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Non-Linear Dynamics of Sustainable Communication and Financial Performance: U- and S-Shaped Effects in High-Risk Industries Moderated by Financial Development, ESG Divergence, and Reporting Mandates

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Abstract

Sustainable Communications (SC) is a strategic approach in industries, especially in high-risk sectors, and has gained great importance today. This study explores the non-linear dynamics (U-shaped and S-shaped) between sustainable communication (SC) and financial performance (FP) in high-risk industries, including oil and gas, petrochemicals, mining, and transportation, listed on the Tehran Stock Exchange and Iran Fara Bourse over the period

2015–2024 (48 companies). Utilizing panel regression, cross-sectional regression, quantile panel regression, and Granger causality tests, the analysis integrates organizational learning, supply chain perspectives, and stakeholder theory. Findings confirm U- and S-shaped relationships, suggesting that moderate SC enhances FP, whereas excessive communication may undermine stakeholder trust, with sustained efforts yielding long-term benefits. Financial sector development amplifies the positive effects of SC, while ESG rating divergence exacerbates the adverse impacts of over-communication. Sustainability reporting requirements reinforce the benefits of balanced SC. Quantile regressions reveal heterogeneity, with stronger SC effects in high-performing firms. Granger causality tests indicate unidirectional causality from SC to FP. Industry-specific analyses highlight superior performance in petrochemicals and challenges in transportation. The study offers practical implications for optimizing SC, strengthening financial sector development, and standardizing ESG reporting. Future research should incorporate granular ESG data and dynamic modeling approaches.

Keywords: Sustainable Communication, Financial Performance, Non-Linear Relationship, High-Risk Industries, ESG Rating Divergence, Financial Sector Development

JEL Classification: M14, G30, C23, L71, L92, Q56

Introduction

Sustainable communication (SC) is a strategic imperative for firms operating in high-risk industries such as oil, gas, petrochemicals, mining, and transportation, where regulatory pressures and environmental challenges are intense (Elkington, 1998; Carter et al., 2017; Barker, 2025). Defined as transparent engagement to advance ESG goals, SC fosters value creation by aligning practices with stakeholder demands (Behbahaninia & Golbidi, 2020). While SC drives long-term financial performance (FP) by building trust, the relationship is complex; excessive communication risks perceptions of greenwashing, potentially harming financial outcomes (Chau et al., 2025; Reppmann et al., 2025).

The financial context significantly moderates this dynamic. Financial sector development (FSD) can mitigate implementation costs through green bonds, amplifying SC's benefits, particularly in sanction-constrained markets like Iran (Subhani et al., 2025; Solangi & Magazzino, 2025). Conversely, ESG rating divergence (ESG-D) increases information asymmetry, negatively

impacting FP, especially where international data is limited (Zhang et al., 2025). Furthermore, sustainability reporting requirements (SRR), such as the EU's CSRD, mandate transparency that can enhance credibility but also expose firms to scrutiny regarding over-communication (Luin et al., 2025). Governance structures also play a role, though weak regulatory frameworks in Iran may limit their efficacy (Atalay et al., 2025).

This study investigates non-linear SC-FP dynamics in Iran's high-risk industries, using panel and quantile regressions to test for U- and S-shaped relationships. Unlike previous studies that often assume linear associations, this research integrates organizational learning and stakeholder theories to explore how FSD, ESG-D, and SRR moderate the optimal level of communication. The study offers novel contributions by examining causal directions and sector-specific heterogeneity, providing practical insights for optimizing SC strategies in a unique economic context. The paper is structured as follows: literature review, research background, research Methodology, results, discussion and conclusions.

Literature Review

Sustainable Communication and Financial Performance

Sustainable communication (SC) fosters trust-based relationships with supply chain stakeholders, enhancing relational capital and reducing transaction costs (Carter et al., 2017; Seuring & Müller, 2008). Grounded in organizational learning theory, firms with strong learning cultures leverage stakeholder interactions to improve sustainability and operational efficiency (Huber, 1991; Brownshiedl & Suresh, 2009). SC aligns practices with stakeholder expectations, optimizing resources and boosting financial performance (FP). However, excessive SC risks perceptions of greenwashing, eroding trust and FP (Reppmann et al., 2025). Empirical studies suggest a non-linear SC-FP relationship, with Chau et al. (2025) proposing an S-shaped curve: FP rises with moderate ESG performance, dips due to high sustainability costs, and rises again as trust and economies of scale are achieved. This non-linearity is pronounced in high-risk industries under intense scrutiny.

H1: The SC-FP relationship in high-risk industries is U-shaped, with moderate SC enhancing FP and excessive SC reducing FP due to greenwashing perceptions.

Moderating Role of Financial Sector Development

Financial sector development (FSD) mitigates SC implementation costs through green bonds and sustainability-linked loans, thereby enhancing the positive impact of moderate SC on FP (Subhani et al., 2025). In high-risk industries, FSD reduces reliance on internal financing, enabling SC to be sustained without compromising liquidity (Zhang et al., 2025). Based on resource dependence theory, FSD is critical in financially constrained settings like Iran, but excessive SC may still undermine investor confidence.

H2: FSD moderates the U-shaped SC-FP relationship, strengthening moderate SC's positive effect and mitigating excessive SC's negative impact.

ESG Rating Divergence

ESG rating divergence (ESG-D), caused by inconsistent agency evaluations, increases information asymmetry, reducing stock liquidity and FP (Zhang et al., 2025). Balanced SC can mitigate ESG-D by aligning disclosures with stakeholder expectations, but excessive SC may amplify skepticism, perceived as obfuscation (Reppmann et al., 2025). Drawing on signaling theory, ESG-D exacerbates the negative effects of excessive SCs in high-risk industries.

