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DIGITAL TRANSFORMATION AND ECONOMIC DEVELOPMENT: EVIDENCE FROM UZBEKISTAN

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Abstract: This paper examines the long-run and short-run relationship between digital transformation and economic development in Uzbekistan over 2003–2024. A composite digitalisation index (DIGI) is constructed by principal component analysis from three indicators — individuals using the internet (% of population), mobile cellular subscriptions (per 100 people) and fixed broadband subscriptions (per 100 people) — with the first component accounting for 89.1% of total variance. The autoregressive distributed lag (ARDL) bounds testing procedure of Pesaran, Shin and Smith (2001) is applied within an unrestricted error correction framework, supplemented by Toda–Yamamoto (1995) causality testing and CUSUM/CUSUMSQ stability diagnostics.

Three findings emerge. First, in a parsimonious specification the bounds F-statistic ($F = 4.580$) rejects the null of no level relationship at the 10% significance level but is inconclusive at 5%; the estimated long-run digitalisation coefficient is positive and statistically significant (0.127, $p = 0.022$; $p = 0.001$ with HAC standard errors), with an error-correction coefficient of −0.089 implying a half-life of adjustment of approximately 7.4 years. Second, and critically, this specification fails the Ramsey RESET test ($F = 17.788$, $p = 0.001$), indicating functional-form misspecification. Once dummy variables for the 2017 exchange-rate and trade liberalisation and the 2020 pandemic are introduced, RESET is comfortably passed ($p = 0.482$), explanatory power rises sharply ($R^2 = 0.934$), the break dummies are highly significant (2017: −0.030, $p = 0.002$; 2020: −0.048, $p < 0.001$) — and both the error-correction term and the digitalisation coefficient lose statistical significance. Third, the Toda–Yamamoto procedure detects no Granger causality in either direction (DIGI → lnGDPpc: MWald $\chi^2(1) = 2.545$, $p = 0.111$).

The paper concludes that the apparent long-run association between digitalisation and per capita income in Uzbekistan is not robust: the digitalisation variable substantially proxies for a contemporaneous structural policy regime change rather than exerting an independently identifiable growth effect. This result is consistent with the meta-analytic finding of Wang et al. (2024) that ICT effects on economic performance are statistically insignificant in developing countries, and with the "analog complements" argument of the World Bank (2016). Policy implications are drawn for the "Digital Uzbekistan – 2030" strategy.

Keywords: digital transformation, economic growth, Uzbekistan, ARDL bounds test, cointegration, principal component analysis, structural breaks, Toda–Yamamoto causality, ICT, digital economy.

JEL classification: O33, O47, C22, L86, P28.

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Аннотация (рус тилида): В статье исследуется долгосрочная и краткосрочная взаимосвязь между цифровой трансформацией и экономическим развитием Узбекистана за период 2003–2024 гг. Композитный индекс цифровизации (DIGI) построен методом главных компонент на основе трёх показателей — доля пользователей интернета (% населения), количество абонентов мобильной связи (на 100 человек) и количество абонентов фиксированного широкополосного доступа (на 100 человек); первая главная компонента объясняет 89,1% совокупной дисперсии. Применён метод границ ARDL (Pesaran, Shin, Smith, 2001) в рамках неограниченной модели коррекции ошибок, дополненный тестом причинности Тода–Ямамото (1995) и тестами стабильности CUSUM/CUSUMSQ.

Получены три результата. Во-первых, в экономной спецификации F-статистика теста границ (F = 4,580) отвергает гипотезу об отсутствии долгосрочной связи на 10%-ном уровне значимости, но остаётся неопределённой на 5%-ном уровне; долгосрочный коэффициент цифровизации положителен и статистически значим (0,127; p = 0,022), при коэффициенте коррекции ошибок −0,089 (период полуадаптации ≈ 7,4 года). Во-вторых, данная спецификация не проходит тест Рамсея RESET (F = 17,788; p = 0,001). После включения фиктивных переменных для либерализации валютного рынка 2017 г. и пандемии 2020 г. тест RESET проходится (p = 0,482), R^2 возрастает до 0,934, обе фиктивные переменные высоко значимы (2017: −0,030; 2020: −0,048), однако коэффициент коррекции ошибок и коэффициент цифровизации теряют статистическую значимость. В-третьих, процедура Тода–Ямамото не выявляет причинности ни в одном направлении (p = 0,111).

Вывод: наблюдаемая долгосрочная связь между цифровизацией и подушевым доходом в Узбекистане не является робастной — переменная цифровизации в значительной мере отражает одновременное структурное изменение экономической политики, а не самостоятельный эффект роста. Результат согласуется с мета-аналитическим выводом Wang et al. (2024) о статистической незначимости эффектов ИКТ в развивающихся странах.

Ключевые слова: цифровая трансформация, экономический рост, Узбекистан, тест границ ARDL, коинтеграция, метод главных компонент, структурные сдвиги, причинность Тода–Ямамото, ИКТ, цифровая экономика.

Аннотация (ўзбек тилида): Мақолада 2003–2024 йиллар оралиғида Ўзбекистонда рақамли трансформация ва иқтисодий тараққиёт ўртасидаги узоқ ва қисқа муддатли боғлиқлик тадқиқ этилади. Асосий компоненталар таҳлили (PCA) усули ёрдамида учта кўрсаткич — интернетдан фойдаланувчилар улуши (аҳолининг %), мобил алоқа абонентлари (100 кишига) ва қатъий кенг полосали интернет абонентлари (100 кишига) — асосида композит рақамлаштириш индекси (DIGI) шакллантирилди; биринчи компонента умумий дисперсиянинг 89,1 фоизини изоҳлайди. Pesaran, Shin ва Smith (2001) томонидан таклиф этилган ARDL чегаравий тести чекланмаган хатоликларни тузатиш модели доирасида қўлланилди, шунингдек Тода–Ямамото (1995) сабабий боғлиқлик тести ва CUSUM/CUSUMSQ барқарорлик тестлари билан тўлдирилди.

