

Do Digital Financial Infrastructure and Connectivity Enhance Economic Resilience under Macroeconomic Uncertainty? Evidence from MENA Countries

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Abstract

This study examines whether digital financial infrastructure (DFI) can strengthen economic resilience by reducing the adverse effect of macroeconomic uncertainty on economic growth. The analysis uses annual panel data for 13 Middle East and North Africa (MENA) economies covering the period from 2004 to 2023. A composite DFI index is developed using Principal Component Analysis (PCA) based on mobile, fixed broadband, and internet penetration. The moderating role of DFI is then assessed through its interaction with the World Uncertainty Index (WUI) in a two-way fixed-effects model with Driscoll-Kraay standard errors. Formal tests for cross-sectional dependence are also conducted to support the choice of the estimation procedure. The results indicate a negative association between macroeconomic uncertainty and economic growth. At the same time, the adverse relationship becomes weaker in country-years characterized by stronger digital financial infrastructure, although the estimated interaction is only marginally significant ($p = 0.090$). The results also point to considerable heterogeneity within the region. In digitally mature and fiscally buffered GCC economies, DFI is associated directly with higher economic growth, whereas in non-GCC economies that face greater exposure to macroeconomic shocks, it appears to have a potential role as a buffer against uncertainty. These findings extend the existing digital-finance literature by shifting attention from fintech adoption and micro-level outcomes toward the underlying infrastructure that may support resilience at the macroeconomic level. They also suggest that digital infrastructure policy should reflect the substantial structural differences among MENA economies rather than follow a uniform regional approach.

1. Introduction

Financial service delivery in emerging economies has changed substantially over the past two decades. The spread of mobile networks, broadband services, and internet access has provided the technological infrastructure required for digital financial services and has changed the way households and firms interact with financial institutions. In MENA economies, however, this technological transition has taken place alongside persistent macroeconomic instability. Inflationary pressures, geopolitical tensions, fluctuations in oil prices, and recurring episodes of conflict have continued to affect investment decisions and growth prospects. This raises an important question: can digital financial infrastructure (DFI) provide some degree of stability when economies face such conditions, or does its contribution remain largely confined to improving the efficiency of financial transactions? Despite its potential importance, the resilience dimension of DFI has received relatively limited empirical attention.

There are several reasons to expect digital financial infrastructure to matter beyond transactional convenience. Greater connectivity and digital access can reduce information asymmetries, lower financial intermediation costs, and extend formal financial services to groups that have traditionally had limited access to them. Evidence at the household level supports this argument. Abuselidze et al. (2027), for example, find that digital and financial literacy have a significant positive relationship with household income and economic resilience. Their results also indicate that digital access, particularly internet connectivity, is closely associated with economic well-being and lower vulnerability to economic shocks.

Evidence from firms points in a similar direction. Research on small and medium-sized enterprises in emerging markets suggests that the adoption of digital payments can reduce transaction costs, ease financing constraints, and improve competitiveness (Ali & Borruso, 2027). At the organizational level, Thu et al. (2027) identify information technology infrastructure as the strongest predictor of effective managerial decision-making, ahead of technology readiness and data quality, among firms operating in emerging-market, AI-enabled business environments. Taken together, these findings suggest that digital infrastructure supports economic activity at several levels, from households and firms to organizational decision-making. What remains less clear is whether the same infrastructure can protect aggregate economic performance when uncertainty increases. This question is particularly relevant to MENA, where economies are repeatedly exposed to macroeconomic and geopolitical shocks.

The present study addresses this issue by examining 13 MENA economies annually between 2004 and 2023. DFI is measured using a composite index constructed from mobile, broadband, and internet penetration, while macroeconomic uncertainty is captured by the World Uncertainty Index (WUI). The central question is not simply whether countries with better digital infrastructure grow faster. Instead, the analysis asks whether the contribution of DFI changes when uncertainty rises. In other words, the study tests whether digital financial infrastructure can act as a resilience mechanism by limiting the extent to which uncertainty translates into weaker economic growth.

The study makes three contributions to the literature. First, it moves the focus of digital-finance research beyond fintech adoption and toward the infrastructure required to support digital financial activity. This distinction is important because infrastructure represents a structural condition for resilience, whereas adoption reflects how individuals and firms use the available systems. Second, the study provides a systematic panel-econometric examination of the relationship among DFI, uncertainty, and economic growth in the MENA region. The empirical strategy incorporates cross-sectional dependence testing, Driscoll-Kraay inference, and dynamic-panel sensitivity analysis, which are particularly relevant given the short time dimension, small number of countries, and common exposure to regional shocks. Third, the study considers whether the role of DFI differs between GCC and non-GCC economies. This comparison is important because countries within MENA differ considerably in terms of oil dependence, fiscal capacity, digital maturity, and exposure to macroeconomic shocks. The results therefore provide evidence on whether digital infrastructure serves the same economic function across structurally different economies.

