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Assessing The Impact of Fintech Development on Financial Inclusion in the MENA Region: Evidence from Panel Data Models

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ABSTRACT

This study investigated the transitional impact of bank-led FinTech adoption on financial inclusion using a panel of 253 commercial banks across the MENA region from 2008 to 2022. Employing both static models and a System GMM estimator, the findings revealed that, in the short to medium term, digital transaction expansion significantly enhanced the density of physical banking infrastructure, supporting the omnichannel complementarity perspective. Increased digital payment activity promoted credit penetration by reducing information asymmetries between banks and borrowers. Although static estimations suggested a positive relationship between FinTech and account ownership, dynamic estimations indicated a negative long-run elasticity. This contrasting result highlighted a structural substitution effect, whereby advanced FinTech ecosystems increasingly shifted financial activity away from traditional bank accounts toward mobile-first and decentralized payment platforms. The results demonstrated that FinTech affected financial inclusion unevenly across its dimensions and underscored the need for transaction-oriented regulatory frameworks and hybrid banking strategies to foster sustainable financial inclusion in the MENA region.

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1. INTRODUCTION

One of the most transformative forces recently emerging in the global financial ecosystem is financial technology, or FinTech. Broadly defined, FinTech refers to the use of innovative digital technologies to deliver financial services in a more efficient, affordable, and inclusive manner. Its expansion has reshaped traditional banking models and introduced new channels through which individuals and businesses can access credit, save and transfer money, make payments, and insure against risk. This innovation wave is particularly significant in regions with underdeveloped financial infrastructure or large segments of the population excluded from formal financial systems.

A key development challenge that FinTech is expected to address is financial inclusion, understood as the availability and effective use of affordable financial services, especially for historically underserved populations. Financial inclusion is widely recognized by global development institutions as a crucial driver of sustainable growth and poverty reduction, as it enables households and firms to smooth consumption, save securely, invest, and withstand economic shocks. However, despite substantial international efforts over the past two decades, large segments of the population - particularly in low- and middle-income regions- remain financially excluded. In this context, FinTech has increasingly been regarded as a mechanism capable of reaching marginalized groups cost-efficiently and at scale.

Despite this potential, the relationship between FinTech and financial inclusion remains theoretically and empirically ambiguous. While digital innovation may reduce barriers to access, its effectiveness depends on broader economic, institutional, and technological conditions. Unequal internet access, limited digital literacy, and regulatory or socio-cultural constraints may restrict or even offset the expected benefits of digital financial solutions, making the overall impact of FinTech on inclusion highly context-dependent and far from settled.

Therefore, while the literature examining the nexus between financial technology and financial inclusion has grown exponentially, two critical gaps remain unaddressed, which this study systematically resolved. First, there was a micro-institutional granularity gap. In fact, the vast majority of empirical studies (Allen et al., 2016; Demirgüç-Kunt et al., 2022; Ozili, 2018) evaluated financial inclusion using macro-level, aggregate country indicators (such as Findex data). While informative, country-level analyses operated as a "black box," treating the financial sector as a homogenous monolith. They failed to capture how individual banking institutions adapted their asset structures, physical networks, and credit allocation strategies in response to digital payment shocks. By deploying an extensive bank-level dataset of 253 institutions, this study bridged the macro-micro divide, observing the transmission mechanism of FinTech from the lens of institutional supply-side dynamics. Second, there was an empirical ambiguity and multi-dimensionality gap. Prior regional studies frequently relied on a single, isolated proxy for financial inclusion (account ownership), leading to overgeneralized conclusions. However, financial inclusion is inherently multi-dimensional, spanning physical access, usage, and depth/quality. Existing empirical work rarely tracked how a single FinTech shock can simultaneously trigger opposing dynamics, such as complementing physical infrastructure while substituting traditional deposit accounts. This study addressed this gap by executing a multi-faceted assessment across four distinct dimensions of inclusion within a unified econometric framework.

This ambiguity was particularly pronounced in the Middle East and North Africa (MENA) region. The MENA region served as a compelling, paradoxical laboratory that challenges conventional assumptions about digital finance for several institutional reasons: the MENA region exhibited some of the highest mobile connectivity and smartphone penetration rates globally, yet it simultaneously suffered from the world's largest financial inclusion gap, where over 50% of adults remain unbanked, and small- and medium-sized enterprises (SMEs) faced severe credit rationing. This stark disconnect implied that technological availability did not automatically translate into financial access, rendering the region an ideal setting to test the frictions governing FinTech transmission. Also, the region was structurally characterized by deeply entrenched informal cash economies and a pervasive deficit in institutional trust. Testing FinTech here allowed us to evaluate whether digital payments acted as a powerful formalization mechanism or if traditional cultural preferences for physical cash-out points froze the expansion of digital ecosystems. Unlike East Africa, where telecom-led models (e.g., M-Pesa) bypassed banks, or Western economies with decentralized FinTech platforms, digital financial transformation in the MENA region was heavily regulated and inherently bank-led. Commercial banks either developed internal digital platforms or partnered closely with FinTechs. Our bank-level data matched this institutional design. Although the region had witnessed a rapid expansion of FinTech activities and digital banking initiatives, financial inclusion levels remained persistently low, especially among women, rural populations, and informal workers. Structural features -such as the dominance of traditional banking institutions, uneven digital infrastructure, and fragmented regulatory frameworks- further complicated the interaction between digitalization and financial inclusion. These features created a paradoxical environment in which FinTech development was growing rapidly, yet financial exclusion remained widespread.

Within this context, a central scientific problem arose: whether FinTech adoption within bank-based financial systems effectively enhanced financial inclusion, or whether it primarily reshaped existing financial structures without substantially reducing exclusion. Addressing this problem was particularly relevant for MENA economies, where ambitious digital finance strategies coexisted with persistent structural barriers and limited empirical evidence on their actual inclusiveness.

In light of the aforementioned gaps, this study advanced the existing empirical literature in three distinct ways. First, we introduced a heightened level of methodological rigor designed to systematically counter the pervasive issue of reverse causality and endogeneity. Unlike earlier cross-sectional or static panel studies conducted within the MENA context, this study deployed a dynamic System Generalized Method of Moments (GMM) framework. This advanced econometric technique explicitly controlled for the high persistence characterizing financial development indicators. More importantly, it effectively addressed severe endogeneity biases, such as the inherent reverse causality where higher initial credit penetration or denser banking infrastructure might naturally accelerate the adoption of digital payment systems, rather than vice versa. Second, this research benefited from an unprecedented longitudinal depth and a highly granular sample horizon. By tracking 253 individual commercial banks across an unbalanced panel spanning from 2008 to 2022, our dataset encompassed several critical macroeconomic and institutional cycles. Specifically, the data captured the structural realignments of the post-Arab Spring era, as well as the unprecedented acceleration of digitalization triggered by the COVID-19 pandemic. This extensive institutional framework allowed us to observe long-term supply-side behaviors that aggregated macroeconomic data fail to capture. Finally, this study provided granular policy and operational insights by moving away from uniform assumptions regarding technological impacts. By isolating and contrasting

the distinct elasticities of FinTech across four separate dimensions - namely automated teller networks, branch density, bankarization rates, and credit penetration- this study fundamentally shifted the regional academic discourse. Instead of merely questioning whether FinTech promotes financial inclusion, this comprehensive framework uncovered where and through which specific channels its impact was optimized, and where it faced institutional or structural constraints within developing financial ecosystems.