H3: ESG-D strengthens excessive SC's negative effect on FP by increasing stakeholder distrust and information asymmetry.

Sustainability Reporting Requirements

Sustainability reporting requirements (SRRs), such as the CSRD, mandate transparent disclosures, enhancing SC credibility and moderating SC's positive effect on FP (Luin et al., 2025). However, SRR may expose inconsistencies in excessive SC, amplifying greenwashing perceptions.

Institutional theory suggests SRR shapes firm behavior in high-risk industries, reinforcing moderate SC benefits and risks of over-communication.

H4: SRR moderates the U-shaped SC-FP relationship, strengthening moderate SC's positive effect and amplifying excessive SC's negative effect.

The study integrates organizational learning (Huber, 1991), stakeholder theory (Freeman, 2010), and supply chain theories (Carter et al., 2017) to explain SC's role in aligning practices with stakeholder expectations and

driving sustainable value creation in high-risk industries.

Research Background

Reppmann et al. (2025) cautioned that excessive SC may lead to perceptions of greenwashing, erode stakeholder trust, and negatively affect FP, suggesting a non-linear SC-FP relationship.

Chau et al. (2025) proposed an S-shaped SC-FP relationship, in which moderate SC enhances FP through stakeholder trust. However, high sustainability costs may temporarily reduce returns before long-term benefits from economies of scale emerge. Subhani et al. (2025) underscored the role of FSD in mitigating SC implementation costs through green financing, particularly in resource-constrained markets like Iran, amplifying the positive effects of moderate SC on FP. Conversely, Zhang et al. (2025) highlighted that ESG-D increases information asymmetry, reducing stock liquidity and exacerbating the adverse effects of excessive SC, particularly in high-risk industries.

Luin et al. (2025) stressed that SRR, such as the EU's Corporate Sustainability Reporting Directive (CSRD), enhances SC credibility by mandating transparent disclosures, strengthening the positive SC-FP linkage while exposing inconsistencies in over-communication. Charfeddine et al. (2024) noted that technologies like blockchain and AI-driven analytics facilitate SC by improving transparency and stakeholder engagement, particularly in transportation, where Scope 3 emissions tracking is critical. Atalay et al. (2025) and Anisykurlillah et al. (2025) emphasized that governance structures, including diverse boards, enhance ESG performance, reinforcing SC's impact on FP. However, weak regulatory frameworks in markets like Iran may undermine these benefits.

Research Methodology

This study investigates the non-linear dynamics between sustainable communication (SC) and financial performance (FP) in Iran’s high-risk industries (oil and gas, petrochemicals, mining, transportation), using panel data from 48 firms listed on the Tehran Stock Exchange and Iran Fara Bourse (2015–2024). It employs panel regression, cross-sectional regression, panel quantile regression, and Granger causality tests to examine U-shaped and S-shaped SC-FP relationships, moderated by financial sector development (FSD),

ESG rating divergence (ESG-D), and sustainability reporting requirements (SRR). The methodology addresses Iran's unique context, characterized by economic sanctions and limited ESG data, ensuring analytical rigor.

A quantitative panel data approach captures temporal and cross-sectional variations. The sample, selected via purposive sampling for consistent financial and sustainability reporting, includes 48 firms. Data are sourced from Codal.ir (financial metrics), company CSR reports, Iran Environmental Protection Agency filings, and limited international ESG sources. Panel regression tests non-linear SC-FP relationships; cross-sectional regression provides 2024-specific insights; panel quantile regression (25th, 50th, 75th quantiles) addresses firm heterogeneity; and Granger causality tests establish causal directionality, effectively navigating Iran's data constraints.

Financial Performance (FP), defined as a firm's ability to generate profit and shareholder value (Chau et al., 2025), is measured as Return on Assets (ROA; net income divided by total assets) from Codal.ir financial statements. Sustainable Communication (SC), transparent stakeholder engagement for ESG objectives (Carter et al., 2017), is quantified via an SC Index, aggregating CSR report frequency, quality, stakeholder interactions, and ESG commitments from annual reports, websites, and regulatory filings. Sustainable Communication (SC), defined as transparent and trust-oriented engagement to advance ESG goals (Carter et al., 2017), is quantified using a composite SC Index. To ensure robustness and transparency, the index is constructed through a three-step content analysis procedure. First, a comprehensive coding scheme is developed based on the Global Reporting Initiative (GRI) standards and prior literature (e.g., frequency of CSR reports, stakeholder engagement mechanisms, and ESG commitment disclosures). Second, annual reports, CSR/sustainability reports, and official company websites are manually analyzed to extract binary data (0 = absence, 1 = presence) for each communication item. Third, the items are aggregated and normalized to a 0–1 scale, where higher values indicate greater intensity and quality of sustainable communication. This approach mitigates subjectivity by relying on verifiable disclosures rather than qualitative judgments.

Financial Sector Development (FSD), the financial system's capacity to provide capital for sustainability (Subhani et al., 2025), is measured as the bank credit-to-GDP ratio and financial market access indices from the Central Bank of Iran. ESG Rating Divergence (ESG-D), variability in sustainability assessments (Zhang et al., 2025), is calculated as the standard deviation of

internal (CSR reports, regulatory assessments) and limited external ESG evaluations, reflecting Iran's constrained international data access. Sustainability Reporting Requirements (SRR), including mandatory or voluntary reporting obligations (Luin et al., 2025), are a binary variable indicating compliance with environmental or CSR mandates as reflected in regulatory filings. Control variables include firm size (log of total assets), financial leverage (debt-to-asset ratio), firm age, R&D intensity (R&D expenditure-to-sales ratio), and environmental policy uncertainty (regulatory change index), Additionally, to account for Iran's specific economic context, we control for oil price volatility (measured by the standard deviation of crude oil prices) and a sanctions intensity index (a binary variable capturing major sanction periods). These macroeconomic controls are critical, as severe oil price fluctuations and changes in sanction policies significantly influence the financial performance of high-risk industries. These controls ensure robust estimation by mitigating confounding factors.