Учта натижа олинди. Биринчидан, ихчам спецификацияда чегаравий тестнинг F-статистикаси (F = 4,580) узоқ муддатли боғлиқлик йўқлиги ҳақидаги нол гипотезани 10% даражада рад этади, аммо 5% даражада ноаниқ бўлиб қолади; рақамлаштиришнинг узоқ муддатли коэффициенти мусбат ва статистик жиҳатдан аҳамиятли (0,127; p = 0,022); хатоликни тузатиш коэффициенти −0,089 бўлиб, ярим мослашув даври тахминан 7,4 йилни ташкил этади.

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Иккинчидан, бу спецификация Рамсей RESET тестидан ўтмайди (F = 17,788; p = 0,001). 2017 йилги валюта ва савдо либерализацияси ҳамда 2020 йилги пандемия учун фиктив ўзгарувчилар киритилгач, RESET тести муваффақиятли ўтади (p = 0,482), R^2 0,934 гача кўтарилади, ҳар икки фиктив ўзгарувчи юқори аҳамиятли бўлади (2017: −0,030; 2020: −0,048), бироқ хатоликни тузатиш коэффициенти ҳам, рақамлаштириш коэффициенти ҳам статистик аҳамиятини йўқотади. Учинчидан, Тода–Ямамото усули ҳар икки йўналишда ҳам сабабий боғлиқликни аниқламайди (p = 0,111).

Хулоса: Ўзбекистонда рақамлаштириш ва жон бошига даромад ўртасидаги кўринарли узоқ муддатли боғлиқлик мустаҳкам эмас — рақамлаштириш ўзгарувчиси мустақил ўсиш самарасини эмас, балки бир вақтда содир бўлган таркибий сиёсат ўзгаришини акс эттиради. Натижа Wang ва бошқаларнинг (2024) ривожланаётган мамлакатларда АКТ самараларининг статистик жиҳатдан аҳамиятсизлиги ҳақидаги мета-таҳлилий хулосасига мос келади.

Калит сўзлар: рақамли трансформация, иқтисодий ўсиш, Ўзбекистон, ARDL чегаравий тести, коинтеграция, асосий компоненталар таҳлили, таркибий силжишлар, Тода–Ямамото сабабийлиги, АКТ, рақамли иқтисодиёт.

1. INTRODUCTION

Digital transformation occupies a central position in Uzbekistan's development agenda. Presidential Decree PF-6079 of 5 October 2020 approved the "Digital Uzbekistan – 2030" strategy, which sets targets including a 2.5-fold increase in the size of the digital economy, a ten-fold expansion of software exports to US$500 million, and the extension of the fibre-optic network beyond 220,000 km by 2025 [27]. Progress against the intermediate indicators has been substantial. Uzbekistan's position in the United Nations E-Government Development Index rose from 87th (score 0.6665) in 2020 to 69th (0.7265) in 2022 and 63rd (0.7999) in 2024, entering the "Very High EGDI" group for the first time [21]. The ITU ICT Development Index placed Uzbekistan at 84.9 in 2024 and 86.5 in 2025, above the global average of 74.8 and 78.2 respectively [10].

The underlying penetration data are equally striking. Over the two decades covered by this study, internet penetration in Uzbekistan rose from 1.9% of the population in 2003 to 89.5% in 2024; mobile cellular subscriptions increased from 1.2 to 110.5 per 100 people; and fixed broadband subscriptions expanded from 0.01 to 34.7 per 100 people [24]. By any conventional measure, this constitutes one of the more rapid digital diffusion episodes in the post-Soviet space.

Whether this diffusion has translated into measurable gains in aggregate economic performance is, however, a separate and empirically open question. The relevant descriptive fact is uncomfortable for the optimistic reading: over precisely the period in which digitalisation accelerated most sharply, the growth rate of real GDP per capita *decelerated*. Average annual log growth fell from 6.28% over 2004–2010 to 5.73% over 2011–2016, 3.83% over 2017–2019, and 3.64% over 2020–2024 (author's calculations from [24]; the corresponding arithmetic-mean growth rates are 6.48%, 5.90%, 3.91% and 3.73%). This co-movement — rising digital penetration alongside falling per capita growth — does not by itself establish anything causal, but it does establish that the relationship deserves formal econometric treatment rather than assertion.

Three considerations make Uzbekistan an analytically interesting case. First, the country's digital expansion coincided almost exactly with a comprehensive macroeconomic policy reorientation beginning in 2017 — currency convertibility, trade liberalisation, tax reform — which makes the identification of a distinct digitalisation effect genuinely difficult and therefore worth doing carefully.

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Second, the existing Uzbekistan-specific evidence is mixed rather than uniformly positive: Amirov and Avazov [1], using data for 2010–2021, report *negative* coefficients on mobile subscriptions, broadband subscriptions and secure internet servers, while finding strong positive effects for FDI and trade openness. Third, the regional panel literature reports substantial country heterogeneity in ICT effects across Central Asia [11; 19], which limits what can be inferred about Uzbekistan from panel averages.

The aim of this paper is to test, using formal time series econometrics, whether digital transformation exerts a statistically identifiable long-run effect on economic development in Uzbekistan over 2003–2024.

The following **tasks** are set: 1. to construct a composite measure of digitalisation that avoids the multicollinearity problem inherent in using several highly correlated ICT indicators simultaneously in a short sample; 2. to establish the order of integration of all series; 3. to test for the existence of a long-run level relationship using the ARDL bounds testing procedure; 4. to estimate long-run and short-run coefficients and subject them to a full battery of diagnostic and stability tests; 5. to test the robustness of the results to structural breaks, alternative ICT proxies and alternative control sets; 6. to examine the direction of causality using a procedure robust to the integration order of the variables.

The **scientific novelty** of the paper lies in three elements: it is, to the author's knowledge, the first application of a PCA-based composite digitalisation index within an ARDL framework to Uzbekistan's *aggregate growth* relationship; it reports a negative and carefully documented result on the robustness of the digitalisation–growth link; and it demonstrates econometrically that the failure of the naïve specification is attributable to structural breaks rather than to nonlinearity in the digital variable itself.

