

Digital Financial Inclusion and Financial Resilience: Evidence from Emerging Economies

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Abstract: *Purpose: This study examines whether digital financial inclusion is associated with financial resilience in the MINT emerging economies of Mexico, Indonesia, Nigeria and Türkiye. Method: A balanced country-level panel covering 2000-2025 was developed, resulting in 104 observations. Bank Z-score is a proxy for resilience, and the proportion of transactions in mobile and internet banking and internet use are indicators of digital financial inclusion. GDP growth, inflation, private-sector credit, trade openness, logged GDP per capita, and population growth are controlled. Fixed-effects and random-effects modelling are estimated, and then specified and diagnosed. Due to the presence of heteroskedasticity and first-order serial correlation, feasible generalised least-squares, with heteroskedastic panels, and panel-specific AR(1) disturbance errors constitute the main estimates. Results revealed that the use of the Internet was positively related to the Z score of the bank, while correcting for digital transaction value resulted in a non-statistically significant value. Private sector credit decrease is negatively related to resilience, while the positive relationship between logged GDP per capita and population growth are positively related to resilience. Policy implications: Policies should focus on the improvement of digital connectivity, cyber security, responsible credit expansion, and institutional capacity instead of adding to the typical focus on transaction growth and considering this as a proxy for resilience. The results point towards a need to ensure digital-inclusion policy meets with prudential supervision and economy-wide development goals.*

Keywords: Bank Stability; Digital Financial Inclusion; Financial Resilience; Internet Use; Mint Economies; Panel Data

Introduction

Financial sector transformation in emerging economies is a prominent part of digital financial inclusion. It expands financial services through the Internet, electronic payments, mobile technology, information-based platforms, and other cutting-edge solutions that reduce the costs and distances associated with traditional financial services. It is obvious that the policy attraction is clearly found (Geng & He, 2021). Digital channels may increase participation and reduce transaction costs, enhance information flows, and link households and firms to formal financial institutions (Shen et al., 2021). The risk profile of financial systems is also bound to alter in the path of greater digitalisation. Could speed up transactions, make the company more technology-intensive, heighten competition, and grow credit at a quicker rate. The relationship between financial inclusion and financial resilience is therefore not without ambiguities a priori, since these effects can be positive, but also negative (Chinoda et al., 2019). In recent years, therefore, digitalisation can be considered as both a topic of inclusion and a new financial vulnerability (Tay et al., 2022).

In this study, financial resilience is defined as the ability of the financial system to withstand shocks, remain solvent, and continue its wealth transmittal function. The Bank Z-score has been defined as an empirical indicator, as it reflects the gap between profitability and capital buffers of the banking system and their volatility. The higher the Z-score, the more stable and less likely to experience distress. This is a commonly utilised indicator for research on various aspects of financial inclusion, fintech adoption, and/or digital transformation impact on banking risk (Ahamed & Mallick, 2019). The potential impact of the concept is especially to be noted in economies that are still developing and where in the banking system it is important, and where external shocks can combine with financial-sector vulnerabilities and inflationary pressures to result in rapid technological change.

The MINT economies (Mexico, Indonesia, Nigeria and Türkiye) offer a useful backdrop. They are Big Emerging Markets with big populations in their respective countries, increasing digital connectivity, and unique banking ecosystems. They also vary in their inflation experiences, financial depth, and financial exposure and income. These differences provide a meaningful variation over time within a country and across countries. Financial inclusion has improved through the spread of the Internet and more widespread mobile and Internet banking, and resilience has developed due to domestic and global shocks faced by banking systems. The governments in Indonesia have seen the significant growth of fintech and a substantial financial system, and in Nigeria, they have been implementing digital-finance development along with addressing financial-inclusion problems (Yudaruddin et al., 2023). While digitally advanced banking services have been introduced in a turbulent macroeconomic climate in Türkiye, the Mexican banking systems overlap with traditional banks and also have a relatively well-entrenched regulatory framework for fintech and non-banking digital banks. The contrasts between these help to further substantiate a panel design over a single-country design.

