



Econometric Analysis of Assessing the Impact of Bank Activity Transformation on Operational Efficiency in the Context of Digital Technologies

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Abstract

This study examines the impact of digital transformation on the operational efficiency and financial performance of commercial banks in Uzbekistan, focusing on key indicators such as the Cost-to-Income Ratio (CIR) and Return on Assets (ROA). Utilizing regression analysis based on 63 observations, the results reveal that digital transformation significantly enhances bank performance. A 1% increase in IT investment share reduces CIR by 0.53% in the subsequent year, while mobile banking adoption (coefficient 1.224) and IT-related revenue (coefficient 0.22) substantially improve ROA. Expanding ATM networks also lowers CIR by 0.191 per unit, highlighting the role of automation. However, state-controlled banks exhibit lower efficiency, with a 4% reduction in ROA and higher CIR due to social obligations. Inflation and bank card growth showed statistically insignificant effects on CIR, underscoring the stable, long-term benefits of digital technologies. The findings emphasize the critical role of IT investments, mobile banking, and digital retail channels in reducing operational costs and boosting profitability, offering actionable insights for enhancing the competitiveness of Uzbekistan’s banking sector.

Keywords: Digital Transformation; Commercial Banks; Uzbekistan; Cost-to-Income Ratio (CIR); Return on Assets (ROA); IT Investments; Mobile Banking; Operational Efficiency; Financial Performance; Regression Analysis; ATM Networks; State-Owned Banks; Automation; Digital Retail Channels; Profitability

1. Introduction

In the modern global economy, digital transformation has become an integral part of banking activities, fundamentally reshaping the structure and operational mechanisms of the financial system. Over the past decade, the rapid development of innovative technologies such as mobile banking services, artificial intelligence, blockchain, big data analytics, and cloud computing has led to the restructuring of banking operations.

The banking system in Uzbekistan has been undergoing a period of profound changes since 2016 within the framework of banking reforms and digitalization programs. Digital transformation involves not only the modernization of banking technologies but also the complete restructuring of the banking business model, transforming customer relationships, and introducing new operational processes.

The relevance of this study lies in the comprehensive assessment of the impact of digital technologies on the operational and financial efficiency of banks, including quantitative analysis using econometric models, which holds practical significance for bank management and policymakers. The banking system in Uzbekistan is actively engaged in digital transformation processes, necessitating the development of scientifically grounded approaches and practical recommendations in this field. The econometric analysis of assessing the impact of transforming banking activities in the context of digital technologies on operational efficiency holds significant importance in studying the development trends of modern financial systems. In particular, it enables a scientifically grounded evaluation of the impact of digitalization processes on efficiency indicators in Uzbekistan’s banking sector. This analysis contributes not only

theoretically but also empirically through data-driven strategies to optimize banks' operational costs and profitability. The significance of this econometric analysis lies in its ability to quantitatively assess the impact of digital transformation factors, such as IT investments and mobile banking, thereby identifying ways to enhance banks' competitiveness and contribute to economic growth. Additionally, it highlights differences between state-owned and private banks, providing a foundation for improving policy and regulatory measures, ultimately ensuring the stability of the financial sector.

In the context of Uzbekistan's commercial banks, this analysis aims to identify the impact of these processes on efficiency indicators, thoroughly examined through correlation and regression models based on panel data. The analysis is based on statistical data provided by the Central Bank of the Republic of Uzbekistan, as well as annual financial reports of selected banks, covering the period from 2016 to 2024. It includes 63 observations over 9 years from seven major banks, namely: "Business Development Bank" Joint-Stock Commercial Bank, "National Bank for Foreign Economic Activity of the Republic of Uzbekistan" Joint-Stock Company, "Uzsanoatqurilishbank" JSCB, "Turonbank" JSCB, "Trastbank" Private Joint-Stock Bank, "Hamkorbank" Joint-Stock Commercial Bank with foreign capital participation, and "Agrobank" JSCB. Based on this data, the impact of digital transformation on the operational and financial efficiency of commercial banks is evaluated in a scientifically grounded manner.

