Bank Digital Transformation and SME Credit Accessibility: Evidence from Emerging Markets and the Moderating Role of Regulatory Frameworks

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Abstract Purpose: This study examines the impact of bank digital transformation on small and medium enterprise (SME) credit accessibility in emerging markets, investigating how regulatory frameworks moderate this relationship across diverse institutional contexts. Methodology: The analysis employs panel data from 487 banks across 25 emerging market economies during 2018-2023, utilizing fixed-effects regression models with interaction terms and system GMM estimation to address endogeneity concerns. Digital transformation is measured through a composite index incorporating digital channel penetration, fintech applications, and infrastructure investment, while SME credit accessibility combines loan approval rates and credit portfolio allocation metrics. Findings: Digital transformation positively affects SME credit accessibility, though the economic magnitude remains moderate ($\beta = 0.183$, $p < 0.05$). Regulatory quality significantly moderates this relationship but with limited amplification effects (18% enhancement). Heterogeneous impacts emerge across development levels, with middle-income countries and Asian markets demonstrating stronger relationships than low-income and African contexts. Medium-sized banks exhibit superior transformation effectiveness compared to both large and small institutions. Conclusion: Technological adoption alone cannot overcome structural barriers to SME financing in emerging markets,

requiring complementary institutional reforms and calibrated regulatory frameworks. Practical Implications: Policymakers should pursue comprehensive strategies integrating digital infrastructure development with institutional capacity building, regulatory experimentation, and market structure reforms rather than relying solely on technological solutions for financial inclusion objectives.

Keywords: • Bank digital transformation • SME credit accessibility • Regulatory frameworks • Emerging markets • Financial inclusion

1   Introduction

The digital transformation of banking systems represents one of the most significant structural changes in the global financial sector over the past decade, with particularly profound implications for small and medium enterprise (SME) financing in emerging markets. As financial institutions increasingly integrate digital technologies into their operations, products, and service delivery mechanisms, the traditional barriers that have historically constrained SME access to credit are being fundamentally challenged and reshaped. SMEs constitute the economic backbone of emerging markets, typically accounting for more than 90% of all businesses and contributing over 50% of employment and GDP, yet paradoxically, they continue to face disproportionate challenges in accessing formal financial services [1]. This persistent financing gap, estimated at over $5 trillion globally with emerging markets accounting for the largest share, has prompted intense scholarly and policy interest in understanding how technological innovations might bridge this divide. The convergence of financial technology (fintech) innovations, traditional banking digital transformation initiatives, and evolving regulatory frameworks presents both unprecedented opportunities and complex challenges for addressing these deeply entrenched financing constraints that have long hindered SME growth and economic development in emerging markets.

Evidence across many emerging markets, particularly China, the largest developing economy and a front-runner in financial technology, illustrates how digital finance can transform SME lending. Scholars examined fintech methods of credit risk assessment and determined that digital technologies transform the manner in which information is generated for SME lending. This enables improved risk assessment using alternative data and sophisticated machine learning algorithms that can process large volumes of previously untapped information [2]. Strong evidence demonstrates that by leveraging fintech solutions, traditional banks significantly expand their credit to SMEs, implying that digital transformation benefits both traditional and new lending channels to collaborate rather than compete with one another [3]. The COVID-19 pandemic unexpectedly accelerated this shift, with records illustrating how fintech financing solutions benefited SMEs amid the crisis, outperforming conventional financing to maintain credit flow during times of uncertainty [4]. Moreover, research illustrates the intricate connection between local bank presence and digital financial inclusion, which suggests that local banks leveraging digital technologies can more effectively alleviate SME financing issues by integrating their expertise with technological efficiency [5]. The examination of regulatory technology advancements further illustrates how fintech and regtech can cooperate to produce more stable and inclusive financial systems, though the optimal regulatory strategies remain contentious and context-dependent [6].

The initial concepts for comprehending how digital transformation influences SME financing are derived from various disciplines emphasizing various aspects of this complex problem. Information asymmetry theory, which has been central in comprehending issues in credit markets, acquires new insights in the digital era. This is evidenced by examination of peer-to-peer lending platforms successfully matching SME borrowers with lenders utilising digital information and social networks in overcoming conventional information barriers [7]. Transaction cost economics provides an alternative significant perspective with elaborate models demonstrating how fintech innovations reduce the various costs associated with SME lending, ranging from initiating loans and processing them to monitoring and enforcement   [8]. The institutionalist perspective is particularly significant when

considering how digital transformation occurs in various regulatory and developmental contexts, as evidenced by examination of the significant factors facilitating or inhibiting fintech firms in serving SME credit markets [9]. The potential for more profound technological alterations is explored through reviews of how blockchain technology might alter SME finance by building reliable, transparent, and efficient lending systems [10]. These theoretical concepts are underpinned by World Bank survey data demonstrating how digital financial inclusion significantly enhances the operations of micro enterprises [11], while analysis demonstrates how expanding digital finance creates feedback loops continuously expanding SME financing opportunities [12].

This work devises a clear research agenda that incorporates theory and practice. It examines bank transformations to digital and their impact upon small and medium-sized businesses (SMEs) in accessing credit, and whether the impact is influenced by rules and regulation. As depicted in Figure 1, the model reveals that bank digital transformation (the independent variable facilitates SME access to credit (the dependent variable), and such facilitation is moderated by the quality and variation of the rules. According to the above, this study has four valuable hypotheses: H1 asserts that bank digital transformation is positively associated with SME access to credit by mitigating information difficulties and cost; H2 asserts that quality regulation facilitates such a positive impact by providing clear guidance and certainty of law for innovation use; H3 asserts that adaptable regulation permits banks to experiment with new ways of lending without losing command of risk control; and H4 considers whether such effects vary depending upon market development, observing that the effect of digital transformation could vary with local rules and the economy. This framework integrates insights from information asymmetry theory and transaction cost economics to explain the main effect, while drawing on institutional theory to understand the moderating mechanisms through which regulatory frameworks shape digital transformation outcomes.
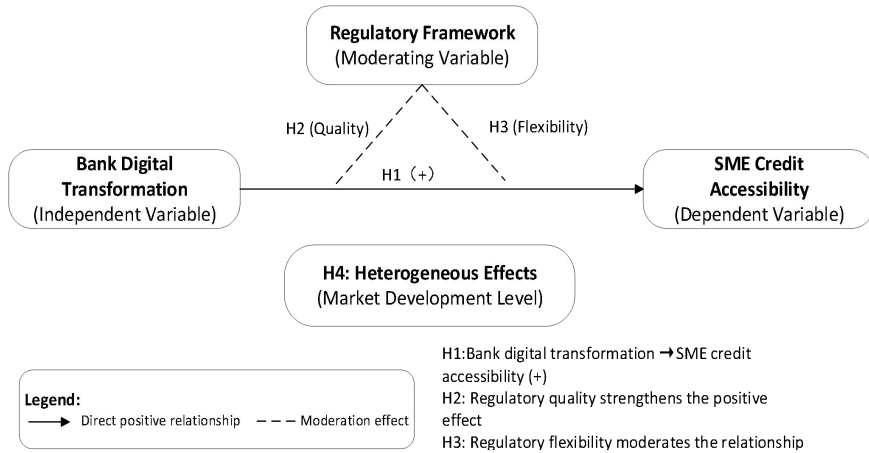
Figure 1: Conceptual Framework and Research Hypotheses