2. LITERATURE REVIEW

The foundational literature. Empirical study of the relationship between telecommunications infrastructure and economic development was placed on a rigorous footing by Röller and Waverman [18], whose simultaneous-equations approach addressed the endogeneity of infrastructure to demand and introduced the notion of a "critical mass" threshold below which telecommunications investment yields limited returns. Czernich, Falck, Kretschmer and Woessmann [4] extended this to broadband, exploiting the historical structure of pre-existing voice and cable networks for identification across OECD countries. Qiang and Rossotto [17], in the most widely cited policy estimate, report that a ten percentage point increase in broadband penetration is associated with 1.21 percentage points of additional per capita growth in high-income countries and 1.38 percentage points in developing countries — though the developing-country coefficient is significant only at the 10% level, a qualification frequently omitted when the figure is cited in policy documents.

Growth accounting evidence is provided by Jorgenson and Vu [8], who decompose world economic growth into ICT capital deepening, non-ICT capital, labour quality and total factor productivity. Vu [23] reports a finding of direct relevance to a middle-income economy: the marginal effect of ICT penetration diminishes as penetration rises, with internet usage exerting a larger effect than mobile telephony, which in turn exceeds the effect of personal computers.

The counter-literature. A parallel body of work casts doubt on the generality of the positive result. Solow's remark that "you can see the computer age everywhere but in the productivity statistics" [20] framed the productivity paradox that Brynjolfsson and Hitt [3] later resolved at firm level while leaving the macroeconomic puzzle in developing economies substantially open. Dewan and Kraemer [5], using country-level data for 1985–1993, find returns to IT capital positive and significant in

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developed countries but statistically insignificant in developing countries, where returns to non-IT capital remained strong — the origin of the complementary-assets or absorptive-capacity argument. Niebel [15], covering 59 countries over 1995–2010, finds no statistically significant difference in the ICT output elasticity between developing, emerging and developed subsamples, directly contradicting the leapfrogging narrative that features prominently in Central Asian policy discourse.

The most consequential recent contribution is the meta-analysis of Wang, Sun, Yang, Su and Yang [25], covering 1,082 estimates from 65 studies. Precision-effect testing and funnel asymmetry diagnostics confirm publication bias favouring positive results. A genuine positive effect survives correction in the full sample, but effects in developing countries are found to be insignificant, and the authors state that adverse effects of ICT on economic performance in developing countries "cannot be ignored." The World Bank's *World Development Report 2016* [26] supplies the interpretive framework: digital dividends underperform where the "analog complements" — regulation that fosters competition, skills that allow workers to exploit technology, and institutions that hold governments accountable — are weak.

Central Asian and Uzbekistan-specific evidence. Shodiev, Turayev and Shodiyev [19], using panel data for Central Asian countries over 2000–2018, report long-run elasticities of 0.167 for fixed broadband and 0.222 for internet usage. Kurmanov et al. [11] apply ARDL to all five Central Asian republics over 1992–2022, finding effects strongest in Kazakhstan and Uzbekistan but heterogeneous across countries depending on digital infrastructure and institutional quality. For Uzbekistan specifically, Kasimov, Omonova and Kasimov [9] construct a PCA-based composite digital governance index for quarterly data over 2004–2024 and identify a nonlinear, U-shaped relationship with government revenue, implying that digitalisation is fiscally costly below a threshold and beneficial only above it. Amirov and Avazov [1], as noted, report mixed and partly negative coefficients for Uzbekistan over 2010–2021.

Methodological precedents. The bounds testing approach of Pesaran, Shin and Smith [16] is the standard method for single-country series of the length available here, since it accommodates regressors that are I(0), I(1), or mutually cointegrated and performs comparatively well in small samples. Narayan [14] provides critical values adjusted for small samples, which are systematically higher than the asymptotic values and therefore imply a more conservative inference. The Toda–Yamamoto [22] procedure supplies causality inference that is agnostic with respect to integration order, and Barzhaksyyeva et al. [2] demonstrate the feasibility of ARDL estimation for Kazakhstan on only fourteen annual observations, using HAC estimators and explicit structural-break dummies.

Research gap. Three gaps are apparent. First, no published study applies the ARDL bounds framework to Uzbekistan's aggregate per capita income using a composite digitalisation index. Second, the existing Uzbekistan literature does not reconcile the positive panel-based estimates with the negative single-country coefficients reported by Amirov and Avazov [1]. Third, and most importantly, no existing study of Uzbekistan tests whether estimated digitalisation effects survive the introduction of controls for the 2017 policy regime change — an omission that is potentially decisive, since the timing of the reform coincides with the acceleration of digital diffusion.

3. RESEARCH METHODOLOGY

3.1. Data

The study employs annual data for Uzbekistan over 2003–2024 (N = 22), drawn from the World Bank's World Development Indicators database [24]. The sample start date is determined by the availability of fixed broadband subscription data, which begins in 2003. Variables are as follows:

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Symbol	Variable	Units	WDI code
GDPPC	Real GDP per capita	constant 2015 US$	NY.GDP.PCAP.KD
INT	Individuals using the internet	% of population	IT.NET.USER.ZS
MOB	Mobile cellular subscriptions	per 100 people	IT.CEL.SETS.P2
BBD	Fixed broadband subscriptions	per 100 people	IT.NET.BBND.P2
GCF	Gross capital formation	% of GDP	NE.GDI.TOTL.ZS
TRD	Trade openness (exports + imports)	% of GDP	NE.TRD.GNFS.ZS
FDI	Foreign direct investment, net inflows	% of GDP	BX.KLT.DINV.WD.GD.ZS

Lower-case prefixed variables denote natural logarithms (lgdppc, lgcf, ltrd); *lbbd* denotes ln(1 + BBD), a transformation adopted because broadband penetration takes values near zero at the start of the sample.

