“Does digital banking adoption mediate the link between public-sector digital maturity and banking stability? Evidence from post-socialist transition economies, with a focus on Ukraine, Armenia, and Kazakhstan”

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DOES DIGITAL BANKING ADOPTION MEDIATE THE LINK BETWEEN PUBLIC-SECTOR DIGITAL MATURITY AND BANKING STABILITY? EVIDENCE FROM POST-SOCIALIST TRANSITION ECONOMIES, WITH A FOCUS ON UKRAINE, ARMENIA, AND KAZAKHSTAN

Abstract

Whether digital transformation in the public sector and in financial services jointly contributes to banking stability – or whether the two strands proceed along parallel trajectories – remains an open empirical question for post-socialist economies undergoing both reforms simultaneously. This study addresses the question in three components. First, a cross-country mediation analysis covers up to 130 economies over 2018–2024 (853 country-year observations), drawing on the World Bank GovTech Maturity Index, the IMF Financial Access Survey, and the IMF Financial Soundness Indicators, with panel OLS, country-clustered standard errors, and bootstrap mediation tests. Second, the results are decomposed via fixed-effect deviations for three post-Soviet economies from distinct EBRD regions: Ukraine, Armenia, and Kazakhstan. Pre-shock GovTech maturity is positively associated with digital banking adoption ($\beta = +2.91$, $p = 0.017$); sub-pillars differ in channel: core government systems for transaction intensity, public service delivery for account ownership. Bootstrap mediation tests do not support the indirect path through digital banking adoption (six specifications, lowest $p = 0.132$). GovTech maturity instead shows a substantial direct association with the non-performing-loan ratio – a 13-percentage-point reduction per unit increase in GTMI ($p = 0.037$) – plausibly operating through institutional infrastructure such as property registries, e-courts, and tax-credit information systems. The two strands are linked but not chained: GovTech is associated with digital banking adoption, yet the route to lower non-performing loans runs through institutional infrastructure. Country-level decomposition reveals heterogeneous GTMI trajectories and identifies reform priorities across public service delivery and core government systems.

Keywords GovTech maturity, digital banking, bank stability, mediation analysis, transition economies, financial inclusion

JEL Classification G21, G28, O33, H11

INTRODUCTION

Digital transformation of the public sector has become a defining feature of the international development agenda over the past decade. The World Bank's GovTech Maturity Index tracks the maturity of 197 economies across 48 indicators organized into four focus areas: core government systems, online public service delivery, digital citizen en-

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gagement, and GovTech enablers (World Bank, 2025). Parallel transformations are underway in banking: mobile and internet banking transactions per adult in emerging market and developing economies rose from 55 to 251 between 2017 and 2024, while digital remittances climbed from 13% in 2019 to 46% in 2024 of cross-border flows (IMF, 2025a). However, the GTMI 2025 update documents that progress has been uneven, with low-income economies lagging behind higher-income peers across several sub-pillars even as higher-income economies advance (World Bank, 2025).

The transition economies of Central and Eastern Europe, the Western Balkans, the Eastern Partnership, and Central Asia occupy a heterogeneous position in this dual transformation. Their inherited socialist banking infrastructure, post-1990 reforms, and exposure to the post-2022 geopolitical shock produce a structurally distinct setting. Asset quality in the European banking sector has remained broadly stable – the ECB's significant institutions reported a non-performing-loan ratio of 1.9% in 2024 – yet stress is accumulating in vulnerable portfolios such as SME lending (4.9%) and commercial real estate (European Central Bank, 2025). Within this post-socialist core, banking-sector resilience varies substantially across reform trajectories, capital positions, and exposure to the post-2022 shock (EBRD, 2024). Ukraine, simultaneously at war and rapidly digitalizing its public services through the Diia platform, embodies the central question of whether GovTech investments can substitute for disrupted physical banking infrastructure.

Despite the parallel evolution of these literatures, two notable gaps remain. Cross-country research typically uses aggregate GovTech indices without decomposing them into operational sub-pillars, obscuring asymmetric transmission. And formal mediation testing of whether digital banking adoption channels public-sector digital reforms into bank-stability outcomes is rare. This study, therefore, asks: Does pre-shock GovTech maturity translate into post-shock digital banking adoption, and does that adoption in turn mediate a downstream relationship to bank stability? Using an unbalanced panel of up to 130 economies and up to 853 country-year observations over 2018–2024, the analysis decomposes the GovTech maturity index into its four sub-pillars, tests formal mediation against bank-stability outcomes, and identifies country-level deviations for benchmarking.

1. LITERATURE REVIEW

Research on public-sector digitalization has evolved from case-based assessments of design-reality mismatches in administrative information systems (Heeks, 2002) toward whole-of-government frameworks integrating institutional, regulatory, and infrastructural dimensions of digital state capacity (Dener et al., 2021; World Bank, 2025), with citizen trust acting as a precondition for effective digital service delivery (Litovtseva et al., 2022). The GovTech Maturity Index (GTMI), developed by the World Bank, organizes 48 indicators into four focus areas: Core Government Systems (CGSI), online Public Service Delivery (PSDI), Digital Citizen Engagement (DCEI), and GovTech Enablers (GTEI) (Dener et al., 2021; World Bank, 2025). The 2025 GTMI update documents uneven progress, with low-income economies lagging across several sub-pillars (World Bank, 2025). Empirical applications increasingly treat GovTech as a multi-dimensional variable: self-organizing maps cluster European economies by digital-transformation patterns (Pakhnenko et al., 2025), e-government maturity links to health-expenditure effectiveness across 191 countries (Hrytsenko et al., 2026), and digital-readiness scores correlate with the combined burden of corruption and cyber-threats (Yarovenko et al., 2025a). Adjacent evidence connects AI-driven public-sector tools to employment-structure adjustments (Kuzior et al., 2025a), corruption reduction (Yefimenko et al., 2025), and health-expenditure gaps (Megbowon & Zerihun, 2025). The next question is how this capacity reaches the retail-banking margin.

The empirical literature on digital banking adoption is anchored in two complementary traditions. The first uses the Technology Acceptance Model and its extensions to study individual-level determinants of mobile and internet banking uptake (Hbibi & Makhrout, 2025; Hedau, 2025): perceived

usefulness, ease of use, and self-efficacy emerge as dominant adoption drivers. Mediation evidence links digital banking among Indian gig workers to sustainable behavioural outcomes via financial-inclusion channels (Singh & Vaish, 2024). The second tradition examines adoption at the financial-system level, treating mobile money and internet banking as forces that expand formal-financial-services access; long-run causal evidence from M-PESA in Kenya estimates that mobile-money adoption lifted 2% of households out of poverty (Suri & Jack, 2016). Adjacent evidence locates financial inclusion as a driver of economic growth globally (Saienko et al., 2025) and in Sub-Saharan Africa (Marozva et al., 2026), while IMF data document its role in cross-border financial integration (IMF, 2025b). Recent contributions document bank-adjacent digital products: LendTech and BNPL reshape consumer credit (Waliszewski et al., 2024, 2025), AI-driven personalisation reshapes retail banking (Rysin et al., 2023), AI chatbots raise sales on commerce platforms (Spivakovskyy et al., 2025), and a systematic review documents AI, cloud, and blockchain integration into fintech (Lăzăroiu et al., 2023). Information-asymmetry-resolving platforms operate as a parallel SME-credit channel (Ivashchenko et al., 2017); single-country evidence shows digital banking mediates banks' social and financial performance (Frecea et al., 2023); and AI adoption extends into insurance (Dewi et al., 2025). The IMF Financial Access Survey provides the dominant cross-country measurement, with mobile and internet banking transactions per adult in emerging markets more than quadrupling between 2017 and 2024 (IMF, 2025b). Whether this translates into improved bank-stability outcomes is the question taken up next.

A long-standing literature attributes variation in bank stability to macroeconomic conditions, institutional quality, and bank-level fundamentals. Non-performing loans in Central, Eastern, and South-Eastern Europe respond strongly to macroeconomic factors – GDP growth, unemployment, exchange rates – with bank-specific characteristics secondary (Klein, 2013). Government-driven policy choices feed into credit risk: priority-sector lending mandates raise NPL ratios (Budhathoki et al., 2025), and government-expenditure shifts transmit into exchange-rate dynamics with balance-sheet effects (Ahmed, 2025). Ukraine-specific country-level financial-security forecasting using neural networks and principal-component methods reinforces this picture (Klochan & Filipov, 2023; Zolkover & Dimitrina, 2023), while SME-level evidence shows how financial constraints shape digital-transformation trajectories under market disruption (Sartamorn et al., 2025). Recent work documents heterogeneous fintech effects on stability: digital financial inclusion improves stability only after surpassing a maturity threshold across 81 economies (Anton & Afloarei Nucu, 2024); a 26-country African panel reveals a U-shaped relationship in which fintech adoption initially raises risk before reducing it (Okoli, 2024); and the fintech–AI–performance nexus among EU banks operates as a "double-edged sword" favoring well-capitalised banks (Siminică et al., 2025). Internal fintech adoption raises profitability in Kosovo's commercial banks while capital-adequacy ratios drag on returns (Berisha & Rayfield, 2025); US evidence shows digital-platform adoption shifts deposit funding toward cheaper but more flight-prone uninsured deposits (Koont, 2024); and regulatory frameworks remain a binding resilience constraint (Morin, 2025). These dynamics play out against a distinctive transition-economy backdrop.

Banking systems in Central and Eastern Europe, the Western Balkans, the Eastern Partnership, and Central Asia inherit a common post-socialist institutional legacy but display substantial cross-country variance in reform trajectories. Non-EU transition banking sectors often maintain elevated capital ratios reflecting state funding and prudential conservatism rather than market efficiency, complicating cross-country stability comparisons (Tarasenko et al., 2022). Institutional quality – proxied by World Governance Indicators – robustly determines economic growth in non-EU post-Soviet economies, with rule of law and government effectiveness carrying the strongest weight (Gasimov et al., 2023). Cognitive mapping identifies public-sector digital transparency as a central node connecting state legitimacy to financial-system development (Lyeonov et al., 2024); ethical leadership and institutional convergence drive cluster-level digital-ecosystem maturity in European management consulting (Kyzenko et al., 2026). Ukrainian cognitive modelling demonstrates that financial digitalization supports finan-

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cial stability by reducing shadow-economy operations to 14.43% of GDP – a 55.8% decline relative to the 2005–2021 average (Bozhenko et al., 2024). Energy-security shocks shape post-2022 economic resilience (Vasylieva et al., 2025); employment vulnerability and public health quality link to labour productivity in European economies (Lyeonov et al., 2025b; Kuzior et al., 2025b). The institutional environment further encompasses business-ethics dimensions of national-security strategy (Hakobyan et al., 2025), education-migration-labour interconnections (Mukhtarova et al., 2024), rule-of-law in public governance (Crowley & Mujtaba, 2026), digital-readiness associations with corruption and cybercrime (Yarovenko et al., 2025a; 2025b), and loan recovery in Central Asian banking (Rakhimzhanova et al., 2025). The Ukrainian case offers the sharpest test of these dynamics.

Ukraine occupies a distinctive position in the transition-economy literature because of the post-2022 full-scale war and the parallel rapid digitalization of public services through the Diia platform. Digital tools – cloud-based ERP, e-document systems, digital-payment integrations – maintained enterprise operations during the early war period (Mykhalchenko et al., 2023); Industry 4.0 contributions to socio-economic-system integrity under wartime identified digital-government interfaces and electronic financial services as critical adaptive mechanisms (Melnyk et al., 2025). Ukraine's foreign-trade resilience concentrated in firms with prior digital-export integration (Tsymbal & Demediuk, 2025), and public-service digitalization acted as a partial substitute for war-disrupted physical infrastructure (Zahorodnia et al., 2026). Adjacent contributions cover smartization in industrial enterprises (Bashynska et al., 2023), innovation-driven inclusive development (Syhyda et al., 2023), digital retraining as an anti-crisis labour-market mechanism (Yeremenko, 2026), dual higher education (Davlikanova, 2025), and household-level energy and pro-environmental behaviours under wartime (Smiech et al., 2025; Havrylenko, 2026; Lyeonov et al., 2025a, 2025c).

