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The Threshold Effects of External Debt on Sustainable Economic Growth Considering Heterogeneity in Regulatory Quality and Government Institutional Quality

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ABSTRACT

The present study examines the threshold effects of external debt on sustainable economic growth while taking into account the heterogeneity in regulatory quality and government institutional quality. Using a Panel Smooth Transition Regression (PSTR) model in which external debt is considered the transition variable, the sustainable development function is modeled. Following confirmation of the nonlinear model, the results of the nonlinear section are analyzed. According to the estimated nonlinear model, the coefficient of external debt (ED) is 0.49, indicating a negative effect of external debt on sustainable development in the selected countries. Given the corresponding probability value of this coefficient (0.0069), which is less than 0.05, this effect is statistically significant at the 95% confidence level. Furthermore, the coefficients and computed probability values for institutional quality, regulatory quality, and rule of law are 0.016, 0.089, and 0.235, with corresponding probability values of 0.0355, 0.0015, and 0.0053, respectively. These results indicate that the effects of regulatory quality, institutional quality, and the rule of law on improving sustainable development are positive and statistically significant.

Keywords: External debt, sustainable economic growth, regulatory quality, government institutional quality, threshold model

Introduction

The cost of capital is a central determinant of banks' strategic choices, pricing of financial products, and long-term resilience in increasingly volatile financial environments. In banking, the weighted average cost of capital reflects not only the price of external funding but also the market's assessment of a bank's risk profile, governance quality, and information environment (1). A lower cost of capital allows banks to expand credit, invest in new technologies, and absorb shocks more effectively, whereas an elevated cost of capital restricts balance sheet flexibility and may amplify the transmission of financial distress across the system (2). Consequently, understanding how various dimensions of banking risk and risk management practices feed into the cost of capital has become a critical issue for regulators, investors, and bank managers.

The risk landscape facing banks has become more complex in recent years due to financial innovation, regulatory reforms, and heightened macroeconomic and geopolitical uncertainty. Banks are exposed simultaneously to credit,

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market, liquidity, interest rate, operational, and macroeconomic risks, and the interaction among these risks may be nonlinear and state-dependent rather than constant over time (3). Studies on bank risk management emphasize that traditional linear models may fail to capture abrupt changes in risk–return trade-offs once certain thresholds in risk indicators are crossed, leading to regime shifts in performance and funding conditions (4, 5). These dynamics are especially salient in emerging and bank-based financial systems, where capital markets are less deep and banks play a dominant role in financial intermediation (6, 7).

A growing body of research has explored the link between risk management and bank performance, often highlighting risk governance structures, capital ratios, and risk culture as key channels. Evidence from the MENA region suggests that robust risk management frameworks are positively associated with bank profitability and risk-adjusted performance (5). Similar conclusions are reported for commercial banks in Vietnam, where different types of financial risks exert heterogeneous effects on performance indicators, implying that risk management must be tailored to the specific risk structure of each institution (4). At the micro level, studies on micro, small and medium-sized enterprises also confirm that formal risk management practices are linked to better performance outcomes, underscoring the universal relevance of risk governance across organizational forms (8). In the banking context, the quality and sophistication of risk management practices influence not only earnings but also external perceptions of risk, thereby affecting funding costs and required returns.

Capital adequacy and solvency indicators constitute another important dimension in the nexus between banking risks and the cost of capital. Empirical research on banks listed in the Iranian capital market shows that risk management and capital adequacy are jointly related to financial distress, suggesting that capital buffers and effective risk controls act as complementary cushions against shocks (6). Similarly, work on the relationship between capital ratios, credit risk, and profitability in Tehran Stock Exchange banks indicates that both capital structure and asset quality condition the sustainability of returns (7). From an international perspective, bank interconnectedness and capital strength have been shown to be crucial for financial stability, as higher capital ratios can mitigate contagion risk in interconnected banking systems (2). In parallel, shadow banking activities can amplify bank risk and weaken capital adequacy if not properly monitored and capitalized, thus indirectly influencing the cost of capital through heightened risk perceptions (9).

Risk culture and disclosure quality play a further role in shaping investors’ required returns. Recent evidence from European banks demonstrates that a stronger risk culture is associated with a lower cost of capital, as investors reward institutions that credibly embed risk awareness, accountability, and transparency into their decision-making processes (1). For listed banks in Iraq, higher financial reporting quality is likewise associated with a lower cost of capital, indicating that timely and reliable information reduces uncertainty premia and improves market discipline (10). Regulatory initiatives aimed at enhancing the quality and comparability of non-financial and corporate social responsibility reporting have also been shown to improve reporting quality, which can ultimately affect stakeholders’ assessments of firms’ risk and capital needs (11). In the Iranian banking sector, comprehensive models of risk management and cost reduction have been proposed, highlighting the role of structured frameworks and reliable information systems in lowering operating risk and funding costs (12).