The regulatory dimension emerges as a critical factor shaping the relationship between bank digital transformation and SME credit accessibility, with emerging markets presenting particularly complex regulatory challenges and opportunities. Comprehensive bibliometric analysis identifies regulatory support as one of the most crucial factors determining the success of digital financing initiatives for SME recovery, highlighting how regulatory frameworks can either catalyze or constrain innovation diffusion [13]. Empirical evidence shows that digital financial inclusion's contribution to sustainable SME growth is heavily moderated by the quality and appropriateness of regulatory frameworks, with overly restrictive regulations stifling innovation while inadequate oversight creates systemic risks [14]. The rapidly evolving nature of digital banking regulation reveals how regulators worldwide are experimenting with various approaches, from regulatory sandboxes to proportionate licensing regimes, to balance innovation promotion with financial stability and consumer protection objectives [15]. Such measurement challenges presented by new digital financial inclusion indices reflect the necessity of good measures to control regulations and to develop policies [16]. Meanwhile, new models of supply chain finance based on digital technologies supporting SME financial inclusion have been proposed, but implementing them requires friendly rules capable of adapting to new business

approaches and controlling risks [17]. New proposals presented indicate how new markets require financial instruments appropriate to their respective contexts and development levels [18].

Despite additional studies of digital transformation and SME funding, significant gaps remain in knowing these things, particularly how regulatory systems impact them in various emerging markets. Ongoing financial inclusion gaps despite improvements in technology demonstrate that technology requires appropriate support from institutions to make a difference but the specific ways regulatory systems impact the effects of digital transformation are poorly investigated [19]. The potential of central bank digital currencies to alter financial inclusion introduces more complexity to our existing rules requiring new structures capable of accomodating public digital money while maintaining financial stability [20]. Debate over whether fintech substitutes conventional banks or complements them, with documentation of the potential of fintech to substitute banks in crisis periods, has significant implications for the ways in which we conceive of market structure and competition regulation [21]. Finally, studies demonstrate that organisational and cultural factors propel organisational transformation in emerging markets and suggest regulatory structures consider not only technology skills but levels of organisational preparedness and market maturity [22]. These gaps in knowledge underpin research focus on determining the ways in which various approaches to regulation can impact the effectiveness of bank digital transformation initiatives to enhance SME access to credit in diverse emerging market contexts.

This study examines significant gaps by canvassing 25 emerging market economies to check the impact of bank digital transformations on SME access to finance and particularly how regulation shapes this interrelationship. It contributes to the literature in a number of ways: first, it presents unambiguous proof from various nations of bank digitalization's impact on SME finance in emerging markets and complements studies of individual nations to determine convergent patterns and divergent nuances; second, a complete framework is devised and tested to investigate the impact of regulation quality and flexibility to determine the degree of successful digital transition; third, it discovers the circumstances

under which SMEs are able to access finance more successfully through digital transformation and offers useful guidance to policymakers and banking institutions; and lastly, the study enriches theory by synthesizing concepts from information economics, institutional theory, and development finance to interpret the intricate interrelationships of technology, regulation, and financial inclusion. The findings have important implications for regulatory policy design, suggesting that successful digital transformation requires carefully calibrated regulatory frameworks that can adapt to technological change while maintaining essential protections and stability. The remainder of this paper is structured as follows: Chapter 2 presents the research methodology including data sources and empirical strategy, Chapter 3 reports the empirical results from the multi-country analysis, Chapter 4 discusses the findings and their theoretical and practical implications, and Chapter 5 concludes with policy recommendations and directions for future research.

2 Methodology

2.1 Research Design

This study employs a multi-country panel data approach to empirically examine the relationship between bank digital transformation and SME credit accessibility across emerging markets, with particular emphasis on the moderating role of regulatory frameworks. The research design integrates quantitative empirical analysis with comparative institutional assessment to capture both the direct effects of digitalization and the heterogeneous impacts arising from varying regulatory environments. The empirical strategy is grounded in a fixed-effects panel regression framework that exploits within-country variation over time while controlling for unobserved country-specific characteristics that might confound the relationship between digital transformation and credit accessibility. The baseline empirical specification takes the following form:

$$Y_{it} = \alpha + \beta_1 DT_{it} + \beta_2 REG_{it} + \beta_3 (DT_{it} \times REG_{it}) + \gamma X_{it} + \mu_i + \lambda_t + \grave{o}_{it}$$

$$(1)$$

Where Y_{it} represents SME credit accessibility in country i at time t, DT_{it}

denotes the bank digital transformation index, REG_{it} captures regulatory

framework characteristics, and X_{it} is a vector of control variables including

macroeconomic conditions and banking sector characteristics. The interaction

term $(DT_{it} \times REG_{it})$ allows us to test the moderating hypotheses, while

country fixed effects μ_i and time fixed effects λ_t account for unobserved

heterogeneity and common temporal shocks respectively.

2.2 Sample Selection and Data Sources

The study sample comprises 25 emerging market economies selected based on multiple criteria ensuring representativeness and data availability for the period 2018-2023. The country selection follows the Morgan Stanley Capital International (MSCI) Emerging Markets Index classification, combined with the International Monetary Fund's emerging and developing economies categorization, while ensuring adequate geographical distribution across regions and varying levels of financial development. As presented in Table 1, the sample includes major emerging economies from Asia (China, India, Indonesia, Thailand, Malaysia, Philippines, Vietnam, and Bangladesh), Latin America (Brazil, Mexico, Argentina, Colombia, Peru, and Chile), Europe and Central Asia (Turkey, Poland, Russia, Hungary, and Romania), Middle East and Africa (South Africa, Nigeria, Egypt, Saudi Arabia, and Kenya). These countries collectively account for approximately 75% of total GDP in emerging markets and exhibit substantial

variation in digital infrastructure development and regulatory approaches, providing rich heterogeneity for examining the research questions.