Across these five literatures, three persistent gaps remain. The GovTech literature rarely decomposes maturity into sub-pillars when assessing financial-sector outcomes; transition economies are typically pooled into generic "emerging markets" or "CEE" aggregates without separating the post-socialist core, the Western Balkans, the war-affected Eastern Partnership, and Central Asia as distinct sub-clusters; and formal mediation testing combining cross-sectional Preacher–Hayes bootstraps with panel cluster-bootstrap analogues remains rare (Baron & Kenny, 1986; Cameron et al., 2008; MacKinnon, 2019; Sitnicki et al., 2021; Kajda & Karwot, 2025).

This study aims to examine how public-sector GovTech maturity relates to banking stability in post-socialist transition economies, and in particular, whether digital banking adoption operates as the mediating channel linking the two. Rather than presuming such a channel, the study tests it explicitly and characterises the heterogeneity of the GovTech–stability relationship across institutional and economic contexts. To achieve this aim, four specific objectives guide the empirical analysis. The first objective is to estimate the average GovTech-to-digital-banking association (Stage 1 a-path) on a cross-country panel of up to 130 economies over 2018–2024, and to decompose GTMI 2022 into its four operational sub-pillars (CGSI, PSDI, DCEI, GTEI) to identify the channels of transmission. The second objective is to test the indirect effect of GovTech maturity on bank-stability outcomes through digital banking adoption via complementary mediation specifications, including a cross-sectional Preacher-Hayes bootstrap and a panel cluster-bootstrap analogue with two-way fixed effects. The third objective is to characterise country-specific deviations from the Stage 1 estimates and to quantify the contribution of Ukraine, Armenia, and Kazakhstan as illustrative post-socialist cases. The fourth objective is to assess robustness across alternative samples, mediator definitions (FA37N for mobile and internet banking transactions; FA30N for deposit accounts), and outlier exclusions. The study's principal contribution is to show that, although GovTech maturity is robustly associated with digital banking adoption, this adoption does not measurably channel the effects of GovTech into banking stability. Instead, the GovTech-stability link appears to operate through the institutional infrastructure of credit.

2. METHODOLOGY

2.1. Data and sample

The empirical analysis combines six publicly available cross-country databases into an unbalanced panel for 2018–2024. Pre-shock GovTech maturity is the World Bank GovTech Maturity Index (GTMI 2022 wave plus four sub-pillars) for up to 198 economies (Dener et al., 2021; World Bank, 2025). Digital banking adoption is captured by IMF FAS indicators FA37N (mobile and internet banking transactions) and FA30N (deposit accounts per 1,000 adults); bank stability by IMF FSIC non-performing-loan and foreign-currency-loan ratios. Macroeconomic and governance controls come from World Bank WDI/WGI; sensitivity checks use Global Findex 2021 and 2024 (Demirgüç-Kunt et al., 2022; Klapper et al., 2025).

Three economies are pre-excluded for non-coverage (Turkmenistan, Kosovo, Serbia); missing values are dropped pair-wise. The two mediators yield non-identical samples because FAS reporting practices differ (Appendix A).

The transition core comprises 28 EBRD countries-of-operations across CEE-EU, the Western Balkans, the Eastern Partnership, and Central Asia. Here, "transition" denotes the full set of EBRD countries of operation, which includes a small number of economies outside the post-socialist core – most notably Türkiye – whereas the post-socialist core proper comprises the CEE-EU, Western Balkans, Eastern Partnership, and Central Asia groupings on which the country-level analysis focuses. Six are flagged as proximate to the 2022 full-scale invasion of Ukraine by Russia: Ukraine (direct) and Hungary, Moldova, Poland, Romania, Slovakia (border). Sample sizes appear in Table 1.

Table 1. Analytical sample composition

Source: Authors' calculations.

Sample	Mediator M	Total countries	Transition (of 28)	Country-years
Sample A	FA37N (mobile/internet banking transactions per 1,000 adults)	102	21	662
Sample B	FA30N (deposit accounts per 1,000 adults)	130	20	853

Note: Sample A excludes UKR, UZB, KGZ, TJK (non-reporting of FA37N); Sample B excludes KAZ, LTU, ROU, SVK, SVN (non-reporting of FA30N).

2.2. Variables

Variable definitions are in Appendix F. The treatment gtmi_2022 is time-invariant: the 2022 wave was fielded between mid-2020 and end-2021, before Russia's full-scale invasion of Ukraine and the post-COVID adoption surge, yielding pre-shock identification. GTMI change between 2022 and 2025 reflects catch-up dynamics rather than structural maturity (r = −0.05 between level and change); we use the level.

Both mediators are right-skewed (Ukraine reports 5,897 deposit accounts per 1,000 adults against ~50 in small island economies); we apply log+1. Outcomes are used in levels.

2.3. Empirical strategy

The strategy proceeds in two stages along the mediation logic X → M → Y: Stage 1 estimates the a-path (X → M) via panel OLS with progressively richer fixed effects; Stage 2 estimates the full mediation structure with bootstrap CIs on a × b, following Preacher and Hayes (2008). Standard errors are clustered at the country level.

Throughout, i indexes countries and t years; M_{it} is the digital-banking mediator (log_FA37N or log_FA30N); Y_{it} is the bank-stability outcome; Z_{it} is the vector of macroeconomic and governance controls (Appendix F); $post\_2022_t$ equals 1 for t ≥ 2022; α is the overall intercept; α_i and λ_t denote country and year fixed effects; β (with β_1-β_4 for sub-pillars) and δ are the slope and interaction coefficients on the treatment.

Stage 1 is estimated under four specifications. Specification 1 is pooled OLS:

$$\log M_{it} = \alpha + \beta \cdot gtmi\_2022_i + \gamma' Z_{it} + \varepsilon_{it}. \quad (1)$$

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Specification 2 adds year fixed effects to absorb common shocks:

$$\log M_{it} = \alpha + \beta \cdot gtmi\_2022_i + \gamma' Z_{it} + \lambda_t + \varepsilon_{it}. \quad (2)$$

Specification 3 adds country fixed effects via a post-2022 interaction; because $gtmi\_2022_i$ is time-invariant, the interaction tests differential post-2022 acceleration:

$$\log M_{it} = \alpha_i + \lambda_t + \delta \cdot (post\_2022_t \cdot gtmi\_2022i) + \gamma' Z_{it} + \varepsilon_{it}. \quad (3)$$

Specification 4 decomposes GTMI into its four sub-pillars – Core Government Systems Index (CGSI), Public Service Delivery Index (PSDI), Digital Citizen Engagement Index (DCEI), and GovTech Enablers Index (GTEI):

$$\log M_{it} = \alpha + \beta_1 CGSI_i + \beta_2 PSDI_i + \beta_3 DCEI_i + \beta_4 GTEI_i + \gamma' Z_{it} + \lambda_t + \varepsilon_{it}. \quad (4)$$

Stage 2 uses two complementary designs. The cross-sectional design collapses the panel to one post-shock observation per country (means over 2022–2024) and follows Preacher-Hayes:

$$M_i = a_0 + a \cdot gtmi\_2022_i + \gamma' Z_{it} + u_i, \quad (5)$$

$$Y_i = c_0 + c \cdot gtmi_{2022i} + \gamma' Z_i + v_i, \quad (6)$$

$$Y_i = b_0 + b \cdot M_i + c' \cdot gtmi\_2022_i + \gamma' Z_i + w_i. \quad (7)$$

Equations (5-7) yield the a-path, total effect c, direct effect c′, and b-path; the indirect effect is a × b. Percentile bootstrap 95% CIs are constructed by resampling country units, 5,000 iterations.

The panel design replaces equations (5-7) with country-year analogues, retaining year FE, and infers via a cluster bootstrap over whole countries, 2,000 iterations (Cameron et al., 2008; MacKinnon, 2019).

2.4. Country-level effects

To assess country-specific heterogeneity, we re-estimate Equation 2, replacing the country-level treatment with country dummies and recover de-meaned country fixed effects on $\log M_{it}$ and on $fsic\_npl\_ratio_{it}$. Deviations are reported in Appendix C and flag "leapfrog" and "lagging" economies.

2.5. Limitations

Three limitations apply. First, identification rests on cross-country variation in pre-shock GovTech maturity rather than within-country variation, leaving time-invariant unobservables uncontrolled. Second, Spain and Luxembourg emerge as country-FE outliers; Appendix E (Tables E1-E2) reports a robustness check excluding both. Third, FA37N and FA30N samples do not perfectly overlap; we report both.

3. RESULTS

3.1. Descriptive statistics

Table 2 reports summary statistics across the global panel, the 28-country transition core (196 country-years), and the six-country war-proximity sub-sample (42 country-years). Three patterns motivate the empirical strategy: a steep cross-country gradient in GovTech maturity, a corresponding gradient in digital banking adoption, and pronounced heterogeneity in bank-stability outcomes.

Pre-shock GovTech maturity (gtmi_2022) averages 0.55 globally (sd = 0.26), 0.69 in the transition sub-sample, and 0.71 in the war-proximity group. The gradient is steepest for PSDI (0.65 / 0.81 / 0.85) and weakest for DCEI (0.45 / 0.61 / 0.53), indicating that participatory e-governance lags behind back-office and service-delivery digitalization. The compressed war-proximity standard deviation (0.09 versus 0.26 globally) reflects EU-adjacent institutional homogeneity; identification therefore relies primarily on the global and transition samples.

Digital banking adoption follows the same gradient: mobile and internet banking transactions per 1,000 adults average 66,649 globally, 77,753 in the transition core, and 72,923 among war-proximate economies; deposit accounts per 1,000 adults rise from 1,652 globally to 2,223 and 2,684, respectively, a 60% premium over the global mean.

Bank-stability outcomes display a different structure. NPL ratios average 6.33% globally and 6.00% in the transition sub-sample but rise sharply to 10.06% among war-proximate economies, driven primarily by Ukraine. FX-loans show the inverse pattern (24.1% / 31.3% / 23.6%): dollarisation and euroisation remain prevalent in the Western Balkans, Eastern Partnership, and Central Asia, while war-proximate EU members have substituted into local-currency or euro-denominated lending. Capital adequacy is comparable across sub-samples (19.6% / 20.8% / 21.3%) with strikingly lower dispersion in the transition core (sd 3.0 versus 6.4 globally), indicating tighter Basel III convergence.

Controls behave as expected: GDP per capita PPP is highest among war-proximate economies (USD 31,134), reflecting EU membership. Internet penetration is markedly higher in the transition (80.0%) and war-proximity (81.6%) sub-samples than globally (64.4%), so the GovTech-mediator relationship is estimated against a backdrop of high baseline connectivity.

3.2. Country trajectories

Figure 1 traces the joint evolution of GovTech maturity, digital banking adoption, asset quality, and capital adequacy from 2018 to 2024 for three post-Soviet transition economies – Ukraine (UKR), Armenia (ARM), and Kazakhstan (KAZ). The three span distinct EBRD operational regions (Eastern Europe, South Caucasus, Central Asia) and three contrasting patterns of structural digitalization: war-affected rapid reform, middle-maturity reform, and resource-economy state-led modernisation.

Panel A documents heterogeneous GTMI trajectories. Ukraine records the steepest rise (0.534 → 0.768 → 0.866 across 2020/2022/2025, +66%), surpassing Armenia at the 2022 wave and approaching Kazakhstan by 2025. Kazakhstan starts from a high baseline (0.736) and reaches 0.945 by 2025, sustaining its Central Asian leadership. Armenia advances more modestly (0.722 → 0.769). Ambitious policy efforts – Ukraine's Diia,

Table 2. Descriptive statistics by sub-sample, 2018–2024

Source: World Bank GTMI (X); IMF Financial Access Survey (M); IMF Financial Soundness Indicators (Y); World Bank WDI and WGI (controls).