3.2. Construction of the composite digitalisation index

The three ICT indicators are strongly collinear (r = 0.858 between INT and MOB; r = 0.933 between INT and BBD; r = 0.714 between MOB and BBD). Including them jointly in a regression with 22 observations would be untenable. Following the approach adopted by Kasimov et al. [9] for Uzbekistan, a composite index is therefore extracted by principal component analysis on the standardised indicators:

DIGI_t = Σ_j w_j · z_{jt}, where z_{jt} = (X_{jt} − X̄_j) / σ_j

and *w_j* are the loadings of the first principal component. The resulting index is used as the single measure of digital transformation.

3.3. Econometric model

The empirical framework is an unrestricted error correction model (UECM) representation of an ARDL(1,1) specification:

Δ lnGDPpc_t = α + φ · lnGDPpc_{t−1} + Σ_j θ_j X_{j,t−1} + β · Δ lnGDPpc_{t−1} + Σ_j γ_j · Δ X_{jt} + Σ_m δ_m D_{mt} + ε_t

where *X* denotes the vector of DIGI and control variables, *D* denotes structural-break dummies, and ε is a white-noise disturbance. The existence of a long-run level relationship is tested through the joint null hypothesis

H₀: φ = θ₁ = … = θ_k = 0

against the alternative that at least one coefficient differs from zero, using the F-statistic and the two sets of critical value bounds of Pesaran, Shin and Smith [16] for Case III (unrestricted intercept, no trend). Long-run coefficients are recovered as −θ_j / φ, with standard errors obtained by the delta method. The coefficient φ is the error-correction or speed-of-adjustment parameter; a negative and statistically significant estimate is a necessary condition for a stable long-run relationship.

Two structural-break dummies are specified on the basis of documented policy and external events rather than data mining: **D2017**, a step dummy equal to unity from 2017 onward, capturing the liberalisation of the foreign exchange market and the associated trade and tax reforms; and **D2020**, an

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impulse dummy for the COVID-19 pandemic year. This follows the practice of Barzhaksyyeva et al. [2].

3.4. Testing procedure

Estimation proceeds in six stages. (i) The order of integration of each series is established using the Augmented Dickey–Fuller and Kwiatkowski–Phillips–Schmidt–Shin tests; the maximum lag is capped at three, in line with the Schwert criterion for a sample of this length, with selection by AIC. (ii) Lag orders are selected by the Schwarz Bayesian criterion, which is preferred to AIC in small samples because it penalises over-parameterisation more heavily. (iii) The bounds F-test is computed. (iv) Long-run and short-run coefficients are estimated. (v) Residual diagnostics are conducted: Breusch–Godfrey tests for serial correlation at one and two lags, Breusch–Pagan and ARCH tests for heteroskedasticity, the Jarque–Bera test for normality, and the Ramsey RESET test for functional-form misspecification; parameter stability is assessed by the CUSUM and CUSUM-of-squares tests of Brown, Durbin and Evans. (vi) Causality is examined by the modified Wald procedure of Toda and Yamamoto [22], in which a VAR of order (p + d_max) is estimated and the restriction is imposed on the first *p* lags only, leaving the augmented lag unrestricted.

All estimation was carried out in Python 3.11 using the *statsmodels* 0.14.6 library. The full replication dataset accompanies this paper.

4. ANALYSIS AND RESULTS

4.1. Descriptive statistics

Table 1. Descriptive statistics, Uzbekistan, 2003–2024 (N = 22)

Variable	Mean	Std. dev.	Minimum	Maximum	Jarque–Bera (p)
GDPPC (const. 2015 US$)	2910.371	925.836	1520.350	4477.910	0.486
INT (% of population)	38.050	30.796	1.913	89.506	0.351
MOB (per 100 people)	65.217	36.347	1.248	110.492	0.341
BBD (per 100 people)	8.317	10.909	0.010	34.740	0.076
GCF (% of GDP)	29.339	4.999	20.800	39.047	0.541
TRD (% of GDP)	55.039	16.278	25.693	79.748	0.496
FDI (% of GDP)	1.903	0.810	0.815	3.301	0.422
DIGI (index)	0.000	1.635	−2.120	3.087	0.493

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Source: author's calculations from [24].

The scale of the digital transition is evident in the ranges: internet penetration spans 1.9% to 89.5% and fixed broadband spans 0.01 to 34.7 subscriptions per 100 people within a twenty-two-year window. Normality is not rejected for any variable at the 5% level.

4.2. The composite digitalisation index

Table 2. Principal component analysis of ICT indicators

Component	Eigenvalue	Proportion of variance	Cumulative
PC1	2.6734	0.8911	0.8911
PC2	0.2926	0.0975	0.9887
PC3	0.0339	0.0113	1.0000

Loadings on PC1: INT = 0.6037; MOB = 0.5540; BBD = 0.5732.

Source: author's calculations.

The first principal component accounts for 89.1% of the total variance of the three standardised indicators, and the loadings are of comparable magnitude and uniform sign. The index therefore admits a clear interpretation as a general measure of digital penetration, and its use resolves the multicollinearity problem without discarding information. The index rises from −2.120 in 2003 to +3.087 in 2024, a total range of 5.207 index units; the increase is near-monotonic, interrupted only by a single reversal in 2012 (−0.440 to −0.619) which is traceable to the reporting discontinuity in the mobile subscription series discussed in Section 5 (Figure 1a).