The remainder of the paper is organized as follows. Section 1 discusses the theoretical foundations, reviews the existing literature, and formulates the research hypotheses. Section 2 reports the data and the methodology on which this study relies by presenting its theoretical and empirical framework. Afterwards, section 3 provides the empirical results by underlining the main insights from our analysis. Section 4 outlines robustness tests. Finally, the paper concludes with all the results summarized and a discussion on the theoretical and practical implications of this research, mentioning suggestions for further work.

2. LITERATURE REVIEW

The relationship between FinTech development and financial inclusion has attracted growing attention in both theoretical and empirical research. Existing studies examined this nexus through multiple perspectives, ranging from technological innovation and cost reduction to institutional quality and digital literacy. However, the evidence remains mixed, with findings varying across countries, financial systems, and empirical approaches. This section reviews the literature by first examining the theoretical mechanisms linking FinTech to financial inclusion, then discussing empirical evidence documenting positive effects, followed by studies highlighting limitations, risks, and heterogeneous outcomes across contexts.

To transition from a descriptive analysis of the FinTech-financial inclusion nexus to a mechanism-driven framework, this study anchored its empirical investigation within four cornerstone economic and technological theories: Financial Intermediation Theory, Technology Acceptance Frameworks, Financial Exclusion Theory, and Digital Finance Ecosystem Frameworks.

Traditional financial intermediation theory, pioneered by Gurley and Shaw (1960) and refined by Diamond (1984), posited that financial institutions exist to minimize transaction costs and resolve market imperfections, specifically asymmetric information (adverse selection and moral hazard). In conventional banking systems, mitigating these asymmetries required collateral, formal credit histories, and physical monitoring, which inherently excluded large segments of the MENA population. FinTech development fundamentally altered the economics of intermediation. By leveraging big data analytics, machine learning algorithms, and real-time transaction tracking, digital financial technologies lowered information gathering and processing costs. Digital payments generated granular, high-frequency "digital footprints" or alternative transactional data. According to information economics, this digital footprint acted as a signaling mechanism that substituted for traditional collateral, allowing banks to perform credit scoring for previously unbanked or informal agents, thereby expanding credit penetration.

Technology acceptance frameworks, particularly the Technology Acceptance Model (TAM) of Davis (1986) and the Unified Theory of Acceptance and Use of Technology (UTAUT2) of Venkatesh et al. (2012), provided additional explanations regarding the adoption of digital financial services. These theories suggested that perceived usefulness, ease of use, accessibility, and trust significantly influenced

individuals' willingness to adopt financial technologies. In the context of financial inclusion, digital payment systems may encourage financially underserved populations to engage with formal financial services by reducing procedural complexity, increasing convenience, and lowering usage costs. Consequently, FinTech adoption may stimulate greater participation in banking and credit activities.

The Financial Exclusion Theory (Kempson & Whyley, 1999) categorized the barriers preventing individuals from accessing formal financial systems into geographical exclusion, access exclusion (prohibitive costs/documentation), and marketing exclusion. Traditional bank-based systems in the MENA region suffered from severe geographical and cost-related barriers due to the high capital expenditure required to establish physical branch networks. From this theoretical perspective, FinTech acted as a disruptive mechanism that deconstructed physical entry barriers.

Finally, to understand the multi-dimensional impact of FinTech across various proxies of inclusion, we deployed the Digital Finance Ecosystem Frameworks (Ozili, 2018). This theory explored whether digital financial innovations operated as a complement to or a substitute for traditional banking architectures. On one hand, Complementarity Theory implied that digital payment systems expanded the volume of formal financial interactions, thereby increasing the operational viability of physical delivery channels. Higher digital transaction volumes generated a residual demand for liquidity cash-out points, expanding automated teller networks and requiring physical branches to manage trust, customer onboarding, and complex financial advisory services, especially in areas with lower digital literacy. On the other hand, the Substitution Theory (or institutional disintermediation) suggested that agile, non-bank FinTech platforms (mobile wallets, third-party payment providers) captured transaction flows directly, reducing individual reliance on traditional core commercial bank deposit accounts. This theoretical tension was vital to explaining why digital payment adoption might simultaneously expand physical access metrics and credit reach, while inducing a contraction or substitution effect on conventional bankarization ratios.

From a conceptual perspective, FinTech is widely regarded as a tool capable of addressing structural inefficiencies inherent in traditional banking systems (Yeyouomo et al., 2023). Digital credit, mobile money, blockchain solutions, and online banking platforms were argued to facilitate faster, more affordable, and more flexible financial services, thereby broadening access for marginalized populations (Tiony & Yin, 2024). By lowering transaction costs and simplifying account ownership, FinTech can reduce social and geographic barriers to financial participation, particularly in rural and low-income areas (Yang & Zhang, 2022). Mobile money, in particular, has been identified as a key channel through which financial services can reach remote communities, enabling more consistent use of payments, savings, and credit services (Shaikh et al., 2023). As a result, FinTech is often viewed as a cost-effective alternative for individuals excluded from formal banking due to administrative, financial, or geographic constraints.

Empirical evidence from various regions supported these theoretical insights. Studies focusing on Asia and other emerging economies documented that the expansion of mobile money and digital financial platforms had significantly increased financial inclusion, especially among rural and low-income populations (Bhattacharyya et al., 2021). Cross-country analyses further indicated that the impact of FinTech was not uniform across economies. While some global studies found no statistically significant average effect, FinTech adoption tended to exert a positive and significant influence in developing countries, suggesting that digital finance may be particularly effective in contexts characterized by limited traditional financial

infrastructure (Cevik, 2024). These findings underscored the importance of complementary factors such as regulatory frameworks, financial education, and institutional quality in shaping FinTech's inclusiveness (Amnas et al., 2024; Kumar et al., 2023; Panos & Wilson., 2020; Ravikumar et al., 2022).

Despite these generally positive assessments, a growing strand of the literature cautions against an overly optimistic view of FinTech's role in financial inclusion. Several studies have emphasized that unequal access to digital infrastructure and limited digital literacy may prevent vulnerable populations from benefiting from FinTech innovations, potentially reinforcing existing inequalities (Khatib et al., 2022; Bongomin et al., 2025). Algorithmic decision-making and automated credit scoring systems have also raised concerns, as they may inadvertently disadvantage individuals with limited digital footprints, including women, older adults, rural residents, and minority groups (Sharma & Munjal, 2024). Consequently, the inclusiveness of FinTech solutions appeared highly contingent on broader structural, technological, and institutional conditions (Zheng et al., 2023; Dagnachew & Mawugatie, 2022).

Recent empirical studies have further refined these insights by developing composite indicators to capture digital financial inclusion across countries and regions. Using principal component analysis, Khera et al. (2021) constructed a Digital Financial Inclusion Index for developing economies and found that digital finance contributed significantly to overall inclusion, with digital indicators often outperforming traditional ones. Large-scale panel studies similarly reported that increases in mobile money adoption and digital transactions were associated with higher levels of account ownership, savings behavior, and credit usage (Sharma & Munjal, 2024; Patnaik et al., 2023). Regional evidence reinforced these conclusions, with studies documenting positive effects of digital financial services on inclusion outcomes in South Asia, North Africa, and other emerging regions (Bajpai, 2024; Kerouat, 2024; Ocharive & Iworiso, 2024; Amnas et al., 2024; Khan et al., 2023; Ediagbonya & Tioluwani, 2023).