Variable	Global mean (sd)	Transition mean (sd)	War-prox mean (sd)	n (G/T/W)	Source
Treatment X (GovTech)					
gtmi_2022	0.55 (0.26)	0.69 (0.19)	0.71 (0.09)	1,386 / 196 / 42	WB
gtmi_cgsi_2022	0.57 (0.24)	0.68 (0.16)	0.71 (0.07)	1,386 / 196 / 42	WB
gtmi_psdi_2022	0.65 (0.28)	0.81 (0.19)	0.85 (0.08)	1,386 / 196 / 42	WB
gtmi_dcei_2022	0.45 (0.31)	0.61 (0.27)	0.53 (0.23)	1,386 / 196 / 42	WB
gtmi_gtei_2022	0.54 (0.28)	0.66 (0.22)	0.75 (0.07)	1,386 / 196 / 42	WB
Mediator M (digital banking adoption)					
fas_mob_internet_bank_tx (per 1k adults)	66,649 (102,995)	77,753 (98,573)	72,923 (48,716)	687 / 147 / 31	FAS
fas_deposit_accounts (per 1k adults)	1,652 (1,451)	2,223 (1,281)	2,684 (1,240)	875 / 134 / 28	FAS
fas_commercial_bank_branches (per 100k)	16.3 (15.6)	22.9 (14.9)	23.1 (5.3)	1,169 / 180 / 42	FAS
Outcomes Y (bank stability, %)					
fsic_npl_ratio	6.33 (7.93)	6.00 (8.50)	10.06 (14.50)	998 / 168 / 42	FSIC
fsic_fx_loans_ratio	24.06 (23.43)	31.33 (16.90)	23.57 (12.54)	802 / 118 / 33	FSIC
fsic_capital_adequacy	19.62 (6.40)	20.78 (3.04)	21.27 (3.36)	992 / 168 / 42	FSIC
fsic_roa	1.79 (1.31)	2.00 (1.20)	1.91 (1.35)	1,001 / 168 / 42	FSIC
fsic_roe	12.58 (8.68)	14.30 (7.46)	13.80 (7.95)	993 / 168 / 42	FSIC
Macro and governance controls					
wdi_gdp_pcap_ppp (USD)	24,969 (24,728)	26,793 (12,647)	31,134 (11,209)	1,716 / 196 / 42	WDI
wdi_internet_users_pct	64.4 (26.5)	80.0 (11.3)	81.6 (7.1)	1,511 / 183 / 42	WDI
wdi_urban_pct	61.0 (22.2)	58.8 (12.6)	57.9 (10.1)	1,855 / 196 / 42	WDI
wgi_rl_est	0.01 (1.00)	−0.01 (0.72)	0.12 (0.44)	1,504 / 196 / 42	WGI
wgi_ge_est	0.08 (0.98)	0.15 (0.61)	0.22 (0.46)	1,483 / 196 / 42	WGI

Note: Means with standard deviations in parentheses. The range column reports the number of country-year observations for the Global / Transition / War-proximate panels, respectively.

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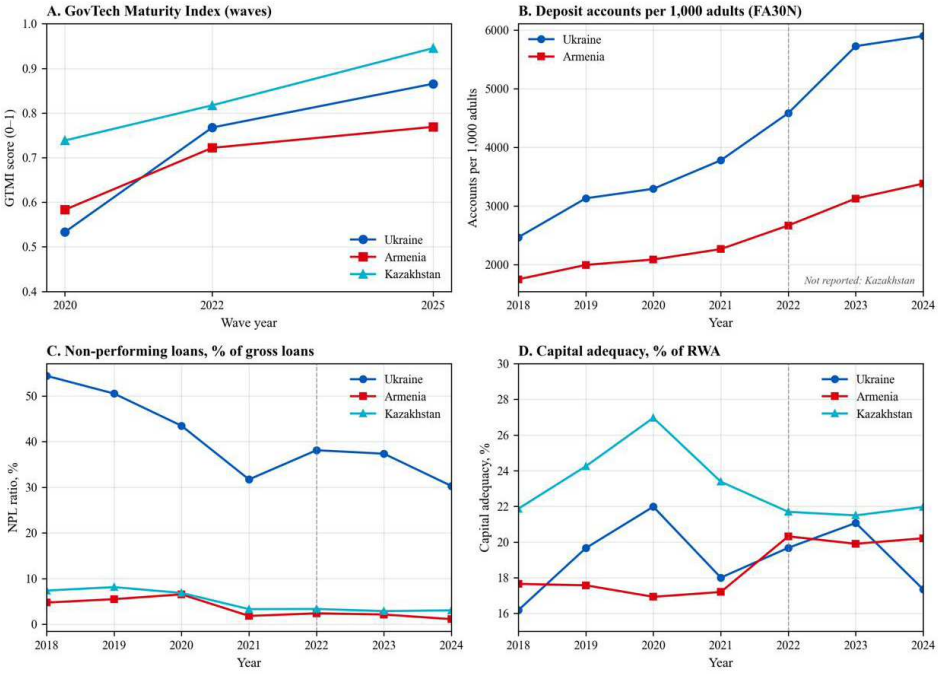
Source: Authors' calculations from World Bank GTMI (Panel A); IMF FAS (Panel B); IMF FSIC (Panels C, D).



Note: Panel A: GovTech Maturity Index (three waves, 2020 / 2022 / 2025). Panel B: deposit accounts per 1,000 adults (Kazakhstan omitted due to non-reporting of FA30N). Panel C: non-performing loans to total gross loans, %. Panel D: regulatory capital to risk-weighted assets, %. Vertical dashed line marks 2022 (Russia's full-scale invasion of Ukraine onset).

Figure 1. Country trajectories: GovTech, digital banking adoption, and bank stability, 2018–2024

Kazakhstan's eGov.kz, Armenia's e-government initiatives – produce very different rates of maturity gain over a five-year window.

Panels B–D show movement in banking-sector indicators alongside the GTMI trajectories. Deposit accounts per 1,000 adults more than double in Ukraine (2,465 → 5,897, +139%) with the visible post-2022 acceleration, while Armenia rises from ~1,800 to 3,400 (+89%); Kazakhstan is omitted because it does not report this indicator (see Methodology, Data and sample). Panel C: Ukraine's NPL ratio descends from 54% in 2018 – a legacy of the 2014–2015 banking-sector reorganization – to 32% by 2021, registers a 6-pp bump in 2022 reflecting the war shock, and resumes its decline to 30% by 2024. Armenia and Kazakhstan hold NPL in the 1–7% band. Panel D shows capital adequacy within the 16-27% band.

Three observations inform the regression analysis. First, all three economies display rising GTMI trajectories with different slopes – the cross-country variation used as the Stage 1 treatment reflects this heterogeneity even within the post-Soviet sub-sample. Second, deposit-account expansion in Ukraine is concentrated in the post-2022 period, suggesting the digital-banking response can be amplified by exogenous shocks that close physical banking channels. Third, Ukraine's NPL trajectory does not fit the conventional crisis pattern of accelerating loan deterioration; the war-period bump is rapidly absorbed.

3.3. Stage 1: GovTech maturity and digital banking adoption

Table 3 reports the a-path estimates linking pre-shock GovTech maturity (gtmi_2022) to subsequent digital banking adoption, separately for the two mediator samples and across the three specifications introduced in Methodology, Empirical strategy. Columns (1)-(3) correspond to Sample A (FA37N) and columns (4)-(6) to Sample B (FA30N). Cluster-robust standard errors at the country level appear in parentheses.

Two patterns emerge. First, the GTMI coefficient is positive, statistically significant, and stable in both samples across the bivariate, macro-augmented, and fully-augmented specifications. In Sample A, it declines from +5.337 ($p < 0.001$) bi-

Table 3. Stage 1 a-path estimates: log(M) on pre-shock GTMI

Statistic	A: (1) Biv	A: (2) +Mac	A: (3) +Gov	B: (4) Biv	B: (5) +Mac	B: (6) +Gov
Spec 1 (Pooled OLS) – gtmi_2022	+5.337*** (0.916)	+3.031* (1.161)	+2.858* (1.190)	+2.273*** (0.307)	+1.050*** (0.242)	+1.069*** (0.290)
Spec 2 (+ Year FE, primary) – gtmi_2022	+5.343*** (0.905)	+3.098** (1.161)	+2.908* (1.198)	+2.267*** (0.304)	+1.054*** (0.241)	+1.075*** (0.290)
Spec 3 (+ Country FE) – post_2022 × gtmi_2022	–	–	−0.563 (0.584)	–	–	−0.044 (0.115)
Observations	662	641	641 / 640	853	821	821
R^2	0.236 / 0.283	0.320 / 0.346	0.342 / 0.368 / 0.925	0.327 / 0.350	0.595 / 0.598	0.597 / 0.600 / 0.968

Note: Cluster-robust standard errors at the country level in parentheses. Column heads encode sample and control set: A = Sample A (FA37N transactions); B = Sample B (FA30N accounts); Biv = bivariate (no controls); +Mac = adds macroeconomic controls (log GDP per capita, internet users, urban share); +Gov = adds governance controls (Rule of Law, Government Effectiveness). Significance: *** p < 0.001, ** p < 0.01, * p < 0.05. R2 values are reported sequentially for Specification 1 / Specification 2 / Specification 3, where applicable.

variate to +2.908 (p = 0.017) once macro and governance controls enter; in Sample B, from +2.273 (p < 0.001) to +1.075 (p < 0.001). The decay reflects absorption of variation by macro controls – particularly log GDP per capita and internet penetration – without overturning sign or significance. Second, the magnitude differs between mediators consistently with the underlying constructs: Sample A captures transaction intensity and shows a much larger response, whereas Sample B captures account onboarding with a more modest response, suggesting GovTech enables existing customers to transact digitally more readily than it expands the underlying banked population.

Specification 2 (year fixed effects) serves as the primary estimate: β = +2.908 (SE = 1.198, p = 0.017, N = 641, R^2 = 0.368) in Sample A and β = +1.075 (SE = 0.290, p < 0.001, N = 821, R^2 = 0.600) in Sample B. A one-standard-deviation increase in pre-shock GTMI within the transition sub-sample (≈ 0.20 units) is associated with a 78% increase in mobile and internet banking transactions and a 24% increase in deposit accounts per 1,000 adults.

Specification 3 introduces country fixed effects through the (post_2022 × gtmi_2022) interaction. The coefficient is −0.563 (p = 0.338) in Sample A and −0.044 (p = 0.707) in Sample B, neither distinguishable from zero. The null admits two readings: high-GTMI countries did not experience differential acceleration after 2022, suggesting the GovTech-mediator relationship is structural rather than crisis-amplified; alternatively, country fixed effects absorb most meaningful variation. We favor the structural reading because the Specification 2 coefficients are highly stable, indicating the underlying relationship is identified at the level rather than at the differential-change margin.

Two ancillary findings deserve note. The GovTech coefficient in Specification 2 is essentially unchanged when WGI Rule of Law and Government Effectiveness are added (Sample A: +3.098 → +2.908; Sample B: +1.054 → +1.075), indicating gtmi_2022 captures a dimension of state digital capacity largely orthogonal to broader institutional quality. Internet penetration enters with a positive and significant coefficient in both samples (+0.045 in A; +0.017 in B), consistent with GovTech and connectivity being complementary inputs rather than substitutes.

3.4. Sub-pillar decomposition

Table 4 decomposes the aggregate GTMI into its four sub-pillars (CGSI, PSDI, DCEI, GTEI) entered jointly with the controls and year fixed effects of Specification 2. The decomposition is informative despite the high pairwise correlation between sub-pillars (0.71-0.94 in our analytical samples; see Figure 2) because it reveals which dimension carries the explanatory weight for each mediator.