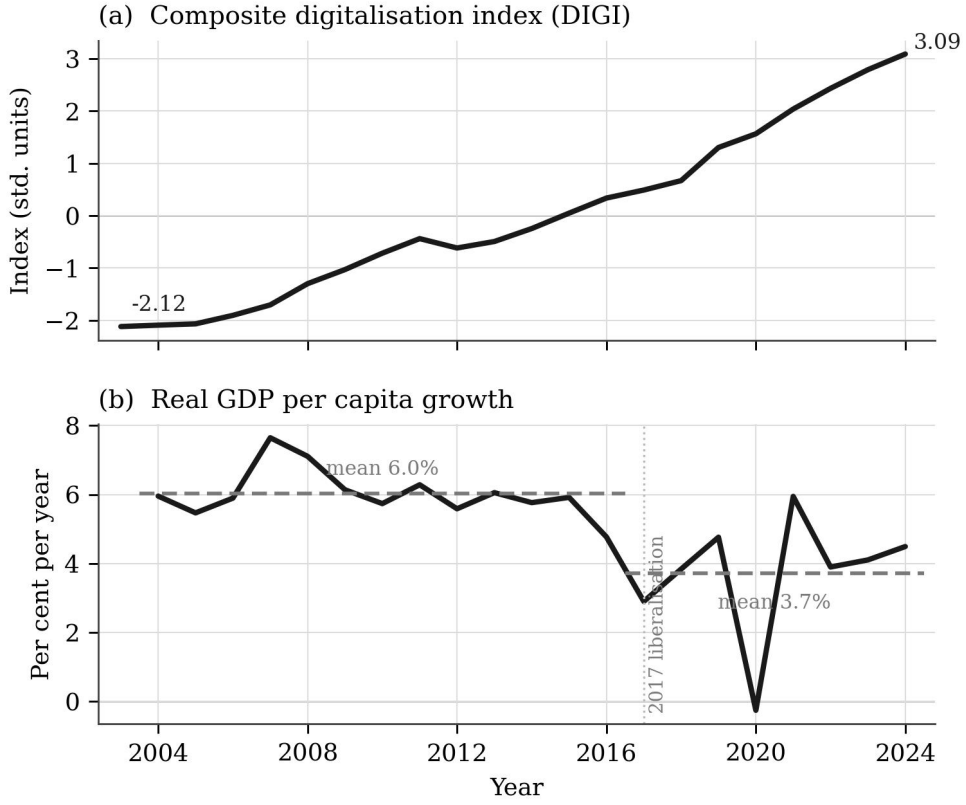


Figure 1. Digitalisation and per capita growth in Uzbekistan, 2003–2024. Panel (a): composite digitalisation index. Panel (b): real GDP per capita growth, with period means. Source: author's calculations from [24].

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4.3. Unit root tests

Table 3. Unit root test results

Variable	ADF (level)	p	ADF (Δ)	p	KPSS (level)	KPSS (Δ)	Conclusion
lgdppc	−0.584	0.980	−0.932	0.777	0.212	0.722	I(1)*
DIGI	−1.167	0.917	−3.400	0.011	0.179	0.446	I(1)
lgcf	−2.037	0.581	−3.448	0.009	0.111	0.089	I(1)
ltrd	−2.100	0.546	−3.460	0.009	0.167	0.142	I(1)
fdi	−3.595	0.030	−7.111	0.000	0.099	0.432	I(0)/I(1)
lbbd	−2.531	0.313	−2.713	0.072	0.146	0.262	I(1)

Notes: ADF in levels includes constant and trend; in first differences, constant only. Maximum lag 3 (Schwert), AIC selection. KPSS 5% critical values: 0.146 (constant and trend), 0.463 (constant).
** For lgdppc the KPSS statistic on first differences with a constant only is 0.722, which would reject stationarity. However, with a constant and trend it falls to 0.091 against a 5% critical value of 0.146, and the ADF test on Δlgdppc with a trend yields t = −4.840 (p = 0.0004). The growth rate of GDP per capita is therefore trend-stationary — reflecting the documented deceleration of growth after 2016 — and lgdppc is treated as I(1).*
Source: author's calculations.

No variable is integrated of order two, which is the condition required for the ARDL bounds procedure to be valid. Most series are unambiguously I(1). The exception is fdi, for which the ADF test rejects a unit root in levels at the 5% level (t = −3.595, p = 0.030) while the KPSS statistic on first differences (0.432) sits just below its 5% critical value; the evidence is therefore mixed between I(0) and I(1). This is not a problem — indeed a mixture of I(0) and I(1) regressors is precisely the situation for which the bounds approach was designed, and is one of its principal advantages over the Engle–Granger and Johansen procedures.

4.4. Bounds tests

Table 4. ARDL bounds tests across specifications (dependent variable: lnGDPpc)

Model	Regressors	k	N	Bounds F	ECT	t(ECT)	Verdict (10%)	Verdict (5%)
M1	DIGI, lgcf	2	20	**4.580**	−0.0894	−1.951	**reject**	inconclusive
M2	DIGI, lgcf, ltrd	3	20	3.129	−0.1452	−1.478	inconclusive	no
M3	DIGI, lgcf + breaks	2	20	3.728	−0.0018	−0.079	inconclusive	no
M4	DIGI, lgcf, ltrd + breaks	3	20	4.355	−0.0037	−0.090	reject	reject
M5	lbbd,	2	20	2.667	−0.0032	−0.073	no	no

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Model	Regressors lgcf	k	N	Bounds F	ECT	t(ECT)	Verdict (10%)	Verdict (5%)
M6	DIGI, lgcf, ltrd, fdi	4	20	2.425	−0.1582	−1.549	no	no

Critical values, Pesaran, Shin and Smith [16], Case III (unrestricted intercept, no trend), where k is the number of regressors: k = 2 — 10% [3.174, 4.108], 5% [3.802, 4.812], 1% [5.172, 6.322]; k = 3 — 10% [2.730, 3.747], 5% [3.229, 4.322], 1% [4.311, 5.543]; k = 4 — 10% [2.457, 3.516], 5% [2.877, 4.010], 1% [3.780, 5.050]. These reproduce PSS (2001) Table CI(iii). Practitioners should note that at least one widely used software implementation indexes this table by the number of regressors plus one; using the shifted row would spuriously convert the M1 result below into a 5% rejection.

Source: author's calculations.

The evidence for a level relationship is specification-dependent and, on balance, weak — which is itself the paper's first substantive finding. The parsimonious specification M1 yields an F-statistic that rejects the null at the 10% level but falls inside the inconclusive band at 5% (3.802 < 4.580 < 4.812). Adding trade openness (M2) pushes the statistic into the inconclusive region at 10% and below the lower bound at 5%; adding FDI (M6) places it below the lower bound at every conventional level. Substituting broadband penetration for the composite index (M5) yields no evidence of cointegration whatsoever — a result consistent with the negative broadband coefficients reported for Uzbekistan by Amirov and Avazov [1]. It should further be noted that Narayan [14] shows the asymptotic bounds used here to be systematically too permissive in samples of this size; against small-sample critical values the M1 evidence would be weaker still.