However, empirical findings remained far from unanimous. Some studies reported substitution effects between digital and traditional financial services, whereby increased FinTech adoption was associated with reduced usage of conventional banking products such as loans, deposits, branches, or ATMs (Kamara & Yu, 2024; Gyamerah & Tetteh, 2024). Evidence also suggested that digital lending and machine-learning-based credit scoring may exacerbate exclusion by penalizing vulnerable groups or amplifying risk differentiation in the absence of adequate regulation (Kumar et al., 2023; Cevik, 2024). These contrasting results highlighted the heterogeneity of financial ecosystems and the critical role played by contextual factors, including regulatory quality, market structure, digital infrastructure, and literacy levels (Asif et al., 2023; Okičić & Kokorović Jukan, 2023).

The literature has indicated that FinTech holds substantial potential to enhance financial inclusion, yet its effects varied considerably across technologies, populations, and institutional settings (Ong et al., 2023; Chen et al., 2024). While the prevailing evidence pointed to generally positive outcomes, persistent challenges and contradictory findings have suggested that FinTech does not automatically translate into greater inclusiveness, particularly in developing regions (Daud et al., 2022; Bajunaied et al., 2023).

Drawing on the theoretical arguments discussed above, the study developed a set of testable predictions regarding the relationship between digital payments and financial inclusion. Based on the Digital Finance Ecosystem Theory, the relationship between digital financial technology and physical brick-and-mortar

infrastructure can follow a complementary trajectory. While digitization reduced the necessity for routine face-to-face transactions, it simultaneously increased the aggregate velocity of money and formal financial system participation. According to the complementarity hypothesis, an expansion in digital payments sparks a heightened need for physical cash conversion and liquidity access points, particularly in developing networks where cash-dominant cash-out behaviors persist. Furthermore, under Financial Exclusion Theory, branches ceased to be transaction processors and instead transformed into human hubs for onboarding, building trust, and providing digital literacy training to marginalized segments. Therefore, we hypothesized:

H1: FinTech development is positively associated with ATM density in the MENA region.

H2a: FinTech development positively affects bank branch density through a complementarity (onboarding and digital literacy) effect.

H2b: FinTech development negatively affects bank branch density through a substitution (network rationalization) effect.

The impact of digital transactions on formal bank account ownership can be theoretically evaluated through competing lenses: network expansion versus institutional substitution. In a bank-led financial system like the MENA region, digital payment integration facilitated account usage by eliminating transactional frictions and reducing account maintenance costs (Financial Exclusion Theory). However, under the Substitution Theory, rapid digital innovation enabled non-bank actors and decentralized digital wallets to disintermediate traditional commercial banks. Individuals can execute transfers, pay bills, and store value digitally without maintaining a traditional deposit account. To capture this theoretical tension and test the bank-led digital ecosystem efficiency, we formulated:

H3: FinTech development significantly influences formal bank account ownership in the MENA region.

By mobilizing the Financial Intermediation Theory, the nexus between digital payments and credit penetration was fundamentally driven by information asymmetric mitigation. Traditional banking models excluded potential borrowers due to the "hard information" deficit (lack of formal income statements, auditing records, or collateral). FinTech adoption transformed this paradigm. A rising volume of digital transactions converted opaque economic activities into transparent, verifiable electronic records. This transaction-based screening provided banks with alternative data stream to evaluate creditworthiness, model cash flows dynamically, and lower screening costs, thereby extending loans to previously rationed credit applicants (Financial Exclusion Theory). Admittedly, digital footprints alleviated information asymmetry (Diamond, 1984), thereby facilitating greater credit extension. However, FinTech credit-scoring algorithms may also exhibit higher severity or automatically exclude low-income profiles due to a lack of historical data (algorithmic bias), thus perpetuating credit rationing. Thus, we hypothesize:

H4a: FinTech development positively affects credit penetration by reducing information asymmetry through the use of alternative digital data.

H4b: FinTech development negatively affects credit penetration due to algorithmic risk aversion and the exclusion of low-information borrowers.

3. METHODOLOGY

The sample consisted of 253 banks operating across multiple MENA countries, categorized by size into 102 large banks, 52 medium banks, and 99 small banks. Banks were selected based on the availability of data and their distribution across different countries, ensuring a diverse representation in terms of bank size, ownership structure, and levels of FinTech adoption.

The empirical analysis monitored a multi-country panel layout spanning a 15-year horizon from 2008 to 2022. This specific observation window was intentionally selected based on strict macroeconomic and data availability criteria. First, the year 2008 represented a vital structural break in global and regional banking architectures. By anchoring our longitudinal baseline immediately following the onset of the 2007-2008 Global Financial Crisis, the dataset captured the modern era of structural banking reforms, asset reclassification, and modernized prudential supervision mandates implemented across the MENA region. Second, this fifteen-year window perfectly encapsulated the evolutionary lifecycle of financial technology in emerging markets, moving from a pre-digitization baseline (2008-2012) to the initial emergence of bank-led digital payment frameworks (2013-2018), and finally covering the hyper-accelerated digital adaptation phase triggered by institutional shifts and pandemic-related structural disruptions (2019-2022). Third, the temporal ceiling was bounded at 2022 to guarantee the absolute structural balance of the panel dataset. At the time of this study's systematic data collection, 2022 represented the final fiscal year for which fully audited, verified, and standardized financial disclosures, central bank statistical bulletins, and commercial balance sheet metrics were uniformly available across all 253 sampled banking institutions.

Financial inclusion, the dependent variable, was measured through four proxies widely used in recent studies (Khera et al., 2021; Kamara & Yu, 2024; Kerouat, 2024): the number of ATMs per 100,000 adults (ATM), the number of bank branches per 100,000 adults (BRANCH), adult bank account ownership rate (BANKR), and the credit penetration ratio (PENR), which reflected borrowing activity.

To align our empirical framework with international financial inclusion nomenclature, it was necessary to explicitly operationalize the term "bankarization" (BANKR). While widely employed in francophone economic literature and regulatory reports across the MENA region, international banking literature frequently framed this concept as retail deposit account penetration or formal financial account density. In this study, bankarization did not merely capture the aggregate size of bank balance sheets, but specifically measured the structural capacity of the formal banking system to onboard the civilian population. It was operationalized as the ratio of total retail deposit accounts per 1,000 adults. This metric served as a direct proxy for access and basic usage, reflecting the proportion of the population that has successfully crossed the threshold from cash-based exclusion to formal institutional financial participation.

To capture the depth and usage dimensions of financial inclusion, this study operationalized the Credit Penetration Ratio (PENR). Within international financial economics, this metric served as a standard proxy for credit availability and financial deepening, tracking the structural capacity of the commercial banking sector to funnel capital into the private economy. In our empirical design, PENR was measured as the ratio of total outstanding commercial and retail loans to gross domestic product (Loans/GDP) at the institutional-macro nexus, or alternatively scaled at the bank level as the volume of customer credit distributed per 1,000 corporate and retail clients. While access metrics (such as ATM and BRANCH) merely reflected physical

proximity to financial touchpoints, PENR assessed active usage. It quantified the degree to which formal financing is structurally integrated into the economic activities of households and small-to-medium enterprises (SMEs) within the MENA region. Consequently, examining the dynamic elasticity of DIGPMT on PENR allowed us to evaluate whether bank-led digital transformations succeed in mitigating historical credit rationing, reducing informational asymmetry, and fostering long-term credit depth.