The pattern is striking and asymmetric. In Sample A, CGSI is the only sub-pillar with a significant coefficient (+6.758, p = 0.019); the remaining three are insignificant. In Sample B, the picture inverts:

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Table 4. Sub-pillar decomposition: log(M) on GTMI sub-pillars

Sub-pillar (entered jointly)	Sample A: log(FA37N)	Sample B: log(FA30N)
gtmi_cgsi_2022 (Core Gov Systems)	+6.758* (2.843)	−0.224 (0.627)
gtmi_psdi_2022 (Public Service Delivery)	+0.784 (1.988)	+1.428*** (0.396)
gtmi_dcei_2022 (Digital Citizen Engagement)	−0.671 (1.002)	+0.175 (0.315)
gtmi_gtei_2022 (GovTech Enablers)	−2.295 (2.506)	−0.202 (0.509)
Observations	641	821
R^2	0.406	0.622

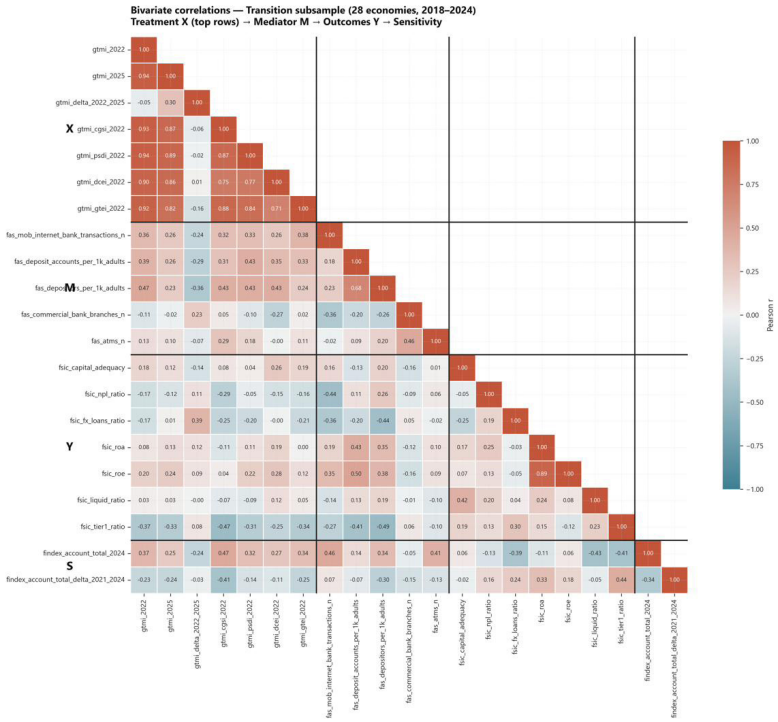
Note: Specification 2 layout (year fixed effects, country-clustered SE) with all four sub-pillars entered jointly. Cluster-robust standard errors in parentheses. Significance: *** p < 0.001, ** p < 0.01, * p < 0.05.

PSDI is the only significant predictor (+1.428, p < 0.001), while CGSI is essentially zero (−0.224, p = 0.722). This CGSI–PSDI asymmetry – CGSI associated with transaction intensity, PSDI with account onboarding – is consistent with two distinct mechanisms. Mature core government systems (e-procurement, public financial management, document management) support the technological substrate within which existing banked individuals transact more frequently; mature public service delivery (digital identity, social payments, e-tax, e-permitting) draws new individuals into the formal banking system through the practical necessity of holding an account. The two channels are complementary, but their identification is enabled by the differential sensitivity of the two mediators; aggregating GTMI into a single index masks this internal structure.

3.5. Auxiliary diagnostics: correlation structure

Figure 2 displays the bivariate Pearson correlation matrix among the treatment sub-pillars (the full matrix across all variables is in Appendix B), the two mediators, the bank-stability outcomes, and

Source: Authors' calculations.



Note: Layout: pre-shock GovTech and sub-pillars (X), mediators (M), bank-stability outcomes (Y), and Findex sensitivity variables (S) shown along both axes; cells display correlation coefficients and use a diverging colour scale.

Figure 2. Pairwise Pearson correlations among Stage 1 and Stage 2 variables, transition sub-sample (n = 28 economies, 2018–2024)

the financial-inclusion sensitivity variables for the transition sub-sample. Three features stand out. First, GTMI sub-pillars are highly intercorrelated (CGSI–PSDI: r = 0.87; CGSI–gtmi_2022: r = 0.93), confirming the multicollinearity that motivated reporting both aggregate and sub-pillar specifications. Second, the GTMI–mediator correlations are positive and meaningful (gtmi_2022: +0.36 with FA37N, +0.39 with FA30N; PSDI: +0.43 with FA30N), consistent with the regression estimates once controls are partialled out. Third, FA37N correlates −0.44 with NPL and −0.36 with FX-loans – the bivariate analogue of the b-path estimated in Stage 2.

3.6. Stage 2: Mediation analysis with robustness checks

Stage 2 examines whether digital banking adoption mediates the GovTech-stability relationship. The indirect effect a × b is estimated under two complementary designs – cross-sectional Preacher-Hayes with 5,000 percentile bootstrap iterations (Table 5) and panel two-way fixed-effects with 2,000 cluster bootstrap iterations (Table 6) – across two outcomes (NPL ratio and FX-loans ratio) and two mediator samples.

Table 5 reports cross-sectional results. The a-path is positive in all four specifications and significant in the two FA30N samples (β = +1.464 for NPL; β = +1.923 for FX-loans, both p < 0.001). The b-path is negative in three of four, the direction predicted by the mediation hypothesis. The indirect effect a × b is negative in three of four (range −0.93 to −2.02), but no percentile bootstrap 95% CI excludes zero; closest is Sample A NPL with CI [−3.67, +0.30] and p = 0.134. Sample B-fx returns a positive indirect effect (+2.711), inconsistent with the hypothesis, driven by a wrong-signed b-path on FA30N – a pattern recurring in the panel design.

Table 6 reports the panel analogue (577 / 695 country-year observations). Panel A aligns with the cross-section: a = +1.917 (p = 0.105), b = −0.509 (p = 0.085), indirect = −0.976, 95% cluster bootstrap CI [−4.13, +0.19], p = 0.132 – the lower bound again falls just short of excluding zero. In Panel B, the b-path is small and positive (+0.258, p = 0.848), and the indirect effect is positive and non-significant. The most striking Panel B feature is the c′-path: the direct effect of GovTech on the NPL ratio, conditional on the mediator, is −13.007 (SE = 6.174, p = 0.037) – a 13-percentage-point reduction per unit GTMI operating outside the digital-banking-adoption channel.

Three findings emerge. First, the formal mediation hypothesis cannot be supported: no bootstrap CI on the indirect effect excludes zero in any of six specifications (lowest p = 0.132). Second, the partial-effect directions in FA37N specifications – positive a-path, negative b-path – are consistent with the theoretical mechanism, but confidence intervals are too wide to reach significance, reflecting limited cross-country variation surviving after macro and institutional controls. Third, the Panel B direct effect of −13.0 pp on NPL is large

Table 5. Cross-sectional Preacher-Hayes mediation: indirect effect of GTMI on bank stability through digital banking adoption

Source: Authors' calculations.

Path	NPL × Sample A (FA37N)	NPL × Sample B (FA30N)	FX × Sample A (FA37N)	FX × Sample B (FA30N)
a-path (X → M)	+1.773 (1.168)	+1.464*** (0.394)	+1.421 (1.303)	+1.923*** (0.391)
b-path (M → Y)	−0.646. (0.362)	−0.735 (1.507)	−1.926 (2.201)	+1.406 (2.890)
c-path (X → Y total)	−0.842 (1.825)	−11.323* (5.764)	−20.801 (17.509)	+2.369 (12.898)
c′-path (X → Y direct)	+0.303 (1.793)	−10.247. (5.483)	−18.065 (18.492)	−0.334 (13.105)
Indirect (a × b)	−0.933	−1.017	−2.016	+2.711
95% bootstrap CI	[−3.67, +0.30]	[−5.48, +3.22]	[−14.89, +3.87]	[−8.69, +14.48]
p-value (indirect)	0.134	0.595	0.452	0.604
Observations	88	104	70	85

Note: Cluster-robust standard errors at the country level in parentheses. Column heads encode outcome (NPL or FX) × sample (Sample A uses FA37N mediator; Sample B uses FA30N). Indirect effect a × b is the product of the a-path (X → M) and b-path (M → Y) coefficients. Bootstrap CIs are bias-corrected percentile intervals from 5,000 country-level resamples. *** p < 0.001, ** p < 0.05, *p < 0.10.

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Table 6. Panel two-way fixed-effects mediation: indirect effect of GTMI on the NPL ratio

Source: Authors' calculations.

Path	Panel A: log(FA37N) → NPL	Panel B: log(FA30N) → NPL
a-path (X→M)	+1.917 (1.181)	+1.232*** (0.324)
b-path (M→Y)	−0.509. (0.296)	+0.258 (1.344)
c′-path (X→Y direct)	−0.481 (2.043)	−13.007* (6.174)
Indirect (a × b)	−0.976	+0.318
95% cluster bootstrap CI	[−4.13, +0.19]	[−2.73, +4.31]
p-value (indirect)	0.132	0.829
Observations / countries	577 / 93	695 / 112

Note: Cluster-robust standard errors at the country level in parentheses. Bootstrap CIs are percentile intervals from 2,000 cluster resamples that sample whole countries with replacement (Cameron et al., 2008). *** p < 0.001, ** p < 0.05, * p < 0.10.

and significant at 5%. GovTech maturity is therefore associated with lower NPLs, but the operative channel is not digital banking adoption itself – it appears to operate through institutional channels not captured by FA37N or FA30N (digitalized property registries, electronic courts, integrated tax-and-credit information systems). The Sample B specification includes Ukraine, where each dimension has been actively reformed since 2014.

Robustness checks reinforce the picture. The choice of outcome (NPL vs FX loans) does not alter the conclusion. The choice of mediator matters more: FA37N produces the consistently signed a- and b-paths predicted by the hypothesis, whereas FA30N yields a wrong-signed or near-zero b-path in three of four panels – account stock and transaction flow are structurally different channels for bank stability. The choice of design (cross-sectional vs panel) affects precision without altering direction.

3.7. Country-specific deviations

Table 7 reports country-level deviations from the demeaned country fixed effects in Equation 2 (with country dummies replacing the country-level treatment, as in Methodology, Country-level effects) for the global sample (Panels A and B), the transition sub-sample (Panel C), and the three focal economies from §4.2 (Panel D). Deviations are interpreted as country-specific shifts in log(M) and the NPL ratio after partialling out macro and governance controls. Full country tables appear in Appendix C (Sample A, 93 economies) and Appendix D (Sample B, 134 economies).

Panel A documents a coherent group of leapfrog economies: Malawi, Madagascar, Mozambique, Cambodia, and Solomon Islands record positive log(M) deviations between +3.65 and +4.44 – far above what GDP per capita, internet penetration, urbanisation, and governance quality alone predict. All five are low-income economies where mobile-money platforms have substituted for traditional banking infrastructure. The NPL deviations for the first three are large and negative (−12.30, −15.41, −16.66), consistent with the mobile-money-driven financial inclusion literature.

Panel B documents the opposite extreme. Iraq's −8.18 deviation reflects a post-conflict banking sector; Guatemala (−4.95) and Morocco (−4.47) are consistent with cash-heavy informal-economy structures. The Spanish (−7.15) and Luxembourgish (−3.59 on log(M); +10.98 on NPL) deviations are the two outliers acknowledged in Methodology, Limitations; Tables E1 and E2 in Appendix E report a robustness check excluding both, in which the Stage 1 a-path coefficient changes by less than 5%.

Panel C zooms into the transition sub-sample. Kazakhstan's +1.74 reflects the Halyk Bank and Kaspi.kz digital-finance ecosystem; Moldova (+1.55) and Georgia (+1.39) place above the transition mean. At the lower end, Albania (−1.61), Montenegro (−0.89), and Bulgaria (−0.68) display modest negative deviations. The within-transition spread (range ≈ 3.4) is substantially smaller than the global (≈ 12.6), consistent with the post-socialist core operating as a relatively cohesive analytical unit.