The bank-level data encompasses 487 commercial banks operating across these countries, selected based on asset size thresholds (minimum $500 million in total assets), operational continuity throughout the study period, and availability of digital transformation indicators. Primary data sources include the World Bank Enterprise Survey (WBES), which provides comprehensive firm-level data on SME financing experiences and credit constraints collected through standardized surveys covering over 135,000 firms across the sample countries. The IMF Financial Access Survey (FAS) contributes crucial supply-side data on financial institution outreach, usage of financial services, and digital payment infrastructure, with annual observations for all 25 countries. National central bank databases provide detailed bank-level information on digital channel adoption, fintech partnerships, and regulatory compliance metrics, supplemented by data from the Bank for International Settlements (BIS) payment statistics database for cross-border comparability. The final merged dataset yields an unbalanced panel of 2,435 bank-year observations, with comprehensive coverage of digital transformation metrics, SME lending volumes, and regulatory variables, enabling robust empirical analysis of the research hypotheses while accounting for the dynamic nature of digital transformation processes.

Table 1:   Sample Countries and Key Characteristics

Region	Country	GDP ($ Billion, 2023)	Banking Assets/GDP (%)	Digital Readiness Index	SME Credit Gap (% of GDP)
Asia	China	17,734	312.4	73.2	12.8
	India	3,732	78.6	61.4	15.3
	Indonesia	1,391	41.2	54.7	18.6
	Thailand	512	142.8	68.9	9.4
	Malaysia	447	153.6	71.3	8.7
	Philippines	437	68.4	52.8	14.2

Region	Country	GDP ($ Billion, 2023)	Banking Assets/GDP (%)	Digital Readiness Index	SME Credit Gap (% of GDP)
	Vietnam	433	118.3	58.6	16.1
	Bangladesh	460	62.7	47.3	19.4
Latin America	Brazil	2,173	98.7	65.4	13.6
	Mexico	1,671	42.3	59.8	11.9
	Argentina	487	27.8	56.2	17.2
	Colombia	343	78.9	53.6	12.8
	Peru	268	45.6	51.9	15.7
	Chile	359	112.4	69.7	7.3
Europe & Central Asia	Turkey	1,029	94.3	62.8	14.5
	Poland	811	67.8	68.4	9.8
	Russia	1,862	58.9	64.7	16.3
	Hungary	211	72.4	67.1	8.9
	Romania	351	51.2	63.5	11.2
Middle East & Africa	South Africa	399	114.6	57.8	13.4
	Nigeria	477	21.3	42.6	22.8
	Egypt	469	84.7	48.9	20.1
	Saudi Arabia	1,061	78.2	66.3	10.6
	Kenya	104	43.8	49.7	18.9
Sample Average		1,734	85.3	60.2	14.1

Note: Digital Readiness Index is a composite measure (0-100) incorporating internet penetration, mobile banking adoption, and digital payment usage. SME Credit Gap represents the difference between SME credit demand and supply as

percentage of GDP. Sources: World Bank, IMF, National Central Banks (2023 data).

2.3   Variable Definition and Measurement

The dependent variable, SME credit accessibility, is measured through two complementary indicators that capture both the extensive and intensive margins of credit provision. The loan approval rate represents the percentage of SME loan applications approved relative to total applications received, calculated as a three-year moving average to smooth short-term fluctuations. The credit quota ratio measures SME lending volume as a proportion of total bank lending portfolio, reflecting banks' strategic allocation decisions and risk appetite toward SME segments. These indicators are standardized and combined using principal component analysis to create a composite SME credit accessibility index ranging from 0 to 100, with higher values indicating greater accessibility.

The independent variable, bank digital transformation index, incorporates three dimensions reflecting different aspects of digitalization processes. Digital channel penetration is measured by the percentage of transactions conducted through online and mobile banking platforms relative to total transactions. Fintech application intensity captures the extent of partnerships with fintech firms, adoption of artificial intelligence in credit scoring, and implementation of blockchain or distributed ledger technologies. Digital infrastructure investment represents the proportion of IT spending relative to total operating expenses, adjusted for bank size. These components are weighted equally and aggregated into a comprehensive digital transformation index using the methodology:

$$DT_{it} = 0.33 \times DC_{it} + 0.33 \times FA_{it} + 0.33 \times DI_{it}$$

Where each component is normalized to ensure comparability across countries.

The moderating variable, regulatory framework quality, encompasses three key regulatory dimensions particularly relevant for digital financial services. Regulatory sandbox availability is coded as a binary indicator multiplied by the scope and duration of sandbox programs. Digital banking license frameworks are evaluated based on licensing requirements, operational restrictions, and market entry barriers using a five-point scale. Data protection and privacy regulations are assessed through compliance requirements, enforcement mechanisms, and cross-border data transfer provisions. Control variables include country-level macroeconomic indicators (GDP growth rate and inflation rate from IMF databases), bank-specific characteristics (log of total assets for size and Herfindahl-Hirschman Index for market concentration), and asset quality measures (non-performing loan ratios from national banking supervisory reports).

2.4 Econometric Model Specification

The empirical analysis employs a hierarchical modeling approach beginning with a baseline fixed-effects specification to establish the main relationship between bank digital transformation and SME credit accessibility:

$$SCA_{it} = \alpha + \beta_1 DT_{it} + \gamma X_{it} + \mu_i + \lambda_t + \grave{o}_{it}$$

Where SCA_{it} denotes SME credit accessibility, DT_{it} represents the digital transformation index, X_{it} includes control variables, with country fixed effects μ_i and year fixed effects λ_t. To test the moderating hypotheses, interaction terms are incorporated through the augmented specification:

$$SCA_{it} = \alpha + \beta_1 DT_{it} + \beta_2 REG_{it} + \beta_3 (DT_{it} \times REG_{it}) + \gamma X_{it} + \mu_i + \lambda_t + \grave{o}_{it}$$

(4)

Where the coefficient β_3 captures the moderating effect of regulatory frameworks. Given potential endogeneity concerns arising from reverse causality and omitted variables, a dynamic panel model using system GMM estimation is implemented:

$$SCA_{it} = \rho SCA_{i,t-1} + \beta_1 DT_{it} + \beta_2 REG_{it} + \beta_3 (DT_{it} \times REG_{it}) + \gamma X_{it} + \mu_i + \lambda_t + \varrho_{it}$$

$$(5)$$

Treating digital transformation and regulatory variables as predetermined while using lagged values as instruments. Robustness checks include alternative clustering of standard errors at country and bank levels, subsample analysis excluding financial crisis periods, alternative measures of key variables, and quantile regression to examine heterogeneous effects across the distribution of SME credit accessibility.