The independent variable, FinTech adoption (DIGPMT), was proxied by the volume of digital payments relative to total financial transactions, capturing the integration of digital technologies into banking services and the degree of client engagement with digital channels. While we explicitly acknowledged that FinTech was an inherently multidimensional phenomenon encompassing diverse technological disruptions, our empirical architecture intentionally prioritized the transactional vector of digital finance. This operational boundary was dictated by two major structural constraints within the MENA region. First, alternative FinTech verticals, such as peer-to-peer (P2P) digital lending, crowdfunding platforms, equity-based crowdfunding, and decentralized platform finance, were still heavily fragmented, highly concentrated in a few specific jurisdictions (UAE and Saudi Arabia), and largely operated outside the standard reporting disclosure mandates of traditional commercial banks. Second, independent mobile wallets and retail digital wallet networks were frequently managed by non-bank electronic money institutions (EMIs) or telecommunication conglomerates, making their micro-level data systematically unavailable for long-term bank-level panel series. Consequently, while DIGPMT served as an excellent, highly reliable, and standardized proxy for the velocity of bank-integrated digital finance, it did not capture the full spectrum of alternative digital ecosystems. Therefore, components directly relating to autonomous digital lending frameworks, marketplace lending, and non-bank platform finance were excluded from the current empirical scope.

Control variables included bank size (SIZE, log of total assets), profitability (ROA, net income over total assets), and operational efficiency (CIR, operating expenses over operating income). Data were collected from the World Bank, Global Findex, Global Data Explorer, and Refinitiv (Thomson Reuters Eikon). To ensure consistency in scale and reduce skewness, all continuous variables were log-transformed.

A detailed description of all variables and data sources is provided in Table 1.

Table 1. Variable descriptions and data sources

Category	Variable	Symbol	Description	Data Source
Dependent variable	Financial Inclusion	FI	Measured through four key indicators : (i) microcredit penetration rate, (ii) adult bank account ownership rate, (iii) number of ATMs per 100,000 adults, and (iv) number of bank branches per 100,000 adults	World Bank, Global Findex
Independent Variable	Financial Technology Development	DIGPMT	Measured by the percentage of digital payments over total financial transactions	World Bank, Global Data Explorer, Global Findex

Category	Variable	Symbol	Description	Data Source
Control Variables	Return on Assets	ROA	Net income divided by total assets, measuring banks' profitability	Refinitiv (Thomson Reuters Eikon)
	Bank Size	SIZE	Natural logarithm of total assets	Refinitiv (Thomson Reuters Eikon)
	Cost-to-Income Ratio	CIR	Ratio of operating expenses to operating income	Refinitiv (Thomson Reuters Eikon)

Source: Authors' contributions.

Financial inclusion indicators (ATM density, branch density, bank account ownership, and credit penetration) were measured at the country-year level. These indicators were merged with bank-level observations based on country and year identifiers, resulting in identical macroeconomic values across banks within the same country-year cell. This multi-level structure may generate within-cluster correlation and lead to downward-biased standard errors if not properly addressed (Moulton, 1990). To address this issue, all estimations used heteroskedasticity-robust standard errors clustered at the country-year level, consistent with multi-level panel data applications in banking and financial inclusion literature. Within any given country-year cell, the baseline macro-inclusion ceiling remained identical across bank observations. Running a standard pooled OLS or uncorrected panel regression on nested data would assume that observations within the same country-year were independent, leading to severely downward-biased standard errors and inflated t-statistics. To completely neutralize this issue, all static panel specifications (Fixed Effects and Random Effects) and Feasible Generalized Least Squares (FGLS) estimations were conducted using Huber-White sandwich standard errors clustered at the country-year level.

The empirical strategy followed a panel data approach. For each financial inclusion proxy, the baseline regression model related FI to DIGPMT and control variables while accounting for bank-specific and time-specific unobserved effects:

$$FI_{c(i)t} = \alpha + \beta_1 DIGPMT_{it} + \beta_2 SIZE_{it} + \beta_3 ROA_{it} + \beta_4 CIR_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

Where $FI_{c(i)t}$ represented the indicator of financial inclusion of the country c (to which bank i belongs) at time t , given that there were four indicators of financial inclusion being studied. By indexing the dependent variable as $c(i)t$, we explicitly accounted for the nested structure of our data, where bank-level observations were nested within country-level macro indicators. The estimation unit remained the bank-year observation (i,t). $DIGPMT_{it}$ represented the number of digital payments of the bank i at time t , which served as the proxy of FinTech. $SIZE_{it}$, ROA_{it} , and CIR_{it} denoted the control variables that captured bank-specific characteristics that were, respectively, bank size, profitability, and operational efficiency. μ_i and λ_t respectively accounted for bank-specific unobserved effects and time-specific unobserved effects. ϵ_{it} was the error term. When estimated using the GMM, the model used internal instruments from the lagged values of the variables in order to adjust for endogeneity and produce reliable estimates. The dynamic model equation was specified as follows:

$$FI_{c(i)t} = \gamma FI_{c(i)t-1} + \beta_1 DIGPMT_{it} + \beta_2 SIZE_{it} + \beta_3 ROA_{it} + \beta_4 CIR_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (2)$$

$FI_{c(i)t-1}$ denoted the lagged dependent variable that captured the over-time persistence of financial inclusion. To isolate the parameters from common macro-economic trends, global cyclical variations, and regional regulatory shocks (such as the 2008 financial crisis thresholds or the 2020 pandemic disruptions), yearly time fixed effects (λ_t) were explicitly introduced via a full set of annual time dummies. This specification helped reduce the risk that the error term violated the assumption of cross-sectional independence, preventing the structural parameters from capturing spurious temporal associations.

In our primary dynamic specifications, the System GMM estimator natively addressed these unobserved common shocks. By utilizing a collapsed instrument matrix and implementing the Windmeijer (2005) finite-sample correction for two-step covariance matrices, the model ensured that the standard errors were fully robust to heteroskedasticity, country-level cross-sectional dependence, and within-cluster correlation. Conceptually, this design perfectly aligned with our research objective. This study did not treat banks as isolated islands; rather, it sought to investigate how bank-level micro-decisions regarding digital transaction enablement (DIGPMT) aggregated and spilled over to influence country-wide societal financial inclusion outcomes. Accounting for the nested error structure guaranteed that our reported positive and negative elasticities were econometrically valid and free from artificial inflation.

Before estimating the regression models, several diagnostic tests were conducted to ensure the econometric validity of the analysis. A summary of the results is presented in Table 2.

Table 2. Diagnostic tests

Test	Method and Hypothesis	Main Results	Conclusion
Multicollinearity	Variance Inflation Factor (VIF) H_0 : No multicollinearity	All VIF < 1.2 (Mean VIF = 1.09)	No multicollinearity detected
Stationarity – First Gen.	Levin-Lin-Chu (LLC) H_0 : Unit root (non-stationary)	ATM, BRANCH, DIGPMT, ROA, SIZE, CIR = Stationary BANKR, PENR = Non-stationary even in first difference	But invalid due to cross-sectional dependence
Cross-sectional Dependence	Pesaran (2007) CD test H_0 : No cross-sectional dependence	CD = 71.35, $p = 0.000$	Strong cross-sectional dependence detected → first-generation tests invalid
Stationarity – Second Gen.	Pesaran (2007) CADF H_0 : Unit root	ATM, BRANCH, DIGPMT, ROA = Stationary at level BANKR, PENR, SIZE, CIR = Stationary after 1st diff.	Retain ATM, BRANCH, DIGPMT, ROA at level; use BANKR, PENR, SIZE, CIR in differenced form
Cointegration	Westerlund (2007) ECM test H_0 : No cointegration	All statistics $p = 1.000$	No long-run equilibrium relationship.
Panel Structure	Fisher F-test H_0 : Pooled OLS is valid	All dependent variables: $p = 0.000$	Reject pooled OLS → Use panel estimators (FE/RE)

Source: Authors' calculations.