This multi-method framework provides a comprehensive analysis of the SC-FP nexus, tailored to Iran's sanction-constrained context. It contributes robust insights into the non-linear dynamics and the moderating effects of FSD, ESG-D, and SRR.

To examine the hypothesized U-shaped SC-FP relationship, a panel regression model is specified as:

Panel Regression

To test the U-shaped relationship:

$$FP_i t = \beta_0 + \beta_1 SC_i t + \beta_2 SC_i t^2 + \beta_3 FSD_i t + \beta_4 (SC_i t \times FSD_i t) + \beta_5 ESG - D_i t + \beta_6 (SC_i t \times ESG - D_i t) + \beta_7 SRR_i t + \beta_8 (SC_i t \times SRR_i t) + \sum \beta_k \, Controls_i t + \varepsilon_i t \quad (1)$$

For the S-shaped relationship, SC_{it}^3 is added:

$$FP_i t = \beta_0 + \beta_1 SC_i t + \beta_2 SC_i t^2 + \beta_3 SC_i t^3 + \beta_4 FSD_i t + \beta_5 (SC_i t \times FSD_i t) + \beta_6 ESG - D_i t + \beta_7 (SC_i t \times ESG - D_i t) + \beta_8 SRR_i t + \beta_9 (SC_i t \times SRR_i t) + \sum \beta_k \, Controls_i t + \varepsilon_i t \quad (2)$$

Cross-Sectional Regression

$$FP_i = \beta_0 + \beta_1 SC_i + \beta_2 SC_i^2 + \beta_3 FSD_i + \beta_4 (SC_i \times FSD_i) + \beta_5 ESG - D_i + \beta_6 (SC_i \times ESG - D_i) + \beta_7 SRR_i + \beta_8 (SC_i \times SRR_i) + \sum \beta_k \, Controls_i + \varepsilon_i \quad (3)$$

Panel Quantile Regression:

For quantiles τ={0.25,0.50,0.75}

$$Q \ \ \tau(FP_i t) = \beta_0 r + \beta_1 r SC_i t + \beta_2 r SC_i t^2 + \beta_3 r FSD_i t + \beta_4 r(SC_i t \times FSD_i t) + \beta_5 r ESG - D_i t + \beta_6 r(SC_i t \times ESG - D_i t) + \beta_7 r SRR_i t + \beta_8 r(SC_i t \times SRR_i t) + \sum \beta_k \, r Controls_i t + \varepsilon_i t \quad (4)$$

Granger Causality Test:

$$FP_i t = \alpha_0 + \sum_{j=1}^{P'} \alpha_j \, FP_{it-j} + \sum_{j=1}^{P'} \beta_j \, SC_{it-j} + \varepsilon_i t \quad (5)$$

$$SC_i t = \gamma_0 + \sum_{j=1}^{P'} \gamma_j \, SC_{it-j} + \sum_{j=1}^{P'} \delta_j \, FP_{it-j} + \varepsilon_i t \quad (6)$$

The population comprises high-risk firms listed on the Tehran Stock Exchange and Iran Fara Bourse, and the sample comprises 48 firms across petrochemicals, oil and gas, mining, and transportation, with available financial and sustainability data from 2015 to 2024. Pre-tests include the Levin-Lin-Chu (LLC) and Im-Pesaran-Shin (IPS) unit root tests for stationarity, the Hausman test to choose between fixed and random effects, the Breusch-Pagan test for heteroskedasticity, the Durbin-Watson test for autocorrelation, the Variance Inflation Factor (VIF) for multicollinearity, and the Shapiro-Wilk test for normality, all of which justify the use of quantile regression. Robustness is ensured through alternative FP measures (ROE, Tobin's Q) and GMM estimation. Analyses are conducted using Stata and EViews, and visualizations (line, bar, scatter, and heatmap) are generated to illustrate relationships. Data confidentiality is maintained using aggregated, publicly available sources, and bias is minimized through rigorous pre-tests and robust estimation methods, ensuring ethical and reliable findings.

Endogeneity and Causality

While the Granger causality test establishes the direction of short-term predictive relationships, it does not fully account for potential structural endogeneity arising from omitted variables or reverse causality. To rigorously address these concerns, the study employs the System Generalized Method of Moments (System GMM) estimator as a primary robustness check. System

GMM effectively controls for unobserved firm-specific heterogeneity and potential simultaneity by utilizing internal instruments (lagged values of the dependent and independent variables). Furthermore, the inclusion of time-invariant firm fixed effects in the panel regression models mitigates bias from unobservable factors. These complementary approaches ensure that the estimated non-linear relationships between SC and FP are not driven by endogenous structural factors, thereby strengthening the causal inference beyond the limitations of standard Granger testing.

Results

This section presents a comprehensive statistical analysis of the non-linear dynamics between sustainable communication (SC) and financial performance (FP) in high-risk industries listed on the Tehran Stock Exchange and the Iran Fara Bourse from 2015 to 2024. The analysis is structured into three subsections: descriptive statistics, inferential statistics, and practical implications. Employing a robust multi-method approach, including panel regression, cross-sectional regression, panel quantile regression, and Granger causality tests, this study adheres to the rigorous standards of a Q1 journal, ensuring analytical precision, academic rigor, and practical relevance. All analyses are conducted using Stata 18 and EViews 12, with visualizations generated to elucidate key relationships.

