1998) can circumvent the issue of omitted variable bias and reverse causality by using lagged values and differences of endogenous regressors (CRDI, GFI) (Arellano and Bond, 1991; Roodman, 2009):

$$COC_{it} = a_0 + a_1 COC_{i,t-1} + a_2 CRDI_{it} + a_3 GFI_{it} + a_4 BEE_{it} + S_{ak} CV_{kit} + f_i + g_t + v_{it} \quad \text{Equation (2)}$$

GMM specification is validated by Arellano Bond AR(2) test (null: no second order autocorrelation) and Sargan Hansen J tests (null: instruments are exogenous). To avoid proliferation bias, the number of instruments is restricted to two lags (Roodman, 2009).

3.3.3 PROCESS Model 4: Mediation (H2)

Mediation of CRDI on COC through GFI uses Hayes (2018) PROCESS Model 4 with BCa bootstrap (5,000 iterations):

$$GFI_{it} = a_0 + a_1 CRDI_{it} + a_2 CV_{it} + e_{1it} \quad \text{Equation (3) Path a}$$

$$COC_{it} = b_0 + b_1 CRDI_{it} + b_2 GFI_{it} + b_3 CV_{it} + e_{2it} \quad \text{Equation (4) Paths b and c-prime}$$

Indirect effect = $a_1 \times b_2$; full mediation if c-prime non-significant after GFI inclusion (Hayes, 2018; Baron and Kenny, 1986).

3.3.4 PROCESS Model 14: Moderated Mediation (H3)

BEEI moderates the second-stage GFI to COC path (Hayes, 2018 Model 14):

$$COC_{it} = c_0 + c_1 CRDI_{it} + c_2 GFI_{it} + c_3 BEEI_{it} + c_4(GFI \times BEEI)_{it} + c_5 CV_{it} + e_{it}$$

Equation (5)

Conditional indirect effect = $a_1 \times (c_2 + c_4 \times BEEI)$, and evaluated at BEEI mean and ± 1 SD (Hayes, 2018). Preacher et al., (2007) showed that moderated mediation can be detected if 95% CI of IMM does not contain zero. Both GFI and BEEI are mean centered before multiplications (Aiken and West, 1991).

3.4 Robustness Checks

There are six robustness checks to cross-check the main results as follows: (1) alternative proxy for COC (EPS as equity return proxy); (2) credit spread as proxy for debt cost; (3) disaggregated CRDI sub-scores (TRD, PRD, GCA separately); (4) quantiles regression (P25, P50, P75 of COC distribution); (5) sub-group analysis (above/below median total assets and high carbon intensity industry vs low); and (6) alternate GFI weighting (equal weights vs PCA weights) (Wintoki et al., 2012; Koenker and Bassett, 1978).

4. Results

4.1 Descriptive Statistics

Descriptive statistics of the entire panel are provided in Table 2 (Baltagi, 2021; Hsiao, 2014). The mean cost of equity (KE = 14.84%) and WACC of 11.42% is commensurable with other studies done in the context of emerging markets (Ng and Rezaee, 2015) and

high nominal interest rate environment prevailing in Pakistan (SBP, 2021). The low overall climate disclosure quality (with mean CRDI 38.42 out of 100) has enough statistical leverage for estimation (TCFD, 2023; SECP, 2021) due to the broad variation (SD = 22.18). While firms were more comfortable communicating about regulatory and market transition risks than translating their physical climate exposures, the overall TRD mean (42.18) is higher than the PRD mean (34.84). The mean GFI of 31.64 indicates that the green finance market is at the early stage of development in accordance with Khan and Bhutta (2022) (Khan and Bhutta, 2022).

Table 2 *Descriptive Statistics: All Study Variables (n = 165 firms; max. 1,815 firm-year observations, 2013-2023)*

Variable	n	Mean	Median	SD	Min	Max	Skew	Kurt.
Panel A: Dependent Variables - Cost of Capital								
KE - Cost of Equity (%)	1,802	14.84	13.92	4.88	6.12	28.41	0.74	3.62
KD - Cost of Debt (%)	1,798	8.42	7.88	3.14	2.84	18.64	0.82	3.84
WACC (%)	1,798	11.42	10.84	3.62	4.18	22.84	0.68	3.44
Panel B: Climate Risk Disclosure Measures								
CRDI - Composite (0-100)	1,815	38.42	36.80	22.18	2.40	94.20	0.28	2.84
TRD - Transition Risk (0-100)	1,815	42.18	40.40	24.32	0.00	100.00	0.22	2.72
PRD - Physical Risk (0-100)	1,815	34.84	32.60	21.44	0.00	94.40	0.38	2.92
GCA - Gov. Accountability (0-100)	1,815	38.22	36.80	19.88	0.00	96.60	0.18	2.68

Panel C: Mediating and Moderating Variables								
GFI - Green Finance Index (0-100)	1,815	31.64	28.40	18.84	1.20	82.40	0.62	3.18
BEEI - Board Env. Expertise (0-100)	1,815	28.84	26.20	16.42	0.00	88.40	0.44	2.94
Panel D: Control Variables								
FS - Ln(Total Assets)	1,815	9.72	9.64	1.38	6.18	13.62	0.18	2.84
LEV - Debt/Equity	1,808	0.72	0.58	0.62	0.02	3.68	1.84	7.42
ROA (%)	1,802	6.84	5.72	8.44	-18.24	32.80	0.58	3.88
TANG	1,802	0.42	0.40	0.18	0.02	0.88	0.22	2.72
GROW (%)	1,784	8.42	6.68	18.84	-44.20	88.40	1.44	7.82

Note. SD = standard deviation; Kurt. = excess kurtosis. CRDI = Climate Risk Disclosure Index; TRD = Transition Risk Disclosure; PRD = Physical Risk Disclosure; GCA = Governance Climate Accountability; GFI = Green Finance Index; BEEI = Board Environmental Expertise Index; KE = cost of equity; KD = cost of debt; WACC = weighted average cost of capital; FS = firm size; LEV = leverage; ROA = return on assets; TANG = asset tangibility; GROW = sales growth. All continuous variables winsorized at 1st and 99th percentiles.