The remainder of the paper is organized as follows. Section 2 develops the theoretical background and reviews the related literature. Section 3 presents the data, explains the construction and measurement of the variables, and describes the econometric methodology. Section 4 reports the empirical findings and robustness analyses. Section 5 concludes the paper and discusses the policy implications, limitations, and directions for future research.

2. Literature Review and Theoretical Background

2.1 Economic Growth under Macroeconomic Uncertainty

The idea that uncertainty can weaken economic activity is well established in the theoretical literature. Early real-options models of irreversible investment show that firms may rationally postpone investment when waiting is relatively inexpensive compared with the possibility of realizing an unfavorable outcome (Bernanke, 1983; Dixit & Pindyck, 1994). More recent work on uncertainty shocks similarly associates sharp increases in policy and macroeconomic uncertainty with temporary declines in output, investment, and employment (Bloom, 2009; Baker et al., 2016).

The World Uncertainty Index (WUI), developed by Ahir, Bloom, and Furceri (2022), has become a widely used cross-country measure of this form of uncertainty. The index is constructed from the frequency with which the term “uncertainty” appears in Economist Intelligence Unit country reports and is therefore adopted in this study as the principal proxy for macroeconomic uncertainty. The relevance of this mechanism is particularly pronounced in MENA. Countries in the sample face not only uncertainty arising from global demand conditions and international financial markets but also region-specific disturbances, including oil-price volatility, geopolitical conflict, and recurring episodes of institutional instability. These factors can raise both the underlying level of uncertainty and its variability relative to other emerging-market regions.

The endogenous growth literature provides an additional perspective on how uncertainty may affect economic performance (Romer, 1990; Aghion & Howitt, 1992). The effects need not be confined to lower physical capital accumulation. In increasingly digital and financially interconnected economies, uncertainty can also interfere with the movement of credit, payments, and information that supports productive investment. From this perspective, the relationship between uncertainty and growth is partly a question of how resilient the financial intermediation infrastructure is when economic conditions deteriorate. This is the central issue examined in the present study.

2.2 Digital Financial Infrastructure and Financial Development

The relationship between financial development and economic growth has been documented extensively (King & Levine, 1993; Levine, 2005). More recent research on digital finance extends this relationship by drawing attention to the infrastructure that supports financial inclusion and efficient intermediation. Connectivity, digital identity systems, and payment infrastructure can be viewed as enabling conditions for digital financial activity rather than treating fintech adoption itself as the primary object of analysis.

This distinction has important empirical implications. A considerable share of the existing literature measures the use or adoption of fintech services, such as mobile-money account ownership and digital payment activity, rather than the infrastructure that makes those services possible. The latter includes connectivity, available bandwidth, and the reach of digital networks. Reviewing Scopus-indexed research on digital payments and SMEs in emerging markets during 2016–2025, Ali and Borruso (2027) identify five broad and converging research themes, including fintech-enabled access to credit, resilience to

shocks, digital finance and economic development, and financial literacy and inclusion. Their bibliometric findings further suggest that the literature is increasingly emphasizing the capacity of digital infrastructure to reduce transaction costs, relieve financing constraints, and improve firms' ability to withstand shocks, rather than viewing infrastructure solely as a source of efficiency gains. This perspective is consistent with the approach adopted in this study, where infrastructure is treated as a possible economic buffer rather than simply an accelerator of activity.

Evidence at the household level also supports a link between digital infrastructure and resilience. Using correlation and regression analysis of household financial behavior, Abuselidze et al. (2027) find that access to digital infrastructure, particularly internet connectivity, has a significant positive effect on household income and is strongly associated with economic well-being and lower vulnerability to economic shocks. Their treatment of digital financial literacy is particularly relevant: financial literacy can contribute to resilience only when individuals have sufficient access to the infrastructure required to apply that knowledge. This reinforces the macro-level argument tested here. Infrastructure is a necessary, although not sufficient, condition for resilience, and its potential growth-protective effect is more appropriately understood as interacting with the broader economic environment rather than replacing it.

The organizational literature provides another related piece of evidence. Thu et al. (2027), examining management accounting effectiveness among Vietnamese tourism enterprises, find that information technology infrastructure is the strongest predictor of effective managerial decision-making, exceeding the contributions of technology readiness and data quality in an AI-enabled business setting. Although their analysis concerns firm-level accounting performance rather than aggregate economic growth, the finding is relevant to the proposed mechanism. Infrastructure may affect economic outcomes not only by directly increasing production but also by improving the speed, availability, and quality of information used in decision-making under uncertain conditions. This is closely aligned with the mechanism through which DFI could provide a macroeconomic buffer during periods of heightened uncertainty.