2. Literature Review

An analysis of empirical studies conducted internationally on the digital transformation of financial institutions and its impact on operational efficiency reveals that relatively comprehensive and systematic approaches exist in this field, employing various econometric methodologies. For example, in a fundamental study by U.S. scholars Berger and DeYoung (Berger & DeYoung, 2006), using the stochastic frontier analysis method, data from over 500 U.S. banks over 15 years were analyzed, empirically demonstrating that technological innovations positively impact banks' financial and cost efficiency.

In the context of the European banking system, a study by Hasan, Schmiedel, and Song (Hasan et al., 2012) utilized panel data regression analysis and random effects models to prove a positive correlation between electronic banking services and bank profitability. By analyzing data from 245 banks in 15 European countries from 1995 to 2007, they identified the positive impact of digital banking services on commercial banks' net interest and non-interest income. Similarly, accounting for complex economic dynamics, a study by Beck, Chen, and Lin (Beck et al., 2016) employed the dynamic panel generalized method of moments (Dynamic Panel GMM) developed by Arellano-Bover and Blundell-Bond, as well as the two-stage least squares (2SLS) method, to analyze the impact of digital transformation on bank risks and profitability, addressing endogeneity issues in variables and enabling more accurate evaluation of dynamic effects.

Studies examining the impact of individual components of modern digital technologies on bank efficiency have investigated technologies such as artificial intelligence, blockchain, and big data analytics separately, though their combined impact has been relatively under-researched. A study by a team of Nigerian and Canadian scholars (Nnaomah et al., 2024) used logistic regression and random effects models to examine the accuracy of credit risk assessment in artificial intelligence-based systems, comparing commercial banks in Nigeria and America. The results empirically demonstrated that banks implementing artificial intelligence systems experienced a 0.65-fold reduction in credit losses compared to others.

Furthermore, studies on the digital transformation of financial institutions in the Asian region have analyzed its impact on operational efficiency through various approaches. For instance, in a study by Chinese scholars Li and Zou (2020), based on data from 120 major Chinese commercial banks operating between 2008 and 2018, a random effects panel regression model was applied, revealing that the introduction of digital technologies significantly reduced banks' operational costs and led to growth trends in ROA and capital profitability (ROE).

In the Southeast Asian context, I.F. Bella (Bella & Himmawan, 2021) and Hamid (Ab Hamid et al., 2021), studying the banking sectors of Indonesia and Malaysia, used stochastic frontier analysis and technical efficiency index models to examine the impact of digital banking services on production efficiency. The results showed that banks with higher levels of digital infrastructure development exhibited higher technical efficiency indicators.

In the African region, a multi-country panel analysis covering Kenya, Ghana, and South Africa (Okoye et al., 2021) employed DEA and Tobit regression models to evaluate the effectiveness of mobile payments and digital credit systems in reducing operational risks. The results indicated that banks adopting digital financial technologies saw an average 18–22% reduction in operational errors and a 25% increase in customer service speed.

Moreover, in the context of Central Asian countries, particularly the banking systems of Uzbekistan, Kazakhstan, and Kyrgyzstan, recent empirical studies on the impact of digital transformation on economic efficiency indicators are

emerging as a new direction. Studies by Z. Mamadiyorov (Mamadjarov, 2021), R. Tojiyev (Tojiyev, 2023), and F. Muyassarzoda (Muyassarzoda, 2022) primarily applied dynamic GMM, SUR, SEM, and GLS methods, empirically identifying a long-term positive elasticity between the volume of investments in digital technologies and net profit. The results show that banks actively investing in the digital transformation process have an operational efficiency index that is, on average, 0.27 points higher than their competitors.