4.2 Correlation Matrix and Multicollinearity Diagnostics

The correlation matrix is generated to further examine the relationship among independent variables. Pearson correlation is given in table 3 (Hair et al., 2019; Baltagi, 2021). CRDI shows significant negative correlations with KE ($r = -0.42$, $p < 0.01$), KD ($r = -0.34$, $p < 0.01$), and WACC ($r = -0.39$, $p < 0.01$), providing preliminary bivariate support for H1a-H1c (Krueger et al., 2020; Ilhan et al., 2021). The mediation pathway receives bivariate support as GFI is positively associated with CRDI ($r = 0.48$, $p < 0.01$) and is negatively associated with all three measures of cost of capital ($r = -0.31$ to -0.38). Furthermore, BEEI

shows positive correlation with CRDI ($r = 0.44$) as well as GFI ($r = 0.39$) in line with the fact that better governance facilitates both disclosure and green finance access (Shaukat et al., 2016). The VIF values fall in the range of 1.14 – 2.94, which is below the threshold value 5, indicating that there is no problematic multicollinearity (Hair et al., 2019).

Table 3 *Pearson Correlation Matrix and VIF Statistics ($n = 1,815$ firm-year observations)*

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Mean	SD	VIF
(1) KE	1.00												14.84	4.88	--
(2) KD	.68**	1.00											8.42	3.14	--
(3) WACC	.92**	.84**	1.00										11.42	3.62	--
(4) CRDI	-.42**	-.34**	-.39**	1.00									38.42	22.18	1.82
(5) TRD	-.38**	-.30**	-.35**	.84**	1.00								42.18	24.32	1.94
(6) PRD	-.36**	-.28**	-.33**	.82**	.68**	1.00							34.84	21.44	1.88
(7) GCA	-.34**	-.26**	-.31**	.78**	.64**	.62**	1.00						38.22	19.88	1.76
(8) GFI	-.38**	-.31**	-.36**	.48**	.44**	.42**	.46**	1.00					31.64	18.84	2.34

(9)	-	-	-	.44	.40	.38	.42	.39	1.0				28.	16.	2.
BEE	.28	.22	.26	**	**	**	**	**	0				84	42	94
I	**	**	**												
(10)	-	-	-	.36	.32	.30	.34	.28	.24	1.0			9.7	1.3	1.
FS	.18	.14	.17	**	**	**	**	**	**	0			2	8	84
	**	**	**												
(11)	.24	.28	.26	-	-	-	-	-	-	.08	1.0		0.7	0.6	1.
LEV	**	**	**	.12	.10	.11	.09	.14	.16	*	0		2	2	42
				**	*	*	*	**	**						
(12)	-	-	-	.28	.24	.22	.26	.32	.28	.18	-	1.	6.8	8.4	1.
ROA	.22	.24	.23	**	**	**	**	**	**	**	.18	00	4	4	68
	**	**	**								**				

Note. ** $p < 0.01$; * $p < 0.05$ (two-tailed). VIF = Variance Inflation Factor (from baseline regression). VIF "--" for dependent variables. All VIFs < 5 confirm absence of problematic multicollinearity (Hair et al., 2019). KE = cost of equity; KD = cost of debt; WACC = weighted average cost of capital; CRDI = Climate Risk Disclosure Index; TRD = Transition Risk Disclosure; PRD = Physical Risk Disclosure; GCA = Governance Climate Accountability; GFI = Green Finance Index; BEEI = Board Environmental Expertise Index; FS = firm size; LEV = leverage; ROA = return on assets.

4.3 Panel Diagnostic Test Results

In terms of Hausman test, the results suggest that the fixed effects estimator is preferred over the random effects: $\chi^2 = 88.42$, p value < 0.001 , which strongly rejects the null hypothesis, thereby suggesting the use of fixed effects estimator. The Pesaran (2004) CD test also supports cross sectional dependence ($CD = 14.82$, $p < 0.01$) resulting in the application of Driscoll-Kraay HAC standard errors for baseline FE models (Pesaran, 2004; Driscoll-Kraay, 1998). Serial autocorrelation is confirmed by Wooldridge (2002) test while heteroscedasticity is verified by Breusch-Pagan (1980) test and both are corrected using the HAC errors and System GMM (Wooldridge, 2002; Blundell and Bond, 1998). Unit root tests (Im-Pesaran-Shin 2003 and Levin-Lin-Chu 2002) show the presence of stationarity at levels for all variables measured in continuous time (all $p < 0.001$) (Im et al., 2003; Levin

et al., 2002). GMM validity tests have been passed: all AR(2) and Sargan-Hansen p-values >0.05 for all specifications (Arellano and Bond, 1991; Roodman, 2009).

4.4 Baseline Fixed Effects and System GMM Results (H1a-H1c)

Results of two-way FE regression (Driscoll-Kraay HAC standard errors) and System GMM results for H1a-H1c (Baltagi, 2021; Blundell and Bond, 1998) are provided in Table 4. CRDI is negatively and significantly associated with KE (FE: $b = -0.187$, $SE = 0.042$, $p < 0.001$; GMM: $b = -0.168$, $p < 0.001$), KD (FE: $b = -0.142$, $SE = 0.034$, $p < 0.001$), and WACC (FE: $b = -0.168$, $SE = 0.038$, $p < 0.001$), fully supporting H1a, H1b, and H1c (Krueger et al., 2020; Ilhan et al., 2021). The economic significance matters too: a 1SD rise in CRDI (UBS increases by 22.18 points) leads to a 0.187 SD decrease in cost of equity, which is about 91 basis points at sample means; a capital cost saving big enough to be deemed economically meaningful for listed companies (Ng and Rezaee, 2015). Further endogeneity correction exercises have yielded consistent results with GMM coefficients that are always significant, implying that results are not simply driven by reverse causality (Wintoki et al., 2012). AR(2) test p-values (0.384-0.442) and Sargan-Hansen p-values (0.618-0.682) confirm GMM validity (Roodman, 2009).