The risk environment of banks has been further reshaped by exogenous shocks, such as geopolitical conflicts and global uncertainty. The Russia–Ukraine war, for example, had measurable impacts on global stock market returns, underscoring how geopolitical risk propagates across financial markets and affects the pricing of risk (13). Measures of market attention and uncertainty, including Google search trends and related sentiment indicators, have also been linked to stock market dynamics, indicating that investor attention and perceived uncertainty can move asset prices independently of fundamentals (14). These developments suggest that banks' cost of capital may respond not only to internal risk metrics but also to global risk sentiment and macro-financial shocks, especially in open economies that are increasingly integrated into international capital markets (15).

At the same time, the rapid expansion of cryptocurrency markets, digital assets, and decentralized finance has introduced new sources of risk and competition for the traditional banking sector. Research on global spillovers between cryptocurrencies and financial markets documents significant bidirectional linkages, implying that crypto shocks can transmit to conventional financial assets and vice versa (15). Studies on cryptocurrency volatility synthesize a broad set of risk determinants and identify high and persistent volatility as a structural feature of these markets (16). Work on cryptomarket discounts and liquidity provision further shows that pricing anomalies and liquidity risk are systematically priced in crypto assets, offering both opportunities and risks for intermediaries engaging in these markets (17, 18). Moreover, the capitalization of cryptocurrencies has been found to influence banking deposits in some jurisdictions, hinting at a potential substitution or diversification effect between traditional bank intermediation and decentralized finance channels (19). For banks, these developments can alter funding structures, competitive pressures, and perceived risk, thereby feeding into the cost of capital.

Digital transformation and FinTech adoption add another layer of complexity to bank risk management and capital costs. The emergence of digital banking channels, open-banking platforms, and data-driven credit assessment creates both new opportunities for efficiency and new operational, cyber, and model risks (20). Modern approaches and tools in bank risk management increasingly emphasize advanced analytics, stress testing, and scenario analysis to capture these evolving risks (21, 22). In the Iranian context, stress testing has been used to assess the sensitivity of bank returns and risks to macro-financial shocks, providing a structured framework for evaluating resilience under adverse scenarios (23). Studies on digital banking risk management highlight challenges related to technology infrastructure, regulatory frameworks, and human capital, which can influence both risk outcomes and the cost of implementing robust controls (20). At the same time, FinTech innovation can enhance customer reach and operational efficiency, potentially lowering the marginal cost of funding if risks are properly mitigated (24).

Within banks, governance structures and internal committees are central to operationalizing risk management. Evidence from banks listed on the Tehran Stock Exchange shows that the establishment and effectiveness of specialized risk committees help to identify, measure, and monitor risk exposures more systematically, contributing to more accurate risk pricing and more resilient balance sheets (25). Board characteristics and oversight have also been found to influence financial performance and capital outcomes through the mediating role of risk management, underscoring the importance of governance quality as an indirect determinant of the cost of capital (26). Studies in the Iranian banking system highlight that risk management practices can mediate the relationship between risk exposures and financial performance, suggesting that similar mediation mechanisms may exist between risk exposures and the cost of capital (5, 27). Additionally, risk management has been explicitly linked to reducing the severity and propagation of financial crises in banks, which in turn should be reflected in lower risk premia and funding costs (28).

From a risk taxonomy perspective, the banking literature stresses the need to consider the full spectrum of major risks—credit, liquidity, market, interest rate, operational, and macro-price level risks—and to understand their interactions (3). In Iran, recent research has used smooth transition regression models to identify the components influencing liquidity risk in listed banks, providing direct evidence that risk behavior may change across regimes defined by key risk indicators (24). Similarly, studies on banks' exposure to specialized risk committees and risk management frameworks show that risk profiles are multidimensional and sensitive to both internal policies and external shocks (25). Domestic work on risk management methods in banking accounting further highlights the need to integrate risk metrics into accounting and reporting systems so that internal and external stakeholders can assess risk-adjusted performance more accurately (22). These findings collectively support the view that the relationship between risk indicators and bank outcomes, including cost of capital, may be nonlinear and contingent on underlying risk regimes.

Despite these advances, several gaps remain in the literature, particularly in relation to emerging markets and bank-based financial systems. First, while many studies investigate the impact of risk management on profitability or financial stability, fewer explicitly focus on the cost of capital as the main outcome, especially using comprehensive sets of banking risk indicators that encompass credit, market, liquidity, interest rate, operational, and macro-price risks (4, 5, 8). Second, most empirical works adopt linear specifications that may not capture threshold effects or regime-dependent sensitivities, even though theoretical and empirical arguments point to the possibility of sharp changes in the risk–cost of capital relationship beyond certain critical values of risk indicators (13, 24). Third, relatively little attention has been paid to integrating FinTech intensity, competitiveness conditions, and disclosure quality into a unified framework for explaining variations in banks' cost of capital, particularly in the context of banks listed on the Tehran Stock Exchange (10, 12, 20). Finally, in the Iranian setting, although several studies have examined risk management, capital ratios, and performance separately, there is still a need for models that jointly incorporate risk indicators, risk management practices, governance-related variables, and market structure features in explaining the cost of capital (6, 7, 21, 28).