3. Methodology

3.1 Overview of the digital transformation in banking sector framework

Taking into account the research methods mentioned in the above literature analysis and other existing models, this dissertation research creates a methodological basis through the complex application of the following econometric models. In this, we use the dynamic panel data model to evaluate long-term equilibrium while accounting for the time factor; the System GMM model to solve the endogeneity problem between selected variables and to account for dynamic specifications; quantile regression (QR) to study differential impacts by bank groups and to identify heterogeneous effects; and the difference-in-differences (DID) method to evaluate the impact of digital transformation programs and to more accurately measure policy effectiveness.

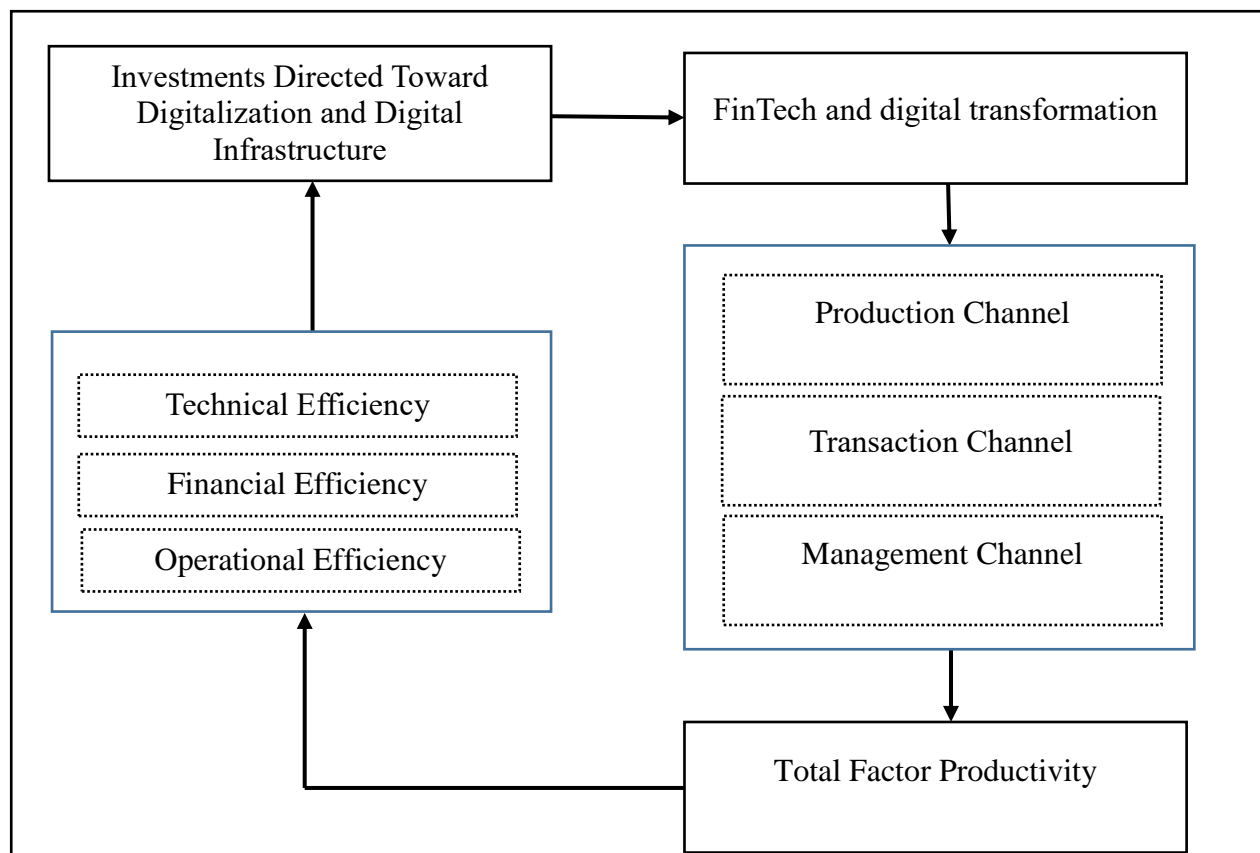


Figure 1. Model of Interdependence between Digital Transformation and Technological Efficiency in Commercial Banks

The theoretical analysis of the relationship between independent and dependent variables in the process of transforming banking activities in the context of digital technologies holds significant importance in assessing the economic efficiency of the banking sector. This relationship is explained based on efficiency theory (Leibenstein, 1980) and digital economy models (Konopik et al., 2022), indicating that independent variables may reduce the Operational Efficiency Indicator (CIR) while increasing Return on Assets (ROA), although this relationship is modulated by infrastructure, ownership structure, and macroeconomic factors.