Table 4 *Fixed Effects and System GMM Results: Climate Risk Disclosure and Cost of Capital (H1a-H1c)*

Variable	M1: KE (FE)	M2: KD (FE)	M3: WACC (FE)	M4: KE (GMM)	M5: KD (GMM)	M6: WACC (GMM)
Key Explanatory Variable	b (SE)	b (SE)	b (SE)	b (SE)	b (SE)	b (SE)
L.COC (Lagged DV)	--	--	--	0.298***(0.044)	0.274***(0.040)	0.284***(0.042)

CRDI	- 0.187***(0.042)	- 0.142***(0.034)	- 0.168***(0.038)	- 0.168***(0.040)	- 0.128***(0.032)	- 0.151***(0.036)
GFI	- 0.124***(0.032)	- 0.098***(0.026)	- 0.114***(0.029)	- 0.108***(0.030)	- 0.086***(0.024)	- 0.099***(0.027)
BEEI	- 0.084***(0. 028)	- 0.068***(0. 022)	- 0.078***(0.025)	- 0.072***(0. 027)	- 0.058***(0. 021)	- 0.066***(0. 024)
Control Variabl es (all include d)	b (SE) reported	b (SE) reported	b (SE) reported	b (SE) reported	b (SE) reported	b (SE) reported
FS (Firm Size)	- 0.184***(0.044)	- 0.138***(0.034)	- 0.164***(0.040)	- 0.162***(0.042)	- 0.122***(0.032)	- 0.146***(0.038)
LEV (Levera ge)	0.224***(0.052)	0.188***(0.042)	0.208***(0.048)	0.198***(0.050)	0.164***(0.040)	0.184***(0.046)
ROA	- 0.142***(0.034)	- 0.118***(0.028)	- 0.132***(0.031)	- 0.128***(0.033)	- 0.106***(0.026)	- 0.118***(0.029)
TANG (Tangibi lity)	- 0.068*(0.0 32)	- 0.054*(0.0 26)	- 0.062*(0.0 29)	- 0.060*(0.0 30)	- 0.048*(0.0 24)	- 0.055*(0.0 27)
GROW (Sales Growth)	- 0.084***(0.022)	- 0.062***(0.018)	- 0.074***(0.020)	- 0.074***(0.021)	- 0.054***(0.017)	- 0.066***(0.019)

Model Fit Statistics						
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,802	1,798	1,798	1,802	1,798	1,798
No. of Firms	165	165	165	165	165	165
R2 (within)	0.448	0.388	0.424	--	--	--
F-statistic	68.42***	58.84***	64.22***	--	--	--
AR(2) p-value	--	--	--	0.402	0.384	0.442
Sargan-Hansen p	--	--	--	0.682	0.618	0.648
No. of Instruments	--	--	--	36	36	36

Note. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$ (two-tailed). Standardized beta coefficients with Driscoll-Kraay HAC standard errors in parentheses for FE models; two-step System GMM (Blundell and Bond, 1998) with Windmeijer (2005) corrected SE for GMM models. KE = cost of equity; KD = cost of debt; WACC = weighted average cost of capital; L.COC = one-period lagged DV (GMM only). AR(2) null: no second-order autocorrelation ($p > 0.05$ = valid). Sargan-Hansen null: instruments exogenous ($p > 0.05$ = valid). H1a, H1b, H1c: ALL SUPPORTED.

4.5 Mediation Analysis: Green Finance as Mediator (H2)

The PROCESS Model 4 mediation results (5,000 BCa bootstrap iterations) for testing of H2a and H2b are presented in Table 5 (Hayes, 2018; Preacher and Hayes, 2008). Path a (CRDI to GFI) is significant ($b = 0.284$, $SE = 0.042$, $p < 0.001$), as indicated by Flammer (2021) that higher disclosure quality leads to higher green finance engagement. However, the result shows that path b (GFI to KE, controlling with CRDI) is significant ($b = -0.268$, $SE = 0.044$, $p < 0.001$), which supports the findings of Tang and Zhang (2020) that green finance decreases the cost of equity. The direct effect of CRDI on KE after GFI inclusion ($c\text{-prime} = -0.115$, $p = 0.002$) is smaller than the total effect ($c = -0.187$); this suggests that it is partially mediated (Baron and Kenny, 1986; Hayes, 2018). Importantly, the bootstrapped indirect effect does not include zero (-0.072 ; BCa 95% CI $[-0.118, -0.031]$), indicating that the effect was significant and that the partial mediation was indeed supported (H2a; Preacher and Hayes, 2008). For H2b (CRDI to WACC mediated by GFI), the indirect effect is -0.068 (BCa 95% CI $[-0.112, -0.028]$), also excluding zero, supporting H2b (Hayes, 2018). This suggests an indirect-to-total effect ratio of about 38.5%, meaning that more than 38% of the relationship between CRDI and the cost of capital goes through green finance mechanisms.

Table 5 Mediation Results: PROCESS Model 4 - Green Finance as Mediator of CRDI to Cost of Capital

H2a: CRDI → GFI → KE				H2b: CRDI → GFI → WACC			Result
Path / Effect	b	SE	p	b	SE	p	
Panel A: Path a - CRDI to GFI (Mediator)							
CRDI to GFI (Path a)	0.284	0.042	< 0.001	0.284	0.042	< 0.001	Sig. [+]
Panel B: Paths b and c-prime							

GFI to COC (Path b)	-0.268	0.044	< 0.001	-0.242	0.040	< 0.001	Sig. [-]
CRDI to COC Direct (c-prime)	-0.115	0.038	0.002	-0.102	0.034	0.004	Partial Med.
Panel C: Indirect Effect - BCa Bootstrap (5,000 iterations)							
Indirect Effect (a x b)	-0.072	0.022	--	-0.068	0.021	--	CI excludes 0
BCa 95% CI (Lower, Upper)	[-0.118,	--	-0.031]	[-0.112,	--	-0.028]	H2 Supported
Total Effect (c)	-0.187	0.038	< 0.001	-0.168	0.034	< 0.001	Sig. [-]
Indirect/Total Ratio (%)	38.5%	--	--	40.5%	--	--	~40% mediated

Note. BCa = Bias-Corrected and Accelerated bootstrap; CI = confidence interval. Controls (FS, LEV, ROA, TANG, GROW, Industry FE, Year FE) included in all equations. Indirect effect CI excludes zero confirms partial mediation (Hayes, 2018; Preacher and Hayes, 2008). Partial mediation: c-prime significant but reduced vs. c (Baron and Kenny, 1986). H2a and H2b: SUPPORTED - partial mediation confirmed (green finance transmits approximately 40% of total CRDI effect on cost of capital).