Panel D presents fixed effects for the three focal economies. Kazakhstan combines a high positive log(M) (+1.74) with a positive NPL (+8.80): high digital adoption that does not translate in-

Table 7. Country-specific deviations from the panel two-way fixed-effects model

Country	Region	FE log(M)	FE NPL	GTMI 2022	Notes
Panel A. Top 5 positive deviations on log(M) – Sample A					
MWI	Sub-Saharan	+4.44	–12.30	0.34	Mobile-money leapfrog
MDG	Sub-Saharan	+4.21	–15.41	0.34	Mobile-money leapfrog
MOZ	Sub-Saharan	+4.02	–16.66	0.40	Mobile-money leapfrog
KHM	South-East Asia	+3.89	–4.05	0.50	Wing/Pi Pay penetration
SLB	Pacific	+3.65	–6.03	0.34	Mobile-first Pacific
Panel B. Top 5 negative deviations on log(M) – Sample A					
IRQ	MENA	–8.18	+5.82	0.39	Post-conflict banking sector
ESP	Western Europe	–7.15	+2.44	0.74	Outlier; see Limitations
GTM	Latin America	–4.95	–7.37	0.41	Cash-heavy informal economy
MAR	MENA	–4.47	–7.77	0.65	Cash-heavy informal economy
LUX	Western Europe	–3.59	+10.98	0.85	Outlier; see Limitations
Panel C. Transition sub-sample, top 3 / bottom 3 – Sample A					
KAZ	Central Asia	+1.74	+8.80	0.82	Transition leader
MDA	Eastern Partn.	+1.55	+7.29	0.62	Transition leader
GEO	Eastern Partn.	+1.39	–0.32	0.84	Transition leader
ALB	Western Balk.	–1.61	+2.45	0.55	Transition lagging
MNE	Western Balk.	–0.89	+3.51	0.42	Transition lagging
BGR	CEE-EU	–0.68	+3.05	0.65	Transition lagging
Panel D. Focal economies (Section 4.2)					
UKR	Eastern Europe	+1.09	+30.01	0.77	Sample B FE; high digital + cleanup-legacy NPL
ARM	South Caucasus	+0.17	–3.59	0.72	Sample A FE; institutional-channel pattern
KAZ	Central Asia	+1.74	+8.80	0.82	Sample A FE; null-mediation pattern

Note: Demeaned country fixed effects from Equation 2 with country dummies replacing the country-level treatment, conditional on macro and governance controls. Positive FE log(M) identifies economies with digital-banking adoption above the level predicted by observables ("leapfrog"); negative FE log(M) identifies "lagging" economies.

to below-average NPLs, consistent with the null mediation result of §4.6. Armenia shows a modest positive log(M) (+0.17) paired with substantial negative NPL (–3.59) – an asset-quality advantage largely orthogonal to digital-banking position, consistent with the institutional-channel interpretation. Ukraine (Sample B; excluded from Sample A by FA37N non-reporting) shows the most pronounced decoupling: log(M) of +1.09 with NPL of +30.01, by far the largest. The Ukrainian NPL reflects the 2014–2015 reorganization legacy, not current deterioration: as in §4.2, the ratio has declined from a 54% peak. The three profiles support the central interpretation – "linked but not chained" in Ukraine and Kazakhstan, a cleaner institutional channel in Armenia.

4. DISCUSSION

Pre-shock GovTech maturity is robustly associated with subsequent digital banking adoption, with the magnitude varying systematically by mediator and sub-pillar. The positive a-path coefficients on both transaction intensity and account onboarding are broadly consistent with the adoption-side evidence in Hedau (2025), although our country-level estimates capture a system-level association that individual studies cannot identify. The sub-pillar decomposition reveals an asymmetric channel structure in which Core Government Systems is associated with transaction intensity while Public Service Delivery is associated with account onboarding, complementing the cluster-based evidence on European digital transformation in Pakhnenko et al. (2025), where heterogeneous digitalization profiles likewise track distinct functional channels.

The GovTech–NPL association appears more consistent with institutional than with retail-adoption channels. Although the formal mediation hypothesis cannot be supported in any of the six bootstrap specifications, the direct effect on NPL in Sample B is substantial, indicating that the GovTech–NPL association persists after conditioning on the digital-banking mediator. This aligns with Klein (2013), whose CESEE evidence places structural-institutional factors at the centre of NPL determi-

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nation; our results are consistent with extending this intuition to GovTech maturity. The threshold-based non-linear findings of Anton and Afloarei Nucu (2024) are not reproduced – a divergence reflecting measurement scope, since FAS mediators capture transaction and account volumes but not the credit-risk-relevant institutional infrastructure that may underlie the residual association (see Conclusion for specific components).

The null indirect effect and the significant direct effect together locate the GovTech–stability channel outside the digital-banking-adoption mediator. Two limitations qualify these conclusions. First, the cross-country design leaves time-invariant unobservables uncontrolled. Second, FA37N and FA30N yield different sample compositions, with FA37N consistently exhibiting the predicted pattern while FA30N delivers a stronger a-path but weaker b-path identification – pointing toward future work with mediators that capture credit-risk-relevant digital infrastructure more directly, such as regulatory sandboxes, open-banking APIs, and CBDC pilot data.

CONCLUSION

This study set out to test whether digital banking adoption mediates the link between pre-shock public-sector digital maturity and bank stability. Using an unbalanced panel of up to 130 economies and 853 country-year observations over 2018–2024 with panel OLS and bootstrap mediation tests, it finds that the two transformations are linked but not chained: pre-shock GovTech maturity is positively associated with digital banking adoption ($\beta = +2.91$, $p = 0.017$ for transactions; $\beta = +1.08$, $p < 0.001$ for accounts), with an asymmetric sub-pillar pattern (CGSI on transaction intensity; PSDI on account onboarding), yet the indirect path through digital banking adoption is not supported. Instead, GovTech maturity displays a substantial direct association with the NPL ratio ($c' = -13.007$, $p = 0.037$), consistent with its link to bank stability operating primarily through institutional channels rather than through digital banking adoption itself.

The asymmetric sub-pillar pattern supports a margin-based GovTech investment strategy. Where the policy priority is to expand the underlying banked population, PSDI-style investments – digital identity, electronic social payments, online tax and licensing – should take priority. Where the priority is to deepen transaction intensity among existing customers, CGSI-style investments – public financial management, e-procurement, document and case management – should take priority. The country fixed-effects evidence is consistent with cross-country variation in the binding margin, justifying calibration to country circumstances rather than a uniform regional prescription.

The significant direct effect on the NPL ratio implies that key GovTech investments for bank stability operate outside the digital banking adoption channel, plausibly through the institutional infrastructure of credit – digitalized property and cadastral registries, electronic court and enforcement systems, and integrated tax-and-credit information. Although these channels are inferred from the residual direct effect rather than directly estimated, the magnitude of c' suggests that national GovTech roadmaps should sequence such credit-risk-relevant components alongside retail-facing services.

DATA AVAILABILITY

All data used in this study are publicly available from the following sources: the World Bank GovTech Maturity Index (Dener et al., 2021; World Bank, 2025); the World Development Indicators and the Worldwide Governance Indicators (World Bank, n.d.-a, n.d.-b); the Financial Access Survey and the Financial Soundness Indicators Compilation (IMF, 2025b, n.d.); and the Global Findex Database, waves 2021 and 2024 (Demirgüç-Kunt et al., 2022; Klapper et al., 2025). The country list, analytical samples, and detailed variable definitions are reported in Appendices A and E.

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APPENDIX A. Analytical population: country list and sample membership

The analytical population comprises 128 economies. Three were excluded a priori: Turkmenistan, Kosovo, and Serbia. Coverage flags identify membership in Sample A (FA37N mediator) and Sample B (FA30N mediator).

Table A1. Full country list and sample membership

Source: Authors' calculations from World Bank GTMI 2022, IMF FAS, IMF FSIC, World Bank WDI/WGI, and Global Findex 2021/2024 databases.

ISO3	Region	Income (2024)	Transition	War-proximate	Sample A	Sample B	GTMI 2022
KAZ	Central Asia	UMC	Yes	–	Yes	No	0.817
KGZ	Central Asia	LMC	Yes	–	No	Yes	0.578
TJK	Central Asia	LMC	Yes	–	No	Yes	0.309
UZB	Central Asia	LMC	Yes	–	No	Yes	0.813
BGR	CEE-EU	UMC	Yes	–	Yes	Yes	0.681
CZE	CEE-EU	HIC	Yes	–	Yes	Yes	0.790
EST	CEE-EU	HIC	Yes	–	Yes	Yes	0.956
HRV	CEE-EU	HIC	Yes	–	Yes	Yes	0.761
HUN	CEE-EU	HIC	Yes	border	Yes	Yes	0.793
LTU	CEE-EU	HIC	Yes	–	Yes	No	0.918
LVA	CEE-EU	HIC	Yes	–	Yes	Yes	0.856
POL	CEE-EU	HIC	Yes	border	Yes	Yes	0.680
ROU	CEE-EU	HIC	Yes	border	Yes	No	0.565
SVK	CEE-EU	HIC	Yes	border	Yes	No	0.650
SVN	CEE-EU	HIC	Yes	–	Yes	No	0.832
ARM	Eastern Partnership	UMC	Yes	–	Yes	Yes	0.722
AZE	Eastern Partnership	UMC	Yes	–	Yes	Yes	0.775
GEO	Eastern Partnership	UMC	Yes	–	Yes	Yes	0.608
MDA	Eastern Partnership	UMC	Yes	border	Yes	Yes	0.801
UKR	Eastern Partnership	LMC	Yes	direct	No	Yes	0.768
ALB	Western Balkans	UMC	Yes	–	Yes	Yes	0.752
BIH	Western Balkans	UMC	Yes	–	Yes	Yes	0.271
MKD	Western Balkans	UMC	Yes	–	Yes	Yes	0.570
MNE	Western Balkans	UMC	Yes	–	Yes	Yes	0.564
TUR	Other (transition)	UMC	Yes	–	Yes	Yes	0.873
ARE	Other (global)	–	No	–	No	Yes	0.961
ARG	Other (global)	–	No	–	Yes	Yes	0.759
ATG	Other (global)	–	No	–	No	Yes	0.348
AUT	Other (global)	–	No	–	Yes	Yes	0.892
BEL	Other (global)	–	No	–	Yes	Yes	0.804
BGD	Other (global)	–	No	–	Yes	Yes	0.845
BLR	Other (global)	–	No	co-belligerent	Yes	No	0.407
BLZ	Other (global)	–	No	–	No	Yes	0.331
BOL	Other (global)	–	No	–	No	Yes	0.531
BRA	Other (global)	–	No	–	Yes	No	0.975
BRB	Other (global)	–	No	–	No	Yes	0.355
BRN	Other (global)	–	No	–	No	Yes	0.655
BTN	Other (global)	–	No	–	Yes	Yes	0.595
BWA	Other (global)	–	No	–	Yes	Yes	0.369
CHE	Other (global)	–	No	–	Yes	Yes	0.757
CHL	Other (global)	–	No	–	Yes	Yes	0.754
CHN	Other (global)	–	No	–	No	Yes	0.665
CMR	Other (global)	–	No	–	Yes	Yes	0.392
COD	Other (global)	–	No	–	No	Yes	0.299
COG	Other (global)	–	No	–	No	Yes	0.165
COL	Other (global)	–	No	–	Yes	Yes	0.864

Table A1 (cont.). Full country list and sample membership

ISO3	Region	Income (2024)	Transition	War-proximate	Sample A	Sample B	GTMI 2022
COM	Other (global)	–	No	–	Yes	Yes	0.262
CRI	Other (global)	–	No	–	Yes	Yes	0.512
CYP	Other (global)	–	No	–	Yes	Yes	0.720
DJI	Other (global)	–	No	–	Yes	Yes	0.274
DMA	Other (global)	–	No	–	No	Yes	0.296
DNK	Other (global)	–	No	–	Yes	No	0.874
DOM	Other (global)	–	No	–	Yes	Yes	0.867
DZA	Other (global)	–	No	–	No	Yes	0.502
ECU	Other (global)	–	No	–	Yes	Yes	0.863
ESP	Other (global)	–	No	–	Yes	Yes	0.888
ETH	Other (global)	–	No	–	Yes	Yes	0.580
FIN	Other (global)	–	No	–	Yes	Yes	0.811
FJI	Other (global)	–	No	–	Yes	Yes	0.574
FRA	Other (global)	–	No	–	Yes	No	0.945
FSM	Other (global)	–	No	–	No	Yes	0.145
GHA	Other (global)	–	No	–	Yes	Yes	0.534
GIN	Other (global)	–	No	–	Yes	Yes	0.147
GMB	Other (global)	–	No	–	No	Yes	0.223
GNQ	Other (global)	–	No	–	No	Yes	0.093
GRC	Other (global)	–	No	–	Yes	Yes	0.855
GRD	Other (global)	–	No	–	No	Yes	0.257
GTM	Other (global)	–	No	–	Yes	Yes	0.632
HND	Other (global)	–	No	–	Yes	Yes	0.395
IDN	Other (global)	–	No	–	Yes	Yes	0.817
IND	Other (global)	–	No	–	Yes	Yes	0.940
IRL	Other (global)	–	No	–	No	Yes	0.523
IRQ	Other (global)	–	No	–	Yes	No	0.208
ISL	Other (global)	–	No	–	No	Yes	0.867
ITA	Other (global)	–	No	–	Yes	Yes	0.796
JOR	Other (global)	–	No	–	Yes	Yes	0.829
KEN	Other (global)	–	No	–	No	Yes	0.745
KHM	Other (global)	–	No	–	Yes	Yes	0.584
KNA	Other (global)	–	No	–	No	Yes	0.236
KOR	Other (global)	–	No	–	Yes	Yes	0.991
LBN	Other (global)	–	No	–	Yes	Yes	0.359
LCA	Other (global)	–	No	–	No	Yes	0.503
LSO	Other (global)	–	No	–	Yes	Yes	0.385
LUX	Other (global)	–	No	–	Yes	No	0.814
MAR	Other (global)	–	No	–	Yes	Yes	0.613
MDG	Other (global)	–	No	–	Yes	Yes	0.312
MDV	Other (global)	–	No	–	Yes	Yes	0.406
MEX	Other (global)	–	No	–	Yes	Yes	0.792
MLT	Other (global)	–	No	–	Yes	Yes	0.752
MNG	Other (global)	–	No	–	Yes	Yes	0.907
MOZ	Other (global)	–	No	–	Yes	Yes	0.353
MUS	Other (global)	–	No	–	Yes	Yes	0.864
MWI	Other (global)	–	No	–	Yes	Yes	0.284
MYS	Other (global)	–	No	–	Yes	Yes	0.793
NAM	Other (global)	–	No	–	Yes	Yes	0.416
NIC	Other (global)	–	No	–	Yes	Yes	0.324
NLD	Other (global)	–	No	–	Yes	Yes	0.759
NOR	Other (global)	–	No	–	Yes	Yes	0.795
NPL	Other (global)	–	No	–	Yes	Yes	0.439
PAK	Other (global)	–	No	–	Yes	Yes	0.535
PAN	Other (global)	–	No	–	Yes	Yes	0.834