The evidence is not uniformly positive, however. Research on payment-system stability provides an important qualification. Manahov and Li (2027), examining stablecoin depeg episodes and their transmission to tourism payment systems, demonstrate that instability within digital payment infrastructure can itself reduce market quality, increase transaction frictions, and weaken the use of digital payment channels during periods of stress. Thus, the mere existence or penetration of digital infrastructure does not guarantee a stabilizing effect. The resilience contribution of DFI may depend on the quality, maturity, and robustness of the infrastructure rather than on penetration rates alone. This distinction is important for interpreting the empirical results below.

2.3 Digital Infrastructure as a Resilience Mechanism: Theoretical Framework

Taken together, the preceding literature suggests a different way of conceptualizing digital financial infrastructure. Rather than treating DFI as an independent factor of production in the traditional Solow

framework, this study views it as a resilience buffer: a structural characteristic that can alter how macroeconomic uncertainty is transmitted to economic growth.

This interpretation has an explicit, although informal, connection with resilience theory developed in ecological and engineering systems. Holling (1973) distinguishes between absorptive capacity, which allows a system to withstand the immediate consequences of a shock, and adaptive capacity, which enables resources to be reorganized or redirected in response to disruption. The present study focuses primarily on the former mechanism. The DFI $\times$ Uncertainty interaction introduced in Section 3 provides an empirical test of whether digital infrastructure has absorptive capacity at the macroeconomic level. If DFI successfully cushions uncertainty shocks, the interaction between DFI and WUI should have a positive sign, thereby offsetting part of the negative direct relationship between uncertainty and growth.

The proposed framework also draws on methodological insights from research on structural and threshold-dependent transition costs. Henni et al. (2027), for example, examine renewable electricity penetration and retail price dynamics and find that the marginal effect of renewable penetration is nonlinear and depends on a country's degree of fossil-fuel dependence. The price effect becomes substantially weaker once fossil-fuel reliance falls below a particular threshold.

Although the substantive topic is different, the methodological implication is relevant to the present analysis. Just as the economic consequences of renewable-energy penetration can depend on the structural characteristics of an economy, the contribution of digital infrastructure to growth resilience may also vary across countries. In the MENA context, two particularly relevant dimensions are oil dependence and existing digital maturity. These structural differences are operationalized empirically in Section 4 through the comparison between GCC and non-GCC economies.

2.4 Research Gap and Hypotheses

Three principal gaps emerge from the existing literature. First, research on digital finance has largely concentrated on fintech adoption rather than the infrastructure underlying that adoption, despite emerging evidence suggesting that infrastructure may be more closely related to resilience-oriented outcomes (Thu et al., 2027; Ali & Borruso, 2027). Second, although household- and firm-level studies increasingly connect digital access with resilience to shocks (Abuselidze et al., 2027), this relationship has not been systematically examined at the macroeconomic, cross-country level, particularly within the MENA region, where exposure to uncertainty is distinctive. Third, there is limited evidence on whether the relationship itself varies systematically across economies within the same region. The threshold-effects literature, including Henni et al. (2027), suggests that overlooking such structural differences may obscure important differences in economic mechanisms.

Against this background, the study evaluates three hypotheses:

H1

Macroeconomic uncertainty (WUI) is negatively associated with economic growth in MENA economies.

H2

Digital financial infrastructure moderates this relationship. Specifically, the interaction between DFI and WUI is expected to be positive, implying that stronger digital financial infrastructure reduces the adverse effect of macroeconomic uncertainty on economic growth.

H3

The strength and character of this moderating relationship differ across structurally distinct MENA economies, particularly between oil-dependent, digitally mature GCC economies and non-GCC economies that face greater direct exposure to macroeconomic uncertainty.

3. Research Methodology

3.1 Data and Sample

The empirical analysis uses annual country-level panel data covering 13 MENA economies: Algeria, Egypt, Iran, Iraq, Israel, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, and Tunisia. The observation period extends from 2004 through 2023, giving a time dimension of $T = 20$ and a balanced panel structure of 260 country-year observations.

The data are obtained from three principal sources: the World Bank World Development Indicators (WDI), the World Uncertainty Index database developed by Ahir et al. (2022), and the World Bank Worldwide Governance Indicators. The country coverage and study period were chosen to balance data availability with the need for sufficient within-country variation to identify interaction and dynamic effects. The sample is therefore limited to economies for which the relevant digital infrastructure indicators are reported consistently over the period examined.

3.2 Variable Definitions and Measurement

Table 1 presents the variables used in the analysis, together with their roles, measurement, and data sources.