Against this background, the present study focuses on banks listed on the Tehran Stock Exchange and examines how multiple dimensions of banking risk—credit, market, liquidity, interest rate, operational, and general price level risks—together with competitiveness, financial stability, capital adequacy, disclosure, and FinTech activity, jointly shape the cost of capital through potentially nonlinear and threshold-dependent mechanisms using a panel smooth transition regression framework (1, 5, 12, 23, 24). Therefore, the aim of this study is to investigate the threshold effects of banking risk management indicators on the cost of capital in banks listed on the Tehran Stock Exchange, with a particular emphasis on the role of competitiveness, financial stability, capital adequacy, disclosure quality, and FinTech intensity in a nonlinear panel setting.

Methods and Materials

In this study, the threshold effects of banking risks on the cost of capital in banks listed on the Tehran Stock Exchange, with an emphasis on the competitiveness index, are examined during the period **2018 to 2024** using the **Panel Smooth Transition Regression (PSTR)** approach. The statistical sample includes Bank Eghtesad Novin, Bank Parsian, Bank Pasargad, Bank Karafarin, Bank Saman, Bank Sarmayeh, Bank Day, Bank Saderat, Bank Mellat, Bank Tejarat, and Bank Iran Zamin. The study is applied in purpose and descriptive-analytical in nature. The regression model is presented as follows:

$$\text{WACC}_{i,t} = \alpha_0 + \beta_1(\text{Operational Risk}_{i,t}) + \beta_2(\text{Credit Risk}_{i,t}) + \beta_3(\text{Market Risk}_{i,t}) + \beta_4(\text{Interest Rate Risk}_{i,t}) + \beta_5(\text{Liquidity Risk}_{i,t}) + \beta_6(\text{Price-Level Risk}_{i,t}) + \beta_7(\text{Performance}_{i,t}) + \beta_8(\text{Competition}_{i,t}) + \beta_9(\text{FinTech}_{i,t}) + \beta_{10}(\text{Size}_{i,t}) + \beta_{11}(\text{Z}_{i,t}) + \beta_{12}(\text{DSFI}_{i,t}) + \beta_{13}(\text{CAR}_{i,t}) + (\theta_1\ \text{Operational Risk}_{i,t} + \theta_2\ \text{Credit Risk}_{i,t} + \theta_3\ \text{Market Risk}_{i,t} + \theta_4\ \text{Interest}$$

$$\text{Rate Risk}_{i,t} + \theta_5 \text{ Liquidity Risk}_{i,t} + \theta_6 \text{ Price-Level Risk}_{i,t} + \theta_7 \text{ Performance}_{i,t} + \theta_8 \text{ Competition}_{i,t} + \theta_9 \text{ FinTech}_{i,t} + \theta_{10} \text{ Size}_{i,t} + \theta_{11} Z_{i,t} + \theta_{12} \text{ DSFI}_{i,t} + \theta_{13} \text{ CAR}_{i,t}) \times F(S_t, \gamma, c) + u_{i,t}$$

The transition function is defined as:

$$F(\gamma, S_t, c) = 1 / (1 + e^{(-\gamma(S_t - c))})$$

To examine the PSTR model with a logistic transition function based on van Dijk (1999), the dependent variable is assumed to depend only on its lagged values. Assuming a two-regime transition function, the model is written as:

$$wacc_t = (\theta_0 + \theta_1 wacc_{t-1} + \ldots + \theta_p wacc_{t-p}) + (\varphi_0 + \varphi_1 wacc_{t-1} + \ldots + \varphi_p wacc_{t-p}) \times G(wacc_t, \gamma, c) + u_t$$

Where:

$$G(wacc_t, \gamma, c) = 1 / (1 + \exp(-\gamma(wacc_t - c)))$$

This results in a two-regime PSTR model, where the location parameter c identifies the transition point between the two regimes G = 0 and G = 1, with the midpoint at:

$$G(wacc_t, \gamma, c) = 0.5$$

The parameter **γ** represents the speed of transition; higher γ indicates a faster shift between regimes.

In this model, **i** denotes the bank and **t** denotes the year.

WACC refers to the Weighted Average Cost of Capital.

The cost of capital is measured using the Capital Asset Pricing Model (CAPM). The widely used formula for the Weighted Average Cost of Capital is:

$$WACC = (E/V) \times R_e + (D/V) \times R_d \times (1 - T_c)$$

Where: **E** = equity, **D** = debt, **V = E + D**, **R_e** = expected return on equity, **R_d** = expected return on debt, **T_c** = tax rate.