Model M4 does reject at 5% (F = 4.355 against an upper bound of 4.322), but the rejection cannot be taken at face value: its error-correction coefficient is −0.0037 with a t-statistic of −0.090. A bounds rejection accompanied by an adjustment coefficient indistinguishable from zero is the classic signature of a degenerate case, in which the F-test is driven by the significance of the lagged regressors rather than by any genuine error-correction mechanism. The same applies to M3. This is the first indication of the result developed in Section 4.6.

4.5. Baseline estimates (M1)

Table 5. Model M1: unrestricted error correction estimates *Dependent variable: Δ lnGDPpc*

Regressor	Coefficient	Std. error	t	p
Constant	0.9785	0.454	2.156	0.050
lnGDPpc_{t−1} (ECT)	−0.0894	0.046	−1.951	0.073
DIGI_{t−1}	0.0113	0.010	1.110	0.287
lgcf_{t−1}	−0.0657	0.040	−1.660	0.121
Δ lnGDPpc_{t−1}	−0.1749	0.246	−0.711	0.490
Δ DIGI_t	0.0499	0.026	1.919	0.077
Δ lgcf_t	−0.0277	0.036	−0.772	0.454

R^2 = 0.552; Adjusted R^2 = 0.345; N = 20.

Long-run coefficients (delta-method standard errors)

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Variable	Long-run coefficient	Std. error	t	p
DIGI	**0.1266**	0.0554	2.285	**0.022**
lgcf	−0.7350	0.3788	−1.940	0.052

Diagnostic tests

Test	Statistic	p
Breusch–Godfrey LM(1)	$\chi^2 = 0.371$	0.543
Breusch–Godfrey LM(2)	$\chi^2 = 1.231$	0.540
Breusch–Pagan	$\chi^2 = 9.517$	0.147
ARCH LM(1)	$\chi^2 = 0.306$	0.580
Jarque–Bera	JB = 2.074	0.355
Ramsey RESET(2)	**F = 17.788**	**0.001**

Source: author's calculations.

Taken at face value, model M1 supports the conventional narrative. The error-correction coefficient is negative and significant at the 10% level, implying an adjustment speed of 8.9% per year and a half-life of approximately 7.4 years. The long-run digitalisation coefficient is 0.127 and significant at the 5% level; with Newey–West HAC standard errors it becomes stronger still (standard error 0.0397, t = 3.191, p = 0.001), and the HAC bounds statistic rises to 5.848. The short-run coefficient on ΔDIGI is 0.050 (p = 0.077). Residuals display no serial correlation, no heteroskedasticity, no ARCH effects and no departure from normality. CUSUM and CUSUM-of-squares statistics remain within their 5% bands throughout (Figure 2), indicating parameter stability.

The magnitude is economically substantial. Because the dependent variable is in logarithms and DIGI is an unstandardised principal component score (standard deviation 1.635 index units, Table 1), the coefficient implies that a one-unit increase in the index is associated with a long-run level of GDP per capita higher by approximately 12.7% in log terms, or 13.5% exactly; a one-standard-deviation increase corresponds to 20.7% (23.0% exactly). Applied to the full observed range of the index over 2003–2024 (5.207 units), the point estimate would imply a cumulative long-run level effect of roughly 66% — which is, on its face, implausibly large relative to Uzbekistan's actual per capita income trajectory, and constitutes an early warning that the specification is absorbing more than digitalisation alone. Direct comparison with the elasticities of 0.167–0.222 reported by Shodiev et al. [19] is not possible, since those are log–log elasticities with respect to individual ICT indicators, whereas the coefficient here is a semi-elasticity with respect to a composite index score.

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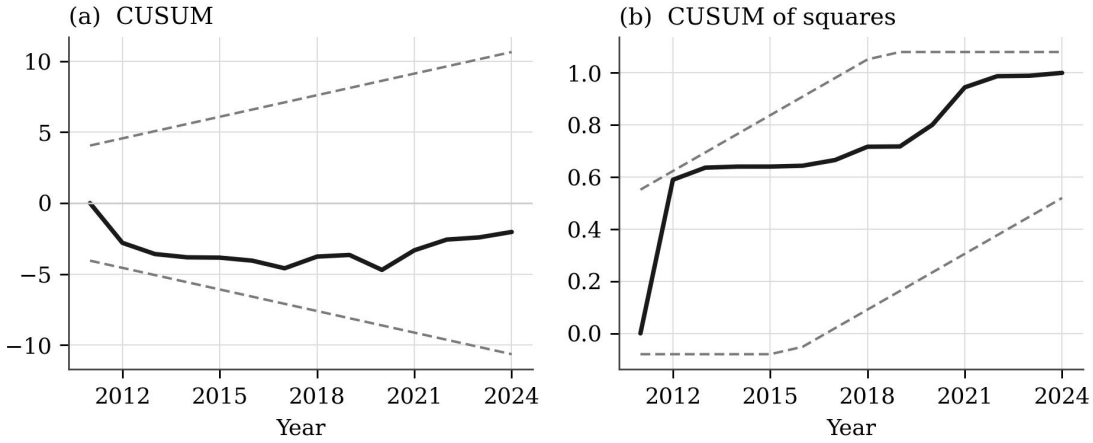


Figure 2. Parameter-stability tests for model M1. Panel (a): CUSUM. Panel (b): CUSUM of squares. Dashed lines denote 5% significance bands. Source: author's calculations.

However, the specification fails the Ramsey RESET test decisively (F = 17.788, p = 0.001). This indicates functional-form misspecification, and no coefficient from a misspecified equation can be interpreted with confidence. The remainder of the analysis is devoted to identifying the source of that failure.

4.6. Diagnosing the misspecification

Two candidate explanations were tested.