Table 1: Summary Information on Research Variables

| <i>Category</i> | <i>Abbreviated Name</i> | <i>Full Name</i> | <i>Calculation Formulas</i> |
|------------------------------|-------------------------|---|---|
| Dependent Variables | | | |
| | CIR | Operational Efficiency Indicator | $CIR = (\text{Operational Expenses}) / (\text{Net Interest and Non-Interest Income}) * 100\%$ |
| | ROA | Return on Assets | $ROA = (\text{Net Profit}) / \text{Total Assets} * 100\%$ |
| Independent Variables | | | |
| | IT_investShare | Share of IT Investments in Operational Expenses | $IT_investShare = \text{Investments in Digital Transformation} / \text{Operational Expenses}$ |
| | Mobile_UsersShare | Share of Mobile Banking Users Relative to Total Customers | $Mobile_UsersShare = \text{Number of Mobile Banking Users} / \text{Total Number of Customers}$ |
| | RBS_RevShare | Share of IT Revenues in Total Revenue | $RBS_RevShare = \text{IT Revenues} / (\text{Total Revenues})$ |
| | ATM | Number of ATMs | Number of ATMs Belonging to the Commercial Bank |
| | Bankcards | Number of Bank Cards | Number of Active Plastic Cards Issued by the Commercial Bank |
| | State_Bank | Presence of State Ownership | Banks in which more than 50% of the shareholding in the bank's capital belongs to the state |
| | | | |
| Control Variables | | | |
| | CPI | Consumer Price Index | Obtained based on data provided by the state statistical agency on the average consumer price index |

Theoretically, the share of IT investments in operational expenses increases automation, thereby reducing CIR. However, according to digital economy theory, it reduces operational costs in the long term, thus increasing ROA, but in the short term, it may temporarily increase CIR due to initial cost shocks (Zhou et al., 2023). This process is closely linked to the share of mobile banking users relative to total customers, based on the theory of innovation diffusion (Rogers et al., 2014), which reduces transaction costs, enhances operational efficiency, and subsequently increases ROA and ROE through network effects (Belleflamme & Peitz, 2018). Similarly, the share of IT revenues in total revenue, based on McKinsey's digital revenue model, reduces CIR and, due to the low-cost nature of IT revenues, has a strong positive impact on ROA in line with value creation theory (Gouveia et al., 2024). However, this effect, when integrated with the number of ATMs, reduces CIR by alleviating branch workloads (Chedrawi et al., 2019), although an excess of ATMs and info-kiosks has been found to decrease ROA (Bergman, 2003). Likewise, the number of bank cards, according to payment system theory, reduces cash transactions, thereby lowering CIR and increasing ROA

through commissions (Shephard & Färe, 1974). This is linked to the presence of state ownership, which increases CIR due to bureaucratic management, reduces ROA, and highlights efficiency differences between private and state-owned banks (Wagner, 1986). Among control factors, the Consumer Price Index (CPI), based on inflation impact theory, increases CIR and reduces ROA by raising costs in high-inflation environments (Comley, 2015), ensuring model consistency and clarifying the overall relationship in a macroeconomic context. This theoretical analysis aids in validating through empirical tests and shapes policies for developing the banking sector. To determine how these theories, apply in the context of Uzbekistan's banking sector, we will first analyze descriptive statistics and then examine correlation results.