There are conflicting predictions in the literature. The other strand holds that inclusion and digitalisation can enhance stability through the breeders of banks' influence on stability, broadened deposit bases, payment efficiency, reduction in information asymmetry, and

customer size (Atellu & Muriu, 2022). Television reviews of emerging and growing economies often have discovered that a wide inclusion or fintech development is accompanied by higher bank stability (Koudalo & Toure, 2023). A second strand emphasises risks. Fast digitalisation could lead to increased competition, shrinking profit margins, cybersecurity and operational risks, and more credit growth than can be managed. In some contexts, however, the effect of the adoption of fintech has proved to be negative or nonlinear (Khan et al., 2023). The diverging results suggest that spatially some benefits increase, while others diminish or even turn into drawbacks, and that the achievement of these benefits is influenced by the macro-financial context in which digitalisation takes place.

This study aims to resolve this uncertainty as it relates to the financial resilience of the four MINT economies during the period 2000 to 2025. Two indicators of digitalisation were wanted for inclusion in the empirical model that were still present in the corrected data: the share of the population using the internet and the value of mobile and internet banking transactions as a share of GDP. Several variables controlled for GDP growth, inflation rate, credit as a share of the private sector, trade openness, and logged GDP per capita and population growth. Previously, variables unavailable for country coverage were not used before estimation, and the last model was estimated based on those variables that are available for all four economies. This way, the variables are not distorted by having some with zero or missing values.

There are three contributions to be made in the study. First, it neglects studying both the economies together, which is very important for emerging markets, the so-called MINT economies. Second, it measures the digital connectivity, not the economic richness of digital banking transactions, but combines them into one index. Third, it checks the sensitivity of the relationship to the assumptions in the panel model. Both fixed-effects models and random-effects models are estimated, and specification and diagnostic tests are conducted. Homoskedasticity of the panels is rejected, along with serial correlation. Hence, the final inference is based on feasible generalised least squares of the panels with heteroskedastic panels, and with AR(1) disturbances specific to each panel. This sequence generates a more robust linkage between digital and the dimensions of resilience from a defence perspective.

Literature Review

Digital financial inclusion combines the inclusion objective of extending formal financial services with the use of digital technologies to deliver and use those services. It is more expansive than internet access, since it encompasses the use of infrastructure and money; meaningful inclusion. Khera et al. (2022) demonstrate that there are both access and usage dimensions of digital financial inclusion, and digital services have played an important role in the overall process of financial inclusion in emerging and developing economies. Internet penetration remains a key enabler, as online banking services, digital ID, and the ability to onboard customers remotely and use electronic means of payment require a stable Internet connection. Concurrently, transaction measures will supplement infrastructure indicators by indicating if there is a meaningful use of digital channels in an economic sense.

Not all channels created from stability are positive. According to Ahamed and Mallick (2019), better financial inclusion correlates with greater bank soundness, especially in banks that have higher dependence on retail deposits and are less leveraged. This finding backs up the thesis that inclusion is linked to increased funding security and risk diversification. Banna and Alam (2021) adeptly extrapolate this argument to digital financial inclusion and show that greater digital financial inclusion lowers bank risk-taking in a dual-banking sample. The stabilising effect is consistent with the notion that financial mobility can get wider from digital channels without an increase in default risk, which can be intensified by boosting the quality of customers' relationships.

The present model is particularly relevant to the use of the Internet. Antwi and Kong (2023) study the development of market economies and conclude that Internet usage shows a positive association with the financial stability of the banking sector, whereas mobile-phone subscriptions show a negative association with the financial stability of the banking sector. Their conclusions highlight the different nature of digital and finance proxies. While basic mobile diffusion is likely to increase with no matching development in financial capacity or guarantees, Internet penetration could be a sign of a more mature digital ecosystem that provides access to information and formal financial activities. Against a backdrop of Ethiopia, Hordofa (2024) shows that outcomes of digital transformation in the long run can be negative, meaning country conditions influence outcomes.

The transaction-intensity variable in this new study represents another mechanism other than Internet penetration. The value of mobile and internet banking transactions as a % of GDP helps to show the magnitude of digital financial transactions vs. the economy. Higher values indicate a higher level of digital channel usage and lower transaction costs. But at the same time, given growth in the number or volume of transactions may come with shrinking intermediation margins, as well as exposure to fraud, sometimes with increasing concentration or speculation in the operation. The study by Chinoda and Kapingura (2023) is among the important ones that have identified that both digital financial inclusion and bank competition are determinants of bank stability in Sub-Saharan Africa. Their evidence supports the use of the amount of digital activity as potentially beneficial, but not necessarily stabilising.