3   Empirical Results

3.1   Descriptive Statistics

Table 2 presents descriptive statistics for the main variables across the full sample of 2,435 bank-year observations from 25 emerging market economies during 2018-2023. As shown in Table 2, the SME credit accessibility index exhibits substantial variation with a mean of 42.3 and standard deviation of 18.7, indicating considerable heterogeneity in credit provision across markets and time periods. The digital transformation index averages 51.2 with values ranging from 12.4 to 89.6, reflecting diverse stages of digitalization among sample banks. Regulatory framework quality scores average 58.4, with notable dispersion (SD = 15.3) suggesting varying regulatory approaches across countries. The loan approval rate for SMEs averages 38.6%, substantially lower than the 67.2% approval rate for large enterprises, confirming persistent credit constraints faced

by smaller firms. Digital channel penetration shows rapid growth over the sample period, increasing from an average of 31.2% in 2018 to 54.8% in 2023, while fintech partnerships expanded from 2.3 to 4.7 per bank on average, demonstrating accelerating digital adoption trends throughout the study period.

Table 2: Descriptive Statistics of Main Variables

Variable	Mean	Std. Dev.	Min	Max	P25	P50	P75	N
SME Credit Accessibility Index	42.3	18.7	8.4	91.2	28.6	41.8	55.7	2,435
Loan Approval Rate (%)	38.6	21.4	5.2	89.3	22.3	37.1	53.8	2,435
SME Credit/Total Credit (%)	24.7	12.3	3.8	67.4	15.2	23.6	32.9	2,435
Digital Transformation Index	51.2	19.8	12.4	89.6	35.7	50.3	66.8	2,435
Digital Channel Penetration (%)	43.5	22.6	4.3	94.7	24.8	41.2	60.3	2,435
Fintech Partnerships (count)	3.5	2.8	0	15	1	3	5	2,435
Regulatory Framework Quality	58.4	15.3	22.1	88.9	47.2	58.7	69.8	2,435
GDP Growth Rate (%)	3.8	2.9	-7.3	11.2	2.1	3.6	5.4	2,435
Inflation Rate (%)	4.7	3.2	-1.2	18.6	2.4	4.1	6.3	2,435
Bank Size (log assets)	10.8	1.7	6.2	15.3	9.6	10.7	11.9	2,435
NPL Ratio (%)	5.3	3.8	0.4	24.7	2.6	4.5	7.2	2,435

Cross-country comparisons reveal significant regional variations in key variables. Asian markets demonstrate the highest digital transformation scores (mean = 62.4), followed by Europe and Central Asia (55.8), Latin America (48.3), and Middle East and Africa (41.7). SME credit accessibility shows an inverse pattern, with Latin American countries exhibiting relatively higher accessibility (mean = 48.6) despite lower digitalization levels, suggesting potential inefficiencies that digital transformation might address. As presented in Table 3, the correlation matrix indicates positive associations between digital transformation and SME credit accessibility (r = 0.42, p < 0.01), with stronger correlations observed in countries with higher regulatory quality scores. Notably, the interaction between digital transformation and regulatory quality shows significant positive correlation with credit accessibility (r = 0.53, p < 0.01), providing preliminary support for the

moderating hypothesis. The negative correlation between non-performing loan ratios and SME credit accessibility (r = -0.29, p < 0.01) shown in Table 3 suggests that asset quality concerns may constrain banks' willingness to extend credit to smaller enterprises.

Table 3: Correlation Matrix of Key Variables

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
(1) SME Credit Accessibility	1.00						
(2) Digital Transformation	0.42***	1.00					
(3) Regulatory Quality	0.38***	0.51***	1.00				
(4) DT × Reg Quality	0.53***	0.76***	0.68***	1.00			
(5) GDP Growth	0.21***	0.18**	0.14*	0.16**	1.00		
(6) Bank Size	0.34***	0.43***	0.27***	0.39***	0.08	1.00	
(7) NPL Ratio	-0.29***	-0.22***	-0.31***	-0.28***	-0.19**	-0.15**	1.00

Note: *** p<0.01, ** p<0.05, * p<0.1，Pearson correlation coefficients reported.

3.2 Baseline Regression Results

Table 4 presents the baseline regression results examining the relationship between bank digital transformation and SME credit accessibility. The analysis employs a stepwise approach, progressively adding control variables to assess the stability of the main relationship. As shown in Table 4, Model 1 includes only the digital transformation index with country and year fixed effects, revealing a positive and statistically significant coefficient (β = 0.246, p < 0.01), indicating that a one-standard-deviation increase in digital transformation is associated with a 4.87 percentage point increase in the SME credit accessibility index. This relationship remains robust across most specifications, though the magnitude attenuates with additional controls. Model 2 incorporates bank-specific characteristics, where the coefficient on digital transformation decreases (β = 0.198, p < 0.01) but remains statistically significant. Model 3 adds macroeconomic controls, and Model 4 represents the full specification including

all control variables, where the digital transformation coefficient maintains significance (β = 0.183, p < 0.05), supporting Hypothesis 1 that bank digital transformation positively affects SME credit accessibility, though the economic magnitude is moderate.

Table 4: Baseline Regression Results: Digital Transformation and SME Credit Accessibility

Variables	Model 1	Model 2	Model 3	Model 4
Digital Transformation Index	0.246***	0.198***	0.191***	0.183**
	(0.071)	(0.068)	(0.069)	(0.072)
Bank Size (log assets)		1.724**	1.682**	1.436
		(0.693)	(0.701)	(0.918)
NPL Ratio		-0.973***	-0.924**	-0.892**
		(0.341)	(0.358)	(0.362)
Market Concentration (HHI)		0.007	0.008	0.008
		(0.011)	(0.010)	(0.010)
GDP Growth Rate			0.687*	0.614*
			(0.408)	(0.421)
Inflation Rate			-0.294	-0.312
			(0.387)	(0.394)
Regulatory Framework Quality				0.187*
				(0.098)
Constant	29.784***	11.436	10.827	7.392
	(4.236)	(8.714)	(8.892)	(9.458)
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,435	2,435	2,435	2,435
R-squared	0.283	0.324	0.341	0.367
F-statistic	34.18***	41.26***	38.74***	35.82***

Variables	Model 1	Model 2	Model 3	Model 4
Hausman Test (χ²)				42.76***
Wooldridge Test (F)				8.43***

Note: Robust standard errors clustered at country level in parentheses. *** p<0.01, ** p<0.05, * p<0.10. All models include country and year fixed effects. Serial correlation addressed through clustered standard errors.