Explanatory Variables

Credit Risk Index:

Lending is the core activity of most banks and requires evaluating the borrower's repayment ability. These predictions may be inaccurate, and borrower creditworthiness may deteriorate over time, making credit risk one of the major risks banks face.

Market Risk Index:

Market risk originates from losses caused by fluctuations in the prices of balance-sheet and off-balance-sheet items. Currency risk constitutes a specific part of market risk. During periods of currency instability, foreign-exchange-related risks rise significantly.

Interest Rate Risk Index:

Interest rate risk concerns assets and liabilities whose values move inversely with interest rate changes. It affects a bank's profitability and the economic value of assets, liabilities, and off-balance-sheet exposures.

Liquidity Risk Index:

Liquidity risk results from a bank's inability to reduce liabilities or obtain funds to expand assets. Insufficient liquidity undermines profitability and may result in bankruptcy under severe conditions.

Operational Risk Index:

Operational risk includes deficiencies in internal controls, corporate governance, system failures, human errors, fraud, and major technological or natural disruptions.

Risk of Changes in the General Price Level:

Inflation increases the general price level and affects the cost of market inputs, influencing bank performance. It is also known as purchasing-power risk because rising prices reduce the real value of financial assets.

Performance (Bank Performance Index):

Measured using the Return on Assets:

$$ROA = \text{Net Income After Tax} / \text{Total Assets}$$

Competition (Bank Competition Index):

Bank competition affects efficiency. The Herfindahl–Hirschman Index (HHI) is used:

$$HHI_{i,t} = (\text{Deposits of Bank i in year t} / \text{Total Deposits of Listed Banks in year t})^2$$

FinTech Index

FinTech includes mobile-based payments and online banking services. In this study, the FinTech index includes:

- **NBT:** Value of non-cash kiosk terminal transactions
- **MOBIL:** Value of mobile banking transactions
- **INT:** Value of internet banking transactions

The index is computed using Principal Component Analysis (PCA).

Bank Size:

$$Size = Log(\text{Total Assets})$$

Capital Adequacy Ratio (CAR):

$$CAR = (\text{Tier 1 Capital} + \text{Tier 2 Capital}) / \text{Risk-Weighted Assets}$$

Financial Stability Index (Z-Score):

$$Z = (k + \mu) / \delta$$

Where k is the equity-to-total-assets ratio, μ is the return on assets, and δ is the standard deviation of asset returns.

DSFI: Disclosure of Strategic Financial Information

This variable is measured using a checklist developed from Iranian Accounting Standards and the Tehran Stock Exchange Disclosure Directive (approved July 25, 2007). The checklist includes general company information, financial statements, board reports, and other relevant disclosures. Each bank's disclosure level is measured by matching checklist items with information disclosed in annual reports.

Findings and Results

First, the reliability (stationarity) of the research variables is examined.

Table 1. Results of the unit root test for the variables

Variable	Test statistic	p-value	Order of integration
Capital adequacy index	-9.18582	0.0000	I(0)
Competitiveness index	-3.17002	0.0008	I(0)
Information transparency index	-3.75467	0.0001	I(0)
FinTech index	-16.5196	0.0000	I(0)
Credit risk index	-2.44083	0.0073	I(0)
Interest rate risk index	-4.03011	0.0000	I(0)
Liquidity risk index	-2.10969	0.0174	I(0)
Market risk index	-2.13257	0.0165	I(0)
Operational risk index	-3.79828	0.0001	I(0)
General price level risk index	-5.38482	0.0000	I(0)
Banking performance index	-2.86575	0.0021	I(0)
Bank size	-6.93978	0.0000	I(0)

Financial stability index	-12.3861	0.0000	I(0)
Cost of capital index	-3.59626	0.0002	I(0)

The results of Table 1 and the examination of the calculated statistics and their associated probabilities show that all research variables are stationary at level.

Most economic theories express the long-run relationship between variables in level form. To ensure the existence of a long-run relationship among the variables in the model, these variables must be stationary or, if non-stationary, must share the same order of integration. Therefore, to detect the presence of a long-run relationship among the variables, their stationarity or cointegration must be examined using various tests. Accordingly, if the residuals obtained from the estimated regressions are I(0) or stationary, we can be confident about the existence of a long-run relationship among the variables. In the present study, to ensure the existence of a long-run equilibrium relationship, the Kao panel cointegration test is used.

Table 2. Results of the Kao cointegration test

Kao test	Test statistic	p-value
ADF	-2.942923	0.0016

Given that the significance level is less than 0.05, the null hypothesis of no cointegrating relationship among the variables is rejected, and the variables are cointegrated in the long run and exhibit a long-run relationship.

The results of the Limer test are presented in the table below.