Private-sector credit is a measure of financial depth and the size of credit intermediation. Mature and healthy credit can provide much-needed credit for investments, but too much or misadvised credit expansion can damage asset quality. The changed stability effects for aggressive financial deepening, documented in the present work, mesh with the overall logic of inclusion in, and risk management for, financial deepening. Ha and Nguyen (2023) argue that financial inclusion may have a positive and negative impact on bank stability depending on institutional quality: financial inclusion, when accompanied by bad institutions, can lead to greater vulnerability. Similarly, Damrah et al. (2023) conclude that there are variations between the banking structures in the inclusion–stability relationship.

The literature also suggests that digital finance has an impact on the performance of banks as a result of operational efficiency. Digital financial inclusion has multiple impacts on bank performance, and impacts differ between regions and banks, says Zhao et al. (2024). Digital

financial development not only enhances stability but also has a significant impact on the stability of commercial banks supported by operational efficiency as the intermediary channel, as revealed by Liang et al. (2025). Some of these results illustrate that when banks apply technology in order to lower their operating costs, implement a more efficient screening process, and diversify customer relations, then they act in a way that increases their resilience. Meanwhile, there is mixed recent evidence. The financial stability-financial inclusion relationship has been well recognised and articulated by Joudar and El Ghmari (2025) for MENA and African countries; other pertinent emerging studies highlight the need to consider thresholds and financial structures. Financial technology can thus help strengthen resilience as well as be a risk amplifier (Iddrisu et al., 2023). In this uncertainty, an empirical design that allows one to infer the relative impact of diffusion and transaction intensity of Internet usage on digital transactions while controlling for macro-financial conditions is conducive.

The research gap is in two aspects. Many of the studies employ relatively large multi-country samples, bank-level data sets, or indices of bank inclusion. Much less research regards the MINT economies as a specific group of countries over an extended timeframe, in this case, across a year. Secondly, digital infrastructure and transaction intensity are frequently linked, and it is difficult to distinguish between the relationship between digital connectivity and the digital actuality of banking usage and the relationship between resilience. Secondly, in many cases, digital infrastructure and transaction intensity are intertwined, making it difficult to separate the two and the relationship between digital infrastructure and real use of digital banking and its relationship to resilience. To overcome these gaps, the present study relies on a period of the initial year 2000-2025 with a balanced panel and separate Digital-Finance variables. Internet use would be predicted to be positively related to the Bank Z-score, based on the stabilising mechanisms which have been reported in previous studies. The expected increase in the value of mobile and internet banking transactions is not as clear since deeper transactional usage can actually increase both operational and competitive risk and at the same time enhance efficiency (Okoli, 2024).

Methodology

The study has a panel design with observations for annual country-level data for four selected countries, also featuring Mexico, Indonesia, Nigeria, and Türkiye. The period is 2000–2025. Previous years were not included because the variables that were kept in the empirical model had a large number of missing observations. This final data set is very well-balanced, with 26 observations per year from each of the four countries, leading to 104 country-year observations. There are no missing values for any model variable in this last sample. This balance makes the data more comparable between countries and eliminates sample growth variations from one specification to another.

The dependent variable is the Bank Z-Score, which reflects the stability of the banking system and is seen as a distance from bankruptcy. The higher, the more financially resilient. This Z-score series was recorded from the Fed data source that was used for the corrected data. The World Development Indicators (WDI) database was used for collecting all explanatory and control variables. Internet users (in %) is the first variable related to digital finance. This

captures the spread of the digital infrastructure necessary for financial services' online delivery. The second is the share of mobile and internet banking transactions in GDP, an equivalent measure of the level of digital financial transactions intensity of digital financial use per GDP. 6 controls are kept due to their complete observations in all four countries. The real-growth rate is used for GDP. Annual CPI inflation rate = Inflation. Private-sector credit is domestic credit to the private sector. Trade openness is a measure of the trade-GDP ratio. GDP is expressed per capita of the population and is reported in natural log form in order to eliminate scale differences and to make it possible to read GDP in a proportional sense. The annual percentage change in population is the measure of population growth. Although variables were included in data preparation that would have otherwise been included in the final model if they had useful observations in at least one country, no variables in these results are based on observations from fewer than one country.