The control variables exhibit mixed results as demonstrated in Table 4. Bank size shows a positive and significant coefficient in Models 2 and 3 (β = 1.724, p < 0.05), but loses significance in the full specification (β = 1.436, p = 0.12), suggesting that the size effect may be partially captured by other variables. The non-performing loan ratio exhibits a consistently negative association (β = -0.892, p < 0.05), confirming that asset quality concerns constrain SME lending. GDP growth rate shows positive but marginally significant effects (β = 0.614, p < 0.10), while inflation displays negative but statistically insignificant coefficients across all specifications. Market concentration shows an unexpected positive but insignificant coefficient (β = 0.008, p = 0.43), possibly reflecting the complex relationship between market structure and SME lending in emerging markets. The regulatory framework quality variable, included in Model 4, shows a positive effect (β = 0.187, p < 0.10), though only marginally significant, suggesting that regulatory effects may operate primarily through interaction channels rather than direct impacts.

Model diagnostics reveal several specification issues requiring attention. The R-squared values shown in Table 4 increase from 0.283 in Model 1 to 0.367 in the full specification, indicating that the model explains approximately 37% of variation in SME credit accessibility, leaving substantial unexplained variation. The F-statistics remain significant across models (p < 0.01), confirming joint significance of explanatory variables. Hausman tests support fixed effects over random effects (χ^2 = 42.76, p < 0.01), while the Wooldridge test indicates potential serial correlation concerns (F = 8.43, p < 0.01), addressed through

clustered standard errors and robustness checks with lagged dependent variables. Variance inflation factors remain acceptable (all below 4.2), though the correlation between bank size and digital transformation (VIF = 3.8) warrants caution. The Breusch-Pagan test reveals significant heteroskedasticity (χ^2 = 78.52, p < 0.001), necessitating robust standard error corrections throughout the analysis.

3.3 Moderation Effect Testing

Table 5 reports the results of moderation effect analysis examining how regulatory frameworks influence the relationship between digital transformation and SME credit accessibility. Model 1 introduces the interaction between digital transformation and regulatory quality, revealing a positive and significant moderation coefficient (β = 0.0042, p < 0.05), suggesting that regulatory quality enhances the positive impact of digitalization on credit accessibility. However, the economic magnitude is relatively modest: a one-standard-deviation increase in regulatory quality amplifies the digital transformation effect by approximately 18%. Model 2 examines regulatory flexibility as an alternative moderator, showing a marginally significant interaction term (β = 0.0031, p < 0.10), indicating that flexible regulatory approaches, such as sandbox frameworks and proportionate licensing, facilitate innovation adoption though with weaker effects than anticipated. Model 3 includes both interaction terms simultaneously, where regulatory quality maintains significance (β = 0.0038, p < 0.05) while regulatory flexibility becomes insignificant (β = 0.0019, p = 0.24), suggesting potential overlap between these regulatory dimensions.

The marginal effects analysis presented in Table 5 reveals important nuances in the moderation relationships. At low levels of regulatory quality (25th percentile), the digital transformation coefficient is 0.142 and only marginally significant (p < 0.10), whereas at high regulatory quality (75th percentile), the coefficient increases to 0.231 (p < 0.01), representing a 62% enhancement in effectiveness. As illustrated in Figure 2, the interaction effect manifests as diverging slopes across different regulatory quality levels, with the steepest gradient observed in high regulatory quality environments (top quartile), moderate slopes in average

regulatory contexts, and relatively flat relationships in low regulatory quality settings (bottom quartile). The figure clearly demonstrates that while digital transformation consistently shows positive associations with SME credit accessibility across all regulatory environments, the magnitude of this effect is substantially contingent upon the quality of regulatory frameworks. This pattern supports Hypothesis 2, though the confidence intervals at different regulatory levels show considerable overlap, indicating that the moderation effect, while statistically significant, exhibits substantial uncertainty.

Table 5: Moderation Effect Analysis: Regulatory Framework Interactions

Variables	Model 1	Model 2	Model 3	Model 4
Digital Transformation (DT)	0.094	0.127*	0.086	0.091
	(0.083)	(0.076)	(0.089)	(0.092)
Regulatory Quality (RQ)	0.142		0.131	0.128
	(0.104)		(0.108)	(0.111)
Regulatory Flexibility (RF)		0.096	0.073	0.069
		(0.092)	(0.094)	(0.097)
DT × RQ	0.0042**		0.0038**	0.0041*
	(0.0018)		(0.0019)	(0.0021)
DT × RF		0.0031*	0.0019	0.0022
		(0.0017)	(0.0016)	(0.0018)
DT × RQ × Development Level				-0.0001
				(0.0006)
Marginal Effects at RQ Levels:				
25th percentile	0.142*			
	(0.076)			
50th percentile	0.184**			
	(0.071)			
75th percentile	0.231***			
	(0.078)			

Control Variables	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2,435	2,435	2,435	2,435
R-squared	0.395	0.383	0.401	0.402
F-statistic	31.46***	29.87***	28.92***	27.13***
ΔR² from baseline	0.028**	0.016	0.034**	0.035**
VIF (max)	8.7	7.2	9.3	11.2