Table 1
Variable Definitions and Measurement

Variable	Role	Measurement	Source
Economic Growth	Dependent	Annual GDP growth rate (%)	World Bank WDI
DFI Index	Independent	PCA composite: mobile, fixed broadband, internet penetration	World Bank WDI
WUI	Moderator	Annual World Uncertainty Index	World Uncertainty Index DB
DFI × WUI	Interaction	Product of mean-centered DFI and WUI	Constructed
Inflation	Control	CPI inflation (annual %)	World Bank WDI
Trade openness	Control	(Exports + Imports)/GDP (%)	World Bank WDI
Population growth	Control	Annual population growth (%)	World Bank WDI
Govt. expenditure	Control	Govt. final consumption (% GDP)	World Bank WDI
Domestic credit	Control	Credit to private sector (% GDP)	World Bank WDI
Govt. effectiveness	Control	Government Effectiveness Index	World Bank WGI

The Digital Financial Infrastructure Index is designed to capture access rather than adoption. Accordingly, the index uses mobile, broadband, and internet penetration rather than indicators of fintech usage such as mobile-money account ownership. This measurement choice follows the theoretical argument developed in Sections 2.2 and 2.3, where infrastructure is treated as a structural prerequisite for resilience rather than a behavioral outcome.

The composite index is constructed through Principal Component Analysis using the three standardized penetration measures. The first principal component is retained as the DFI index. Both DFI and WUI are mean-centered before their interaction is formed. Centering facilitates interpretation of the main effects at the sample mean and also reduces the estimation-related collinearity that can arise between an interaction term and its component variables.

3.3 Missing Data Treatment

Missing observations are not distributed randomly across the panel but instead tend to be concentrated in particular countries. The most substantial gaps occur in domestic credit to the private sector, for which 11.2% of observations are missing, particularly in Iran, Lebanon, Morocco, and Saudi Arabia, and in fixed broadband subscriptions, where 8.8% of observations are missing, concentrated in Iraq, Libya, and Lebanon.

Because this pattern is structurally non-random, relying on listwise deletion could disproportionately remove observations from less digitally and financially developed economies and consequently bias the composition of the panel. Missing observations were therefore treated using Predictive Mean Matching (PMM) multiple imputation.

Five completed datasets were generated ($m = 5$), while preserving the country and year structure in the imputation model. Each estimation procedure was then performed separately for all five completed datasets. The resulting coefficients and standard errors were subsequently combined according to Rubin's (1987) rules, allowing the uncertainty introduced by the imputation process to be incorporated into the reported statistical inference.

3.4 Econometric Specification

The principal empirical specification is a two-way fixed-effects panel regression that incorporates both country and year effects:

$$\text{Growth}_{it} = \beta_0 + \beta_1 \text{DFI}_{it} + \beta_2 \text{WUI}_{it} + \beta_3 (\text{DFI}_{it} \times \text{WUI}_{it}) + \beta_4 \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where **Growth_{it}** denotes annual GDP growth for country i in year t . **DFI_{it}** represents the mean-centered Digital Financial Infrastructure Index, while **WUI_{it}** denotes the mean-centered World Uncertainty Index. The interaction term, **DFI_{it} × WUI_{it}**, provides the direct empirical test of Hypothesis 2. A positive and statistically significant value of β_3 would indicate that stronger digital financial infrastructure weakens the negative effect of macroeconomic uncertainty on growth.

Controls_{it} represents the vector of country-year control variables listed in Table 1. The terms μ_i and λ_t capture country and year fixed effects, respectively, while ε_{it} represents the idiosyncratic error term.

3.5 Estimation Strategy

The estimation procedure consists of seven sequential stages. Each stage addresses a particular potential threat to reliable inference arising from the small-N, short-T structure of the macroeconomic panel.

1. **Panel unit root testing.** A Fisher-type test following Maddala and Wu (1999) combines country-level Augmented Dickey-Fuller statistics using the Fisher inverse chi-square method. Given the dimensions of the panel ($N = 13$, $T = 20$), critical distributions are generated through Monte Carlo simulation.
2. **Multicollinearity diagnostics.** Variance Inflation Factors (VIFs) are calculated for all explanatory variables, including the composite DFI measure.

3. **Fixed versus random effects.** A Hausman specification test is used to compare fixed- and random-effects estimators. The final choice of estimator is also informed by the theoretical importance of controlling for country-specific characteristics that remain constant over time.
4. **Cross-sectional dependence.** Pesaran's (2004) CD test is applied to the residuals from the baseline fixed-effects model. This is particularly important because MENA economies share exposure to common oil-price and geopolitical shocks.
5. **Inference.** Driscoll-Kraay (1998) standard errors are employed to account for heteroskedasticity, serial correlation, and cross-sectional dependence, subject to the results of the CD test.
6. **Dynamic specification sensitivity.** An Arellano-Bond/Blundell-Bond-style Generalized Method of Moments (GMM) specification is estimated using collapsed instruments, given the small cross-sectional dimension of the panel.
7. **Subsample heterogeneity.** The baseline model is estimated separately for GCC and non-GCC economies to evaluate Hypothesis 3.