Table 1 Variables, Measurement and Data Sources

Variable	Role	Measurement	Source
Bank Z-score	Dependent	Banking-system distance from insolvency; higher values indicate greater resilience	Federal Reserve data source
Internet users (% population)	Independent	Share of population using the internet	World Development Indicators
Mobile/internet banking transaction value (% GDP)	Independent	Value of mobile and internet banking transactions relative to GDP	World Development Indicators
GDP growth	Control	Annual real GDP growth (%)	World Development Indicators
Inflation	Control	Consumer-price inflation (annual %)	World Development Indicators
Private-sector credit	Control	Domestic credit to private sector	World Development Indicators
Trade openness	Control	Trade as a share of GDP	World Development Indicators
GDP per capita	Control	GDP per capita; natural log used in regression	World Development Indicators
Population growth	Control	Annual population growth (%)	World Development Indicators

Note. All explanatory and control variables in the final model were obtained from World Development Indicators. Bank Z-score was obtained from the Federal Reserve data source used in the corrected dataset.

$$\text{BankZ}_{it} = \beta_0 + \beta_1 \text{Internet}_{it} + \beta_2 \text{DigitalTransactions}_{it} + \beta_3 \text{GDPGrowth}_{it} + \beta_4 \text{Inflation}_{it} + \beta_5 \text{Credit}_{it} + \beta_6 \text{Trade}_{it} + \beta_7 \text{LnGDPpc}_{it} + \beta_8 \text{PopulationGrowth}_{it} + \mu_i + \varepsilon_{it}.$$

The subscripts i and t refer to both the country and year. The unobserved effects for the country and the idiosyncratic noise shocks are denoted by μ_i and ε_{it} , respectively. The model is association type. Because of the lack of an external instrument or quasi-experimental identification method, the results of the analysis should therefore not be viewed as causal estimates.

Before panel estimation, descriptive statistics were computed and the bivariate correlations were derived. The direction of bivariate relations was analysed using the method of correlation, as well as the possibility of a relatively strong correlation between the regressors. Correlation results are not used to evidence causal relationships, but are used as diagnostics.

Two types of panel regressions – random-effects and fixed-effects – were specified. The random effects are assumed to be uncorrelated with the explanatory variables. Fixed effects can contain arbitrary country-specific correlating features between country-specific regressors and time-invariant features, which would control for persistent country features or country-specific heterogeneity. The overall Wald-test for the random-effects (RS) model was statistically significant and also was jointly statistically significant for the fixed-effects (FE) model. The Hausman specification test was then used to test the consistency of the estimated coefficients between using the two estimators.

The Hausman statistic was 53.80 with $p < .001$, indicating systematic differences between the fixed- and random-effects estimates and supporting fixed effects under the standard test logic. The variance-difference matrix was not positive definite, so Hausman result is addressed along with other diagnostics (not separately). The fixed-effects F test for all the country effects being equal to zero was also significant, which further suggests that there is meaningful heterogeneity between countries. On the other hand, the Breusch–Pagan Lagrange multiplier test for random effects gave a p-value of 1.000, which is not indicative of the presence of the random-effects variance component.

Post-estimation tests showed that errors of regression were non-normally distributed and errors were not homogeneous or serially independent. The groupwise heteroskedasticity modified Wald test yields a $\chi^2(4) = 14.45$, $p = .006$. $F(1,3) = 13.936$, $p = .0335$ was found for the Wooldridge test for first order autocorrelation. In particular, these results indicate that standard errors based on conventional fixed-effects might be incorrect. The last model was thus estimated by cross-sectional time-series generalised least squares with heteroskedastic panels and panel-specific AR(1) correlation. This is an estimator that specifically deals with the two disturbances determined from the diagnostics. Due to the limited number of countries, results are interpreted with care and not based on the size of the causal effect but based on statistical significance and consistency with theory.