Table 3. Results of the model selection test for the return on assets model

Type of test	Test statistic	Degrees of freedom	p-value
Limer test	4.670363	(10, 53)	0.0075
Panel data	29.170766	10	0.0052

According to the above table and the fact that the p-value is less than 0.05, the null hypothesis that the model should be estimated using pooled data is rejected, and the research model is selected as a panel data model.

To examine the existence of a linear or nonlinear relationship between the model variables, it must be checked whether m (the number of regime parameters) is equal to one or not. It should be noted that in the following tests, the null hypothesis assumes a linear model, and the alternative hypothesis assumes a logistic PSTR model ($m = 1$) or an exponential PSTR model ($m = 2$). The results of the diagnostic test in Table 4 show that the linearity of the model (null hypothesis) is rejected; therefore, there is a nonlinear relationship between the banking risk indices and the cost of capital of the banks under study, and consequently, to estimate the model parameters, the PSTR method must be used.

Table 4. Results of the linearity hypothesis test (BBC test)

Null hypothesis	F-statistic	p-value
Wald test	3.785	0.000
Fisher test	2.638	0.001
LRT test	2.957	0.012

As is evident from the test results in Table 4, the hypothesis of linearity of the relationship between the variables is rejected; therefore, the possibility of a linear relationship between the variables is ruled out. It should also be noted that the proposed PSTR model with the market risk index as the transition variable is selected as the optimal model for estimating the cost of capital in listed banks. For this purpose, following González et al. (2005) and

Colletaz and Hurlin (2006), the null hypothesis of a PSTR model with one transition function is tested against the alternative of a PSTR model with at least two transition functions, and the results are reported in Table 5. The findings show that the null hypothesis of sufficiency of one transition function is not rejected in both the single-threshold and double-threshold cases; therefore, a single transition function is sufficient to characterize the effect of banking risk management and the other explanatory variables on the cost of capital in banks listed on the Tehran Stock Exchange.

Table 5. Test of the existence of a nonlinear relationship in the residuals

	LMw (M = 1, one threshold)	LMf (M = 1, one threshold)	LR (M = 1, one threshold)	LMw (M = 2, two thresholds)	LMf (M = 2, two thresholds)	LR (M = 2, two thresholds)
Value	1.352 (0.743)	1.471 (0.630)	1.432 (0.654)	1.425 (0.675)	1.362 (0.751)	1.297 (0.802)

H_0: r = 1, H_1: r = 2

With confirmation of the existence of a nonlinear relationship among the variables and the sufficiency of a single transition function to characterize nonlinear behavior, it is then necessary to select the optimal case between a model with one or two threshold values. For this purpose, the PSTR model corresponding to each case is estimated, and the optimal model is selected based on the criteria of the sum of squared residuals, Schwarz, and Akaike. The PSTR model with one threshold is identified as the optimal model; thus, a PSTR model with one transition function and one threshold is selected to examine the nonlinear relationship among the variables under study.

Using a PSTR model in which the transition variable is market risk, the cost of capital function in banks listed on the Tehran Stock Exchange is modeled. Given confirmation of the nonlinear model, the results of the nonlinear part of the model are analyzed in the following.

According to the estimation results in the nonlinear part, the coefficients of operational risk, credit risk, market risk, interest rate risk, liquidity risk, and general price level risk are 0.110132, 0.237879, 0.559445, 0.491977, 0.438141, and 0.423817, respectively, indicating a direct effect of these variables on the cost of capital in listed banks. The corresponding p-values are 0.0491, 0.0001, 0.0042, 0.0398, 0.0265, and 0.0331, respectively, which shows that these variables have a statistically significant impact on the cost of capital in the selected banks at the 95% confidence level. In addition, the coefficients of the competitiveness index, banking performance, FinTech index, bank size, financial stability, and capital adequacy on the cost of capital in listed banks are negative and statistically significant at the 5% error level.

Table 6. Estimation of the model using the PSTR approach

Variable	Coefficient	Standard error	t-statistic	p-value
Estimation of the linear part of the model				
Constant	0.329059	0.136048	2.418698	0.0234
Index Operational risk	0.158886	0.075984	2.091051	0.0419
Index Credit risk	0.582868	0.239013	2.438644	0.0149
Index Market risk	0.096233	0.026454	3.637702	0.0003
Index Interest rate risk	0.496421	0.175702	2.825358	0.0069
Index Liquidity risk	0.212527	0.090308	2.353357	0.0356
Index Risk of changes in the general level of prices	0.393667	0.142781	2.757139	0.0201
Performance	-0.089278	0.027937	-3.195642	0.0015
Competition	-0.097980	0.028983	-3.380603	0.0008
FinTech	-0.521556	0.300193	-1.737401	0.0823
Size	-0.204690	0.089165	-2.295631	0.0300
Z (financial stability index)	-0.016559	0.007091	-2.335214	0.0355
DSFI (disclosure index)	0.289564	0.208206	1.390754	0.1664
CAR (capital adequacy ratio)	-0.035862	0.014372	-2.495362	0.0129