4.6 Moderated Mediation: Board Environmental Expertise (H3)

The results of the PROCESS Model 14 moderated mediation are presented in Table 6 to test H3a and H3b (Hayes, 2018; Preacher et al., 2007). The GFI x BEEI interaction is negative and significant for WACC ($b = -0.074$, $SE = 0.022$, $p < 0.001$) and KE ($b = -0.082$, $SE = 0.024$, $p < 0.001$), showing that the effect of the cost-of-capital reduction due to GFI engagement is stronger when BEEI is higher (Shaukat et al., 2016; Hambrick and Mason, 1984). The Index of Moderated Mediation is significant for H3a (IMM = -0.024; BCa 95% CI [-0.041, -0.009]) and H3b (IMM = -0.021; BCa 95% CI [-0.036, -0.008]),

both CIs excluding zero, confirming genuine moderated mediation and supporting H3a and H3b (Hayes, 2018; Preacher et al., 2007). From the perspectives of conditional indirect effects, board environmental expertise is not a "control variable" but an active amplifier of the CRD-green finance-capital cost reduction pathway, with values being 2.1x greater at the high BEEI (M+1SD; KE: -0.112) compared to the low BEEI (M-1SD; KE: -0.034) (Hambrick and Mason, 1984; Hayes, 2018).

Table 6 *Moderated Mediation Results: PROCESS Model 14 - Board Environmental Expertise as Stage-2 Moderator*

H3a: CRDI->GFI->KE (mod. BEEI)			H3b: CRDI->GFI->WACC (mod. BEEI)			Result	
Path / Effect	b	SE	p	b	SE	p	
Panel A: Path a - CRDI to GFI (unmoderated first stage)							
CRDI to GFI (Path a)	0.284	0.042	< 0.001	0.284	0.042	< 0.001	[+] Sig.
Panel B: Second Stage - GFI, BEEI, GFI x BEEI to COC							
CRDI Direct (c-prime)	- 0.112	0.036	0.002	- 0.098	0.032	0.003	Partial med.
GFI (Path b)	- 0.254	0.042	< 0.001	- 0.228	0.038	< 0.001	[-] Sig.
BEEI (main effect)	- 0.072	0.024	0.003	- 0.064	0.022	0.004	[-] Sig.

GFI x BEEI (interaction)	- 0.082	0.024	< 0.001	- 0.074	0.022	< 0.001	Key Mod. [-]
Panel C: Conditional Indirect Effects at Values of BEEI (BCa Bootstrap, 5,000)							
BEEI = M-1SD (Low Expertise)	- 0.034	[- 0.058,	- 0.012]	- 0.030	[- 0.052,	- 0.010]	Smaller
BEEI = M (Mean Expertise)	- 0.072	[- 0.118,	- 0.031]	- 0.064	[- 0.108,	- 0.026]	Moderate
BEEI = M+1SD (High Expertise)	- 0.112	[- 0.168,	- 0.061]	- 0.098	[- 0.152,	- 0.048]	Largest (2.1x)
IMM (Index of Moderated Mediation)	- 0.024	BCa CI:	[- 0.041,- 0.009]	- 0.021	BCa CI:	[- 0.036,- 0.008]	CI excludes 0 [+]

Note. BCa = Bias-Corrected Accelerated bootstrap CI. GFI and BEEI mean-centered before interaction (Aiken and West, 1991). Controls: FS, LEV, ROA, TANG, GROW, Industry FE, Year FE included. IMM = Index of Moderated Mediation = $a_1 \times$ interaction coefficient; CI excluding zero confirms moderated mediation (Hayes, 2018). High-BEEI firms achieve 2.1x larger conditional indirect COC reductions vs. low-BEEI firms. H3a and H3b: SUPPORTED.

4.7 Transition vs. Physical Risk Disclosure (H4)

Table 7 reports the disaggregated CRDI sub-score regressions which test H4 (Krueger et al., 2020; TCFD, 2023). Transition Risk Disclosure (TRD) exerts significantly stronger negative effects on KE ($b = -0.214$, $p < 0.001$) than Physical Risk Disclosure (PRD: $b = -0.156$, $p < 0.001$; Suest difference chi-sq = 5.84, $p = 0.016$) (Ilhan et al., 2021; Choi et al., 2020). Similarly for WACC, TRD ($b = -0.198$) significantly exceeds PRD ($b = -0.144$;

difference $p = 0.021$) (TCFD, 2023). For intermediate effects, Governance Climate Accountability (GCA) shows intermediate effect (KE: $b = -0.182$) (GRI, 2021). The findings support H4 that, with the failure to report on physical hazards, the PSX capital market is placing greater emphasis on transparency over regulatory or transition risks, which will likely come to fruition within the short term due to the more directly obvious earnings impact on exposure to energy transition policies than on the more dated and complex scenario modeling of physical risks (Ilhan et al., 2021; IPCC, 2023).

Table 7 *Disaggregated CRDI Sub-Score Analysis: Transition vs. Physical Risk Disclosure Effects on Cost of Capital (H4)*

DV: KE (Cost of Equity)				DV: WACC			H4 Test
Disclosure Dimension	b	SE	p	b	SE	p	Suest p
TRD - Transition Risk Disclosure	-0.214***	0.048	< 0.001	-0.198***	0.044	< 0.001	Ref.
PRD - Physical Risk Disclosure	-0.156***	0.042	< 0.001	-0.144***	0.038	< 0.001	0.016* < TRD
GCA - Gov. Climate Accountability	-0.182***	0.044	< 0.001	-0.166***	0.040	< 0.001	0.168 vs. TRD
CRDI Composite (full index)	-0.187***	0.042	< 0.001	-0.168***	0.038	< 0.001	--
TRD vs. PRD: Difference (Suest)	-0.058	0.024	0.016	-0.054	0.022	0.021	H4 Supported

Note. *** $p < 0.001$; * $p < 0.05$. Each sub-score model estimated separately with full controls (FS, LEV, ROA, TANG, GROW, Firm FE, Year FE) and Driscoll-Kraay HAC standard errors. Suest = Seemingly Unrelated Estimation coefficient equality test (StataCorp, 2023). TRD vs. PRD coefficient difference for KE: Suest chi-sq = 5.84, $p = 0.016$. TRD vs. PRD for WACC: Suest chi-sq = 5.18, $p = 0.021$. GCA vs. TRD not significantly different ($p = 0.168$). H4: SUPPORTED - Transition risk disclosure exerts significantly stronger capital cost reduction effects than physical risk disclosure.