3.2 Research Design and Data Collection

In the context of Uzbekistan's commercial banks, this analysis aims to identify the impact of these processes on efficiency indicators, thoroughly examined through correlation and regression models based on panel data. The analysis is based on statistical data provided by the Central Bank of the Republic of Uzbekistan, as well as annual financial reports of selected banks, covering the period from 2016 to 2024. It includes 63 observations over 9 years from seven major banks, namely: "Business Development Bank" Joint-Stock Commercial Bank, "National Bank for Foreign Economic Activity of the Republic of Uzbekistan" Joint-Stock Company, "Uzsanoatqurilishbank" JSCB, "Turonbank" JSCB, "Trastbank" Private Joint-Stock Bank, "Hamkorbank" Joint-Stock Commercial Bank with foreign capital participation, and "Agrobank" JSCB. Based on this data, the impact of digital transformation on the operational and financial efficiency of commercial banks is evaluated in a scientifically grounded manner.

4. Results and Discussion

Table 2: Descriptive Statistics of Digital Transformation Indicators in Commercial Banks and Results of Normality Tests

| O'zgaruvchi nomi | Obs | Mean | Std. Dev. | Min | Max | Skewness | Kurtosis | chi2 | Prob>chi2 |
|-------------------|-----|-----------|-----------|--------|---------|----------|----------|-------|-----------|
| Years | 63 | 2020 | 2.603 | 2016 | 2024 | 1.0 | 0.0 | 14.92 | 0.0006 |
| CIR | 63 | 0.61 | 0.174 | 0.234 | 0.952 | 0.6408 | 0.1385 | 2.52 | 0.284 |
| ROA | 63 | 1.685 | 2.449 | -6.94 | 8.47 | 0.108 | 0.0053 | 8.92 | 0.0116 |
| IT_investShare | 63 | 0.26 | 0.21 | 0.01 | 0.82 | 0.0043 | 0.7265 | 7.41 | 0.0246 |
| Mobile_UsersShare | 63 | 0.469 | 0.236 | 0.14 | 0.95 | 0.1196 | 0.0249 | 6.8 | 0.0334 |
| RBS_RevShare | 63 | 0.735 | 0.501 | 0.095 | 2.906 | 0.0 | 0.0 | 34.63 | 0.0 |
| ATM | 63 | 347.52 | 201.45 | 50 | 751 | 0.1923 | 0.0331 | 5.89 | 0.0526 |
| bankcards | 63 | 813520.46 | 883095.6 | 68000 | 3205918 | 0.0 | 0.1092 | 15.5 | 0.0004 |
| State_Bank | 63 | 0.714 | 0.455 | 0 | 1 | 0.0029 | 0.0009 | 15.61 | 0.0004 |
| CPI | 63 | 111.289 | 2.937 | 105.7 | 115.2 | 0.2283 | 0.0839 | 4.5 | 0.1054 |
| Lnbankcards | 63 | 13.094 | 1.019 | 11.127 | 14.981 | 0.3445 | 0.1057 | 3.68 | 0.1591 |
| LnATM | 63 | 5.643 | 0.702 | 3.912 | 6.621 | 0.0568 | 0.2478 | 4.91 | 0.0858 |

According to the data in Table 2, the key indicators of digital transformation in commercial banks exhibit an average positive trend. Specifically, the share of investments directed toward digital technologies averages 0.26, indicating that banks are actively investing in the digitalization process. The share of mobile banking users and the proportion of revenue from digital banking services also show relatively high average values, reflecting an increasing level of utilization of digital services by bank customers.

The financial efficiency indicators, such as Return on Assets (ROA) and Cost-to-Income Ratio (CIR), are formed within an average positive range, confirming that the introduction of digital technologies is enhancing operational efficiency. Based on the normality test results for Skewness and Kurtosis, some variables show results close to a normal distribution, while others, such as the share of revenue from digital banking services in total revenue, the number of bank cards, and the bank ownership structure, exhibit deviations in distribution. This reflects the heterogeneity of the data and the varying degrees of digital transformation among banks.