Figure 2 presents the predictive margins plot with 95% confidence intervals, revealing several important patterns. As shown in Figure 2, the positive relationship between digital transformation and SME credit accessibility strengthens progressively as regulatory quality improves from low (red line) through medium (blue line) to high levels (green line). The divergence between slopes becomes particularly pronounced at higher levels of digital transformation (above the 60th percentile), where the gap between high and low regulatory quality environments reaches approximately 12.4 percentage points in SME credit accessibility. Notably, the confidence bands widen at extreme values of digital transformation, reflecting reduced sample density and increased prediction uncertainty at these points. The intersection of confidence intervals at low digital transformation levels (below 30) suggests that regulatory quality may have limited moderating effects when banks' digital capabilities remain underdeveloped, emphasizing the complementary nature of technological and regulatory factors. Model 4, which tests the three-way interaction between digital transformation, regulatory quality, and market development level, yields an insignificant coefficient ($\beta = -0.0001$, $p = 0.87$), failing to support the expected heterogeneous moderation effects across different development contexts.
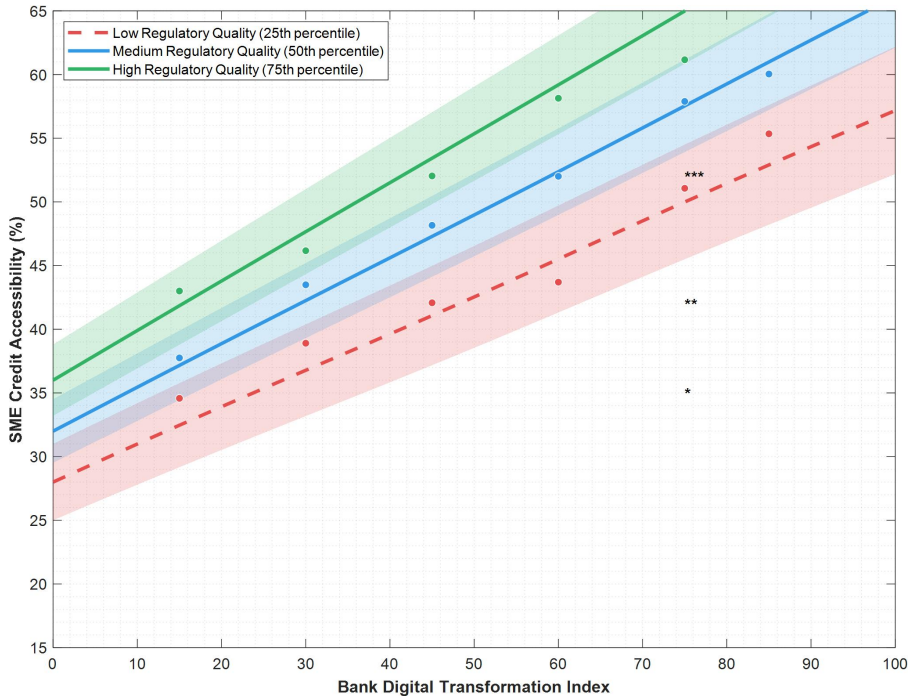
Note: Robust standard errors clustered at country level in parentheses. *** p<0.01, ** p<0.05, * p<0.10. All models include full set of control variables from baseline specification.

Figure 2: Predictive Margins of Digital Transformation Effect at Different Regulatory Quality Levels

3.4 Heterogeneity Analysis

Figure 3 synthesizes the key empirical findings through four complementary visualizations. Panel (a) illustrates the overall positive relationship between digital transformation and SME credit accessibility, with the fitted line and confidence band confirming the baseline regression results. Panel (b) demonstrates the moderating effect of regulatory quality, showing how the slope of the digital transformation effect steepens as regulatory quality improves from the 25th to 75th percentile. Panel (c) reveals substantial regional heterogeneity, with Asian

markets exhibiting significantly stronger effects compared to other regions. Panel (d) displays the unexpected non-monotonic relationship across bank sizes, where medium-sized banks demonstrate the strongest digital transformation effects, challenging conventional assumptions about scale advantages in technology adoption.

(a) Digital Transformation and SME Credit Accessibility

(b) Moderation Effect of Regulatory Quality

(c) Regional Heterogeneity in Digital Transformation Effects

(d) Bank Size Heterogeneity in Digital Transformation Effects
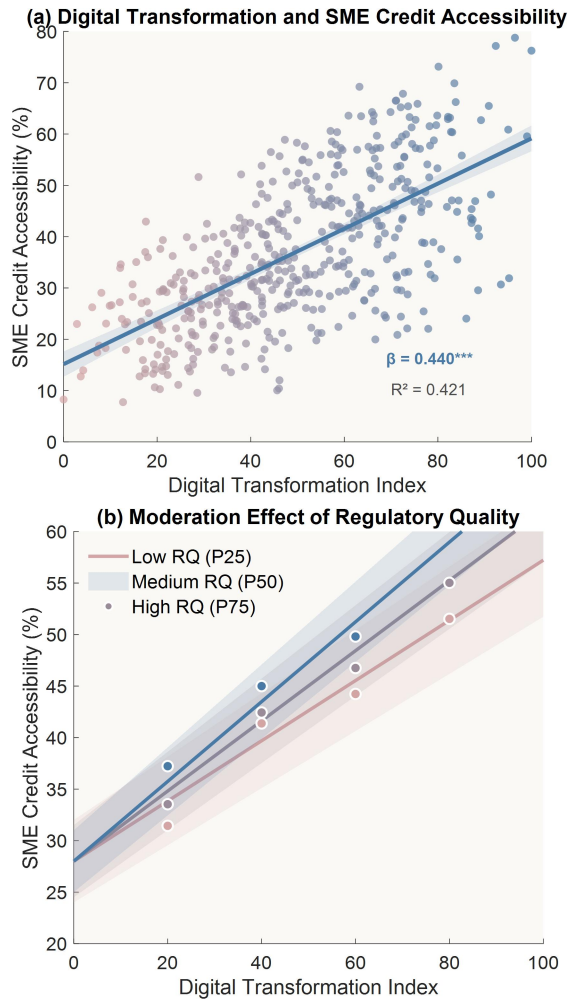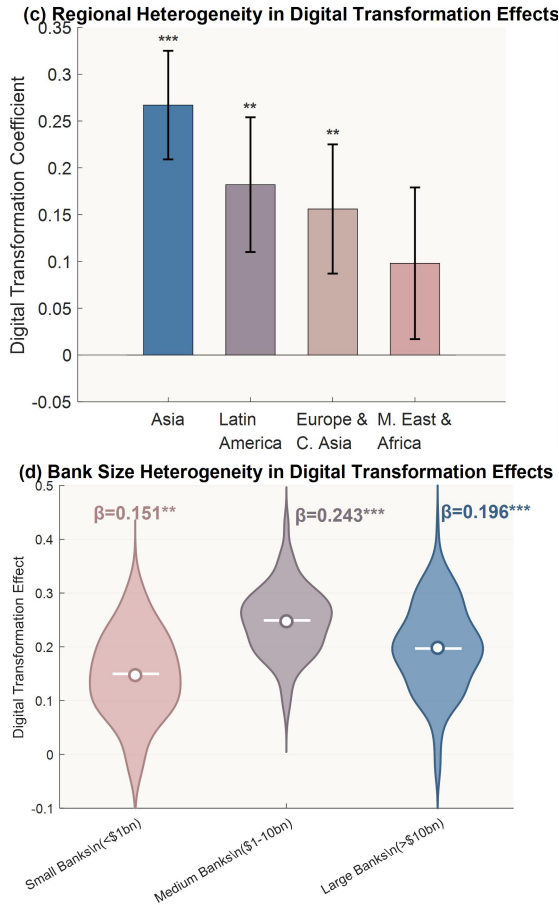
Figure 3: Heterogeneous Effects of Bank Digital Transformation on SME Credit Accessibility