To ensure model consistency and prevent spurious regressions, our empirical specifications strictly adhered to the properties revealed by the second-generation Pesaran (2007) CADF stationarity tests. Since the unit root tests indicated that ATM, BRANCH, DIGPMT, and ROA were I(0) (stationary at level), while BANKR, PENR, SIZE, and CIR are I(1) (stationary only after first differencing), we applied a hybrid differencing strategy depending on the econometric estimator used.

For the static estimations, variables identified as I(1) entered the models exclusively in their first-differenced form. Consequently, we estimated two distinct sets of specifications based on the stationarity of the dependent variable:

For I(0) Dependent Variables (ATM and BRANCH):

$$ATM_{c(i)t} = \alpha + \beta_1 DIGPMT_{it} + \beta_2 \Delta SIZE_{it} + \beta_3 ROA_{it} + \beta_4 \Delta CIR_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (3)$$

$$BRANCH_{c(i)t} = \alpha + \beta_1 DIGPMT_{it} + \beta_2 \Delta SIZE_{it} + \beta_3 ROA_{it} + \beta_4 \Delta CIR_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (4)$$

For I(1) Dependent Variables (BANKR and PENR):

$$\Delta BANKR_{c(i)t} = \alpha + \beta_1 DIGPMT_{it} + \beta_2 \Delta SIZE_{it} + \beta_3 ROA_{it} + \beta_4 \Delta CIR_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (5)$$

$$\Delta PENR_{c(i)t} = \alpha + \beta_1 DIGPMT_{it} + \beta_2 \Delta SIZE_{it} + \beta_3 ROA_{it} + \beta_4 \Delta CIR_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (6)$$

Where Δ represented the first-difference operator ($\Delta SIZE_{it} = SIZE_{it} - SIZE_{i,t-1}$). This explicit formulation guaranteed that all variables on both sides of the equations were strictly stationary, thus preserving the asymptotic properties of our static estimators.

For our primary dynamic specifications, the use of the Blundell and Bond (1998) System GMM estimator naturally resolved the stationarity dilemma without requiring manual differencing of the variables. The System GMM framework constructed a simultaneous system of two equations: an equation in levels, which was instrumented by the lagged first differences of the variables, and an equation in first differences, which was instrumented by the lagged levels of the variables. By utilizing this orthogonal dual-system design, the System GMM estimator retained the long-run structural relationships embedded in the level data while systematically neutralizing the unit roots and bank-specific fixed effects through internal differencing. Therefore, model consistency was perfectly preserved, and the long-run equilibrium relationships remained highly meaningful and statistically robust.

4. RESULTS AND DISCUSSION

To establish the statistical validity of the baseline models, a sequence of diagnostic tests was systematically executed. Following the application of the Hausman specification test, the Breusch-Pagan Lagrange Multiplier test for random effects, and the Wooldridge test for serial correlation, the simultaneous presence of both severe heteroskedasticity and first-order autoregressive [AR(1)] autocorrelation was confirmed. Furthermore, to systematically neutralize the potential "duplication bias" arising from nesting macro-level country dependent indicators within a micro-level bank panel, all static specifications were estimated utilizing Huber-White sandwich standard errors clustered at the country-year level. To effectively mitigate

the combined distortion of heteroskedastic error structures, cross-sectional dependence, and within-cluster serial correlation, the models were re-estimated using Feasible Generalized Least Squares (FGLS) with multi-way clustering, as summarized in Table 3.

Table 3. Feasible Generalized Least Squares (GLS) Results

Variable	ATM	BRANCH	Δ BANKR	Δ PENR
DIGPMT	0.2331*** (69.48)	0.5181*** (98.58)	1.6195*** (69.01)	0.2890* (17.29)
ROA	0.0046*** (12.43)	-0.0152*** (-13.35)	-0.0082*** (-4.78)	-0.0094*** (-13.94)
Δ SIZE	-0.2377*** (-48.22)	0.5829*** (52.03)	0.0604*** (4.21)	-0.0006 (-0.06)
Δ CIR	0.0063*** (12.76)	0.0076*** (3.54)	0.0289*** (14.99)	-0.0152*** (-20.25)
Constant	3.5975*** (165.04)	-0.7998*** (-19.79)	-6.4133*** (-49.58)	2.1346*** (20.46)

Note : Z-statistics are reported in parentheses. *** and * denote statistical significance at the 1 and 10% levels, respectively. Δ denotes the first-difference operator applied to integrate I(1) variables in their stationary form, in accordance with the unit root test diagnostics. Standard errors are fully robust and clustered at the country-year level to control for cross-sectional duplication bias.

Source: Authors' calculations.

To fully account for potential reverse causality, time-invariant bank heterogeneity, and the persistent nature of financial indicators, we deployed the two-step dynamic System Generalized Method of Moments (GMM) estimator formalized by Blundell and Bond (1998). This framework constructed an orthogonal dual-system design, combining equations in levels with equations in first differences to resolve non-stationarity without losing underlying structural information. To guarantee the asymptotic efficiency of this estimator and prevent the structural biases associated with "too many instruments" (Roodman, 2009), this study implemented a strict instrument containment protocol. When the cross-sectional units ($N = 253$) were exposed to a multi-year horizon ($T = 15$), unrestricted lag allocation can cause the number of instruments to exceed N , which dangerously weakens the power of overidentification tests and falsely inflates the significance of endogenous parameters. To systematically counter this, we applied two primary remedies across all four specifications. First, the lag structure for endogenous and predetermined instruments was truncated, strictly restricting the framework to use only the second and third deep lags ($t-2$ and $t-3$). Second, we employed the "collapse" sub-command (Arellano & Bond, 1991), which forced the instrument vector to be horizontal rather than blocking it by individual time periods, drastically minimizing the instrument count. Furthermore, because the traditional Sargan statistic was heavily altered by the presence of heteroskedasticity and autocorrelation, we systematically reported the Hansen J-test for overidentifying restrictions as our baseline validity test, alongside the Arellano-Bond AR(1) and AR(2) tests. A failure to

reject the null hypothesis of the Hansen test ($p > 0.10$) confirmed that our restricted instrument pool supported the exogeneity assumption and uncorrelated with the dynamic error term. The empirical outputs resulting from this optimized architecture are summarized in Table 4.

Table 4. System GMM Estimation Results

Variable	ATM	BRANCH	Δ BANKR	Δ PENR
Y_{t-1}	0.9540*** (374.61)	0.9280*** (421.04)	1.3280*** (10.81)	0.9620*** (43.17)
DIGPMT	0.0030** (2.39)	0.0043*** (2.83)	-0.4450*** (-2.85)	0.0230*** (3.33)
ROA	-0.0001* (-1.85)	0.00016 (0.36)	0.8800 (1.14)	-0.0980 (-1.64)
Δ SIZE	-0.0019 (-0.57)	0.0098*** (3.06)	-0.8200** (-2.06)	-0.0740 (-1.32)
Δ CIR	-0.00059 (-0.66)	-0.00026 (-0.33)	-0.1150 (-0.51)	-0.0465* (-1.69)
Constant	0.2150*** (14.72)	0.2670*** (25.23)	41.9200** (2.18)	0.4040 (1.34)
Bank Fixed Effects	YES	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES
AR(1) Test	0.012	0.003	0.021	0.015
AR(2) Test	0.345	0.218	0.196	0.224
Hansen J-Test	0.450	0.284	0.512	0.375
Number of Instruments (J)	32	32	32	32

Note: Z-statistics are reported in parentheses below the coefficients. AR(1) and AR(2) are Arellano-Bond tests for first and second-order serial correlation in the first-differenced residuals. Hansen J-test is a test of over-identifying restrictions. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Source: Authors' calculations.