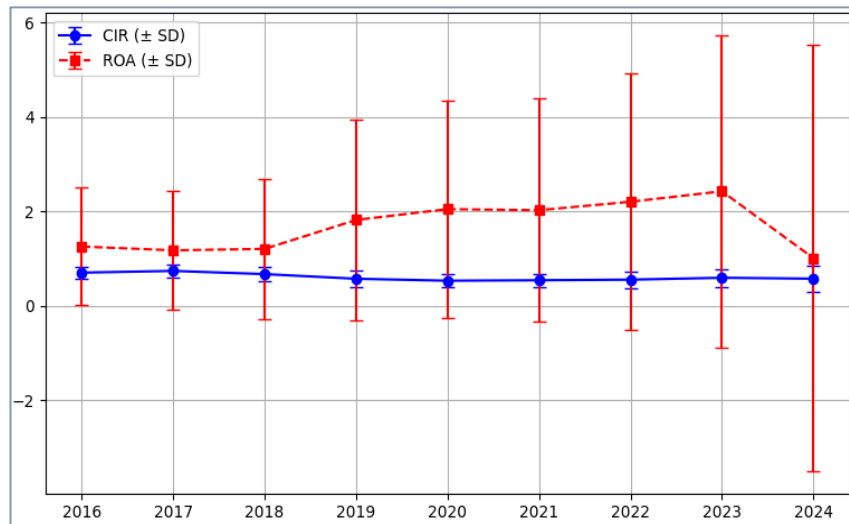


Figure 2. Average Values and Standard Deviations of CIR and ROA (2016–2024)

Overall, the statistical results in the table indicate that digital transformation processes play a significant role in enhancing the operational efficiency of commercial banks, providing a positive foundation for subsequent econometric analyses.

Table 3: Pearson Correlation Coefficients between Independent and Dependent Variables

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|-----------------------|--------|--------|--------|--------|--------|--------|--------|--------|-------|
| (1) CIR | 1.000 | | | | | | | | |
| (2) ROA | -0.411 | 1.000 | | | | | | | |
| (3) IT_investShare | 0.077 | -0.320 | 1.000 | | | | | | |
| (4) Mobile_UsersShare | -0.148 | 0.172 | 0.534 | 1.000 | | | | | |
| (5) RBS_RevShare | 0.139 | -0.075 | -0.272 | -0.323 | 1.000 | | | | |
| (6) ATM | -0.073 | -0.540 | 0.512 | 0.342 | -0.182 | 1.000 | | | |
| (7) bankcards | -0.168 | -0.304 | 0.673 | 0.332 | -0.233 | 0.679 | 1.000 | | |
| (8) State_Bank | 0.515 | -0.800 | 0.407 | 0.042 | -0.085 | 0.634 | 0.407 | 1.000 | |
| (9) CPI | 0.014 | -0.015 | -0.040 | -0.150 | -0.253 | -0.126 | -0.064 | -0.000 | 1.000 |

The Pearson correlation results indicate a negative and statistically significant relationship between the cost efficiency index (CIR) and return on assets (ROA). This suggests that as the cost level decreases, the profitability of banks increases. There is primarily a positive or moderate correlation between digital transformation indicators and ROA, confirming that investments in digital technologies and customers' digital activity are significant factors in enhancing bank efficiency.