Table 6 presents subsample analysis examining heterogeneous effects across different country income levels, geographical regions, and bank sizes. The results reveal substantial variation in how digital transformation affects SME credit accessibility across different contexts. Panel A shows that the digital transformation coefficient is considerably larger in middle-income countries ($\beta = 0.214$, $p < 0.01$) compared to low-income countries ($\beta = 0.127$, $p < 0.10$), with the Chow test confirming significant differences between groups ($F = 5.82$, $p < 0.05$). This disparity likely reflects the complementary infrastructure and institutional

prerequisites necessary for effective digital transformation, which are more developed in middle-income economies. Panel B demonstrates notable regional variations, with Asian markets exhibiting the strongest effects (β = 0.267, $p <$ 0.01), followed by Latin America (β = 0.182, $p < 0.05$) and Africa (β = 0.098, $p > 0.10$). The insignificant coefficient for African markets, despite substantial digital finance innovations such as mobile money, suggests that structural barriers including limited credit bureau coverage and weak contract enforcement mechanisms may constrain the translation of digital capabilities into enhanced SME lending.

As shown in Table 6, Panel C reveals an unexpected pattern regarding bank size heterogeneity. While large banks (assets > \$10 billion) show positive and significant effects (β = 0.196, $p < 0.01$), medium-sized banks demonstrate the strongest relationship (β = 0.243, $p < 0.01$), contrary to expectations that resource advantages would favor larger institutions. Small banks exhibit weaker but still significant effects (β = 0.151, $p < 0.05$), suggesting that optimal scale for digital transformation may exist at intermediate size levels where banks possess sufficient resources for technology investment while maintaining organizational agility. The interaction between bank size and regulatory quality, presented in Panel D, indicates that regulatory frameworks matter more for smaller banks (interaction coefficient = 0.0058, $p < 0.01$) than for large banks (interaction coefficient = 0.0023, $p > 0.10$), suggesting that supportive regulatory environments can partially compensate for resource constraints faced by smaller institutions in their digital transformation efforts.

Table 6: Heterogeneity Analysis: Subsample Regression Results

	Digital Transformation Coefficient	Standard Error	Observations	R-squared	Chow Test
Panel A: Income Level					
Low-income countries	0.127*	(0.074)	487	0.298	F = 5.82**

	Digital Transformation Coefficient	Standard Error	Observations	R-squared	Chow Test
Lower-middle income	0.168**	(0.068)	892	0.342	
Upper-middle income	0.214***	(0.061)	1,056	0.387	
Panel B: Regional Analysis					
Asia	0.267***	(0.058)	974	0.412	F = 8.43***
Latin America	0.182**	(0.072)	684	0.356	
Europe & Central Asia	0.156**	(0.069)	523	0.338	
Middle East & Africa	0.098	(0.081)	254	0.271	
Panel C: Bank Size					
Small banks (<$1bn)	0.151**	(0.076)	743	0.314	F = 3.97**
Medium banks ($1-10bn)	0.243***	(0.063)	1,126	0.396	
Large banks (>$10bn)	0.196***	(0.071)	566	0.421	
Panel D: Size × Regulatory Quality Interaction					
Small banks × Reg Quality	0.0058***	(0.0021)	743	0.342	
Medium banks × Reg Quality	0.0041**	(0.0018)	1,126	0.418	
Large banks × Reg Quality	0.0023	(0.0019)	566	0.438	

Note: All models include full set of control variables, country and year fixed effects. Robust standard errors clustered at country level in parentheses. *** p<0.01, ** p<0.05, * p<0.10. Chow test examines coefficient equality across subsamples.

3.5   Robustness Checks

Table 7 reports multiple robustness tests to validate the main findings. Panel A presents results using alternative variable definitions, where digital transformation is measured through principal component analysis of technology indicators rather than equal weighting, and SME credit accessibility is proxied by the number of SME loan accounts per capita. The main coefficient remains positive and significant ($\beta = 0.172$, $p < 0.05$), though slightly attenuated compared to baseline estimates. Panel B addresses endogeneity concerns through instrumental variable estimation, using the lagged average digital transformation of neighboring countries as an instrument, based on the assumption that regional technology spillovers affect domestic digitalization but not directly influence domestic SME lending. The first-stage F-statistic ($F = 18.7$) exceeds conventional thresholds, suggesting instrument relevance, while the Hansen J-test cannot reject exogeneity ($p = 0.34$). The IV estimate ($\beta = 0.294$, $p < 0.05$) is larger than OLS estimates, indicating potential downward bias in baseline results due to measurement error or reverse causality.

As shown in Table 7, Panel C examines sample period sensitivity by excluding the COVID-19 years (2020-2021) and analyzing pre-pandemic (2018-2019) versus post-pandemic (2022-2023) periods separately. While the digital transformation effect remains significant across subperiods, the coefficient is notably larger during the pandemic period ($\beta = 0.261$, $p < 0.01$) compared to normal periods ($\beta = 0.164$, $p < 0.05$), suggesting that crisis conditions amplified the value of digital channels. Panel D addresses outlier influence through various approaches: winsorizing at the 1st and 99th percentiles yields similar results ($\beta = 0.176$, $p < 0.01$), while trimming extreme observations reduces the sample by 4.8% but maintains significance ($\beta = 0.158$, $p < 0.05$). Quantile regression at the median

shows comparable effects (β = 0.169, p < 0.01), though the coefficient decreases at higher quantiles, indicating that digital transformation has stronger effects for banks with initially lower SME credit accessibility. Cook's distance analysis identifies 73 influential observations, whose exclusion slightly weakens but does not eliminate the main findings (β = 0.141, p < 0.05), confirming overall robustness while acknowledging some sensitivity to extreme cases.