As detailed in Table 4, the lagged dependent variables for the infrastructure and depth vectors displayed high autoregressive parameters ($\alpha_{ATM} = 0.954$, $\alpha_{BRANCH} = 0.928$, and $\alpha_{PENR} = 0.962$). While parameters approaching unity might superficially trigger concerns regarding dynamic misspecification or a near-unit root process, they represented a structurally coherent economic reality within the MENA

banking framework when contextualized alongside our robust specification tests. From an econometric perspective, extremely high persistence coefficients can emerge as an artifact of overfitting if the instrument count is left unrestricted. However, because our estimation layout forcefully truncated the instrument space through Roodman's (2009) collapse protocol, reducing the total instrument count safely below the number of cross-sectional units, the high values reported were largely protected against instrument proliferation bias. Furthermore, the systematic validity of the Hansen J-tests and the strict absence of second-order serial correlation across these models confirmed that the dynamic specifications were correctly identified and did not suffer from structural misspecification. From an economic and operational standpoint, these high coefficients captured the strong structural inertia and severe adjustment costs that define traditional banking operations: Building brick-and-mortar branches or installing extensive automated teller networks involved massive, irreversible sunk costs, long-term commercial lease agreements, and rigid regulatory approval cycles. Commercial banks cannot scale these networks up or down rapidly in response to short-term market friction. Consequently, current infrastructure density was largely anchored to historical allocations, translating into an operational path-dependency where more than 90% of the current network state is predicted by its immediate past. Also, the credit penetration ratio reflected commercial and retail loan portfolios that were bound by multi-year maturity structures (mortgages, investment credit, and corporate financing). Outstanding loan volumes did not amortize overnight, creating a highly persistent cumulative asset baseline on commercial bank balance sheets. Consequently, rather than indicating statistical vulnerability, these high persistence parameters provided explicit empirical proof of a conditional convergence and gradual adjustment process. This highlighted that while FinTech innovations (DIGPMT) inject dynamic, transformative shifts into the MENA financial ecosystem, their structural transmission operated through highly institutionalized, sticky, and capital-intensive banking frameworks.

For the ATM density model, the GMM estimation revealed a statistically highly persistence effect, evidenced by a lagged dependent coefficient of 0.954. This high autoregressive parameter confirmed that banking infrastructure changes were strictly path-dependent and evolved gradually, given the high sunk costs and long-term capital expenditure commitments required to deploy or decommission automated teller networks. Regarding the focal FinTech proxy, DIGPMT retained a positive and highly significant impact on ATM density. Although the magnitude of the coefficient was naturally compressed compared to the static models due to the absorption of variance by the lagged dependent variable, this finding yielded crucial insights into transitional dynamics. This result confirmed the complementarity trajectory predicted under *H1*: within the MENA context, expanding digital payment channels acts as a catalyst that formalizes economic transactions, thereby amplifying the systemic velocity of money and generating a structural demand for physical liquidity access points. This dual-track evolution refuted the naïve substitution narrative and aligned with the cross-regional findings of Gyamerah and Tetteh (2024) and Yoon et al. (2023).

Following the application of Roodman's (2009) instrument collapse protocol, the dynamic estimation of the BRANCH model exhibited robust specification diagnostics. The Arellano-Bond test confirmed the absence of second-order serial correlation and the Hansen J-test firmly validated the exogeneity of the restricted instrument matrix. With an instrument count safely below our bank sample size, the dynamic elasticity of DIGPMT could be interpreted with considerable confidence. This robust parameter confirmed a persistent complementarity effect (*H2a* is supported whereas *H2b* is rejected), demonstrating that even when accounting for historical endogeneity, digital payment expansion in the MENA region continued to

require a supportive brick-and-mortar physical infrastructure to navigate markets characterized by low digital literacy and high dependency on cash onboarding frameworks (Kumar et al., 2022).

The dynamic estimation focusing on the bankarization ratio (BANKR) revealed a highly innovative institutional phenomenon. The lagged autoregressive coefficient stood at 1.328. In dynamic panels, a persistence parameter exceeding unity structurally reflected a highly non-linear, compounding momentum or a deep structural shift within the banking sector's traditional deposit base. The most compelling revelation of this dynamic model was the sharp, statistically significant negative impact of DIGPMT on the bankarization rate. This complete inversion of the sign compared to the static models provided powerful empirical validation for the disruption and substitution hypothesis. As digital payment volumes scaled up within commercial banks, the proportion of the population holding traditional bank deposit accounts paradoxically decelerated. This negative elasticity captured a profound structural displacement: expanding FinTech ecosystems were actively shifting the gravity center of retail financial activities away from traditional commercial banks toward agile, decentralized, and mobile-based independent platforms (such as mobile wallets, PayPal, or Revolut) (Ha et al., 2025; Mandić et al., 2025). Within many MENA economies characterized by high unbanked segments, these digital vehicles functioned as autonomous financial ecosystems. They allowed users to execute peer-to-peer transfers, settle bills, and store value without ever acquiring formal bank account ownership (Hasan et al., 2021). Because this digital migration induced a partial disintermediation of traditional banking institutions, Hypothesis *H3* was explicitly validated under the dynamic panel specification, confirming that autonomous digital payment solutions stood in a substitutive relationship with traditional bank account ownership, refuting the non-linear substitution patterns identified by Kamara and Yu (2024) and Fernandes et al. (2021).

Finally, the results generated for the credit penetration model (PENR) confirmed a stable dynamic structure. The specification diagnostics were flawless: the Arellano-Bond test confirmed the absence of second-order serial correlation, and the Sargan test confirmed instrument validity. The persistence coefficient remained resiliently high ($\beta = 0.962$). Crucially, the FinTech proxy DIGPMT exerted a positive and significant impact on credit penetration ($\beta = 0.023$). Economically, this relationship demonstrated that digital payment infrastructures served as a powerful engine for softening financial rationing. By capturing extensive data trails regarding payment frequency, income streams, and commercial velocity, FinTech integration built rich digital footprints. Commercial banks systematically exploited these alternative data pools to bypass traditional collateral constraints, optimized algorithmic risk assessment, and accelerated loan approval protocols for previously excluded segments (Feghali et al., 2024). Consequently, the positive and significant coefficients under the dynamic framework resolved the theoretical ambiguity raised in *H4a*, confirming that the information asymmetry mitigation effect ultimately outweighed potential algorithmic risk aversion (*H4b* is rejected).

This part aims at thoroughly discussing the findings of both static and dynamic panel models by identifying key disparities in the results, investigating the possible explanations, highlighting key differences across financial inclusion proxies, comparing them with existing empirical evidence, and deriving the methodological and practical conclusions. The comparative analysis of the findings of both dynamic and static models revealed consistent patterns as well as notable divergences in the way that different proxies of financial inclusion are impacted by FinTech adoption.

When it comes to the bank ATM network's density, the findings demonstrated a positive and statistically significant impact of FinTech on ATM, which indicated that rather than replacing physical financial infrastructure, digital financial services had the potential to complement it and enhanced it by increasing the demand for cash access points. This result was consistent with previous studies such as Khera et al. (2021) and Ozili (2018), which argued that FinTech expansion often increased demand for cash access points, particularly in regions where cash usage remained prevalent. Although this might appear to be theoretically counterintuitive, given the expectations that tend to assume that digital banking tended to lessen the dependency on branches, the results indicated that FinTech seemed to be pursued more as a part of an omnichannel strategy, that is, a business strategy integrating and connecting multiple customer interaction channels such as physical structures, mobile apps, online websites, etc., than as a pure substitution. In this case, banks appeared to be simultaneously expanding both digital and physical access in order to broaden their client base.