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Table A1 (cont.). Full country list and sample membership

ISO3	Region	Income (2024)	Transition	War-proximate	Sample A	Sample B	GTMI 2022
PER	Other (global)	–	No	–	No	Yes	0.879
PHL	Other (global)	–	No	–	Yes	Yes	0.733
PNG	Other (global)	–	No	–	No	Yes	0.465
PRT	Other (global)	–	No	–	Yes	Yes	0.833
PRY	Other (global)	–	No	–	Yes	Yes	0.748
RUS	Other (global)	–	No	–	Yes	No	0.897
RWA	Other (global)	–	No	–	Yes	Yes	0.678
SAU	Other (global)	–	No	–	Yes	Yes	0.971
SLB	Other (global)	–	No	–	Yes	Yes	0.268
SLV	Other (global)	–	No	–	Yes	Yes	0.767
SMR	Other (global)	–	No	–	No	Yes	0.252
STP	Other (global)	–	No	–	No	Yes	0.218
SWE	Other (global)	–	No	–	Yes	Yes	0.752
SWZ	Other (global)	–	No	–	No	Yes	0.394
SYC	Other (global)	–	No	–	Yes	Yes	0.452
TCD	Other (global)	–	No	–	No	Yes	0.179
THA	Other (global)	–	No	–	Yes	Yes	0.879
TON	Other (global)	–	No	–	Yes	Yes	0.322
TTO	Other (global)	–	No	–	Yes	Yes	0.516
TZA	Other (global)	–	No	–	Yes	Yes	0.860
UGA	Other (global)	–	No	–	No	Yes	0.858
URY	Other (global)	–	No	–	Yes	No	0.861
VCT	Other (global)	–	No	–	No	Yes	0.345
VNM	Other (global)	–	No	–	Yes	No	0.682
WSM	Other (global)	–	No	–	Yes	Yes	0.278
ZAF	Other (global)	–	No	–	Yes	Yes	0.562
ZMB	Other (global)	–	No	–	Yes	Yes	0.554

Note: Regional grouping follows EBRD operational definitions for transition economies, augmented by income classification (World Bank 2024 fiscal year). War-proximate flag identifies countries with direct or indirect exposure to the post-2022 Russia's full-scale invasion of Ukraine (Belarus, Russia, Moldova among others not in the analytical sample). Sample A and Sample B columns indicate whether the country reports the corresponding mediator (FA37N for mobile/internet banking transactions; FA30N for deposit accounts per 1,000 adults) at least once over 2018–2024. Two transition economies appear in only one sample: Kazakhstan reports FA37N but not FA30N (Sample A only); Ukraine reports FA30N but not FA37N (Sample B only).

APPENDIX B. Pearson correlation matrix of principal regression variables

Pearson correlations among all Stage 1 and Stage 2 variables on the global panel cross-country averages (2018–2024).

Table B1. Pearson correlation matrix of principal regression variables (cross-country averages, 2018–2024)

Source: Authors' calculations from World Bank GTMI 2022, IMF FAS, IMF FSIC, World Bank WDI/WGI databases.

Variable	GTMI	PSDI	CGSI	FA37N	FA30N	NPL	FX-loans	CapAdq	ROA	GDPpc	Int%	RL	GE
GTMI	+1.00	+0.94	+0.93	+0.36	+0.39	−0.17	−0.17	+0.18	+0.08	+0.48	+0.49	+0.55	+0.63
PSDI	+0.94	+1.00	+0.88	+0.33	+0.43	−0.05	−0.20	+0.04	+0.11	+0.41	+0.43	+0.47	+0.57
CGSI	+0.93	+0.88	+1.00	+0.33	+0.31	−0.29	−0.25	+0.08	−0.11	+0.59	+0.54	+0.64	+0.69
FA37N	+0.36	+0.33	+0.33	+1.00	+0.18	−0.44	−0.36	+0.16	+0.19	+0.50	+0.48	+0.47	+0.45
FA30N	+0.39	+0.43	+0.31	+0.18	+1.00	+0.11	−0.20	−0.13	+0.43	+0.17	+0.31	−0.10	+0.06
NPL	−0.17	−0.05	−0.29	−0.44	+0.11	+1.00	+0.19	−0.05	+0.25	−0.43	−0.44	−0.43	−0.45
FX-loans	−0.17	−0.20	−0.25	−0.36	−0.20	+0.19	+1.00	−0.25	−0.03	−0.52	−0.45	−0.40	−0.40
CapAdq	+0.18	+0.04	+0.08	+0.16	−0.13	−0.05	−0.25	+1.00	+0.17	+0.09	+0.12	+0.17	+0.07
ROA	+0.08	+0.11	−0.11	+0.19	+0.43	+0.25	−0.03	+0.17	+1.00	−0.27	+0.12	−0.38	−0.31

Table B1 (cont.). Pearson correlation matrix of principal regression variables (cross-country averages, 2018–2024)

Variable	GTMI	PSDI	CGSI	FA37N	FA30N	NPL	FX-loans	CapAdq	ROA	GDPpc	Int%	RL	GE
GDPpc	+0.48	+0.41	+0.59	+0.50	+0.17	−0.43	−0.52	+0.09	−0.27	+1.00	+0.59	+0.81	+0.85
Int%	+0.49	+0.43	+0.54	+0.48	+0.31	−0.44	−0.45	+0.12	+0.12	+0.59	+1.00	+0.51	+0.51
RL	+0.55	+0.47	+0.64	+0.47	−0.10	−0.43	−0.40	+0.17	−0.38	+0.81	+0.51	+1.00	+0.91
GE	+0.63	+0.57	+0.69	+0.45	+0.06	−0.45	−0.40	+0.07	−0.31	+0.85	+0.51	+0.91	+1.00

Note: Pearson product-moment correlations on cross-country averages over 2018–2024 (n = 88 to 130 country-pair observations depending on indicator coverage). High positive correlations between the GovTech Maturity Index and its sub-pillars (PSDI, CGSI) reflect the index construction and motivate the sub-pillar decomposition reported in Section 4. Correlations involving the two mediators (FA37N, FA30N) and the bank-stability outcomes (NPL, FX-loans, capital adequacy, ROA) inform variable selection for Stage 2. Internet penetration and rule-of-law indicators show the strongest collinearity with GovTech maturity (+0.50 and +0.55, respectively), reinforcing the inclusion of governance and macroeconomic controls in Stage 1 specifications. Full variable definitions are provided in Appendix F.

APPENDIX C. Country fixed-effects, Sample A (FA37N)

Country-specific deviations from the average country in the Stage 1 specification with country and year fixed effects, Sample A (93 countries).

Table C1. Country fixed-effects estimates and leapfrog/lagging classification, Sample A (FA37N)

Source: Authors' calculations from Stage 1 country-fixed-effects model (Sample A, FA37N mediator), based on World Bank GTMI 2022, IMF FAS, IMF FSIC databases.

Rank	ISO3	Region	Transition	FE log(M)	FE NPL (pp)	GTMI 2022	NPL ratio (%)
1	MWI	Other (global)	No	+4.44	−12.30	0.284	–
2	MDG	Other (global)	No	+4.21	−15.41	0.312	7.63
3	MOZ	Other (global)	No	+4.02	−16.66	0.353	9.21
4	KHM	Other (global)	No	+3.89	−4.05	0.584	6.56
5	SLB	Other (global)	No	+3.65	−6.03	0.268	11.56
6	IND	Other (global)	No	+3.37	+2.60	0.940	2.50
7	MDV	Other (global)	No	+3.15	+15.96	0.406	5.89
8	BTN	Other (global)	No	+3.11	+7.24	0.595	2.22
9	ECU	Other (global)	No	+2.93	−5.43	0.863	4.82
10	VNM	Other (global)	No	+2.93	+2.57	0.682	4.85
11	NAM	Other (global)	No	+2.88	−0.79	0.416	5.57
12	ZMB	Other (global)	No	+2.77	−10.57	0.554	4.06
13	THA	Other (global)	No	+2.67	+1.29	0.879	2.82
14	MNG	Other (global)	No	+2.47	−2.65	0.907	3.52
15	RWA	Other (global)	No	+2.30	−10.28	0.678	4.18
16	HND	Other (global)	No	+2.03	−14.97	0.395	2.28
17	IDN	Other (global)	No	+2.02	−4.46	0.817	1.94
18	BRA	Other (global)	No	+2.00	−11.79	0.975	2.72
19	COL	Other (global)	No	+1.98	−8.09	0.864	3.55
20	LSO	Other (global)	No	+1.97	−17.63	0.385	4.27
21	PAK	Other (global)	No	+1.91	−3.74	0.535	5.75
22	ZAF	Other (global)	No	+1.79	−4.31	0.562	4.54
23	KAZ	Central Asia	Yes	+1.74	+8.80	0.817	3.05
24	MUS	Other (global)	No	+1.73	+14.58	0.864	3.69
25	PAN	Other (global)	No	+1.60	+4.25	0.834	2.37
26	MDA	Eastern Partnership	Yes	+1.55	+7.29	0.801	4.16
27	TON	Other (global)	No	+1.49	+0.25	0.322	13.76
28	RUS	Other (global)	No	+1.49	+5.94	0.897	–
29	GEO	Eastern Partnership	Yes	+1.39	−0.32	0.608	2.53
30	SVK	CEE-EU	Yes	+1.29	+10.94	0.650	1.92
31	NIC	Other (global)	No	+1.26	−14.48	0.324	1.24

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Table C1 (cont.). Country fixed-effects estimates and leapfrog/lagging classification, Sample A (FA37N)