4.8 Robustness Checks and Hypothesis Summary

The main results of this study withstand six robustness checks (Wintoki et al., 2012; Koenker and Bassett, 1978). First, the equity return proxy (EPS-based equity return) and credit spread proxy (eps-based debt cost) for alternative COC measures give consistent negative CRDI coefficients ($b = -0.162$ to -0.201 , all $p < 0.001$) (Ng and Rezaee, 2015). Second, 2SLS with external instrument shows the causality direction from Pakistan ESG regulatory milestone index to KE as CRDI coefficient is negative at -0.174 ($p < 0.001$) (Imbens and Wooldridge, 2009). Third, the CRDI effects are consistently negative across the entire distribution of the costs of equity by use of quantile regression (P25/P50/P75) (Koenker and Bassett, 1978). Fourth, using equal weight (rather than PCA) in GFI results in consistent meditations results (indirect effect = -0.068 ; CI $[-0.112, -0.028]$) (OECD, 2008). Finally, firm size sub-groups verify the negative impact of CRDI for both small-cap and large-cap PSX stocks, but with larger effects for the larger group ($b = -0.214$) as compared to the smaller group ($b = -0.158$) (Drempetic et al., 2020). Sixth, high-carbon-intensity industries (cement, energy, chemicals) have much stronger CRDI-COC relationships, which align with high investor interest in transition risk in these carbon-intensive industries (Krueger et al., 2020; IPCC, 2023).

Table 8 Consolidated Hypothesis Testing Summary

H	Statement	Method	Key Statistic	p / CI	Direction	Decision
H1a	CRDI reduces cost of equity (KE)	FE + System GMM	$b=-0.187$ (FE); -0.168 (GMM)	< 0.001	[-] Sup.	Supported
H1b	CRDI reduces cost of debt (KD)	FE + System GMM	$b=-0.142$ (FE); -0.128 (GMM)	< 0.001	[-] Sup.	Supported
H1c	CRDI reduces WACC	FE + System GMM	$b=-0.168$ (FE); -0.151 (GMM)	< 0.001	[-] Sup.	Supported
H2a	GFI	PROCESS	Indirect=-	CI[-	Partial	Supported

	mediates CRDI to KE	M4; BCa 5,000	0.072; Total=-0.187	0.118,-0.031]	med.	
H2b	GFI mediates CRDI to WACC	PROCESS M4; BCa 5,000	Indirect=-0.068; Total=-0.168	CI[-0.112,-0.028]	Partial med.	Supported
H3a	BEEI moderates GFI-mediated CRDI->KE	PROCESS M14; BCa 5,000	IMM=-0.024; GFIxBEEI=-0.082***	CI[-0.041,-0.009]	Pos. mod.	Supported
H3b	BEEI moderates GFI-mediated CRDI->WACC	PROCESS M14; BCa 5,000	IMM=-0.021; GFIxBEEI=-0.074***	CI[-0.036,-0.008]	Pos. mod.	Supported
H4	TRD > PRD effect on COC	Suest sub-score DiD	TRD: -0.214 vs. PRD: -0.156	Diff p=0.016	TRD>PRD	Supported

Note. *** $p < 0.001$; FE = Two-way Fixed Effects with Driscoll-Kraay HAC SE; GMM = System GMM (Blundell and Bond, 1998); BCa = Bias-Corrected Accelerated bootstrap (5,000 iterations); IMM = Index of Moderated Mediation; CI = 95% BCa confidence interval; CRDI = Climate Risk Disclosure Index; GFI = Green Finance Index; BEEI = Board Environmental Expertise Index; TRD = Transition Risk Disclosure; PRD = Physical Risk Disclosure; KE = cost of equity; WACC = weighted average cost of capital. All eight hypotheses fully supported.

5. Discussion

5.1 Climate Risk Disclosure and Cost of Capital Reduction

The confirmation of H1a–H1c in both fixed effects and System GMM specifications – along with the significance of CRDI coefficients in the post-dynamic panel endogeneity correction – provides the first evidence in Pakistan that good climate risk disclosure lowers cost of equity (-0.187), cost of debt (-0.142), and WACC (-0.168) (Krueger et al., 2020; Ilhan et al., 2021; Ng and Rezaee, 2015). The economic implications are significant, as a 1

standard deviation increase in CRDI (+22.18 points) results in about 91 basis point reduction in cost of equity at sample means, which is not insignificant and has a significant impact on capital cost saving for most PSX firms that can exceed the annual cost of SBP SFF compliance (SBP, 2021; SECP, 2021). The dominant explanation is based on the Information Asymmetry Theory: TCFD-aligned disclosure addresses the information gap between PSX management and external capital providers, quantifying regulatory exposure, physical hazard scenarios, and governance accountability mechanisms that investors are not able to verify (Akerlof, 1970; Myers and Majluf, 1984). Because investors in PSX have even less context in climate disclosure in regards to information asymmetry, the magnitude of the effect is likely larger than for developed markets. This is consistent with the findings of Ng and Rezaee (2015): They report that sustainability performance-cost of equity relationships were stronger in lower transparency market environments (Ng and Rezaee, 2015).

5.2 Green Finance as Value-Transmitting Mediator

The partial mediation result – green finance accounting for about 40% of the effects between CRDI and the cost of capital – offers the first emerging-market panel evidence of such a sequential capital cost reduction mechanism, green finance (Flammer, 2021; Tang and Zhang, 2020). The mechanism of mediation is based on Signaling Theory: high-CRDI firms may access green financial instruments at preferential terms (sustainable loan step-down covenants, green bond certification), thereby facing lower financing costs, and they can also access institutional investors with an ESG mandate that boost their demand for the firms, thereby reducing equity risk premiums (Spence, 1973; Flammer, 2021). The 60% direct effect, bypassing the mediation of green finance instruments, is truly significant and stems from other COC reduction paths generated by CRD quality that are independent of the access to green finance instruments, including stakeholder relationship capital (Freeman, 1984), regulatory compliance cost saving (Suchman, 1995), and reputational premium (Suchman, 1995).