The most notable divergence was observed in the case of bankarization ratio (BANKR). While the static model showed a positive effect of FinTech on the bankrization ratio, this relationship was reversed in sign in the dynamic model. This result contrasted with findings reported by Demirgüç-Kunt et al. (2022) and Kamara and Yu (2024), who documented a generally positive role of digital finance in promoting formal account ownership. Rather than reflecting an empirical contradiction, this structural shift captured the dual-phase transmission channel of FinTech adoption within developing financial ecosystems. In the immediate term, bank-led digital payments acted as an operational gateway. When commercial banks rolled out basic digital transaction capabilities, they initially lowered user friction, optimized onboarding costs, and attracted unbanked individuals into the formal system. This initial phase drove a mechanical increase in traditional deposit account registration.

Crucially, when accounting for time persistence and purging historical endogeneity via the System GMM, the relationship shifted into a structural substitution and disintermediation effect. As the volume and velocity of digital transactions scaled up over consecutive periods, the dynamic network effects decoupled from traditional banking interfaces. This shed light on the substitution effect that FinTech had the potential to have on traditional banking rather than complementing it. FinTech can function as a replacement for official bank accounts. In real-world terms, this can be a reflection of the growing importance of the role of non-bank FinTech services, such as mobile wallets and peer-to-peer payment platforms, that served as alternative financial tools and channels allowing users to engage in financial systems without requiring a traditional bank account.

This dynamic substitution was deeply rooted in the institutional and regulatory evolution of the MENA region over the past decade. Following the structural digitization waves (accelerated post-2015 and finalized during the COVID-19 pandemic), multiple central banks in the region (e.g., Tunisia, Egypt, Jordan, and Saudi Arabia) modernized their regulatory frameworks to authorize Electronic Money Institutions (EMIs) and payment service providers (PSPs) independent of traditional commercial banking licenses. Consequently, retail consumers and small enterprises had aggressively migrated toward agile mobile-first ecosystems and independent digital wallets (such as Vodafone Cash in Egypt, eFAWATEERcom in Jordan, or standalone fintech applications). These platforms allowed users to store value, execute peer-to-peer transfers, receive salaries, and settle transactions natively without ever requiring or maintaining a formal, brick-and-mortar deposit bank account. As a result, traditional bank-level

bankarization suffered a deceleration because financial gravity shifts toward decentralized mobile infrastructures. FinTech ceased to be a mere feeder for traditional banks; it emerges as an autonomous, parallel financial ecosystem that actively disintermediates traditional commercial operations (Ha et al., 2025; Kamara & Yu, 2024).

In contrast, the results related to credit penetration are robust across both static and dynamic models. FinTech adoption exhibited a positive and statistically significant effect on the credit penetration ratio, indicating that digital financial innovations enhanced not only access to credit but also its actual usage. This result aligned with prior studies (Kerouat, 2024), which emphasized the role of digital credit platforms, alternative credit scoring mechanisms, and mobile-based microloans in expanding credit access, particularly for underserved populations. The dynamic model further reinforced this relationship by controlling for historical credit usage, thereby providing stronger evidence of a causal effect.

Combined, the results of the different models, static and dynamic, illustrated that FinTech had a multi-dimensional impact on financial inclusion that depends on the context. In the context of the MENA region, the divergence in some of the results reflected real-world complexities in the way FinTech interacted with formal financial inclusion metrics. While FinTech tended to enhance access to financial infrastructure (ATMs and branches) and credit usage, its effect on formal banking participation may be more complex and influenced by multiple other factors, such as user preferences, financial literacy, and the development of digital ecosystems that increasingly functioned outside the traditional banking bounds. Building on these empirical insights that shed light on the complex and evolving role of FinTech in promoting financial inclusion across the MENA region, it becomes essential to consider how future research can adapt to better capture the nuances of FinTech's influence on inclusion.

A critical boundary condition of our empirical findings lay in the results of the Westerlund (2007) framework, which indicated an absence of a long-run cointegrating vector among the variables. Econometrically, this absence of cointegration prevented this study from claiming a stable, permanent long-run equilibrium relationship toward which FinTech and financial inclusion indicators deterministically converge. Consequently, any purely "long-run" structural claims must be interpreted with caution. However, the lack of cointegration did not invalidate the highly significant elasticities captured in our models; rather, it fundamentally redefined their economic nature. In the context of the MENA region, this result yielded two important insights: the financial ecosystems in the MENA region were currently undergoing a rapid, disruptive, and highly fragmented digital transformation. Because institutions, consumer behaviors, and regulatory frameworks were in a continuous state of flux, the relationship between digital transaction adoption (DIGPMT) and societal inclusion metrics represented a short-to-medium-term transitional dynamic rather than a settled steady-state equilibrium. While static long-run cointegration was absent, our dynamic System GMM specifications effectively captured the highly persistent nature of financial inclusion (with lagged coefficients for ATM, BRANCH, and PENR near or exceeding 0.90). This implied that even if a permanent equilibrium vector is missing, short-term digital payment shocks generated powerful, cumulative, and path-dependent adjustments that reshaped patterns of formal financial participation over multiple consecutive periods. By acknowledging the absence of cointegration, we shifted the narrative from a passive long-term structural guarantee to an active, policy-dependent transitional process. The positive impacts on infrastructure and credit access, as well as the substitution effects observed

in bankarization, should be understood as dynamic conditional tendencies characterizing the current era of digital migration.

5. ROBUSTNESS TESTS

To further evaluate the stability of our baseline findings, an additional robustness exercise was conducted by replacing the primary FinTech proxy (DIGPMT) with an alternative measure of digital financial development (Table 5). Specifically, Mobile Banking Adoption (MBANK), defined as the volume of mobile banking and internet banking transactions relative to total banking transactions, was introduced into the dynamic specifications. Due to limited disclosure and reporting practices across the MENA region, information regarding mobile and internet banking transactions was available only for a restricted subsample of commercial banks. Consequently, the robustness analysis was conducted on a reduced panel comprising 87 banks operating across nine MENA countries over the period 2013-2022.

The bank-level longitudinal data for MBANK over the 2013-2022 horizon was systematically extracted from individual corporate sustainability and digital transition disclosures available in the Refinitiv (Thomson Reuters Eikon) database, national central bank digital finance reports, and IMF Financial Access Survey (FAS). By focusing on transactions conducted via mobile and internet banking platforms, this proxy captures the intensity of digital banking usage at the customer interface.

The rationale behind this robustness check was twofold. First, while digital payments represented the most visible dimension of FinTech diffusion, they may not fully capture the broader digital transformation of banking services. Second, mobile and internet banking platforms constituted the primary channels through which customers interact with financial institutions in increasingly digitized banking ecosystems. Consequently, if the baseline results reflected the influence of FinTech development rather than a measurement artifact associated with digital payments alone, the main relationships should remain statistically and economically consistent when MBANK was employed.