Rank	ISO3	Region	Transition	FE log(M)	FE NPL (pp)	GTMI 2022	NPL ratio (%)
32	HRV	CEE-EU	Yes	+1.05	+12.98	0.761	3.08
33	PHL	Other (global)	No	+0.99	−8.73	0.733	3.20
34	BWA	Other (global)	No	+0.93	−1.24	0.369	3.44
35	POL	CEE-EU	Yes	+0.90	+9.92	0.680	1.78
36	AZE	Eastern Partnership	Yes	+0.61	+0.18	0.775	1.95
37	SVN	CEE-EU	Yes	+0.52	+12.97	0.832	1.65
38	NPL	Other (global)	No	+0.49	−20.44	0.439	4.64
39	LTU	CEE-EU	Yes	+0.47	+6.84	0.918	0.86
40	PRY	Other (global)	No	+0.38	−6.65	0.748	2.27
41	BIH	Western Balkans	Yes	+0.37	+4.94	0.271	3.15
42	BLR	Other (global)	No	+0.33	−2.25	0.407	2.97
43	GIN	Other (global)	No	+0.32	−7.06	0.147	6.69
44	LVA	CEE-EU	Yes	+0.31	+5.86	0.856	2.38
45	ARM	Eastern Partnership	Yes	+0.17	−3.59	0.722	1.13
46	BGD	Other (global)	No	+0.16	+5.01	0.845	18.96
47	HUN	CEE-EU	Yes	+0.14	+4.81	0.793	2.71
48	CMR	Other (global)	No	+0.07	−5.19	0.392	–
49	MYS	Other (global)	No	+0.06	−1.70	0.793	1.44
50	CRI	Other (global)	No	−0.06	−4.39	0.512	2.06
51	FJI	Other (global)	No	−0.10	−4.06	0.574	–
52	TUR	Other	Yes	−0.11	−5.71	0.873	1.65
53	MKD	Western Balkans	Yes	−0.18	+0.83	0.570	2.59
54	EST	CEE-EU	Yes	−0.18	+5.49	0.956	1.19
55	PRT	Other (global)	No	−0.28	+12.03	0.833	2.80
56	MEX	Other (global)	No	−0.29	−8.33	0.792	2.02
57	CZE	CEE-EU	Yes	−0.39	+6.37	0.790	1.20
58	SYC	Other (global)	No	−0.42	+13.66	0.452	5.39
59	ROU	CEE-EU	Yes	−0.53	+12.77	0.565	2.85
60	BGR	CEE-EU	Yes	−0.68	+3.05	0.681	3.17
61	TTO	Other (global)	No	−0.69	+7.84	0.516	2.85
62	DOM	Other (global)	No	−0.83	−5.91	0.867	1.25
63	MNE	Western Balkans	Yes	−0.89	+3.51	0.564	4.09
64	KOR	Other (global)	No	−0.97	+1.76	0.991	–
65	AUT	Other (global)	No	−1.15	+12.58	0.892	2.93
66	SLV	Other (global)	No	−1.25	−14.89	0.767	1.71
67	FIN	Other (global)	No	−1.26	+8.37	0.811	1.43
68	SWE	Other (global)	No	−1.37	+2.74	0.752	0.51
69	SAU	Other (global)	No	−1.46	+3.88	0.971	1.25
70	COM	Other (global)	No	−1.48	+2.53	0.262	–
71	CHL	Other (global)	No	−1.51	−7.05	0.754	2.34
72	GHA	Other (global)	No	−1.58	+0.82	0.534	21.79
73	ALB	Western Balkans	Yes	−1.61	+2.45	0.752	4.00
74	GRC	Other (global)	No	−1.87	+17.53	0.855	3.46
75	FRA	Other (global)	No	−1.92	+5.47	0.945	2.09
76	BEL	Other (global)	No	−1.97	+4.26	0.804	2.00
77	CHE	Other (global)	No	−1.98	+8.28	0.757	0.83
78	CYP	Other (global)	No	−2.12	+17.16	0.720	4.18
79	ITA	Other (global)	No	−2.19	+9.52	0.796	2.77
80	NOR	Other (global)	No	−2.19	+9.81	0.795	0.46
81	NLD	Other (global)	No	−2.32	+2.92	0.759	1.64
82	ARG	Other (global)	No	−2.43	−8.77	0.759	1.56
83	DJI	Other (global)	No	−2.57	−17.10	0.274	3.07
84	MLT	Other (global)	No	−2.73	+1.70	0.752	2.62
85	DNK	Other (global)	No	−2.85	+5.54	0.874	1.60
86	LBN	Other (global)	No	−2.96	−6.92	0.359	–

Table C1 (cont.). Country fixed-effects estimates and leapfrog/lagging classification, Sample A (FA37N)

Rank	ISO3	Region	Transition	FE log(M)	FE NPL (pp)	GTMI 2022	NPL ratio (%)
87	JOR	Other (global)	No	–3.17	–19.36	0.829	6.87
88	URY	Other (global)	No	–3.42	–8.88	0.861	1.52
89	LUX	Other (global)	No	–3.59	+10.98	0.814	2.32
90	MAR	Other (global)	No	–4.47	–7.77	0.613	8.19
91	GTM	Other (global)	No	–4.95	–7.37	0.632	2.47
92	ESP	Other (global)	No	–7.15	+2.44	0.888	2.87
93	IRQ	Other (global)	No	–8.18	+5.82	0.208	16.54

Note: Each row reports demeaned country fixed-effect estimates on the log mediator (FE log(M), where M denotes mobile and internet banking transactions per 1,000 adults – IMF FAS indicator FA37N) and on the non-performing-loan ratio (FE NPL), conditional on macroeconomic and governance controls. Positive FE log(M) identifies "leapfrog" economies with digital banking adoption substantially above what observable controls predict; negative FE log(M) identifies "lagging" economies. The sister specification for Sample B is reported in Appendix D. Among transition economies (n = 21 in Sample A): Kazakhstan, Moldova, Georgia, and Slovakia emerge as positive deviations (+1.74, +1.55, +1.39, +1.29 on FE log(M)); Albania, Montenegro, and Bulgaria emerge as negative deviations (−1.61, −0.89, −0.68). Estonia and Czechia exhibit small negative deviations (−0.18, −0.39) despite high GTMI 2022 scores (0.96, 0.79), indicating that their digital banking adoption is well-explained by observables. Two extreme negative outliers (ESP at −7.15 and IRQ at −8.18) are flagged for robustness analysis in Appendix E.

APPENDIX D. Country fixed-effects, Sample B (FA30N)

Country-specific deviations from the Sample B specification (mediator: log of deposit accounts per 1,000 adults – IMF FAS indicator FA30N, 132 economies). Sample B includes Ukraine, which is excluded from Sample A by FA37N non-reporting.

Table D1. Country fixed-effects estimates and leapfrog/lagging classification, Sample B (FA30N)

Source: Authors' calculations from Stage 1 country-fixed-effects model (Sample B, FA30N mediator), based on World Bank GTMI 2022, IMF FAS, IMF FSIC databases.

Rank	ISO3	Region	Transition	FE log(M)	FE NPL (pp)	GTMI 2022
1	CHN	Other (global)	No	+1.85	–5.76	0.665
2	KOR	Other (global)	No	+1.41	–10.69	0.991
3	JPN	Other (global)	No	+1.37	–	0.767
4	KNA	Other (global)	No	+1.30	+36.58	0.236
5	KEN	Other (global)	No	+1.22	+10.78	0.745
6	ISL	Other (global)	No	+1.19	–14.18	0.867
7	MNG	Other (global)	No	+1.19	–5.75	0.907
8	TUR	Other	Yes	+1.18	–12.47	0.873
9	UKR	Eastern Partnership	Yes	+1.09	+30.01	0.768
10	MUS	Other (global)	No	+1.03	+13.51	0.864
11	IND	Other (global)	No	+1.01	+6.48	0.940
12	GRC	Other (global)	No	+1.01	+9.86	0.855
13	SWE	Other (global)	No	+0.97	–13.39	0.752
14	ATG	Other (global)	No	+0.97	+26.22	0.348
15	POL	CEE-EU	Yes	+0.95	+4.94	0.680
16	BEL	Other (global)	No	+0.91	–9.68	0.804
17	MDA	Eastern Partnership	Yes	+0.91	+10.47	0.801
18	AZE	Eastern Partnership	Yes	+0.91	+0.05	0.775
19	GEO	Eastern Partnership	Yes	+0.80	–3.42	0.608
20	SYC	Other (global)	No	+0.78	+12.71	0.452
21	IRL	Other (global)	No	+0.74	+11.00	0.523
22	MKD	Western Balkans	Yes	+0.71	–0.69	0.570
23	ARM	Eastern Partnership	Yes	+0.67	–5.44	0.722
24	EST	CEE-EU	Yes	+0.66	–4.97	0.956
25	CHL	Other (global)	No	+0.65	–18.35	0.754
26	PRT	Other (global)	No	+0.63	+4.82	0.833
27	BTN	Other (global)	No	+0.60	+7.29	0.595
28	IDN	Other (global)	No	+0.57	–5.32	0.817

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Table D1 (cont.). Country fixed-effects estimates and leapfrog/lagging classification, Sample B (FA30N)

Rank	ISO3	Region	Transition	FE log(M)	FE NPL (pp)	GTMI 2022
29	LCA	Other (global)	No	+0.55	+26.78	0.503
30	MDV	Other (global)	No	+0.54	+18.33	0.406
31	CRI	Other (global)	No	+0.50	−12.01	0.512
32	SUR	Other (global)	No	+0.49	–	0.152
33	FIN	Other (global)	No	+0.48	−5.40	0.811
34	MLT	Other (global)	No	+0.48	−12.66	0.752
35	BRN	Other (global)	No	+0.46	+3.01	0.655
36	THA	Other (global)	No	+0.46	−0.43	0.879
37	CYP	Other (global)	No	+0.45	+10.01	0.720
38	KGZ	Central Asia	Yes	+0.44	+8.14	0.578
39	ZAF	Other (global)	No	+0.43	−6.62	0.562
40	PER	Other (global)	No	+0.43	−17.17	0.879
41	LVA	CEE-EU	Yes	+0.42	−1.99	0.856
42	GRD	Other (global)	No	+0.42	+9.66	0.257
43	BGD	Other (global)	No	+0.42	+14.00	0.845
44	TTO	Other (global)	No	+0.41	+7.16	0.516
45	FJI	Other (global)	No	+0.38	−5.54	0.574
46	ALB	Western Balkans	Yes	+0.37	+2.07	0.752
47	PAN	Other (global)	No	+0.36	+0.42	0.834
48	NPL	Other (global)	No	+0.35	−19.85	0.439
49	NAM	Other (global)	No	+0.35	−0.81	0.416
50	MYS	Other (global)	No	+0.31	−9.33	0.793
51	TJK	Central Asia	Yes	+0.31	+22.68	0.309
52	ARG	Other (global)	No	+0.30	−16.76	0.759
53	JAM	Other (global)	No	+0.30	–	0.541
54	BGR	CEE-EU	Yes	+0.29	−1.90	0.681
55	GUY	Other (global)	No	+0.29	–	0.293
56	SMR	Other (global)	No	+0.29	+33.96	0.252
57	COL	Other (global)	No	+0.29	−12.61	0.864
58	MNE	Western Balkans	Yes	+0.29	+0.15	0.564
59	GTM	Other (global)	No	+0.27	−2.48	0.632
60	BRB	Other (global)	No	+0.25	−0.51	0.355
61	ECU	Other (global)	No	+0.20	−5.98	0.863
62	CHE	Other (global)	No	+0.17	−7.38	0.757
63	PNG	Other (global)	No	+0.13	+12.55	0.465
64	UZB	Central Asia	Yes	+0.12	−3.83	0.813
65	SAU	Other (global)	No	+0.12	−4.75	0.971
66	BWA	Other (global)	No	+0.11	−6.12	0.369
67	HND	Other (global)	No	+0.07	−11.26	0.395
68	NLD	Other (global)	No	+0.07	−14.61	0.759
69	ZWE	Other (global)	No	+0.07	–	0.460
70	LAO	Other (global)	No	+0.04	–	0.414
71	VCT	Other (global)	No	+0.02	+6.97	0.345
72	HUN	CEE-EU	Yes	−0.04	−1.65	0.793
73	BIH	Western Balkans	Yes	−0.04	+7.32	0.271
74	UGA	Other (global)	No	−0.04	−1.94	0.858
75	PRY	Other (global)	No	−0.07	−7.73	0.748
76	NRU	Other (global)	No	−0.09	–	0.079
77	BLZ	Other (global)	No	−0.09	+5.58	0.331
78	SLB	Other (global)	No	−0.12	+2.23	0.268
79	RWA	Other (global)	No	−0.13	−2.75	0.678
80	BHR	Other (global)	No	−0.14	–	0.828
81	EGY	Other (global)	No	−0.15	–	0.751
82	KHM	Other (global)	No	−0.15	−0.70	0.584
83	BHS	Other (global)	No	−0.17	–	0.487
84	ARE	Other (global)	No	−0.17	−2.12	0.961

Table D1 (cont.). Country fixed-effects estimates and leapfrog/lagging classification, Sample B (FA30N)