5.3 Board Governance as Performance Amplifier

The moderated mediation results – that high-BEEI firms result in 2.1 times larger conditional indirect cost reductions (H3a/H3b supported) – support the centrality of

governance quality in turning sustainability commitments into improved financial performance (Hambrick and Mason, 1984; Jensen and Meckling, 1976). This governance amplification is in line with predictions of the Agency Theory: that environmentally knowledgeable boards are able to credibly commit to comply with green finance covenants, which reduces the uncertainty of lenders while amplifying the credit risk reduction premium in sustainable loan instruments (Jensen and Meckling, 1976; Shaukat et al., 2016). The finding not only contributes to the literature on the climate finance domain but also to the upper echelons theory (Hambrick and Mason, 1984), showing that it is not generic board quality but the board's cognitive capabilities specifically relevant for environmental sustainability that matter for financial efficiency of green capital market engagement.

5.4 Transition Risk Premium and Disclosure Prioritization

The higher level of the capital cost reduction effect of TRD relative to PRD shows a unique aspect of PSX investor climate risk pricing (TCFD, 2023; Ilhan et al., 2021). SBP's Sustainable Finance Framework and SECP's ESG guidance also provide explicit regulatory transition risk incentives for investors and have started to consider these in equity valuation, while Pakistani investors seem to be more concerned about the exposure to near-term climate regulatory and market transition risks such as carbon pricing plans, energy transition mandates, and stranded asset risk in fossil fuel segments (SBP, 2021; SECP, 2021). This discovery has significant implications for disclosure strategy; PSX firms aiming to reap the highest benefits from their disclosure investment in the form of lower cost of capital should prioritize disclosure quality over generic physical risk narrative disclosure, such as Scope 1-3 emissions targets and low carbon technology roadmap disclosure (TCFD, 2023 and Krueger et al., 2020).

6. Conclusion, Implications, Limitations, and Future Research

6.1 Conclusion

This study is the first empirical one that indicates the quality of climate risk disclosure significantly lowers the cost of equity, cost of debt and WACC of PSX-listed non-financial firms, and green finance acts as a partial mediator between the aforementioned relationships and board environmental expertise significantly strengthens the green

finance-cost of capital reduction pathway (TCFD, 2023; Blundell and Bond, 1998; Hayes, 2018). An endogeneity correction technique, System GMM, is used along with an eight-hypothesis empirical work on climate disclosure and capital costs, which provides the most comprehensive evidence of all time on such link in Pakistan's emerging Islamic capital market (Baltagi, 2021; Khan and Bhutta, 2022). The four original contributions are: (1) CRDI for PSX non-financial firms disaggregating transition risk (TRD), physical risk (PRD), and governance accountability (GCA); with the impact of TRD being the most significant in reducing the cost of capital, (2) the CRD-COC relationship mediated through green finance, with approximately 40% of the mediation effects in the existing literature being existing emerging market panel evidence, (3) impacts of TRD and PRD on reducing the CRD-COC relationship is amplified by 2.1x when boards are most vs. least informed in the field of the environment, (4) first System GMM panel analysis of the causal relationship between CRD-COC in the context of Pakistan.

6.2 Policy and Managerial Implications

The empirical evidence of important and economically meaningful cost-of-capital savings for high-CRDI firms gives strong justification for progressing beyond voluntary guidance provided by SECP in the form of ESG guidelines and towards mandatory TCFD-aligned climate risk disclosure for PSX-listed firms with a phased implementation, including the KSE-100 index (SECP, 2021; Khan and Bhutta, 2022). According to the evidence of green finance mediation, the SBP's Sustainable Finance Framework (SFF) should be extended to non-financial corporates (NFCs) listed on the PSX, as this will allow for more bankable sustainable financing on preferential rates from SBP (SBP, 2021). The moderated mediation evidence provides an unambiguous strategic message to corporate boards and management: investing in the environmental expertise of the board (for instance, appointing specialist directors, providing environmental governance training, and by establishing a dedicated environment committee) yields tangible capital market returns, by intensifying the cost-of-capital premium that is associated with green finance engagement (Hambrick and Mason, 1984; Shaukat et al., 2016). The transition risk disclosure premium (H4) also suggests that PSX companies should adopt detailed TRD, including scope 1-3 targets, energy transition roadmaps, and carbon pricing sensitivity analysis, as their top priority for capital cost optimization (TCFD, 2023; Krueger et al., 2020).

6.3 Limitations and Future Research

The limitations and future research in this study are presented. There are seven limitations acknowledged (COPE, 2019; Saunders et al., 2019). First, the single-country PSX setting does not allow for cross-market generalizability; extending the sample to some multi-country panel South Asian or OIC emerging-market panel extensions would test cross-institutional environment robustness (Baltagi, 2021). Secondly, the measurement of CRDI is based on GRI-aligned content analysis of self-disclosed reports; satellite-derived emissions data, and third-party verified TCFD reporting, would provide objective CRD quality benchmarks (IPCC, 2023; GRI, 2021). Third, some of the data covered are green finance, which is still limited due to the nascency of the PSX market; once the data of the corporate green bonds are available after SBP, the mediating mechanisms would be richer (SBP, 2021). Fourth, cost of equity CAPM estimation relies on the assumption of beta stability; alternative implied cost of equity models (GLS, OJ) would add a dose of robustness (Fama and French, 1993). Fifth, the board environmental expertise index is based on observable qualifications; a survey-based cognitive index of capabilities could enhance the moderator construct (Hambrick and Mason, 1984). Sixth, the mandatory disclosure rules, which were implemented by the SECP for 2023 onwards are not represented in the panel (SECP, 2021). Seventh, the non-inclusion of the financial sector of PSX due to its separate capital structure norms as well as AAOIFI governance requirements (Iqbal and Mirakhor, 2011) means that, in a sense, the study underestimates the impact of the financial sector.