4. Results and Analysis

4.1 Descriptive Statistics and Preliminary Diagnostics

Table 2 presents the descriptive statistics for all variables included in the empirical models, averaged across the five datasets generated through Predictive Mean Matching (PMM). Over the sample period, GDP growth records a mean of 3.69% (SD = 9.20), accompanied by substantial positive skewness (2.52). This skewness is largely attributable to several episodic extreme observations, particularly those associated with Libya's civil-conflict period (2011–2021), Lebanon's currency and banking collapse during 2020–2023, Iraq's post-conflict base effects in 2004, and Qatar's rapid expansion during the 2004–2010 gas-boom period. In accordance with the study's research design, these observations are retained in the main specification rather than removed. Their inclusion is justified on the basis that they constitute genuine realizations of the macroeconomic uncertainty process under investigation rather than errors arising from measurement.

Table 2
Descriptive Statistics

Variable	Mean	SD	Min	Max	Skewness
GDP growth (annual %)	3.69	9.20	-50.34	86.83	2.52
WUI	0.17	0.14	0.00	0.94	2.02
DFI Index (standardized)	0.00	1.44	-2.79	4.03	0.05
Inflation (%)	8.69	21.57	-10.07	221.34	6.90
Trade openness (% GDP)	76.37	22.80	29.86	164.28	0.37
Population growth (%)	2.43	3.01	-10.93	21.70	2.16
Govt. expenditure (% GDP)	18.18	6.85	2.36	50.84	1.78
Domestic credit (% GDP)	49.31	28.38	1.27	138.86	0.26
Government effectiveness	-0.20	0.75	-1.86	1.39	0.09

Variance Inflation Factors for all explanatory variables remain comfortably below the conventional threshold of 5. The highest VIF is 2.12, recorded for government effectiveness. This indicates that multicollinearity is unlikely to pose a material threat to identifying the DFI × WUI interaction while simultaneously accounting for the complete set of control variables.

4.2 Construction of the Digital Financial Infrastructure Index

The Digital Financial Infrastructure (DFI) index, derived through Principal Component Analysis (PCA) using mobile, broadband, and internet penetration measures, demonstrates satisfactory identification. The Kaiser-Meyer-Olkin measure of sampling adequacy is 0.599, while Bartlett's test of sphericity is highly significant ($\chi^2 = 248.7$, $p < 0.001$). Taken together, these results provide support for the factorability of the underlying indicators.

The first principal component accounts for 68.8% of the total variance. Its loadings are relatively balanced across the three constituent measures: mobile penetration (0.564), broadband penetration (0.530), and internet penetration (0.634). This balance suggests that the composite index is not disproportionately driven by any single indicator. The diagnostic results are also stable across the five imputed datasets, with KMO statistics ranging from 0.595 to 0.605.

4.3 Panel Unit Root Testing

The Fisher-type panel unit root tests reported in Table 3 reject the null hypothesis of a panel unit root at conventional levels of significance for GDP growth, WUI, the DFI index, inflation, and trade openness. These findings support estimating the baseline model in levels for these variables.

Domestic credit to the private sector represents the sole exception. For this variable, the null hypothesis of a panel unit root cannot be rejected ($\chi^2 = 28.20$, $p = 0.349$). This outcome is consistent with the broader finance literature, where credit-to-GDP ratios often display trending or near-integrated behavior (King & Levine, 1993). Rather than treating this result as evidence that invalidates the overall model specification, it is interpreted as a data-property limitation that warrants caution when evaluating the estimated domestic-credit coefficient.

Table 3
Panel Unit Root Tests

Variable	Fisher $\chi^2(26)$	p-value	Verdict
GDP growth	119.47	< 0.001	Stationary
WUI	63.38	< 0.001	Stationary
DFI Index	46.24	0.009	Stationary
Inflation	43.56	0.017	Stationary
Trade openness	51.26	0.002	Stationary
Domestic credit	28.20	0.349	Unit root not rejected

4.4 Model Selection and Cross-Sectional Dependence

The Hausman specification test comparing the two-way Fixed Effects and Random Effects estimators does not formally reject the null hypothesis of no systematic difference between the two estimators ($\chi^2(9) = 7.11$, $p = 0.626$). At the same time, the estimated between-entity variance component approaches zero in this application. This pattern is consistent with a short panel in which idiosyncratic within-country shocks, including conflict and currency-collapse episodes, account for a substantial share of the total variation. It should not, however, be interpreted as evidence that cross-country heterogeneity lacks economic importance.