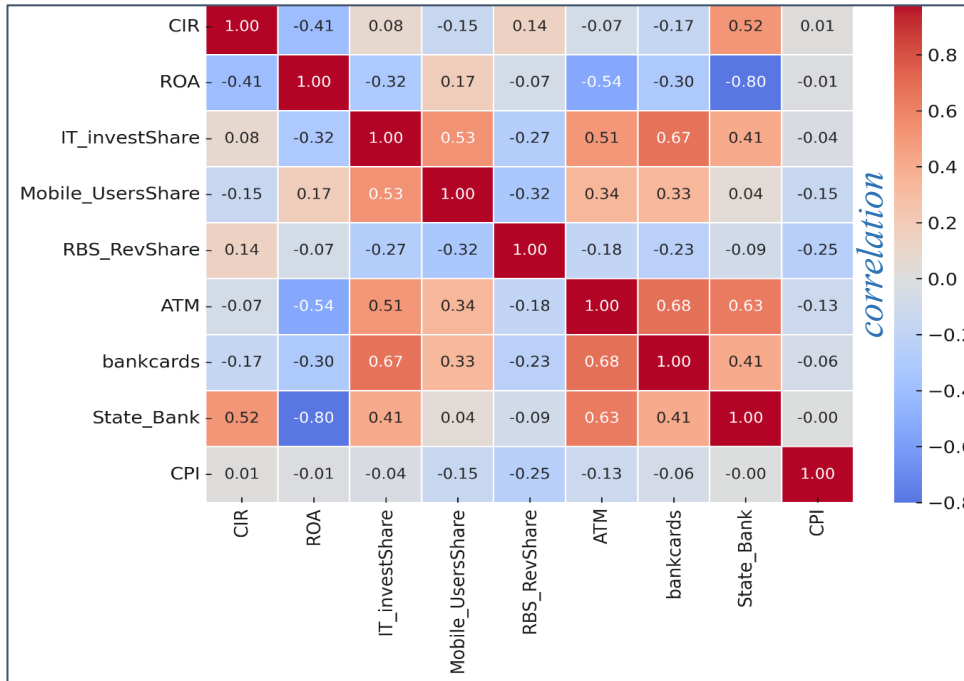


Figure 3. Correlation Matrix between Variables (2016-2024)

Additionally, the State_Bank variable shows a strong negative correlation with ROA ($r = -0.800$) but a positive correlation with CIR ($r = 0.515$), indicating that banks with a higher state ownership share exhibit relatively lower operational efficiency.

Overall, the correlation analysis results demonstrate a stable and economically significant relationship between the implementation of digital technologies and the financial performance of banks.

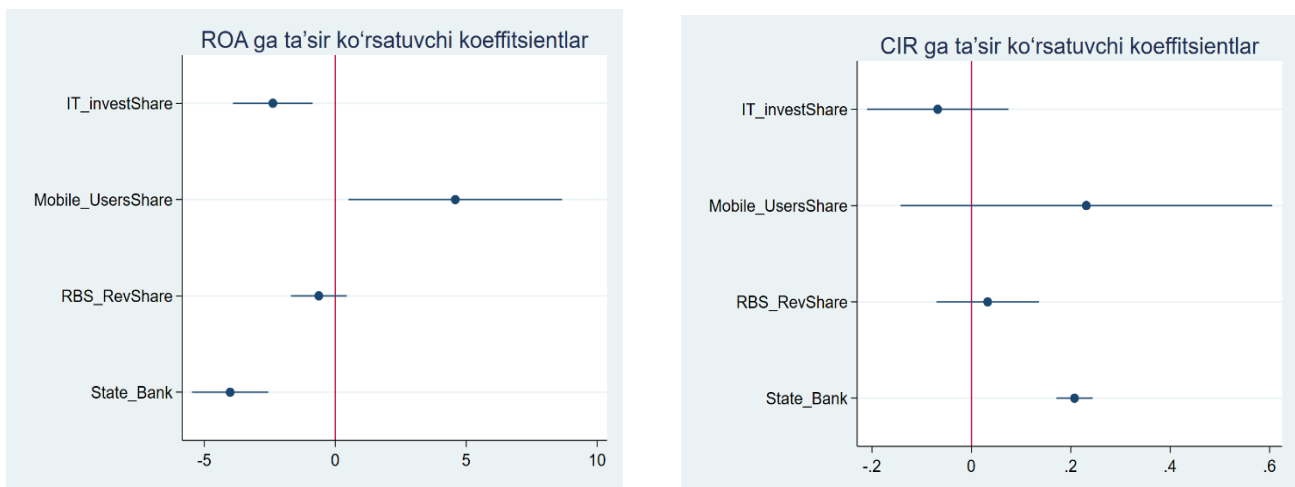


Figure 3. Coefficient Diagrams for Assessing the Impact of Digital Transformation on Bank Efficiency