Future research directions include multi-country comparison of CRD-COC relationships across Pakistan, India, Bangladesh, and Sri Lanka (South Asia; (2) event study analysis of TCFD adoption announcements and stock market reactions on PSX; (3) gender diversity-CRD interaction analysis exploiting SECP's 2021 female director mandate as a natural experiment; (4) physical climate risk-COC analysis using satellite climate exposure data from the ND-GAIN; and (5) development of CRD for Islamic finance, testing whether Maqasid al-Shariah-focused climate disclosure drives differential capital cost premiums over conventional TCFD-based disclosure (Mohammed et al., 2015; ND-GAIN, 2023).

References

1. Aiken, L. S., and West, S. G. (1991). Multiple regression: Testing and interpreting interactions. Sage.
2. Akerlof, G. A. (1970). The market for "lemons": Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics*, 84(3), 488-500. <https://doi.org/10.2307/1879431>
3. Arellano, M., and Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies*, 58(2), 277-297. <https://doi.org/10.2307/2297968>
4. Baltagi, B. H. (2021). *Econometric analysis of panel data* (6th ed.). Springer. <https://doi.org/10.1007/978-3-030-53953-5>
5. Baron, R. M., and Kenny, D. A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, 51(6), 1173-1182. <https://doi.org/10.1037/0022-3514.51.6.1173>
6. Bauer, R., and Hann, D. (2010). Corporate environmental management and credit risk. SSRN Working Paper. <https://doi.org/10.2139/ssrn.1660470>
7. Blundell, R., and Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87(1), 115-143. [https://doi.org/10.1016/S0304-4076\(98\)00009-8](https://doi.org/10.1016/S0304-4076(98)00009-8)
8. Breusch, T. S., and Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies*, 47(1), 239-253. <https://doi.org/10.2307/2297111>
9. CBI. (2023). Green bond/sukuk database 2023. Climate Bonds Initiative. <https://www.climatebonds.net>

10. Choi, B. B., Lee, D., and Psaros, J. (2020). An analysis of Australian company carbon emission disclosures. *Pacific Accounting Review*, 25(1), 58-79. <https://doi.org/10.1108/PAR-04-2012-0012>
11. Clarkson, P. M., Fang, X., Li, Y., and Richardson, G. (2013). The relevance of environmental disclosures: Are such disclosures incrementally informative? *Journal of Accounting and Public Policy*, 32(5), 410-431. <https://doi.org/10.1016/j.jaccpubpol.2013.06.008>
12. COPE. (2019). Core practices. Committee on Publication Ethics. <https://doi.org/10.24318/cope.2019.1.13>
13. Creswell, J. W., and Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage.
14. Deegan, C. (2002). Introduction: The legitimising effect of social and environmental disclosures. *Accounting, Auditing and Accountability Journal*, 15(3), 282-311. <https://doi.org/10.1108/09513570210435852>
15. Donaldson, T., and Preston, L. E. (1995). The stakeholder theory of the corporation: Concepts, evidence, and implications. *Academy of Management Review*, 20(1), 65-91. <https://doi.org/10.2307/258887>
16. Dremptic, S., Klein, C., and Zwergel, B. (2020). The influence of firm size on the ESG score: Corporate sustainability ratings under review. *Journal of Business Ethics*, 167(2), 333-360. <https://doi.org/10.1007/s10551-019-04164-1>
17. Driscoll, J. C., and Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, 80(4), 549-560. <https://doi.org/10.1162/003465398557825>
18. Fama, E. F., and French, K. R. (1993). Common risk factors in the returns on stocks and bonds. *Journal of Financial Economics*, 33(1), 3-56. [https://doi.org/10.1016/0304-405X\(93\)90023-5](https://doi.org/10.1016/0304-405X(93)90023-5)
19. Fama, E. F., and Jensen, M. C. (1983). Separation of ownership and control. *The Journal of Law and Economics*, 26(2), 301-325. <https://doi.org/10.1086/467037>

20. Flammer, C. (2021). Corporate green bonds. *Journal of Financial Economics*, 142(2), 499-516. <https://doi.org/10.1016/j.jfineco.2021.01.010>
21. Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.
22. Ge, W., and Liu, M. (2015). Corporate social responsibility and the cost of corporate bonds. *Journal of Accounting and Public Policy*, 34(6), 597-624. <https://doi.org/10.1016/j.jaccpubpol.2015.05.008>
23. GRI. (2021). *GRI universal standards 2021*. Global Reporting Initiative. <https://www.globalreporting.org>
24. Hair, J. F., Risher, J. J., Sarstedt, M., and Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, 31(1), 2-24. <https://doi.org/10.1108/EBR-11-2018-0203>
25. Hambrick, D. C., and Mason, P. A. (1984). Upper echelons: The organization as a reflection of its top managers. *Academy of Management Review*, 9(2), 193-206. <https://doi.org/10.2307/258434>
26. Harjoto, M. A., Laksmana, I., and Yang, Y. W. (2021). Board diversity and corporate investment oversight. *Journal of Business Research*, 135, 346-358. <https://doi.org/10.1016/j.jbusres.2021.06.035>
27. Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica*, 46(6), 1251-1271. <https://doi.org/10.2307/1913827>
28. Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (2nd ed.). Guilford Press.
29. Hsiao, C. (2014). *Analysis of panel data* (3rd ed.). Cambridge University Press.
30. Ilhan, E., Sautner, Z., and Vilkov, G. (2021). Carbon tail risk. *The Review of Financial Studies*, 34(3), 1540-1571. <https://doi.org/10.1093/rfs/hhaa071>
31. Im, K. S., Pesaran, M. H., and Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, 115(1), 53-74. [https://doi.org/10.1016/S0304-4076\(03\)00092-7](https://doi.org/10.1016/S0304-4076(03)00092-7)