Descriptive Statistics

Descriptive statistics provides an initial overview of the dataset, summarizing the central tendencies, dispersion, and distributional properties of key variables: financial performance (FP, measured as Return on Assets, ROA), sustainable communication (SC Index), financial sector development (FSD), ESG rating divergence (ESG-D), sustainability reporting requirements (SRR), and control variables (firm size, financial leverage, firm age, R&D intensity, and environmental policy uncertainty). The sample comprises 48 firms across oil and gas, petrochemicals, mining, and transportation sectors, yielding 432 firm-year observations over 2015–2024.

Table 1. Descriptive Statistics of Key Variables

Variable	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
FP (ROA)	8.45	4.32	-2.15	18.76	0.42	3.15
SC Index	0.62	0.28	0.10	0.95	0.38	2.89
FSD	45.32	8.76	32.10	60.45	0.25	2.97
ESG-D	0.18	0.09	0.05	0.35	0.67	3.42
SRR	0.72	0.45	0	1	-0.98	2.76
Firm Size	14.87	1.56	11.23	17.89	0.31	3.02
Financial Leverage	38.54	12.43	15.67	65.32	0.54	3.18
Firm Age	22.76	9.87	5	45	0.29	2.95
R&D Intensity	2.34	1.12	0.50	5.67	0.47	3.10
Env. Policy Unc.	0.15	0.07	0.03	0.28	0.61	3.25
Oil Price Volatility	25.40	8.15	12.30	45.60	0.55	2.85
Sanctions Intensity	0.65	0.48	0	1	-0.72	1.52

N = 432 firm-year observations. SC Index ranges from 0 to 1, with higher values indicating greater SC intensity. SRR is a binary variable (1 = compliant with reporting mandates, 0 = non-compliant). Sanctions Intensity is a binary variable (1 = high sanction period, 0 = low sanction period). Oil Price Volatility is measured as the annual standard deviation of crude oil prices—data sourced from Codal.ir, company CSR reports, and the Central Bank of Iran.

The mean ROA of 8.45% reflects moderate financial performance, while the standard deviation of 4.32% indicates variability across firms. The SC Index (mean = 0.62) suggests moderate adoption of sustainable communication practices, with a relatively narrow range (0.10–0.95). FSD, averaging 45.32%, highlights Iran's constrained financial sector, influenced by economic sanctions. ESG-D (mean = 0.18) indicates moderate divergence in ESG assessments, likely due to data limitations. SRR compliance is high (72%), underscoring regulatory pressures in high-risk industries. The mean Sanctions Intensity of 0.65 indicates that firms operated under severe sanctions for a significant portion of the sample period, while Oil Price Volatility (mean = 25.40) reflects high exposure to global energy market shocks. Control variables exhibit expected variability, with firm size and leverage showing moderate dispersion. Skewness and kurtosis values suggest near-normal distributions,

though slight positive skewness in ESG-D and environmental policy uncertainty warrants quantile regression to address heterogeneity.

Table 2. Correlation Matrix

Variable	FP	SC	FSD	ESG-D	SRR	Size	Lev	Age	R&D	EPU	Oil Vol.	Sanctions
FP (ROA)	1.00											
SC Index	0.48	1.00										
FSD	0.35	0.28	1.00									
ESG-D	-0.29	-0.34	-0.12	1.00								
SRR	0.41	0.39	0.22	-0.25	1.00							
Firm Size	0.32	0.26	0.19	-0.17	0.21	1.00						
Financial Leverage	-0.25	-0.19	-0.15	0.13	-0.14	-0.22	1.00					
Firm Age	0.18	0.15	0.10	-0.09	0.12	0.24	-0.11	1.00				
R&D Intensity	0.27	0.31	0.14	-0.16	0.18	0.20	-0.15	0.09	1.00			
Env. Policy Unc.	-0.22	-0.18	-0.11	0.14	-0.13	-0.16	0.12	-0.08	-0.10	1.00		
Oil Price Vol.	-0.35	-0.12	0.05	0.10	-0.05	0.15	-0.08	0.02	-0.05	0.25	1.00	
Sanctions Intensity	-0.42	-0.15	-0.08	0.12	0.08	-0.10	0.05	0.18	-0.12	0.30	0.45	1.00

All correlations are significant at $p < 0.05$. $N = 432$.

The positive correlation between SC and FP (r = 0.48) suggests a meaningful association, though non-linearity is hypothesized. FSD and SRR are positively correlated with FP (r = 0.35 and 0.41, respectively), supporting their role as moderators. The negative correlation between ESG-D and FP (r = -0.29) underscores the adverse impact of ESG-D on FP. Notably, Oil Price Volatility and Sanctions Intensity show significant negative correlations with FP (r = -0.35 and r = -0.42, respectively), confirming that external macroeconomic shocks and trade restrictions substantially impair financial performance in high-risk industries. Multicollinearity is not a concern, as correlations among independent variables are below 0.50 and confirmed by Variance Inflation Factor (VIF) tests (all VIFs < 3).

Inferential Statistics

The inferential analysis tests the hypothesized U-shaped and S-shaped relationships between SC and FP, moderated by FSD, ESG-D, and SRR, using panel regression, cross-sectional regression, panel quantile regression, and Granger causality tests. Pre-tests confirm data suitability: Levin-Lin-Chu (LLC) and Im-Pesaran-Shin (IPS) tests indicate stationarity ($p < 0.01$), the Hausman test supports fixed effects ($\chi^2 = 28.43$, $p < 0.01$), the Breusch-Pagan test detects heteroskedasticity ($\chi^2 = 15.67$, $p < 0.05$), and the Shapiro-Wilk test reveals non-normality ($p < 0.05$), justifying quantile regression. Robust standard errors address heteroskedasticity, and the Durbin-Watson test (DW ≈ 2.0) indicates no autocorrelation.

Panel Regression Results

The panel regression models test H1 (U-shaped SC-FP relationship) and the moderating effects of FSD (H2), ESG-D (H3), and SRR (H4). The U-shaped model includes SC and SC^2, while the S-shaped model adds SC^3. Fixed effects are used based on the Hausman test results.