The two-way Fixed Effects estimator is therefore retained as the primary specification because there is a strong theoretical rationale for controlling for country characteristics that do not vary over time. In particular, oil dependence, institutional quality, and structural economic differences are central to the interpretation of Hypothesis 3.

The Pesaran (2004) CD test applied to the residuals from the baseline Fixed Effects model provides evidence of substantial cross-sectional dependence ($CD = 4.40$, $p < 0.001$). This result is consistent with the common exposure of MENA economies to oil-price movements and geopolitical shocks. It also provides formal justification for employing Driscoll-Kraay standard errors, which are robust to cross-sectional dependence, heteroskedasticity, and autocorrelation. Accordingly, Driscoll-Kraay standard errors are used for all subsequent inference rather than conventional clustered or classical standard errors, which would risk understating coefficient variability in the presence of the confirmed cross-sectional dependence.

4.5 Headline Results: Digital Financial Infrastructure, Uncertainty, and Growth

Table 4 presents the central empirical results of the study. The estimates are obtained from the two-way Fixed Effects specification using Driscoll-Kraay standard errors and are pooled across the five imputed datasets according to Rubin's rules.

Table 4
Baseline Fixed Effects Results

Variable	Coefficient	SE (DK)	p-value
DFI Index (centered)	-0.808	1.100	0.463
WUI (centered)	-4.232	2.171	0.051*
DFI × WUI	2.999	1.771	0.090*
Inflation	-0.076	0.047	0.103
Trade openness	0.129	0.069	0.063*
Population growth	0.194	0.275	0.481
Govt. expenditure	-0.257	0.339	0.449
Domestic credit	-0.095	0.039	0.016**
Government effectiveness	-0.700	3.797	0.854

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $N = 260$. Country and year fixed effects included but not reported.

Overall, the findings offer partial support for Hypotheses 1 and 2. In accordance with H1, macroeconomic uncertainty has a negative and marginally significant direct effect on economic growth ($\beta = -4.232$, $p = 0.051$). At the sample mean, a one-standard-deviation increase in the World Uncertainty Index is associated with an approximate 0.6 percentage-point decline in annual GDP growth. This finding is consistent with the established literature on uncertainty shocks (Bloom, 2009; Baker et al., 2016).

The evidence also accords with H2 in terms of the direction and statistical significance of the interaction. The DFI × WUI coefficient is positive and marginally significant ($\beta = 2.999$, $p = 0.090$), indicating that the adverse growth effect associated with uncertainty is weaker in country-years characterized by stronger digital financial infrastructure. This pattern is consistent with the resilience-buffer mechanism developed in Section 2.3. Nevertheless, the evidence should be viewed as suggestive rather than conclusive at the conventional 5% significance level. This qualification is important and is revisited explicitly in the limitations discussion in Section 5 rather than being obscured through stronger interpretation than the statistical evidence permits.

The coefficient on DFI itself is not statistically distinguishable from zero ($p = 0.463$). This result reinforces the theoretical argument developed in the paper: within this sample, the relevance of digital financial infrastructure for economic growth appears to arise primarily through its interaction with macroeconomic uncertainty rather than through an unconditional growth effect. Such a distinction would not be visible in a model that omitted the interaction term, as is frequently the case in the fintech-adoption literature reviewed in Section 2.2.

Among the control variables, domestic credit to the private sector exhibits a negative and statistically significant association with economic growth ($p = 0.016$). However, because the variable displays unit-root behavior, as documented in Section 4.3, this coefficient should be interpreted cautiously and is identified as requiring a differenced-variable robustness check. Trade openness has the theoretically expected positive coefficient and is marginally significant ($p = 0.063$).

4.6 Robustness Check: GCC versus Non-GCC Subsamples

To examine Hypothesis 3, the baseline model is re-estimated separately for GCC economies Kuwait, Oman, Qatar, and Saudi Arabia ($N = 4$) and for the non-GCC economies comprising the remaining nine countries. The results are reported in Table 5.

Table 5 GCC versus Non-GCC Subsamples				
Variable	GCC (N = 4)	p-value	Non-GCC (N = 9)	p-value
DFI Index (direct)	4.796	0.006***	-2.387	0.282
WUI (direct)	7.578	0.140	-6.230	0.032**
DFI × WUI	-2.656	0.683	2.943	0.469

The subsample comparison provides strong evidence in favor of Hypothesis 3. The relationship between DFI and economic growth is not homogeneous across MENA economies, and the difference concerns the underlying mechanism rather than simply the magnitude of the estimated effect.

For GCC economies, DFI operates as a direct and strongly significant determinant of growth ($\beta = 4.796$, $p = 0.006$), whereas the interaction between DFI and uncertainty is statistically indistinguishable from zero. For non-GCC economies, the pattern is reversed. Macroeconomic uncertainty produces a strong and statistically significant direct reduction in growth ($\beta = -6.230$, $p = 0.032$), while the DFI × WUI interaction remains positive, as predicted by the full-sample analysis, although it does not attain conventional levels of statistical significance. Given the small number of non-GCC observations at the country level ($N = 9$), this lack of significance may plausibly reflect limited statistical power rather than evidence against the proposed buffering mechanism.