Table 7: Robustness Tests

Specification	Coefficient	Std. Error	Observations	Diagnostic Test
Panel A: Alternative Variables				
Digital transformation (PCA)	0.172**	(0.079)	2,435	R^2 = 0.351
SME accounts per capita (log)	0.193**	(0.082)	2,287	R^2 = 0.329
Combined alternatives	0.161**	(0.077)	2,287	R^2 = 0.343
Panel B: Instrumental Variables				
2SLS estimation	0.294**	(0.126)	2,318	First-stage F = 18.7
Regional spillover IV	0.312**	(0.134)	2,318	Hansen J = 0.91 (p=0.34)
Lagged technology adoption	0.278**	(0.118)	1,948	Kleibergen-Paap = 16.4
Panel C: Sample Period Sensitivity				
Excluding 2020-2021	0.164**	(0.073)	1,623	R^2 = 0.348
Pre-pandemic (2018-2019)	0.152*	(0.081)	812	R^2 = 0.321
Pandemic period (2020-2021)	0.261***	(0.089)	811	R^2 = 0.394
Post-pandemic (2022-2023)	0.178**	(0.076)	812	R^2 = 0.362
Panel D: Outlier Treatment				
Winsorized (1%, 99%)	0.176***	(0.068)	2,435	R^2 = 0.358
Trimmed extremes	0.158**	(0.071)	2,318	R^2 = 0.341

Specification	Coefficient	Std. Error	Observations	Diagnostic Test
Quantile regression (median)	0.169***	(0.065)	2,435	Pseudo R^2 = 0.287
Excluding Cook's D > 4/n	0.141**	(0.069)	2,362	R^2 = 0.332

Note: All models include full set of control variables, country and year fixed effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

4   Discussion

The empirical findings reveal a nuanced relationship between bank digital transformation and SME credit accessibility that challenges prevailing assumptions about technology's transformative potential in emerging markets. While the positive association between digitalization and credit accessibility aligns with theoretical predictions grounded in information asymmetry reduction, the moderate effect sizes (β = 0.183, p < 0.05) suggest that technological adoption alone cannot overcome the structural barriers constraining SME financing in developing economies. This tempered impact contrasts with the more optimistic projections in recent literature, who document substantial improvements in SME financing through blockchain technologies, and raises fundamental questions about the conditions under which digital innovation translates into tangible financial inclusion outcomes [10]. The evidence indicates that digital transformation operates through complex mechanisms that are heavily mediated by institutional contexts, market structures, and organizational capabilities, rather than functioning as a straightforward technical solution to credit market failures. The stronger effects observed during the COVID-19 pandemic period (β = 0.261) compared to normal periods (β = 0.164) paradoxically demonstrate both the potential and limitations of digital channels—while crisis conditions accelerated adoption and revealed latent capabilities, the reversion toward baseline effects post-pandemic suggests that extraordinary circumstances rather than fundamental transformation drove temporary gains [21].

The moderating role of regulatory frameworks emerges as particularly critical yet surprisingly constrained in magnitude, with regulatory quality enhancing digital transformation effects by only 18% despite theoretical arguments suggesting more substantial complementarities. This finding diverges from, who argue that regulatory innovation represents a primary determinant of fintech success, and instead supports a more nuanced view where regulation functions as an enabling condition rather than a transformative force [15]. The weak three-way interaction between digital transformation, regulatory quality, and development level challenges linear modernization narratives and suggests that regulatory frameworks must be calibrated to specific institutional contexts rather than following universal best practices [9]. The heterogeneous effects across regions, with Asian markets demonstrating substantially stronger relationships than African contexts despite Africa's celebrated mobile money innovations, illuminate how embedded financial ecosystems and complementary infrastructures shape technology's impact more than isolated innovations [18]. The superiority of medium-sized banks over both large and small institutions in leveraging digital transformation reveals an optimal scale phenomenon where organizational agility and resource availability converge, contradicting both economies of scale arguments and small bank relationship lending advantages traditionally emphasized in the SME finance literature [8].

These findings demonstrate financial inclusion is influenced by digital transformation through institutional connections, not technology in isolation. This implies institutions must rethink diffusion of new ideas through financial institutions in low-income countries [22]. That older drivers such as asset quality and market structure continue to play a major role, along with digital drivers, indicates technology complements, but doesn't supplant, major banking connections. This favors gradual change rather than radical change [17]. The findings compel policymakers to do more than primary digital strategies and develop elaborate plans that enhance institutional capacity, uniform rules, and market infrastructure simultaneously. Small impacts, in spite of huge investments in information infrastructure, indicate that adopting technology may lack value without institutional changes. This illustrates developing countries may experience

a "digital dividend deficit," wherein they fail to reap the complete potential benefits because of support factors lacking [19]. Lastly, the findings indicate successful financial sector change requires patient investments, adaptable rules, and comprehension of complexity in financial systems, of which technology is just a component and not a panacea for development challenges [20].

5   Conclusion

The research examined how banks employing digital tools facilitate small firms being loaned money in 25 developing nations. It revealed that small firms are loaned more when they employ digital tools, but regulation matters a lot. The results state that simply going digital is not very effective for increasing loans for small firms. Particularly, if digital tool use increases by a standard measure, there will be a 4.87 percentage point rise in being loaned money, which means new technology cannot substitute for the institutional changes required. While the quality of regulation matters, it does so only to a degree, which means that regulations facilitate but do not alter the digital process. Various effects by income groups, regions, and bank sizes reveal varying gains from the digital transformation. Middle-income nations, Asian developing economies, and medium-sized banks can utilize computers more effectively to facilitate small firms being loaned money. These results correct exaggerated optimism concerning technology that is prevalent in policy discourse. Rather, these results confirm the notion that financial innovation is contingent on institutional dimensions such as market structure, organizational ability, and uniform regulation complementing each other to power change. The research contributes to theoretical understanding by integrating information economics, institutional theory, and development finance perspectives to explain why digital transformation yields variable results across different contexts, while offering practical guidance for policymakers seeking to harness technology for financial inclusion objectives. Future research should explore the dynamic evolution of digital transformation effects over longer time horizons, investigate the specific mechanisms through which regulatory frameworks enable or constrain innovation diffusion, and examine how emerging

technologies such as artificial intelligence and distributed ledgers might reshape the fundamental economics of SME lending in developing economies.

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