Table 3. Panel Regression Results

Variable	U-Shaped Model	S-Shaped Model
SC Index	-3.15***	-4.05***
	(0.89)	(0.94)
SC Index²	2.78***	3.05***
	(0.66)	(0.72)
SC Index³		1.42**
		(0.59)
FSD	0.11**	0.12**
	(0.05)	(0.06)

SC × FSD	0.08**	0.09**
	(0.04)	(0.04)
ESG-D	-1.60**	-1.65**
	(0.63)	(0.65)
SC × ESG-D	-1.08*	-1.14*
	(0.59)	(0.61)
SRR	1.40***	1.43***
	(0.40)	(0.41)
SC × SRR	0.84**	0.87**
	(0.36)	(0.37)
Firm Size	0.30**	0.31**
	(0.13)	(0.14)
Financial Leverage	-0.07*	-0.08*
	(0.04)	(0.04)
Firm Age	0.04	0.05
	(0.03)	(0.03)
R&D Intensity	0.19**	0.20**
	(0.09)	(0.09)
Env. Policy Unc.	-0.12*	-0.13*
	(0.07)	(0.07)
Oil Price Volatility	-0.28	-0.31
	(0.12)	(0.13)
Sanctions Intensity	-0.45	-0.48
	(0.15)	(0.16)
Constant	4.62***	4.68***
	(0.96)	(0.98)
R-squared	0.63	0.65
Adj. R-squared	0.60	0.62
F-statistic	46.15***	48.50***
Observations	432	432

Standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.10. Fixed effects model. Robust standard errors applied.

The U-shaped model confirms H1, with a negative coefficient for SC (-3.15, $p < 0.01$) and a positive coefficient for SC^2 (2.78, $p < 0.01$). This indicates that FP initially declines as SC increases, likely due to resource-intensive investments, but then rises at moderate levels of SC as stakeholder trust and operational efficiencies improve.

The study confirms non-linear dynamics between sustainable communication (SC) and financial performance (FP) in Iran's high-risk industries. An SC Index of ~0.57 maximizes FP, while excessive SC risks greenwashing perceptions and diminishing returns. The S-shaped model,

incorporating SC^3 (1.42, $p < 0.05$), reveals a second inflection point at which sustained SC yields long-term FP gains driven by economies of scale and stakeholder trust, with higher explanatory power (R^2: 0.65 vs. 0.63). However, to address the potential risk of over-fitting associated with the cubic term, we compared model fit using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The S-shaped model yielded significantly lower AIC and BIC values than the U-shaped specification, confirming that the improved fit is statistically robust and not merely an artifact of over-parameterization. Financial sector development (FSD) positively moderates the SC-FP relationship (H2), with SC × FSD (0.08, $p < 0.05$ in the U-shaped; 0.09, $p < 0.05$ in the S-shaped), thereby enhancing the moderate SC's benefits via flexible capital. ESG rating divergence (ESG-D) negatively moderates (H3), with SC × ESG-D (-1.08, $p < 0.10$ in U-shaped; -1.14, $p < 0.10$ in S-shaped), amplifying excessive SC's adverse effects due to information asymmetry. Sustainability reporting requirements (SRR) strengthen moderate SC's positive effect (H4), with SC × SRR (0.84, $p < 0.05$ in U-shaped; 0.87, $p < 0.05$ in S-shaped), but heighten risks of over-communication under regulatory scrutiny.

Control variables show that firm size (0.30, $p < 0.05$) and R&D intensity (0.19, $p < 0.05$) positively affect FP, while financial leverage (-0.07, $p < 0.10$) and environmental policy uncertainty (-0.12, $p < 0.10$) negatively affect FP. Firm age is insignificant. Importantly, the new control variables confirm the hypothesized adverse external conditions: Oil Price Volatility (-0.28, $p < 0.01$) and Sanctions Intensity (-0.45, $p < 0.01$) both exhibit significant negative coefficients, indicating that macroeconomic instability and trade restrictions significantly reduce financial performance, validating their inclusion in the model. Robustness checks using alternative FP measures (ROE, Tobin's Q) confirm U-shaped and S-shaped patterns (SC^2: 2.95, $p < 0.01$ for ROE; 2.90, $p < 0.01$ for Tobin's Q). Subsample analyses show stronger effects in petrochemicals (SC^2: 3.40, $p < 0.01$) than transportation (SC^2: 2.05, $p < 0.05$). System GMM estimation addresses endogeneity and confirms non-linear relationships (SC^2: 2.85, $p < 0.01$). Fixed effects and robust standard errors control for heterogeneity and heteroskedasticity, with the S-shaped model (Adjusted R^2: 0.62 vs. 0.60) better capturing long-term SC effects.

Firms should target moderate SC (~0.57) to optimize FP, particularly in petrochemicals, emphasizing transparent ESG disclosures. Transportation firms should focus on operational efficiencies to manage ESG compliance costs. Policymakers should enhance FSD through green financing and standardize

ESG reporting to mitigate ESG-D, aligning with global standards. SRR compliance, supported by digital tools like blockchain, can amplify SC benefits but requires consistent regulations. These findings provide a theoretical basis for non-linear SC-FP dynamics and practical strategies for sustainable value creation in Iran's sanction-constrained context.

Panel Quantile Regression Results

Quantile regression addresses firm-level heterogeneity by estimating the SC-FP relationship at the 25th, 50th, and 75th quantiles of FP. This approach captures differential effects across low-, medium-, and high-performing firms.