Estimation of the nonlinear part of the model				
Constant	0.408455	0.097877	4.173135	0.0001
Index Operational risk	0.110132	0.055542	1.982849	0.0491
Index Credit risk	0.237879	0.061631	3.859691	0.0001
Index Market risk	0.559445	0.187604	2.982058	0.0042
Index Interest rate risk	0.491977	0.233624	2.105846	0.0398
Index Liquidity risk	0.438141	0.191908	2.283082	0.0265
Index Risk of changes in the general level of prices	0.423817	0.183618	2.308149	0.0331
Performance	-0.012901	0.004822	-2.675502	0.0077
Competition	-0.164212	0.061974	-2.649681	0.0092
FinTech	-0.014838	0.006607	-2.245690	0.0378
Size	-0.120704	0.060604	-1.991677	0.0487
Z (financial stability index)	-0.071610	0.029185	-2.453674	0.0147
DSFI (disclosure index)	-0.104390	0.041223	-2.532328	0.0121
CAR (capital adequacy ratio)	-0.053752	0.022425	-2.396934	0.0165
Threshold value (C)	0.217254	0.095784	2.268165	0.0272
Slope parameter (γ)	0.735776	0.215697	3.411155	0.0007

Adjusted $R^2 = 0.85$

The comparison of coefficients in the two different regimes is based on the transition variable and its values, and the value of the transition variable can determine the transition function and, consequently, the prevailing regime. In the above estimation, the transition variable is the market risk index, for which the estimated threshold value for listed banks is 0.21. Based on the deviation of the market risk index from this threshold, the model follows two different limiting regimes. Comparing the coefficients of the model in the two regimes shows that when the market risk index crosses the threshold value (0.21) (transition from the linear to the nonlinear regime), the response of the cost of capital to changes in this variable increases sharply; that is, as the market risk index rises, the cost of capital reacts more strongly to it.

In the present study, the Durbin–Watson test is used to examine autocorrelation.

Table 7. Results of the autocorrelation test

F-statistic	p-value	Durbin–Watson
1.235	0.69	2.036

As shown in the above table, the results of the Durbin–Watson autocorrelation test indicate that there is no correlation among the disturbance terms; therefore, the third classical standard assumption of no autocorrelation among the error terms is not violated, and the estimators possess the required properties (minimum variance and efficiency). Another classical standard assumption is homoscedasticity. In the present study, the Breusch–Pagan–Godfrey test is used.

Table 8. Results of the heteroscedasticity test

F-statistic	p-value	Breusch–Pagan–Godfrey
1.298	0.556	1.327

As can be seen in the table, the results indicate the absence of heteroscedasticity.

Test of coefficient stability between the two regimes:

Another useful measure for evaluating the quality of the estimated model is to examine the stability of coefficients between the two regimes. If the estimated model is appropriate, it is expected that the coefficients remain stable and unchanged when the regime changes.

Table 9. Results of the smooth transition parameter stability test

Null hypothesis	F-statistic	p-value
$b_1 = b_2 = b_3 = b_4 = 0$	0.745	0.754
$b_1 = b_2 = b_3 = 0$	0.798	0.712
$b_1 = b_2 = 0$	0.821	0.695
$b_1 = 0$	0.836	0.674

As is also evident from the table, the test of coefficient stability between the two regimes shows that the coefficients do not change as a result of regime shifts.

Discussion and Conclusion

The results of the present study provide a nuanced understanding of how multiple categories of banking risks—credit, market, liquidity, interest rate, operational, and general price level risks—along with structural and institutional characteristics such as competitiveness, financial stability, disclosure quality, capital adequacy, bank size, and FinTech activity, jointly influence the cost of capital in banks listed on the Tehran Stock Exchange through nonlinear and threshold-dependent mechanisms. The significance of nonlinear behavior in the cost of capital confirms that banking risks do not exert uniform effects across all levels of exposure; rather, their marginal influence intensifies when the market risk index surpasses a critical threshold value. This finding is consistent with theoretical arguments and empirical evidence suggesting that bank risk dynamics often undergo regime shifts once particular vulnerabilities cross critical levels, reflecting heightened investor sensitivity, intensified risk perceptions, and increased uncertainty premia (3-5). The identified threshold at approximately 0.21 in the market risk index demonstrates that beyond this point, banks experience a disproportionately higher increase in the cost of capital in response to incremental increases in risk exposure, reaffirming the importance of dynamic risk monitoring frameworks.