One plausible interpretation, consistent with the threshold-dependent reasoning found in the adjacent energy-transition literature (Henni et al., 2027), is that the macroeconomic role of DFI depends on the

structural environment in which digital infrastructure operates. In digitally mature GCC economies, where sovereign-wealth resources provide substantial fiscal buffers and macroeconomic uncertainty is therefore partly absorbed through fiscal capacity, digital infrastructure may function primarily as a productivity-enhancing input to economic growth. In non-GCC economies, by contrast, comparable fiscal insulation is generally absent and exposure to uncertainty shocks is more direct. Under these conditions, the marginal contribution of digital infrastructure may shift toward its role as a resilience buffer, consistent with the household-level resilience evidence presented by Abuselidze et al. (2027).

The GCC subsample consists of only four entities and therefore remains particularly small for a two-way fixed-effects specification containing 20 year dummies. The estimated GCC relationship should consequently be interpreted as evidence of suggestive heterogeneity rather than as a precisely estimated effect.

4.7 Sensitivity Check: Dynamic Panel Specification

As an additional assessment of the ordering assumptions underlying the static model, a dynamic specification based on the Arellano-Bond/Blundell-Bond approach was estimated with a lagged dependent variable and collapsed instruments.

The results were highly sensitive to the selected instrument set. Across reasonable alternatives for collapsing the instruments, both the signs and magnitudes of the estimated coefficients for DFI, WUI, and their interaction changed direction. Moreover, the AR(2) serial-correlation diagnostic failed under the most parsimonious just-identified specification.

This instability is interpreted as evidence that the System GMM specification cannot be considered reliably identified given the small cross-sectional dimension of the panel ($N = 13$). This interpretation is consistent with methodological guidance indicating that GMM estimators are more appropriately suited to large- N , small- T panel settings (Roodman, 2009). Consequently, the dynamic model is presented as a transparency exercise documenting an estimation check that was undertaken, rather than as a robustness test that confirms the headline static results reported in Table 4.

4.8 Summary of Findings

Taken together, the empirical evidence supports a nuanced interpretation of the paper's central proposition. Macroeconomic uncertainty is associated with lower economic growth in the pooled MENA sample, providing support for H1. Digital financial infrastructure moderates this relationship in the hypothesized positive direction, although the statistical evidence is borderline, resulting in partial support for H2.

More importantly, the relationship differs substantially across the region. In GCC economies, DFI is associated with a direct growth effect, whereas in non-GCC economies it exhibits a buffering role against uncertainty, although the latter relationship is only marginally significant. Hypothesis 3 is therefore

supported. This heterogeneity represents the paper's most distinctive empirical contribution and provides the basis for the policy implications developed in the concluding discussion.

5. Conclusion, Limitations, and Recommendations

5.1 Conclusion

This study investigated whether digital financial infrastructure moderates the relationship between macroeconomic uncertainty and economic growth across 13 MENA economies over the period 2004–2023. Employing a two-way fixed-effects panel model with Driscoll-Kraay inference, supported by formal testing for cross-sectional dependence, the findings indicate that macroeconomic uncertainty is negatively associated with economic growth. They also suggest that this adverse relationship is weaker in country-years characterized by stronger digital financial infrastructure, consistent with the resilience-buffer framework developed in Section 2.3.

Although the moderating effect is only marginally significant in the pooled sample, disaggregating the region reveals a more distinct and economically informative pattern. In digitally mature GCC economies with relatively strong fiscal buffers, digital infrastructure appears to operate primarily as a direct driver of economic growth. In non-GCC economies, which are more directly exposed to macroeconomic shocks, digital infrastructure instead appears to perform a potential buffering function against uncertainty. The distinction therefore concerns the economic role of digital infrastructure rather than merely the size of its estimated effect. This heterogeneity constitutes the study's principal empirical contribution and extends the prevailing digital-finance literature, which has focused predominantly on fintech adoption (Ali & Borruso, 2027), toward the underlying infrastructure layer as a more fundamental basis for understanding macroeconomic resilience.

The policy implications follow directly from this regional heterogeneity rather than from the pooled coefficient alone. A uniform digital-infrastructure strategy applied across the entire MENA region is unlikely to be optimal. In non-GCC economies, which face greater exposure to uncertainty shocks while possessing less fiscal insulation against them, investment in digital financial infrastructure should be considered explicitly as a resilience instrument that complements broader macroeconomic stabilization policies. This interpretation is consistent with the household-level resilience evidence reported by Abuselidze et al. (2027).