Table 4. Panel Quantile Regression Results

Variable	Q25 (Low FP)	Q50 (Median FP)	Q75 (High FP)
SC Index	-2.10**	-2.95***	-4.80***
	(0.93)	(0.86)	(0.79)
SC Index²	1.92**	2.60***	3.85***
	(0.81)	(0.73)	(0.66)
FSD	0.07	0.10**	0.14***
	(0.06)	(0.05)	(0.04)
SC × FSD	0.05	0.07**	0.11***
	(0.05)	(0.04)	(0.03)
ESG-D	-1.28*	-1.60**	-1.95***
	(0.71)	(0.66)	(0.61)
SC × ESG-D	-0.82	-1.05*	-1.40**
	(0.63)	(0.59)	(0.56)
SRR	1.08**	1.35***	1.62***
	(0.46)	(0.41)	(0.37)
SC × SRR	0.62*	0.79**	0.98***
	(0.39)	(0.36)	(0.33)
Firm Size	0.28**	0.35***	0.42***
	(0.13)	(0.11)	(0.09)
Financial Leverage	-0.06	-0.09*	-0.12**
	(0.05)	(0.05)	(0.05)
Firm Age	0.03	0.04	0.05
	(0.04)	(0.03)	(0.03)
R&D Intensity	0.15*	0.22**	0.30***
	(0.09)	(0.08)	(0.07)
Env. Policy Unc.	-0.10*	-0.14**	-0.18**
	(0.06)	(0.06)	(0.07)
Oil Price Volatility	-0.25	-0.30	-0.38
	(0.13)	(0.12)	(0.11)
Sanctions Intensity	-0.40	-0.48	-0.55
	(0.16)	(0.15)	(0.14)

Constant	3.95***	4.50***	5.20***
	(1.03)	(0.96)	(0.89)
Pseudo R^2	0.59	0.62	0.66
Observations	432	432	432

Standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.10. Bootstrapped standard errors (1000 replications).

The quantile regression confirms a U-shaped SC-FP relationship across all quantiles, with significant negative SC coefficients (Q25: -2.10, $p < 0.05$; Q50: -2.95, $p < 0.01$; Q75: -4.80, $p < 0.01$) and positive SC^2 coefficients (Q25: 1.92, $p < 0.05$; Q50: 2.60, $p < 0.01$; Q75: 3.85, $p < 0.01$). High-performing firms (Q75) exhibit a stronger U-shape (SC^2: 3.85), benefiting more from moderate SC due to greater resources, stakeholder trust, and ESG alignment. The turning point, calculated as ($\beta 1/(2\beta 2)$), occurs at higher SC levels for Q75, reflecting its capacity to sustain SC before diminishing returns set in.

Financial sector development (FSD) positively moderates the SC-FP relationship, with stronger effects at higher quantiles (Q75: 0.11, $p < 0.01$ vs. Q25: 0.05, $p > 0.10$), as high-performing firms leverage flexible capital to enhance SC benefits. ESG rating divergence (ESG-D) negatively moderates, with a larger impact at Q75 (-1.40, $p < 0.05$ vs. Q25: -0.82, $p > 0.10$), indicating greater sensitivity to information asymmetry and stakeholder skepticism in high-performing firms. Sustainability reporting requirements (SRR) amplify moderate SC's positive effect, with stronger coefficients at Q75 (0.98, $p < 0.01$ vs. Q25: 0.62, $p < 0.10$), highlighting regulatory compliance's role in building trust.

Consistent with the panel regression results, the control variables for macroeconomic instability show significant negative effects across quantiles. Oil Price Volatility and Sanctions Intensity negatively impact FP, with the most pronounced effects observed in high-performing firms (Q75: -0.38 and -0.55, respectively), suggesting that even successful firms are highly vulnerable to external shocks and trade restrictions.

Robustness checks using alternative FP measures (ROE, Tobin's Q) confirm the U-shaped relationship, with larger SC^2 coefficients at Q75 (ROE: 4.05, $p < 0.01$; Tobin's Q: 3.98, $p < 0.01$). Subsample analyses show stronger effects in petrochemicals (Q75 SC^2: 4.35, $p < 0.01$) than transportation (Q75 SC^2: 3.05, $p < 0.05$), reflecting sector-specific ESG dynamics. System GMM estimation, addressing endogeneity, yields consistent results (Q75 SC^2: 3.80, p

< 0.01).

The findings highlight the importance of modeling heterogeneity in high-risk industries, with high-performing firms leveraging SC more effectively. Future studies could use dynamic quantile regression or machine learning to explore time-varying non-linearities. High-performing firms should target moderate SC to maximize FP, leveraging resource advantages to build stakeholder trust. Policymakers should enhance FSD via green financing, particularly for transportation firms facing high ESG compliance costs. To mitigate ESG-D, firms should adopt standardized reporting, especially high-performers sensitive to skepticism. SRR compliance, supported by digital tools like blockchain for Scope 3 emissions, can enhance SC benefits. Petrochemical firms should integrate SC into their core strategies, while transportation firms should prioritize operational efficiencies to offset ESG costs, ensuring sustainable value creation in Iran's sanction-constrained context.

Grounded in organizational learning and stakeholder theories, the initial FP decline reflects knowledge acquisition costs, while the upward slope at moderate SC levels signals enhanced relational capital. The steeper Q75 curve highlights the resource advantages and stakeholder alignment of high-performing firms. Financial sector development (FSD) amplifies SC benefits, with stronger effects at Q75 (SC × FSD: 0.11, $p < 0.01$), enabling sustained SC via flexible capital. ESG rating divergence (ESG-D) exacerbates skepticism, particularly at Q75 (SC × ESG-D: -1.40, $p < 0.05$), while sustainability reporting requirements (SRR) enhance moderate SC's benefits (SC × SRR: 0.98, $p < 0.01$ at Q75) but risk exposing over-communication (Luin et al., 2025; Reppmann et al., 2025).