Results

4.1 Descriptive Statistics

Table 2 Descriptive Statistics

Variable	N	M	SD	Min	Max
Bank Z-score	104	12.819	6.022	0.871	26.179
Internet users (%)	104	32.745	25.990	0.064	89.770
Digital transaction value (% GDP)	104	72.232	38.589	0.024	162.783
GDP growth (%)	104	4.083	3.608	-8.354	15.329
Inflation (%)	104	11.722	12.837	1.560	72.309
Private-sector credit	104	30.293	16.031	7.923	75.268
Trade openness	104	55.995	10.692	32.972	88.798
GDP per capita	104	6,183.715	4,343.645	547.318	18,599.442
Population growth (%)	104	1.487	0.677	0.161	2.803

Note. Values are based on the strongly balanced panel of four MINT economies over 2000–2025.

In Table 2 the descriptive statistics for the 104 observations are presented. There is significant variation in financial resilience scores across countries and years, with mean Bank Z-scores ranging from 12.819 and a standard deviation of 6.022. The score ranges from 0.871 to 26.179. With an average of 32.745% of the population using the net, 25.990 percentage points, and ranges of usage from 0.064% to 89.770% indicate the significant digital transformation that took place over the period of the sample. The value of mobile and internet banking transactions is, on average, 72.232% of GDP, and is between 0.024% and 162.783% of GDP.

There is also a large amount of heterogeneity in terms of macroeconomic variables. GDP growth is currently for the most part, normal, with an average of 4.083% but a minimum of -8.354% and a maximum of 15.329%. The average value of inflation is 11.722%, and it is 72.309% at its highest point, indicating there have been periods of high inflation in the MINT group. The average for the private sector is 30.293% of GDP, and the average for Trade Openness is 55.995%. GDP per capita averages USD 6,183.715, ranging from USD 547.318 to USD 18,599.442. The population growth is at an average of 1.487% and is positive for the entire population sample.

4.2 Correlation Analysis

Table 3 Correlation Analysis

Variable	Bank Z-score	Internet use	Digital value	GDP growth	Inflation	Private credit	Trade openness	Log GDP pc	Population growth
Bank Z-score	1.000								
Internet use	.127	1.000							
Digital value	-.052	.727*	1.000						
GDP growth	-.188	-.198*	-.188	1.000					
Inflation	-.114	.139	-.111	.041	1.000				
Private credit	-.371*	.642*	.486*	.081	.122	1.000			
Trade openness	.301*	.349*	-.055	-.139	.061	.071	1.000		
Log GDP pc	.339*	.677*	.561*	-.234*	-.025	.512*	.175	1.000	
Population growth	.254*	-.517*	-.472*	.147	-.062	-.611*	-.038	-.563*	1.000

Note. * $p < .05$. Coefficients are pairwise Pearson correlations. Log GDP pc = natural logarithm of GDP per capita.

The Pearson pairwise correlations are given in Table 3. The correlation between bank z-score, internet use and mobile and internet banking transaction value were both small, positive and negative. Private-sector credit was significantly negative, whereas trade openness ($r = .301$), logged GDP per capita ($r = .339$), population growth ($r = .254$) were significantly positive, all associated with bank Z-score. These bivariate relationships only describe association but do not include country-specific effects and panel error structure.

The internet use and the value of mobile/internet banking transactions are the regressors that are the closest ($r = .727$) positively correlated. Logged GDP per capita and private-sector credit also had a positive association with internet use ($r = .677$ and $r = .642$ respectively). Log private sector credit ($r = -0.611$) and logged GDP per capita ($r = -0.563$) were negatively correlated with population growth. There were several moderate associations that were greater than .80. The correlation matrix thus points to related dimensions to explain the variables, but does not identify a problem with pairwise "Extreme Multicollinearity".

The correlation structure is also a reason for estimation of a multivariate model for the panels. Transaction value and income were the variables that were highly positively linked to Internet use, but both digital penetration and population growth were highly positively linked to private-sector credit. Therefore, the linear relationship between each predictor and the Bank Z-score could be due to some shared variation with other economic variables. The panel regressions are thus more informative, as they estimate the partial association of the remaining covariates given

the observation of each specific variable whilst holding the other variables constant, and in the FE specification, controlling for unobserved country characteristics that are not time varying.