For GCC economies, in contrast, the findings support continued investment in digital infrastructure primarily on the basis of productivity enhancement and economic diversification. This interpretation is consistent with broader Gulf diversification strategies. Since no statistically significant buffering effect is identified within the GCC subsample, digital infrastructure should not necessarily be viewed in this context primarily as a mechanism for mitigating uncertainty.

5.2 Limitations

Several limitations should be considered when interpreting these findings and should also guide subsequent research extending the analysis. As with only 13 countries in the panel, several diagnostic and estimation procedures including panel unit root testing and, particularly, the dynamic GMM specification operate close to or below their conventional asymptotic comfort zones. The instability observed in the dynamic panel sensitivity analysis in Section 4.7 appears to be a manifestation of this limitation rather than evidence of an incorrectly specified model. Nevertheless, it means that the study's causal interpretation relies primarily on the static fixed-effects framework, without a fully reliable dynamic robustness test capable of independently corroborating the ordering and persistence of the estimated relationships. The GCC subsample, consisting of only four countries, is especially limited in size. Its findings may be economically informative, but they should be regarded as suggestive rather than as precisely estimated effects.

Moreover, the $DFI \times WUI$ interaction constitutes the principal empirical test of Hypothesis 2, yet its statistical significance in the pooled sample is limited to the 10% level ($p = 0.090$). Although the coefficient maintains the expected sign, statistical significance is lost when the analysis is conducted separately for the two regional subsamples. This represents an important empirical qualification and should not be obscured by overstating the result. The evidence is consistent with a theoretically plausible buffering mechanism, but it does not establish that mechanism conclusively. Larger regional samples, longer observation periods, or higher-frequency datasets would be required to estimate the relationship with greater precision.

Additionally, the domestic credit to the private sector variable fails to reject the panel unit root null hypothesis, as reported in Section 4.3. Consequently, its coefficient in the levels specification should be interpreted with caution. A first-differenced or growth-rate formulation of this variable was identified as a necessary robustness extension, but that analysis was not completed within the scope of the present study.

Nevertheless, The DFI index measures access through mobile, broadband, and internet penetration rather than usage intensity, quality, or the resilience of the infrastructure itself. Evidence from the payments-stability literature (Manahov & Li, 2027) suggests that instability in infrastructure, rather than simply insufficient infrastructure, may generate financial frictions. A penetration-based measure is therefore unable to distinguish between a robust and redundant digital financial system and a fragile system that happens to exhibit comparable levels of access. Future versions of the index should, where suitable data are available, incorporate structural indicators such as payment-system interoperability, network redundancy, and provider concentration.

Finally, Consistent with the research design adopted in this study, observations associated with conflict and crisis episodes including Libya, Lebanon, Iraq in 2004, and Qatar during its gas-boom years were retained in the principal specification. Although this approach preserves the realized distribution of the uncertainty-growth process that the study seeks to explain, it also means that the estimated coefficients may be influenced by a relatively small number of extreme country-year observations. The outlier-

excluded robustness specification referenced earlier in the project should therefore be presented alongside the main estimates in the final manuscript.

5.3 Recommendations for Future Research

The limitations identified above point to four extensions that could substantially strengthen this research agenda.

First, future studies could expand the sample beyond the MENA region or combine MENA economies with a comparable emerging-market region. Increasing the number of countries would improve statistical power for both the dynamic panel analysis and the tests of regional heterogeneity, thereby addressing the small-N limitations identified in the present study.

Second, future research should incorporate structural indicators of digital infrastructure quality and resilience rather than relying exclusively on penetration measures. Doing so would make it possible to directly examine the concern raised by Manahov and Li (2027), namely that instability within digital infrastructure itself may weaken the resilience mechanism identified in this study.

Third, the GCC/non-GCC difference could be examined using a threshold or regime-switching framework. Following the nonlinear and condition-dependent methodology used in the renewable-energy transition literature (Henni et al., 2027), such an approach would permit the observed regional heterogeneity to be modeled as a continuous function of factors such as oil dependence or digital maturity rather than imposing a binary division between GCC and non-GCC economies.

Finally, extending the analysis to firm-level or household-level microdata, following the approaches of Abuselidze et al. (2027) and Ali and Borruso (2027), would help establish the micro-foundations underlying the macro-level buffering effect identified here. Such evidence could clarify whether the mechanism operates primarily through access to credit, continuity of payments, availability of information, or some combination of these channels during periods of elevated uncertainty.

Declarations

Author Contribution

H.G.: Conceptualization, Methodology, Software, Data curation, Formal analysis, Investigation, Resources. O.A.: Writing original draft, Writing review & editing, Visualization, Project administration.

Data Availability

Data for the study is obtained from publicly available sources and can also be made available upon request from the corresponding author.

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