Table 5. Robustness Test using an Alternative FinTech Proxy (MBANK)

Variable	ATM	BRANCH	ΔBANKR	ΔPENR
Y_{t-1}	0.951*** (361.42)	0.924*** (395.76)	1.287*** (9.94)	0.956*** (41.88)
MBANK	0.0028** (2.16)	0.0039*** (2.74)	-0.397*** (-2.44)	0.021*** (3.08)
ROA	-0.0001* (-1.44)	0.0002 (0.42)	0.731 (1.03)	-0.084 (-1.39)
ΔSIZE	-0.0015 (-0.48)	0.0091*** (2.88)	-0.751** (-2.01)	-0.068 (-1.24)

Variable	ATM	BRANCH	ΔBANKR	ΔPENR
ΔCIR	-0.0005 (-0.61)	-0.0003 (-0.29)	-0.102 (-0.47)	-0.041* (-1.71)
Constant	0.227*** (13.65)	0.284*** (24.33)	38.517** (2.07)	0.387 (1.28)
Bank Fixed Effects	YES	YES	YES	YES
Time Fixed Effects	YES	YES	YES	YES
AR(1) Test	0.016	0.011	0.024	0.019
AR(2) Test	0.291	0.246	0.183	0.204
Hansen J-Test	0.432	0.318	0.487	0.391
Number of Instruments (J)	29	29	29	29

Note: Z-statistics are reported in parentheses. MBANK denotes mobile banking adoption measured by the volume of mobile banking and internet banking transactions relative to total banking transactions. The models are estimated using the two-step System GMM estimator with collapsed instruments. Δ denotes first-differenced transformations of the dependent variables in models (5) and (6), consistent with their dynamic specification and to ensure model stationarity. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors are fully robust and clustered at the country-year level across all specifications to eliminate cross-sectional duplication biases.

Source: Authors' calculations.

The results reported in Table 5 indicated that the overall conclusions remained remarkably stable. Similar to the baseline specifications, mobile banking adoption exerted a positive and statistically significant effect on ATM density, branch density, and credit penetration. This consistency across alternative proxies mitigated concerns regarding measurement error in the baseline FinTech indicator. More importantly, the negative dynamic effect observed for bankarization remained significant, confirming that advanced digital banking ecosystems may partially substitute traditional deposit account ownership in favor of alternative digital financial channels. The consistency of coefficient signs and significance levels across both FinTech measures provided strong evidence that the findings were not sensitive to the specific operationalization of FinTech development. These results reinforced the central conclusion of this study: FinTech development in the MENA region simultaneously complemented physical banking infrastructure and promoted credit inclusion, while generating a gradual substitution effect regarding traditional bank account ownership. Overall, these results confirmed that our baseline findings were robust to alternative measurements of FinTech development, thereby reinforcing their empirical validity in the MENA context.

6. CONCLUSION

The purpose of this study was to assess the impact of FinTech adoption by banks on financial inclusion in the MENA region using static and dynamic panel data models. By relying on multiple proxies of financial inclusion and controlling for bank-specific characteristics, the analysis provided robust empirical evidence

on the dynamic, short-to-medium-term transitional role of FinTech in shaping inclusive financial systems. Although the absence of structural cointegration precluded the existence of a permanent long-run equilibrium, the highly significant dynamic parameters demonstrated that digital transaction enablement triggers cumulative, path-dependent adjustments across physical and credit dimensions. While the findings confirmed that FinTech adoption acted as an infrastructure catalyst and credit deepener, they simultaneously revealed an active structural substitution effect regarding formal deposit account ownership, highlighting that digital financial innovation did not uniformly affect all inclusion indicators because it negatively affected traditional bank account ownership.

From these empirical insights, several critical strategic and regulatory implications can be formulated. First, FinTech integration within the MENA region should not be treated as a binary choice between pure digital migration and brick-and-mortar liquidation. The confirmed complementarity between digital transaction volumes and physical infrastructure density implied that commercial banking institutions must deploy hybrid, omnichannel frameworks. Physical networks remained indispensable gateway channels for building trust, capturing cash-dependent segments, and onboarding economically vulnerable populations who are transitioning toward digital literacy. Second, the dynamic paradox identified in our bankarization model demonstrated that conventional indicators of financial inclusion were becoming obsolete. Because expanding digital transaction velocities actively displaced traditional formal deposit account holding in favor of decentralized, non-bank digital wallets, monetary authorities must urgently re-engineer regulatory reporting frameworks. Central banks and financial regulators across the MENA region are encouraged to shift from account-centric tracking to transaction-centric metrics, integrating independent Payment Service Providers (PSPs) and Electronic Money Institutions (EMIs) into unified national financial inclusion strategies. Third, the positive elasticity of digital payment adoption on credit penetration underscored that alternative data trails -or digital footprints-effectively mitigate credit rationing. Banks are incentivized to aggressively operationalize these transaction histories via machine-learning risk modeling to safely expand credit access to SMEs and historically collateral-constrained borrowers, transforming technological disruption into a sustainable engine for financial deepening.

Despite the econometric safeguards and the robustness of our empirical findings, this study was subject to specific limitations that open valuable avenues for future academic inquiry. While we successfully addressed initial proxy constraints in our robustness section by testing mobile banking adoption, the primary boundary of our baseline macro-assessment resides in the structural data fragmentation characterizing the MENA region. Due to limited and uneven disclosure practices across regional institutions, our alternative multi-indicator evaluation had to be restricted to a reduced subsample of commercial banks. Furthermore, our empirical design remained inherently bank-centric, meaning it did not fully capture alternative, decentralized, and highly disruptive non-bank dimensions of the broader financial technology landscape, such as standalone peer-to-peer (P2P) lending platforms, crowdfunding infrastructures, and independent telecommunication-led digital wallets that operate outside traditional commercial banking balance sheets.

Future research should aim to bridge this gap by incorporating diversified, multi-indicator proxies or composite indices if disclosure standards improve across the MENA region. Specifically, tracking the direct impact of standalone mobile banking applications, algorithmic digital lending protocols, and crowdfunding infrastructures on bank intermediation will yield a more holistic understanding of financial inclusion

dynamics. Additionally, as central banks in emerging markets gradually deploy open banking APIs and unified regulatory sandboxes, exploring the asymmetric interplay between traditional banking assets and decentralized platform finance will constitute a critical milestone in the contemporary literature. Moreover, the institutional-level focus of the analysis does not account for heterogeneity in digital literacy, infrastructure quality, or consumer behavior across regions. While the use of dynamic panel estimators mitigates endogeneity concerns, the validity of the results remains sensitive to instrument specification.

These limitations open several avenues for future research. Further studies could rely on micro-level or country-specific data to investigate how FinTech affects different demographic groups, such as rural populations, women, or financially vulnerable households. Additionally, future research may benefit from employing advanced analytical techniques, including machine learning and deep learning methods, to capture non-linear relationships and complex interactions inherent in FinTech-driven financial inclusion dynamics.

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8. CONFLICT OF INTEREST STATEMENT

The authors confirm that the manuscript has no actual or potential conflict of interest with any parties, including any financial, personal, or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence or be perceived to influence.

9. AUTHORS' CONTRIBUTIONS

Eya Abidi: Conceptualization, study design, data collection, methodology, investigation, and supervision; **Syrine Ben Romdhane:** Investigation, data analysis, interpretation of results, original draft preparation, theoretical framework development, analytical tools, and formal analysis.

10. DATA AVAILABILITY/SUPPLEMENTARY MATERIALS

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request, subject to the terms and conditions of the original data providers. No supplementary materials are associated with this article.

11. ETHICS STATEMENT

This study was based exclusively on secondary data obtained from publicly available sources and commercial databases. It did not involve human participants, animals, or identifiable personal data. Therefore, ethical approval and informed consent were not required.

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