Nonlinearity in digitalisation. Given the threshold results of Kasimov et al. [9] for Uzbekistan and the diminishing-returns finding of Vu [23], a quadratic term $DIGI^2$ was added. The result was unambiguous: the squared term is entirely insignificant in both the long run (coefficient −0.0001, p = 0.999) and the short run (p = 0.883); the bounds statistic collapses to F = 1.708; and — decisively — **RESET continues to reject (F = 16.832, p = 0.002)**. The misspecification is therefore not a curvature in the digitalisation relationship.

Structural breaks. The alternative hypothesis is that the residual nonlinearity reflects discrete shifts in the growth process. Model M3 adds the two dummy variables described in Section 3.3.

Table 6. Model M3: error correction estimates with structural-break dummies *Dependent variable: Δ lnGDPpc*

Regressor	Coefficient	Std. error	t	p
Constant	−0.0777	0.233	−0.333	0.745
lnGDPpc_{t−1} (ECT)	−0.0018	0.022	−0.079	0.939
DIGI_{t−1}	−0.0013	0.005	−0.265	0.796
lgcf_{t−1}	0.0493	0.022	2.238	0.047
Δ lnGDPpc_{t−1}	−0.2353	0.112	−2.105	0.059
Δ DIGI_t	0.0099	0.013	0.781	0.451
Δ lgcf_t	0.0261	0.019	1.392	0.191
D2017	**−0.0301**	0.007	−4.155	**0.002**
D2020	**−0.0475**	0.008	−5.842	**0.000**

R^2 = 0.934; Adjusted R^2 = 0.885; N = 20. **Ramsey RESET(2): F = 0.532, p = 0.482.** Breusch–Pagan:

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$\chi^2 = 9.362$, p = 0.313. Jarque–Bera: JB = 0.810, p = 0.667. Breusch–Godfrey LM(2): $\chi^2 = 9.156$, p = 0.010. ARCH LM(1): $\chi^2 = 4.513$, p = 0.034.

Source: author's calculations.

The results are decisive on three points. First, the functional-form problem disappears: RESET moves from p = 0.001 to p = 0.482. Second, explanatory power rises dramatically, from $R^2 = 0.552$ to $R^2 = 0.934$, and both dummies are highly significant — the 2017 regime change is associated with a permanent reduction of approximately 3.0 percentage points in the annual growth rate of GDP per capita, and the pandemic with a further temporary reduction of 4.8 percentage points. Third, and most consequentially, **once these breaks are controlled for, both the error-correction term (−0.002, p = 0.939) and the digitalisation coefficient (−0.001, p = 0.796) become statistically indistinguishable from zero.**

The interpretation is that the apparently significant long-run digitalisation effect in model M1 was to a substantial degree the artefact of an omitted variable. The DIGI index trends strongly and near-monotonically upward across the sample; the growth rate shifts downward at a date located within the same period; in the absence of an explicit break control, the trending digital variable partially absorbs the level shift. This is a well-understood hazard in short single-country samples, and it appears to have materialised here.

Two caveats should be entered against model M3 itself. The Breusch–Godfrey test at two lags now rejects (p = 0.010) and the ARCH test rejects at 5% (p = 0.034), indicating that the break-augmented model is not itself free of residual structure. With nine parameters estimated on twenty observations, this is unsurprising, and it counsels against treating M3 as a definitive structural model. What M3 establishes is narrower but sufficient: the M1 result does not survive a theoretically motivated and statistically well-supported extension of the specification.

4.7. Causality analysis

Table 7. Toda–Yamamoto (1995) Granger non-causality tests

VAR lag order selected by SBC: p = 1; d_max = 1; VAR(2) estimated with the augmented lag left unrestricted.

Null hypothesis	Modified Wald χ^2	df	p	Decision
DIGI does not Granger-cause lnGDPpc	2.545	1	0.111	cannot reject
lnGDPpc does not Granger-cause DIGI	0.362	1	0.548	cannot reject

Source: author's calculations.

Neither direction of causality is detected at conventional significance levels. The result for the digitalisation-to-growth direction is not far from the 10% threshold, which — in a sample of twenty usable observations, where power is inevitably low — should be read as inconclusive rather than as firm evidence of absence. The reverse-causality result is comfortably non-significant. Taken together with Section 4.6, the causality evidence provides no independent support for the hypothesis of a growth-generating digitalisation effect.

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5. DISCUSSION

The central empirical result of this paper is negative, and it is worth stating precisely what is and is not being claimed.

What is claimed. Over 2003–2024, Uzbekistan's rapid and well-documented digital diffusion cannot be shown, with the annual aggregate data available, to have exerted a statistically identifiable independent effect on the level or growth rate of real GDP per capita. The single specification that appears to support such an effect rejects the no-cointegration null only at the 10% level, is misspecified on the RESET criterion, implies an implausibly large magnitude, and is resolved by controlling for a structural break which simultaneously eliminates the digitalisation effect itself. The misspecification is demonstrably not attributable to nonlinearity in the digital variable.

What is not claimed. It is not claimed that digitalisation is economically unimportant, nor that its effect is negative. A null result in a sample of twenty usable observations, on a relationship confounded by a contemporaneous policy regime change of first-order magnitude, is evidence of *non-identification*, not of *non-existence*. The distinction matters for policy.

Consistency with the wider literature. The finding aligns closely with the strongest recent evidence. Wang et al. [25], correcting 1,082 estimates for publication bias, find ICT effects on economic performance statistically insignificant in developing countries specifically. Dewan and Kraemer [5] reached the same conclusion for an earlier technological generation, attributing it to the absence of complementary assets. Niebel [15] finds no leapfrogging advantage for poorer countries. Qiang and Rossotto's [17] widely cited developing-country coefficient is itself significant only at 10%. Against this background, a null result for Uzbekistan is unsurprising; what is notable is how consistently the optimistic subset of this literature is cited in regional policy discourse while the null-result subset is not.

The result is also consistent with, and helps explain, the single most relevant piece of prior Uzbekistan evidence. Amirov and Avazov [1] report negative coefficients on mobile subscriptions, broadband subscriptions and secure internet servers for 2010–2021, alongside strong positive effects for FDI and trade openness. This paper's model M5 — using broadband alone — likewise fails to detect any cointegrating relationship ($F = 2.667$, below all lower bounds). The natural reading of both sets of results is that Uzbekistan's digital infrastructure indicators, over this period, were tracking a policy and investment cycle rather than driving output.