The finding that operational, credit, market, interest rate, liquidity, and general price-level risks all exert significant positive effects on the cost of capital aligns with a substantial body of literature asserting that riskier banks face higher required returns from investors due to elevated perceptions of default probability and earnings volatility. The positive and significant influence of credit risk is consistent with evidence that asset quality deterioration and rising non-performing loans increase risk premiums and reduce funding flexibility (6, 7). Moreover, studies conducted in various banking systems indicate that heightened credit risk translates into higher capital costs, as investors price in an additional margin for potential credit losses, particularly in emerging markets where risk transparency may be limited (5). The significant effect of operational risk is similarly compatible with research showing that deficiencies in internal controls, governance weaknesses, and operational disruptions contribute to higher risk pricing because they undermine confidence in the bank's ability to manage routine operations (8). Operational failures often lead to reputational damage and regulatory scrutiny, both of which are capital-intensive and thus directly influence the cost of capital.

The strong positive effect of market risk beyond the identified threshold corroborates evidence from international markets emphasizing the sensitiveness of funding conditions to macro-financial volatility. Market risk becomes particularly impactful during periods of elevated uncertainty, when asset price fluctuations may induce sudden changes in risk perception and investor behavior. This finding aligns with research on global spillovers between cryptocurrency markets and traditional financial markets, which shows that market-wide volatility can transmit quickly across asset classes, raising the cost of financing for institutions exposed to such fluctuations (15). Relatedly, studies examining Google search trends as indicators of investor sentiment suggest that rising uncertainty amplifies reactions in financial markets, consistent with the intensified cost of capital observed beyond the risk threshold (14). These results collectively indicate that banks must adopt robust market risk management practices, as increases in market volatility can significantly tighten funding conditions.

The significant positive effect of interest rate risk on the cost of capital is consistent with findings that mismatches in asset–liability durations expose banks to income volatility and capital erosion when interest rates fluctuate unexpectedly (2). As global financial systems confront new cycles of monetary tightening, interest rate risk magnifies uncertainty in net interest income, leading investors to demand higher compensation. Likewise, the significant positive effect of liquidity risk is consistent with the literature showing that banks with lower liquidity buffers must bear higher borrowing costs due to increased rollover risk and concerns about their ability to meet short-term obligations (4). Liquidity constraints reduce the availability of stable internal funding and force banks to rely on expensive external sources, thereby driving up their cost of capital.

The positive influence of the general price-level risk corresponds to macroeconomic arguments linking inflation volatility to increased financial instability. Higher inflation leads to higher uncertainty about purchasing power and future profitability, reducing investor confidence and increasing required returns on capital-intensive assets. The literature points to the fact that price-level uncertainty affects both real and financial sectors, increasing the costs of hedging, regulatory compliance, and risk evaluation for banks (3). Inflationary conditions also heighten credit risk by impairing borrowers' real repayment capacity, further increasing risk premia.

In contrast to risk variables with positive impacts, the negative and significant effects of competitiveness, banking performance, bank size, FinTech intensity, financial stability, and capital adequacy on the cost of capital provide strong support for the view that structural strength and effective governance reduce external financing costs. The negative coefficient on competitiveness aligns with analytical findings that competitive pressure incentivizes operational efficiency, risk discipline, and innovation in banking services, which improve market perceptions and lower financing costs (24, 28). A more competitive banking environment encourages transparency, better pricing of services, and enhanced financial reporting, all of which reduce information asymmetry and risk premia (11). Moreover, strong competitive environments increase monitoring by market participants, enhancing investor confidence and thereby lowering the cost of capital.

The negative effect of performance (as measured by return on assets) on the cost of capital is consistent with prior studies showing that profitable banks are perceived as safer and more resilient, reducing investor-required returns (5, 8). Higher profitability improves internal capital generation, reduces dependence on external financing, and signals the bank’s capacity to withstand shocks. Similar evidence from global and regional banking systems suggests that profitability acts as a buffer against risk, making banks more creditworthy and thereby reducing their cost of capital (4).

The negative influence of FinTech intensity on the cost of capital reflects ongoing technological transformation in banking. Greater FinTech adoption enhances service efficiency, expands customer access, and reduces operational frictions, thereby strengthening risk management capabilities (20). Furthermore, digitalization improves transaction transparency and reduces fraud risk, increasing investor confidence and decreasing risk premiums. Research shows that FinTech innovations contribute to lower information asymmetry and more efficient capital allocation, which collectively reduce financing costs for technology-enabled banks (16). Additionally, FinTech supports better customer analytics and credit risk assessment, reducing default risk and enhancing capital adequacy.

The finding that financial stability (measured via the Z-score) negatively affects the cost of capital confirms the role of solvency strength in lowering risk premiums. High financial stability signals the bank's resilience to shocks, reducing uncertainty and allowing it to access capital at more favorable rates. Evidence from the literature shows that financial stability reduces the likelihood of systemic spillovers and enhances credibility among investors and regulators (2). Similarly, the negative effect of capital adequacy corroborates research emphasizing that well-capitalized banks are more capable of absorbing losses, reducing default probabilities, and improving creditworthiness (6, 9). Strong capital buffers reassure market participants that the bank can meet regulatory requirements even under stress, thereby reducing required returns on equity and debt.