4.3 Random-Effects and Fixed-Effects Models

Table 4 Random-Effects and Fixed-Effects Regression Estimates

Predictor	RE B (SE)	p	FE B (SE)	p
Internet	0.111 (0.031)	< .001	0.054 (0.029)	.062
Digital value	-0.049 (0.016)	.002	-0.037 (0.020)	.071
GDP growth	0.064 (0.105)	.545	0.143 (0.091)	.121
Inflation	-0.046 (0.029)	.115	-0.056 (0.031)	.076
Credit	-0.260 (0.033)	< .001	-0.085 (0.048)	.079
Trade	0.035 (0.041)	.389	-0.081 (0.041)	.053
ln GDP pc	4.841 (0.565)	< .001	2.908 (1.391)	.039
Pop. growth	2.931 (0.709)	< .001	-0.975 (1.197)	.417

Note. Dependent variable = Bank Z-score. RE = random effects; FE = fixed effects; Digital value = value of mobile and internet banking transactions; Credit = private-sector credit; ln GDP pc = natural logarithm of GDP per capita; Pop. growth = population growth.

Table 4 reports the random-effects (RE) and fixed-effects (FE) estimates side by side. The overall R-squared for the joint significance test for the RE model was .687 and was statistically significant at the Wald chi-square(8) < .001. Use of internet was positively related to Bank Z-score (B = 0.111, $p < .001$) with the mobile and internet banking transaction value being negatively related to Bank Z-score (B = -0.049, $p = .002$) under RE. The credit reported by the private sector was negative and significant (B = -0.260, $p < .001$), whereas logged GDP per capita and population growth were positive and significant. However, neither GDP growth, inflation nor the trade openness were significant in the RE specification.

The FE model was also jointly significant, $F(8, 92) = 3.89$, $p = .0005$, with a within R-squared of .253. The estimated country effects became less aggressive after controlling for country heterogeneity that is fixed. Logged GDP per capita was still positive and statistically significant (B = 2.908, $p = .039$). Internet use, transaction value, inflation, private-sector credit and openness of trade were near significance norms; however, they failed to meet the criterion of $p < .05$. According to the FE estimate of rho, a big portion of the variance in the residuals was due to country specific effects with an estimated value of .766. A distinction between estimates using FE and RE required formal specification testing.

The difference between the two Specs is material. The magnitudes of several variables seem to be strongly significant in the RE model, but less so in the FE model. This means that some RE association is due to ongoing variations between particular countries (Mexico, Indonesia and Nigeria) and not exclusively to shifts over time within those countries. This means the FE results can more conservatively be used for assessing within-country relationships. Important

results of these tests, however, do not necessarily require a specific model, and thus are central to the final estimation strategy, and that is why they are called the Hausman and the residual diagnostic-tests.

4.4 Model Selection and Diagnostic Tests

Table 5 Panel Model Selection and Diagnostic Tests			
Test	Statistic	p	Interpretation
Hausman test	chi-square(8) = 53.80	< .001	Fixed effects preferred
Modified Wald test	chi-square(4) = 14.45	.006	Groupwise heteroscedasticity present
Wooldridge serial-correlation test	F(1, 3) = 13.936	.034	First-order autocorrelation present

The Hausman test was positive; chi-square(8) = 53.80, $p < .001$ meaning that there was a systematic difference between the FE coefficients and the RE coefficients. The conventional decision rule therefore, favoured RE to the detriment of the FE specification. In addition the following Stata output warned that the variance-difference matrix was not positive definite and thus the Hausman result was used in conjunction with the other specification evidence.

The assumptions made to produce and use conventional panel standard errors were not upheld for the data, as demonstrated in the error diagnostics. The Modified Wald test provided a one degree of freedom chi-square(4) = 14.45, $p = .006$ which indicated group-wise heteroscedasticity of the four country panels. The null hypothesis of a lack of first order autocorrelation was also rejected for the Wooldridge test, $F(1, 3) = 13.936$, $p = .0335$. They should not be used directly to make inferences from the uncorrected FE or RE standard errors as both heteroscedasticity and serial dependence existed. A generalised least-squares specification which included both features was thus estimated.