Interpretive framework. The most economical explanation is the "analog complements" argument of the World Bank [26]: digital investment yields dividends only in the presence of competitive regulation, adequate skills, and accountable institutions. Uzbekistan's own indicator profile is consistent with an economy in which infrastructure has run ahead of these complements. The Network Readiness Index 2025 ranks Uzbekistan 72nd of 127 economies overall, with Governance its strongest pillar (71st) but **Impact its weakest (82nd)** [6] — that is, the country converts digital readiness into measured economic and social outcomes less effectively than it builds readiness itself. The Asian Development Bank [7] classifies Uzbekistan within its "low-digitalisation" profile group notwithstanding the penetration statistics. Vu's [23] finding of diminishing marginal returns to penetration offers a complementary reading: with mobile penetration above 110 per 100 people, the remaining growth-relevant margin lies not in connection counts but in fixed broadband quality, fibre depth and, above all, in the productive application of connectivity — margins on which Uzbekistan remains well behind comparators.

The confounding problem, stated directly. The identification difficulty in this paper is not a technical nuisance but the substantive story. The 2017 liberalisation package was associated with a permanent downward shift in measured per capita growth of approximately three percentage points

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(Table 6) — a transition cost widely expected from currency unification and the removal of administrative price and trade controls. The same years saw digitalisation accelerate. Any annual single-country regression on this sample must therefore separate two large, contemporaneous structural changes using very few degrees of freedom. The honest conclusion is that annual data cannot do so.

Limitations. Four should be acknowledged. First, sample size: twenty usable observations after differencing and lag construction is at the lower limit of what the bounds procedure can support, and the asymptotic critical values employed are, per Narayan [14], too permissive at this sample size. Second, the WDI mobile subscription series for Uzbekistan contains implausible year-on-year movements (notably a fall from 88.3 to 69.3 per 100 people between 2011 and 2012, and a rise from 71.7 to 101.3 between 2018 and 2019) which reflect changes in reporting methodology rather than in subscriptions; the PCA composite mitigates but does not eliminate this measurement error. Third, penetration indicators measure access, not use or productive application — the digital economy's contribution to GDP is measured at approximately 1.9–2.1% on the narrow ICT-sector definition [28], and a value-added measure would be preferable were a consistent series available. Fourth, the analysis treats digitalisation as weakly exogenous; Röller and Waverman [18] demonstrate that this assumption is generally violated, though the Toda–Yamamoto results here provide no evidence of reverse causality.

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

This paper has tested for a long-run relationship between digital transformation and economic development in Uzbekistan over 2003–2024, using a PCA-based composite digitalisation index within an ARDL bounds testing framework, supported by causality and stability diagnostics.

Conclusions.

A composite index built from internet, mobile and fixed broadband penetration captures 89.1% of the common variation in Uzbekistan's ICT indicators and provides a statistically tractable single measure of digital diffusion for short-sample analysis.

In a parsimonious two-regressor specification, the bounds test rejects the absence of a level relationship at the 10% level ($F = 4.580$) though it remains inconclusive at 5%, and yields a positive, significant long-run digitalisation coefficient of 0.127 with a well-behaved error correction term of −0.089. The evidence for cointegration is therefore suggestive rather than decisive even before the specification is subjected to further testing.

That specification is nevertheless misspecified, failing the Ramsey RESET test at $p = 0.001$. The misspecification is not attributable to nonlinearity in digitalisation: an explicit quadratic term is wholly insignificant and does not repair the RESET failure. The implied magnitude of the long-run coefficient — a cumulative level effect of some 66% across the observed range of the index — is in any case implausibly large for a single channel.

Introducing dummy variables for the 2017 liberalisation and the 2020 pandemic repairs the functional form (RESET $p = 0.482$) and raises explanatory power to $R^2 = 0.934$, but simultaneously renders both the error-correction term and the digitalisation coefficient statistically insignificant. The measured digitalisation effect in the naïve specification was therefore substantially proxying for a contemporaneous structural policy shift.

The Toda–Yamamoto procedure detects no Granger causality in either direction.

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The overall finding — that ICT effects on aggregate performance are not robustly identifiable in a developing economy — is consistent with the meta-analytic evidence of Wang et al. [25] and with prior mixed results for Uzbekistan [1].

Policy recommendations.
First, for the evaluation of the "Digital Uzbekistan – 2030" strategy: progress indicators should shift from penetration and access metrics toward outcome and productivity metrics. With mobile penetration already exceeding 110 per 100 people, further access gains carry limited informational content about economic impact. The Network Readiness Index diagnosis — Governance strong, Impact weak [6] — identifies the binding constraint precisely.
Second, on complementary investment: the results support prioritising the "analog complements" [26] — digital skills, competitive regulation in telecommunications and platform markets, and enterprise-level digital adoption — over further infrastructure expansion. The relevant policy margin is the conversion of connectivity into productive use, not the extension of connectivity itself.
Third, on measurement: the principal obstacle encountered here is the absence of a consistent, quarterly, value-added-based measure of the digital economy for Uzbekistan. The Statistics Agency and the Ministry of Digital Technologies should prioritise the construction of such a series. The definitional inconsistency in current reporting — the digital economy is variously stated as 1.9%, 2.1%, 3.4% and 8.7% of GDP depending on the source and definition — is itself an impediment to evidence-based policy evaluation.
Fourth, for future research: the identification problem documented here is tractable with better data. Kasimov et al. [9] demonstrate that a quarterly series for Uzbekistan spanning 2004–2024 can be constructed, yielding approximately 84 observations. Replication of the present analysis at quarterly frequency, incorporating endogenous break tests of the Bai–Perron and Zivot–Andrews type, would allow the digitalisation effect and the 2017 regime change to be separated. Firm-level or regional panel data would offer a further and probably superior identification strategy, since cross-sectional variation in digital adoption within a single national policy regime avoids the confounding problem entirely.

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