32. Imbens, G. W., and Wooldridge, J. M. (2009). Recent developments in the econometrics of program evaluation. *Journal of Economic Literature*, 47(1), 5-86. <https://doi.org/10.1257/jel.47.1.5>
33. IPCC. (2023). Climate change 2023: Synthesis report. Intergovernmental Panel on Climate Change. <https://doi.org/10.59327/IPCC/AR6-9789291691647>
34. Iqbal, Z., and Mirakhor, A. (2011). *An introduction to Islamic finance: Theory and practice* (2nd ed.). Wiley.
35. IFSB. (2023). Islamic Financial Services Board annual report. IFSB. <https://www.ifsb.org>
36. Jensen, M. C., and Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, 3(4), 305-360. [https://doi.org/10.1016/0304-405X\(76\)90026-X](https://doi.org/10.1016/0304-405X(76)90026-X)
37. Khan, M. A., and Bhutta, U. S. (2022). Sustainable finance in developing economies: Evidence from Pakistan. *Sustainability*, 14(3), 1523. <https://doi.org/10.3390/su14031523>
38. Kim, E. H., and Lyon, T. (2015). Greenwash vs. brownwash: Exaggeration and undue modesty in corporate sustainability disclosure. *Organization Science*, 26(3), 705-723. <https://doi.org/10.1287/orsc.2014.0949>
39. Koenker, R., and Bassett, G. (1978). Regression quantiles. *Econometrica*, 46(1), 33-50. <https://doi.org/10.2307/1913643>
40. Krippendorff, K. (2018). *Content analysis: An introduction to its methodology* (4th ed.). Sage.
41. Krueger, P., Sautner, Z., and Starks, L. T. (2020). The importance of climate risks for institutional investors. *The Review of Financial Studies*, 33(3), 1067-1111. <https://doi.org/10.1093/rfs/hhz137>

42. Levin, A., Lin, C. F., and Chu, C. S. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, 108(1), 1-24. [https://doi.org/10.1016/S0304-4076\(01\)00098-7](https://doi.org/10.1016/S0304-4076(01)00098-7)
43. Marquis, C., Toffel, M. W., and Zhou, Y. (2016). Scrutiny, norms, and selective disclosure. *Organization Science*, 27(2), 483-504. <https://doi.org/10.1287/orsc.2015.1039>
44. Modigliani, F., and Miller, M. H. (1963). Corporate income taxes and the cost of capital: A correction. *The American Economic Review*, 53(3), 433-443.
45. Mohammed, M. O., Razak, D. A., and Taib, F. M. (2015). The performance measures of Islamic banking based on the Maqasid framework. IIUM International Accounting Conference IV.
46. Myers, S. C., and Majluf, N. S. (1984). Corporate financing and investment decisions when firms have information that investors do not have. *Journal of Financial Economics*, 13(2), 187-221. [https://doi.org/10.1016/0304-405X\(84\)90023-0](https://doi.org/10.1016/0304-405X(84)90023-0)
47. ND-GAIN. (2023). Notre Dame Global Adaptation Initiative country index. University of Notre Dame. <https://gain.nd.edu>
48. Ng, A. C., and Rezaee, Z. (2015). Business sustainability performance and cost of equity capital. *Journal of Corporate Finance*, 34, 128-149. <https://doi.org/10.1016/j.jcorpfin.2015.08.003>
49. OECD. (2008). Handbook on constructing composite indicators: Methodology and user guide. OECD Publishing. <https://doi.org/10.1787/9789264043466-en>
50. Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels (IZA Discussion Paper No. 1240). IZA.
51. Petersen, M. A. (2009). Estimating standard errors in finance panel data sets: Comparing approaches. *The Review of Financial Studies*, 22(1), 435-480. <https://doi.org/10.1093/rfs/hhn053>

52. Preacher, K. J., and Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, 40(3), 879-891. <https://doi.org/10.3758/BRM.40.3.879>
53. Preacher, K. J., Rucker, D. D., and Hayes, A. F. (2007). Addressing moderated mediation hypotheses: Theory, methods, and prescriptions. *Multivariate Behavioral Research*, 42(1), 185-227. <https://doi.org/10.1080/00273170701341316>
54. PSX. (2023). Pakistan Stock Exchange listed companies directory. Pakistan Stock Exchange. <https://www.psx.com.pk>
55. Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. *The Stata Journal*, 9(1), 86-136. <https://doi.org/10.1177/1536867X0900900106>
56. Saunders, M., Lewis, P., and Thornhill, A. (2019). *Research methods for business students* (8th ed.). Pearson.
57. SBP. (2021). State Bank of Pakistan Sustainable Finance Framework. State Bank of Pakistan. <https://www.sbp.org.pk>
58. SECP. (2021). SECP ESG disclosure guidance document. Securities and Exchange Commission of Pakistan. <https://www.secp.gov.pk>
59. Sharpe, W. F. (1964). Capital asset prices: A theory of market equilibrium under conditions of risk. *The Journal of Finance*, 19(3), 425-442. <https://doi.org/10.2307/2977928>
60. Shaukat, A., Qiu, Y., and Trojanowski, G. (2016). Board attributes, corporate social responsibility strategy, and corporate environmental and social performance. *Journal of Business Ethics*, 135(3), 569-585. <https://doi.org/10.1007/s10551-014-2460-9>
61. Spence, M. (1973). Job market signaling. *The Quarterly Journal of Economics*, 87(3), 355-374. <https://doi.org/10.2307/1882010>
62. StataCorp. (2023). Stata statistical software: Release 17. StataCorp LLC.

63. Suchman, M. C. (1995). Managing legitimacy: Strategic and institutional approaches. *Academy of Management Review*, 20(3), 571-610. <https://doi.org/10.2307/258788>
64. Tang, D. Y., and Zhang, Y. (2020). Do shareholders benefit from green bonds? *Journal of Corporate Finance*, 61, 101427. <https://doi.org/10.1016/j.jcorpfin.2018.12.001>
65. TCFD. (2023). Task Force on Climate-related Financial Disclosures: 2023 status report. TCFD Secretariat. <https://www.fsb-tcfd.org>
66. Windmeijer, F. (2005). A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics*, 126(1), 25-51. <https://doi.org/10.1016/j.jeconom.2004.02.005>
67. Wintoki, M. B., Linck, J. S., and Netter, J. M. (2012). Endogeneity and the dynamics of internal corporate governance. *Journal of Financial Economics*, 105(3), 581-606. <https://doi.org/10.1016/j.jfineco.2012.03.005>
68. Wooldridge, J. M. (2002). *Econometric analysis of cross section and panel data*. MIT Press.
69. Yoshino, N., Taghizadeh-Hesary, F., and Otsuka, M. (2021). COVID-19 and optimal portfolio selection for investment in sustainable development goals. *Finance Research Letters*, 38, 101695. <https://doi.org/10.1016/j.frl.2020.101695>