Overall, the combination of significant positive coefficients for risk indicators and significant negative coefficients for structural and governance indicators highlights the delicate balance banks must manage between risk-taking and financial stability. The nonlinear behavior confirmed by the PSTR model underscores the importance of monitoring risk dynamics beyond critical thresholds, as marginal increases in risk can have amplified effects on the cost of capital once nonlinearities are triggered. This finding is consistent with evidence documenting threshold-dependent effects in liquidity risk (24) and broader market conditions shaping financial constraints (13, 15). The results also align with the literature emphasizing the mediating role of risk management in linking risk exposure to performance outcomes (5, 27), and demonstrate that these mediating dynamics likely extend to the relationship between risk and cost of capital.

The results also highlight the integration of digital innovation, disclosure quality, and competitive structure into a more comprehensive framework for understanding banks' cost of capital. Evidence on the role of reporting quality in lowering the cost of capital (10, 11) supports the finding that DSFI contributes to improved risk perception and reduced financing costs, even though its direct effect was not significant in all model specifications. Likewise, studies linking disclosure reforms to enhanced transparency and investor assurance point to the importance of information environments in shaping funding costs (11). Thus, the findings emphasize that banking risks cannot be analyzed in isolation from institutional and market structures.

The present findings also have implications for understanding the interactions between cryptocurrency markets and banking risks. Research documenting spillovers between crypto assets and financial markets (15), cryptomarket volatility (16), and pricing anomalies in liquidity provision (18) suggests that banks may face additional external sources of market instability. These externalities can intensify the effects of market risk on the cost of capital, particularly beyond threshold values. While the present study did not explicitly model cryptocurrency exposures, the significant nonlinear response to market risk indicates that banks may be vulnerable to such spillovers in environments where crypto-financial integration is growing.

In summary, the results demonstrate that banking risks exert heterogeneous and nonlinear effects on the cost of capital in listed banks, shaped by the interaction between internal risk exposure, governance structures, technological sophistication, competitive environments, and macro-financial conditions. The findings reinforce the need for banks to maintain robust risk management frameworks, strengthen capital buffers, enhance transparency, and invest in technological and operational capabilities to mitigate risk premia and improve funding conditions. Moreover, the nonlinear nature of the results suggests that small improvements in risk management may have disproportionately large benefits when implemented before risk indicators cross critical thresholds.

The study has several limitations. First, the analysis focuses exclusively on banks listed on the Tehran Stock Exchange, which limits the generalizability of the results to non-listed banks or other segments of the Iranian financial system. Second, the study relies on aggregate indices for various risk categories, which may not fully capture granular or institution-specific risk exposures such as portfolio composition, off-balance-sheet items, or operational risk subcomponents. Third, the study period includes years of significant economic turbulence, including sanctions and inflationary pressures, which may introduce country-specific shocks not fully separable from structural banking risks. Fourth, the use of the PSTR model, while well-suited for detecting nonlinearities, requires relatively large panel dimensions, and smaller sample sizes may affect the stability of threshold estimates. Finally, the study does not incorporate dynamic feedback effects, whereby changes in the cost of capital might themselves influence subsequent risk-taking behavior, leaving potential endogeneity concerns.

Future research can extend the present analysis in several directions. One avenue is to incorporate dynamic panel models or vector autoregressive frameworks to better capture feedback loops between risk exposures and cost of capital. Another promising direction is to include granular risk data at the loan, sectoral, or business-line level, allowing for a more refined assessment of how specific risk types drive cost-of-capital variations. Future studies could also compare listed and non-listed banks or examine cross-country samples to identify how institutional environments shape nonlinear risk–capital relationships. Incorporating cryptocurrency exposures, cyber risks, and digital asset interactions may further enhance understanding given the fast-growing role of digital finance. Additionally, scenario-based stress testing could be used to examine how extreme but plausible economic conditions interact with threshold dynamics. Lastly, future research could explore how managerial capabilities, governance quality, and risk culture mediate the nonlinear effects observed in the present study.

The findings of the study have several practical implications. Banks should prioritize strengthening their risk management frameworks, recognizing that incremental improvements in credit, market, liquidity, and operational risk controls can yield disproportionately large reductions in the cost of capital when implemented before key risk thresholds are crossed. Managers should invest in enhancing transparency, disclosure quality, and financial reporting systems to reduce information asymmetry and investor uncertainty. Regulatory authorities may consider incentivizing banks to adopt advanced risk analytics, stress testing, and digital risk management tools. Competitive policies that promote market discipline and operational efficiency can also indirectly contribute to reducing capital costs. Finally, given the increasing role of FinTech in improving operational efficiency and customer engagement, banks should continue to expand digital services to enhance stability, reduce operational risks, and improve funding conditions.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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