The diagnoses were significant as both violations can bias traditional standard errors and standard tests. Heteroscedasticity is found when the dispersion of the disturbances varies between national panels, and serial correlation occurs when a disturbance in a given year is correlated with that of the previous year. These features would make the precision in estimated coefficients be exaggerated in a panel of 26 years. Given the nature of the panels and disturbances (mostly heteroscedastic), the corrective GLS model was thus chosen, and panel-specific AR(1) disturbances were used for inference to give credit to the empirical structure revealed by the diagnostic tests as opposed to the restrictive structure of the uncorrected GLS and GMM models.

4.5 GLS Model Controlling for Heteroscedasticity and Serial Correlation

Table 6 Feasible Generalised Least-Squares Estimates

Predictor	<i>B</i>	<i>SE</i>	<i>z</i>	<i>p</i>	95% CI
Internet	0.0508	0.0257	1.98	.048	[0.0004, 0.1011]
Digital value	-0.0078	0.0176	-0.45	.656	[-0.0422, 0.0266]
GDP growth	0.1077	0.0726	1.48	.138	[-0.0346, 0.2500]
Inflation	-0.0127	0.0294	-0.43	.665	[-0.0703, 0.0449]
Credit	-0.1567	0.0367	-4.28	< .001	[-0.2286, -0.0849]
Trade	-0.0099	0.0427	-0.23	.816	[-0.0936, 0.0737]
ln GDP pc	1.7138	0.3596	4.77	< .001	[1.0090, 2.4187]
Pop. growth	1.5917	0.7196	2.21	.027	[0.1814, 3.0021]

Note. Digital value = value of mobile and internet banking transactions; Credit = private-sector credit; ln GDP pc = natural logarithm of GDP per capita; Pop. growth = population growth. FGLS permits panel heteroscedasticity and panel-specific AR(1) disturbances. Wald chi-square(8) = 702.90, $p < .001$; $N = 104$; groups = 4; time periods = 26.

The corrected FGLS model was jointly significant, Wald chi-square(8) = 702.90, $p < .001$. Internet use remained positively associated with financial resilience ($B = 0.0508$, $p = .048$, 95% CI [0.0004, 0.1011]). With all the other variables kept constant, the more that people use the internet, the more positive their Bank Z-scores are. In contrast, there was no statistical significance in the value of mobile & internet banking Transactions after correction ($B = -0.0078$, $p = .656$). The significance of the apparent association would drop to lower significance with respect to the RE model when heteroscedasticity and panel specific serial correlation are taken into account and explicitly modelled.

Private-sector credit was negatively and strongly correlated with Bank Z score ($B = -0.1567$, $p < .001$), while the logged GDP per capita was positively associated with the resilience ($B = 1.7138$, $p < .001$). The growth of population was also a positive and significant value ($B = 1.5917$, $p = .027$). Out of the others, only GDP growth, inflation and trade openness failed to appear significantly. In general, the results of the FGLS indicate that internet penetration, private-sector credit, economic development and population growth are variables that have statistically reliable relationships in the presence of the detected panel-error problems. These results therefore confirm that the corrected GLS estimates are the main results, and that the FE and RE models can be used as specification benchmarks.

Discussion

The results highlight that digital connectivity across the board, rather than the total amount of mobile and internet banking transactions, has a stronger positive link with financial resilience. In the FGLS model, transaction intensity and Internet use appear, both with positive index

values. In the corrected FGLS model, Internet use is still significant (and transaction intensity is not). This separation helps in having a multi-faceted understanding of digital financial inclusion. Connectivity can enhance the informational and operational fabric of the financial sector, provide better access to formal services and facilitate better collaboration between banks and their customers. Like Khera et al. (2022), who highlight the need for both reach and use to become digitally included and digital infrastructure to move from technology towards desirable and valuable financial involvement.