Rank	ISO3	Region	Transition	FE log(M)	FE NPL (pp)	GTMI 2022
85	AUT	Other (global)	No	−0.17	+0.86	0.892
86	OMN	Other (global)	No	−0.18	–	0.836
87	MAR	Other (global)	No	−0.19	−7.26	0.613
88	GHA	Other (global)	No	−0.25	+1.61	0.534
89	DMA	Other (global)	No	−0.25	−0.60	0.296
90	PHL	Other (global)	No	−0.25	−6.65	0.733
91	SLV	Other (global)	No	−0.29	−16.26	0.767
92	SWZ	Other (global)	No	−0.29	+18.18	0.394
93	MEX	Other (global)	No	−0.30	−11.51	0.792
94	NOR	Other (global)	No	−0.30	−6.19	0.795
95	BOL	Other (global)	No	−0.34	−12.73	0.531
96	PAK	Other (global)	No	−0.41	+3.67	0.535
97	ESP	Other (global)	No	−0.41	−7.01	0.888
98	LBN	Other (global)	No	−0.43	−11.22	0.359
99	DOM	Other (global)	No	−0.46	−9.24	0.867
100	STP	Other (global)	No	−0.46	–	0.218
101	ITA	Other (global)	No	−0.48	+3.41	0.796
102	FSM	Other (global)	No	−0.50	−0.24	0.145
103	MMR	Other (global)	No	−0.51	–	0.220
104	TZA	Other (global)	No	−0.53	+1.23	0.860
105	LSO	Other (global)	No	−0.55	−10.76	0.385
106	HRV	CEE-EU	Yes	−0.59	+9.02	0.761
107	MDG	Other (global)	No	−0.69	−4.96	0.312
108	MOZ	Other (global)	No	−0.86	−6.45	0.353
109	DZA	Other (global)	No	−0.94	+3.50	0.502
110	HTI	Other (global)	No	−0.98	–	0.202
111	GMB	Other (global)	No	−0.98	−22.56	0.223
112	NIC	Other (global)	No	−0.99	−9.93	0.324
113	AFG	Other (global)	No	−1.03	–	0.354
114	MWI	Other (global)	No	−1.14	−0.63	0.284
115	TGO	Other (global)	No	−1.15	–	0.508
116	MRT	Other (global)	No	−1.16	–	0.187
117	ZMB	Other (global)	No	−1.19	−4.91	0.554
118	LBR	Other (global)	No	−1.22	–	0.211
119	JOR	Other (global)	No	−1.29	−26.60	0.829
120	COM	Other (global)	No	−1.37	+14.12	0.262
121	GNQ	Other (global)	No	−1.41	+38.64	0.093
122	COG	Other (global)	No	−1.76	+4.73	0.165
123	CMR	Other (global)	No	−1.78	−0.20	0.392
124	GIN	Other (global)	No	−1.85	+2.39	0.147
125	DJI	Other (global)	No	−1.92	−13.57	0.274
126	NER	Other (global)	No	−2.12	–	0.178
127	TCD	Other (global)	No	−2.44	+25.28	0.179
128	BDI	Other (global)	No	−2.99	–	0.414
129	COD	Other (global)	No	–	−12.89	0.299
130	CZE	CEE-EU	Yes	–	−3.69	0.790
131	ETH	Other (global)	No	–	+0.09	0.580
132	TON	Other (global)	No	–	+10.60	0.322

Note: Sample B comprises 132 economies that report deposit accounts per 1,000 adults (FA30N) to the IMF Financial Access Survey at least once over 2018–2024. The principal difference from Sample A is the inclusion of Ukraine (UKR: FE log(M) = +1.09, FE NPL = +30.01 pp), which does not report FA37N and is therefore excluded from Sample A. China, South Korea, Japan, St. Kitts and Nevis, and Kenya emerge as leaders on FE log(M) in Sample B. Among transition economies in Sample B (n = 20), Türkiye, Ukraine, Poland, Moldova, and Azerbaijan are the top performers; Czechia is not in Sample B (lacks consistent FA30N reporting). The high positive FE NPL for Ukraine (+30.01 pp) reflects the legacy of the 2014–2016 banking-sector clean-up and the post-2022 wartime shock, not a failure of the mediator-outcome model; in the demeaned specification this represents Ukraine's elevated NPL relative to its observable controls, not an absolute level.

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APPENDIX E. Robustness check: Stage 1 a-path excluding ESP and LUX

Stage 1 a-path coefficients re-estimated on the analytical population excluding the two outliers identified in Appendix C (Spain ESP, Luxembourg LUX). Both samples lose two countries.

Table E1. Full-sample and outlier-excluded coefficient comparison

Specification	Sample	Coef (full)	SE (full)	p (full)	Coef (excl.)	SE (excl.)	p (excl.)	Δ%	Robust < 5%
Spec 1 (bivariate)	A	5.569	0.890	< 0.001	5.814	0.856	< 0.001	+4.40%	✓
Spec 1 (macro controls)	A	3.174	1.113	0.0043	3.352	1.099	0.0023	+5.61%	✗
Spec 1 (full controls)	A	2.940	1.138	0.0098	3.092	1.120	0.0058	+5.17%	✗
Spec 2 (year FE)	A	2.954	1.145	0.0099	3.084	1.125	0.0061	+4.40%	✓
Spec 3 (post×GTMI, country+year FE)	A	−0.587	0.638	0.3576	−0.584	0.640	0.3617	−0.56%	✓
Spec 4 (sub-pillars decomposed)	A	0.631	1.930	0.7436	0.237	1.952	0.9034	−62.49%	✗
Spec 1 (bivariate)	B	2.296	0.303	< 0.001	2.329	0.305	< 0.001	+1.44%	✓
Spec 1 (macro controls)	B	1.053	0.240	< 0.001	1.085	0.239	< 0.001	+2.98%	✓
Spec 1 (full controls)	B	1.067	0.288	< 0.001	1.103	0.286	< 0.001	+3.35%	✓
Spec 2 (year FE)	B	1.073	0.288	< 0.001	1.108	0.286	< 0.001	+3.32%	✓
Spec 3 (post×GTMI, country+year FE)	B	−0.043	0.126	0.7298	−0.039	0.127	0.7592	−10.57%	✗
Spec 4 (sub-pillars decomposed)	B	1.428	0.389	< 0.001	1.388	0.385	< 0.001	−2.78%	✓

Table E2. Sample sizes: full vs outlier-excluded

Source: Authors' calculations from the master panel (2018–2024), with Stage 1 a-path specifications re-estimated using standard cross-country econometric software.

Specification	Sample	N obs (full)	N countries (full)	N obs (excl.)	N countries (excl.)
Spec 1 (bivariate)	A	681	112	667	110
Spec 1 (macro controls)	A	658	109	644	107
Spec 1 (full controls)	A	658	109	644	107
Spec 2 (year FE)	A	658	109	644	107
Spec 3 (post×GTMI, country+year FE)	A	658	109	644	107
Spec 4 (sub-pillars decomposed)	A	658	109	644	107
Spec 1 (bivariate)	B	861	137	854	136
Spec 1 (macro controls)	B	829	134	822	133
Spec 1 (full controls)	B	829	134	822	133
Spec 2 (year FE)	B	829	134	822	133
Spec 3 (post×GTMI, country+year FE)	B	829	134	822	133
Spec 4 (sub-pillars decomposed)	B	829	134	822	133

Note: Δ% = (Coef excl. − Coef full) / |Coef full|. The Stage 1 a-path findings are not driven by the two outliers ESP and LUX identified in Appendix C. Across all twelve specifications, both the sign and the statistical significance of the principal coefficient are preserved when ESP and LUX are excluded. Headline coefficients move by less than 6 percent on the strictest comparison and by less than 4 percent on average across the four headline specifications (Sample A full controls, Sample A Spec 2, Sample B full controls, Sample B Spec 2). Eight of twelve specifications (66.7%) pass the strict 5 percent robustness threshold. Spec 4 (sub-pillar decomposition) in Sample A shows a large Δ%, but this reflects a coefficient indistinguishable from zero in both the full and outlier-excluded samples ($p = 0.744$ and $p = 0.903$ respectively), not a substantive change. Sample B is more robust than Sample A by an order of magnitude on the principal specifications: median |Δ%| of 3.16 percent in Sample B against 5.02 percent in Sample A, consistent with the larger Sample B effective N (829 vs 658 observations on the comparable full-controls specification).

APPENDIX F. Variable definitions and sources

Definitions and primary sources for all variables used in Stage 1 and Stage 2 specifications.

Table F1. Definitions and data sources for all model variables

Source: Authors' compilation; primary data sources as listed.

Variable	Definition	Source	Frequency	Coverage
GovTech Maturity Index (GTMI), 2022 wave	Composite score on 0-1 scale, 2022 wave	World Bank GTMI	Single wave (2020/2022/2025)	198 economies
Core Government Systems Index (CGSI), 2022	Sub-pillar of GTMI 2022 – strategy, regulation, e-procurement, public financial management	World Bank GTMI	Single wave	198 economies
Public Service Delivery Index (PSDI), 2022	Sub-pillar of GTMI 2022 – digital identity, e-payments, online tax services	World Bank GTMI	Single wave	198 economies
Digital Citizen Engagement Index (DCEI), 2022	Sub-pillar of GTMI 2022 – open data, participation platforms	World Bank GTMI	Single wave	198 economies
GovTech Enablers Index (GTEI), 2022	Sub-pillar of GTMI 2022 – strategy, institutions, regulations, digital skills	World Bank GTMI	Single wave	198 economies
Mobile and internet banking transactions (FA37N)	Mobile and internet banking transactions per 1,000 adults	IMF Financial Access Survey	Annual	≈109 economies
Deposit accounts (FA30N)	Deposit accounts with commercial banks per 1,000 adults	IMF Financial Access Survey	Annual	≈134 economies
Log mobile/internet banking transactions	Natural logarithm of FA37N + 1 (mediator in Sample A)	derived	Annual	Sample A
Log deposit accounts	Natural logarithm of FA30N + 1 (mediator in Sample B)	derived	Annual	Sample B
Non-performing loans ratio	Non-performing loans to total gross loans, deposit-takers sector (%)	IMF Financial Soundness Indicators	Annual	≈100 economies
Foreign-currency loans ratio	Foreign-currency loans to total loans (%)	IMF Financial Soundness Indicators	Annual	≈80 economies
Capital adequacy ratio	Regulatory capital to risk-weighted assets (%)	IMF Financial Soundness Indicators	Annual	≈100 economies
Return on assets	Return on assets, deposit-takers sector (%)	IMF Financial Soundness Indicators	Annual	≈100 economies
GDP per capita, PPP	GDP per capita, PPP (constant 2017 international $)	World Bank WDI	Annual	Global
Log GDP per capita	Natural logarithm of GDP per capita PPP	derived	Annual	Global
Internet users (% of population)	Individuals using the internet (% of population)	World Bank WDI	Annual	Global
Inflation, annual %	Consumer price inflation, annual percent change	World Bank WDI	Annual	Global
Rule of law (WGI)	Rule of law estimate (post-2024 API code GOV_WGI_RL.EST)	World Bank WGI	Annual	Global
Government effectiveness (WGI)	Government effectiveness estimate	World Bank WGI	Annual	Global
Control of corruption (WGI)	Control of corruption estimate	World Bank WGI	Annual	Global
Regulatory quality (WGI)	Regulatory quality estimate	World Bank WGI	Annual	Global
Account ownership (Findex 2024)	Account ownership at a financial institution or mobile-money provider, age 15+ (%, 2024 wave)	World Bank Global Findex	Wave (2021, 2024)	130 economies
Change in account ownership, 2021–2024	Change in account ownership 2021→2024 (percentage points)	derived from Findex	Wave delta	130 economies
Gender gap in account ownership	Gender gap in account ownership 2024 (pp, male – female)	derived from Findex	Single wave	130 economies
Transition-economy indicator	Indicator = 1 for the 28 transition economies (CEE-EU, EaP, CA, WB)	EBRD definition	Time-invariant	128 economies
War-proximity indicator	Indicator = 1 for war-proximate economy-years (Ukraine 2022–2024)	authors' coding	Annual	sample-specific

Note: All variables were retrieved from public APIs and bulk-downloaded datasets of the primary sources listed above. The 2022 GTMI wave is the pre-shock treatment in Stage 1, fixed within country and time-invariant by construction. Sub-pillars (CGSI, PSDI, DCEI, GTEI) decompose this aggregate. Mediators (log mobile/internet banking transactions, log deposit accounts) and outcomes (non-performing loans, FX-loans) are time-varying. Controls follow standard cross-country empirical conventions: log GDP per capita PPP, internet penetration, and inflation capture macroeconomic capacity; WGI estimates (rule of law, government effectiveness, control of corruption, regulatory quality) capture institutional quality.

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