The chart validates quantile regression's ability to capture heterogeneity, with Q75 firms leveraging SC more effectively than Q25 firms, constrained by resources. Furthermore, the analysis highlights that external shocks significantly constrain performance across all quantiles, with Oil Price Volatility and Sanctions Intensity showing the strongest negative impact on high-performing firms (Q75), indicating that even top-tier firms are not immune to macroeconomic instability and trade barriers. Robustness is confirmed via alternative FP measures (ROE, Tobin's Q) and subsample analyses, showing stronger effects in petrochemicals (Q75 SC^2: 4.35, $p < 0.01$) than transportation (Q75 SC^2: 3.05, $p < 0.05$). High-performing firms should target moderate SC (~0.5–0.7) to maximize FP, using transparent ESG disclosures. Policymakers should bolster FSD through green financing,

particularly for transportation firms facing SRR compliance costs (e.g., CSRD). Firms must mitigate ESG-D via standardized reporting, collaborating with Iran's Environmental Protection Agency. Transportation firms should adopt digital tools (e.g., blockchain) to enhance SRR compliance, while petrochemical firms integrate SC into core strategies. Future research could use dynamic quantile plots or machine learning to model time-varying non-linearities. The chart underscores moderate SC's role in driving FP, moderated by FSD, ESG-D, and SRR, offering theoretical insights and practical strategies for sustainable value creation in Iran's high-risk industries.

Granger Causality Test Results

Granger causality tests assess the directionality between SC and FP, using a lag length of 2 based on Akaike Information Criterion (AIC).

Table 5. Granger Causality Test Results

Null Hypothesis	F-Statistic	p-value	Conclusion
SC does not Granger-cause FP	*6.95*	*0.001*	Reject (SC → FP)
FP does not Granger-cause SC	*1.38*	*0.251*	Fail to reject (FP ↛ SC)

Granger causality tests, conducted within a panel vector autoregression (VAR) framework (lag length = 2, selected via AIC), examine the directional relationship between sustainable communication (SC, measured via SC Index) and financial performance (FP, measured as ROA) for 48 firms in Iran's high-risk industries (2015–2024). Stationarity tests (Levin-Lin-Chu and Im-Pesaran-Shin; $p < 0.01$) and robust standard errors ensure reliability. The results show strong unidirectional causality from SC to FP ($F = 6.95$, $p = 0.001$), indicating that past SC values predict future FP, aligning with SC's role in enhancing stakeholder trust and operational efficiencies (Carter et al., 2017; Subhani et al., 2025). This holds in Iran's sanction-constrained context with limited ESG data.

No evidence supports FP Granger-causing SC ($F = 1.38$, $p = 0.251$), suggesting that SC is driven by strategic imperatives, such as regulatory pressures, rather than financial resources. Robustness checks with alternative lag lengths (1, 3) confirm SC → FP causality ($p < 0.05$) and no FP → SC causality ($p > 0.20$). Alternative FP measures (ROE: $F = 6.05$, $p < 0.01$; Tobin's Q: $F = 6.25$, $p < 0.01$) and subsample analyses show stronger causality in petrochemicals ($F = 7.60$, $p < 0.01$) than transportation ($F = 4.25$, $p < 0.05$).

Panel VAR with instrumental variables (lagged environmental policy uncertainty) further validates SC → FP causality ($p < 0.01$).

The unidirectional SC → FP causality supports SC as an exogenous predictor in U-shaped and S-shaped SC-FP models, validating their use in panel regressions. The absence of FP → SC causality challenges resource-based views, emphasizing SC's strategic role in high-risk industries. Future research could explore structural breaks (e.g., sanction periods) or non-linear Granger causality to capture dynamic effects.

Firms, especially in petrochemicals, should prioritize SC to enhance FP by leveraging its strong causal impact through transparent ESG disclosures. Transportation firms need support to manage ESG compliance costs. Policymakers should incentivize SC via tax benefits or green financing, particularly in Iran's constrained environment. Portfolio managers should use SC as a leading indicator in financial models, incorporating time-series approaches for lagged effects. The findings advocate strategic SC investments, targeted policies, and sector-specific strategies to maximize sustainable value creation in Iran's high-risk industries, thereby providing a robust foundation for financial economics and sustainability practices.

Robustness Checks

Robustness is ensured using alternative FP measures (ROE, Tobin's Q) and GMM estimation to address endogeneity. Results remain consistent, with significant U-shaped and S-shaped patterns ($p < 0.01$). The System GMM estimator confirms the non-linear relationships while effectively controlling for unobserved heterogeneity and simultaneity (SC^2: 2.85, $p < 0.01$). Industry-specific analyses reveal stronger SC-FP effects in petrochemicals ($\beta\_SC^2 = 3.40$, $p < 0.01$) and weaker effects in transportation ($\beta\_SC^2 = 2.05$, $p < 0.05$), reflecting sector-specific challenges in ESG compliance.

Practical Implications

The study's findings provide actionable recommendations for financial managers, policymakers, and sustainability practitioners in Iran's high-risk industries (oil and gas, petrochemicals, mining, transportation), leveraging the non-linear SC-FP relationship moderated by financial sector development (FSD), ESG rating divergence (ESG-D), and sustainability reporting requirements (SRR) to optimize sustainable communication (SC) and financial performance (FP).

Firms should target moderate SC levels to maximize FP, as excessive communication risks greenwashing perceptions and erodes trust (Chau et al., 2025; Reppmann et al., 2025). Petrochemical firms, with strong SC-FP linkages, should prioritize transparent ESG disclosures, focusing on verifiable commitments to enhance stakeholder confidence and financial returns without triggering skepticism.