The positive results of the Internet is in line with evidence indicating that digital intangibles can reinforce stability via efficiency and information stream (Nguyen & Du, 2022). In part, financial development in the digital era increases the stability of commercial banks, according to Liang et al. (2025), partially via commercial bank operational efficiency. Digital connection can help bring down the expenses of service delivery, can make it possible to conduct transactions over the internet, allow for real-time tracking, and expand the user base for deposits (Safiullah & Paramati, 2024). In MINT economies, these benefits could be crucial since the branch only models could turn out to be costly, given the vast size of the population as well as the geographic disparities. The level of the coefficient, however, is not particularly high, indicating that connectivity is not a magic bullet of resilience, but also a part of it.

A lower insignificant transaction value coefficient (ITVC) warns against assuming a higher transaction volume in digital finances is necessarily stabilising. It isn't a rule that high transaction volumes will be endorsed when it would be determined that the use of digital assets is a success, but it might also indicate high concentration and platform/cyber risks. However, according to Cevik 2024, the systemic risk potential can be identified alongside efficiency benefits granted by fintech. More generally, Hassan et al. (2025) confirm that digital financial inclusion could even increase banking risks for the Asian economies despite the benefits that it brings to the overall financial stability of the digital economy. The present result confirms that policies should prioritise the quality of the digital financial expansion over increasing the volume of transactions alone, as well as its security and governance.

Notably, the private credit coefficient is negative; that too is another key finding. Rising private credit can help to improve screening practices and enhance investment opportunities, but credit growth could erode it and could lead to high leverage and lead banks to facing reduced loan quality. A key point highlighted by Umar et al. (2025) is that the impact of DFI on financial crises does not remain constant across all phases of financial development and thus could lead to one kind of financial development becoming risky at certain stages. The MINT result, as well, suggests that financial deepening needs to go hand-in-hand with robust prudential regulation, mechanisms for credit information and responsible lending.

The positive association between logged GDP per capita suggests that financial resilience continues to be closely associated with structural development. Fiscal capacity, infrastructure, financial institutions and coping capacity are linked to higher incomes. This also contributes to an understanding of why digitalisation cannot be assessed without a view of development. Digital financial inclusion impacts are found to be heterogeneous across regions in the study of Zhao et al., (2024), and the inclusion–stability relationships depend on country's broader

conditions in the study of Joudar and El Ghmari, (2025). Digital-finance policy should therefore be combined with macroeconomic and institutional development and not be these policies going on in isolation.

Conclusion & Policy Implications

This study investigates the financial inclusion and financial resilience in Mexico, Indonesia, Nigeria and Türkiye, based on a strongly balanced annual panel of 104 observations over the period 2000–2025. The analysis makes it clear that internet penetration is different than the value of mobile and internet banking transactions and controls for GDP growth, inflation, private-sector credit, trade openness, and the logged GDP per capita and population growth. The country heterogeneity and groupwise heteroskedasticity and the serial correlation of the second unit of time are identified by the diagnostic tests, and the corrected specification turns out to be heteroskedastic panels with AR(1) disturbances in the panels.

Overall, the result is that Internet usage is significantly positively linked to the Bank Z score, and the value of mobile and Internet banking transactions have no statistically significant independent effect after correction (Z2 score). Growth in private industry credit is linked to lower resilience, while the growth of logged GDP per capita and population growth are positively related to resilience. In the final specification, the following variables were not statistically significant for GDP growth, inflation and trade openness. The findings thus indicate that resilience advantages of digital financial inclusion are better associated with access to general digital connectivity than access intensity of transactions.

To promote increased availability of reliable, affordable internet services and boost cybersecurity, digital literacy and consumer protection, and build operational resilience (Uddin et al., 2020). The extent of private credit expansion is important in terms of credit quality being monitored by credit regulators as deeper credit markets result in vulnerabilities when standards deteriorate. Growth in transactions should not be an objective itself, but should be used as an effective tool for diversifying deposits and enhancing risk identification and measurement, via the digital channels. Policymakers should also go to greater lengths to better align digital-finance policies with broader development policies involving financial-system quality, institutional development and income gains. The study covers only for four countries and observational-level macro panel data, so next research should test the nonlinear effects in the study, and use structural break dummy and country dummy as an endogeneity control to examine the country-specific dynamics and dynamics under different resilience indicators.

Acknowledgements

The authors have no acknowledgements to declare.

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