Policymakers and financial institutions must strengthen FSD by expanding green financing, such as green bonds and sustainability-linked loans, to alleviate capital constraints (Subhani et al., 2025). This is critical for transportation firms facing high compliance costs under frameworks like the EU's CSRD (Luin et al., 2025). Tailored financial instruments can amplify moderate SC's positive impact on FP, enabling firms to overcome initial cost barriers and sustain long-term sustainability efforts.

To mitigate ESG-D, firms should adopt standardized ESG reporting to reduce information asymmetry and enhance stock liquidity, particularly in Iran's sanction-constrained context with limited access to international ratings (Zhang et al., 2025). Collaboration with local bodies, like the Iran Environmental Protection Agency, can align internal assessments with global standards, minimizing skepticism and bolstering investor confidence, especially for high-performing firms sensitive to ESG-D (Reppmann et al., 2025).

Transportation firms, significant contributors to greenhouse gas emissions, should leverage digital tools such as blockchain to track Scope 3 emissions and comply with SRR, thereby enhancing transparency and trust (Luin et al., 2025). Regulatory bodies must enforce consistent SRR frameworks to reduce compliance costs and ensure uniformity, amplifying moderate SCs' benefits while mitigating the risks of over-communication and exposing inconsistencies.

Sector-specific strategies are essential. Petrochemical firms should integrate SC into core operations, capitalizing on strong SC-FP effects through stakeholder engagement. Transportation firms should prioritize operational efficiencies, like low-emission technologies, to offset ESG costs. Mining and oil/gas firms can address environmental policy uncertainty through proactive SC. These tailored approaches align SC with sector-specific challenges, maximizing sustainable value creation in Iran's high-risk industries while navigating economic and regulatory constraints.

Discussion and Conclusion

This study rigorously analyzes the nonlinear dynamics between sustainable communication (SC) and financial performance (FP) in Iran's high-risk industries (2015–2024), using a multi-method econometric framework (panel, cross-sectional, and quantile regressions, and Granger causality tests) on data from 48 firms. Grounded in organizational learning (Huber, 1991), stakeholder (Freeman, 2010), and supply chain theories (Carter et al., 2017), it confirms U-shaped and S-shaped SC-FP relationships, moderated by financial sector development (FSD), ESG rating divergence (ESG-D), and sustainability reporting requirements (SRR). Moderate SC (SC Index ≈ 0.57) optimizes FP by enhancing trust and efficiencies, while excessive SC risks greenwashing perceptions (Chau et al., 2025; Reppmann et al., 2025). The S-shaped model identifies a second inflection point, reflecting long-term FP gains from sustained SC via economies of scale. FSD amplifies moderate SC's benefits, ESG-D exacerbates the negative effects of over-communication, and SRR enhances balanced SC's impact but heightens risks under scrutiny (Subhani et al., 2025; Zhang et al., 2025; Luin et al., 2025). Quantile regression shows stronger U-shapes for high-performing firms (Q75), with higher SC turning points, while Granger causality confirms SC → FP directionality ($F = 6.95$, $p = 0.001$), not FP → SC (Carter et al., 2017; Subhani et al., 2025).

Theoretically, the study enriches the sustainability literature by validating non-linear SC-FP dynamics in a sanction-constrained context and integrating supply chain perspectives. Methodologically, its multi-method approach sets a benchmark for rigor, addressing heterogeneity and causality. The double materiality perspective highlights SC's financial and societal impacts. Firms should target moderate SC (0.5–0.7) to maximize FP, with petrochemicals leveraging transparent ESG disclosures and transportation firms focusing on operational efficiencies (e.g., low-emission technologies). Policymakers should enhance FSD through green financing to support SC, particularly for transportation's CSRD compliance costs (Luin et al., 2025). Standardized ESG reporting, aligned with global standards through local bodies such as Iran's Environmental Protection Agency, mitigates ESG-D (Zhang et al., 2025). Digital tools (e.g., blockchain) can ensure SRR compliance and enhance transparency.

While this study provides robust insights into the nonlinear dynamics of sustainable communication in Iran's high-risk industries, the findings must be interpreted with caution regarding their generalizability to other markets. The

unique context of Iran—characterized by severe economic sanctions, limited access to international ESG rating agencies, and specific regulatory frameworks—creates a distinct environment for financial and sustainability reporting. Consequently, the observed U- and S-shaped relationships, particularly the moderating roles of financial sector development and ESG rating divergence, may be more pronounced in this setting than in developed markets with established financial systems and transparent data infrastructures. Future research should test the proposed model in different institutional contexts, such as emerging economies without sanctions or developed capital markets, to validate the external validity of these findings and determine if the optimal SC threshold (~0.57) is universally applicable or context-specific.

Limitations and Future Research

Despite its rigorous multi-method approach, this study is subject to several limitations that must be acknowledged. First, the construction of the Sustainable Communication (SC) Index relies heavily on content analysis of corporate reports and disclosures. While this provides verifiable data, it may not fully capture the qualitative nuances of stakeholder engagement or the perceived sincerity of communication, potentially introducing measurement subjectivity. Second, the sample is restricted to 48 firms operating in Iran's high-risk industries, a context characterized by unique economic sanctions and specific regulatory frameworks. Consequently, the generalizability of the findings to developed markets with different institutional settings or to industries with lower risk profiles may be limited. Third, the analysis faces data constraints, particularly regarding ESG ratings. Due to international sanctions, the study relies on internal assessments and limited external data, which may not fully reflect the global ESG divergence experienced by firms integrated into international capital markets. Finally, while the study controls for key macroeconomic factors, unobserved time-varying shocks specific to the Iranian economy could influence the results. Future research should address these limitations by incorporating more granular, perception-based measures of SC, expanding the comparative analysis to other emerging and developed economies, and using dynamic panel models or machine learning techniques to capture better the complex, time-varying, nonlinearities of the SC-FP relationship.

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