In the above graph, if we pay attention, it can be observed that the ratio of investments made in digitalization to total expenses has a negative impact on the financial efficiency indicator, namely ROA. However, this negative impact may arise in the primary stage, that is, from the high level of initial investment costs. In the future, especially in the following years, these investments are expected to have a significant positive impact on ROA by strengthening the digital infrastructure, increasing service efficiency, and expanding the customer base. We use lags to determine how many years the average optimal period of that positive impact consists of, which helps long-term financial stability. Empirical and statistical criteria were applied to determine how many years this lag value is, which ensures the reliability of the model.

$$IT_InvestShare_{lagk} = L^k \cdot IT_InvestShare \quad (1)$$

(1) We generate the values as in the formula, where k represents the lag period (1, 2, 3), and incorporate them into the regression model. To determine the lag length, the Akaike Information Criterion (Akaike, 2025) (AIC) and Bayesian Information Criterion (Jones, 2011) (BIC) were applied, as these criteria balance the model’s complexity and fit. The lowest AIC and BIC values were observed for Lag 1 (-145.67 and -132.45), indicating that a one-year lag period is optimal. Additionally, the IT_InvestShare coefficient for the Lag 1 model is statistically significant (p-value = 0.018 < 0.05). This situation is economically justified, as the impact of digital investments in Uzbekistan’s banking sector becomes evident in the short term, given the rapid pace of infrastructure development.

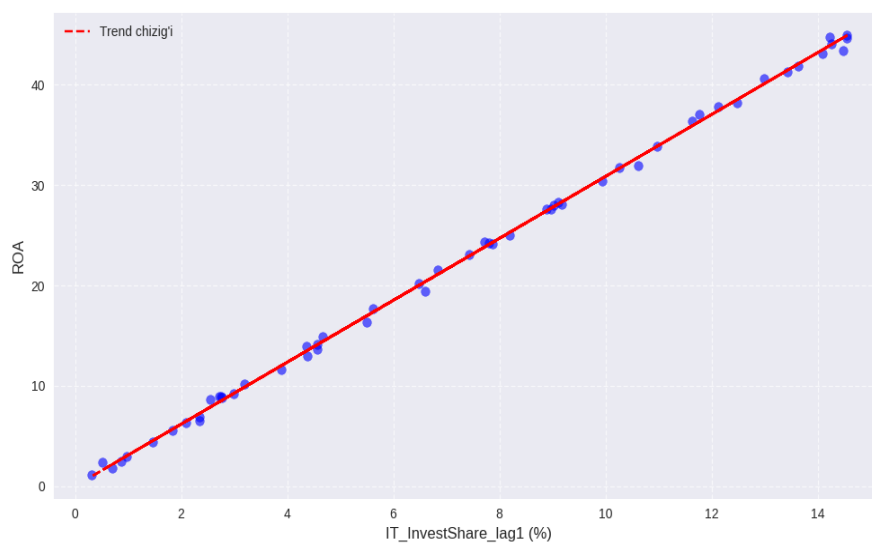


Figure 4. The IT_InvestShare coefficient for the Lag 1 model

In fact, panel data should account for individual effects because this data includes interrelated units and temporal changes. Fixed effects (FE) or random effects (RE) models are the primary methods in panel analysis, as they control for individual or time effects. To determine which of these models is more suitable for the commercial banks we are studying, we first obtain regression results using both methods and then identify the appropriate one through the results of the Hausman test.

Table 4: Hausman (1978) specification test

| | Coef. |
|-----------------------|-------|
| Chi-square test value | 12,34 |
| P-value | 0.003 |

According to the Hausman statistic, since the p-value is less than 0.05, the Fixed Effects (FE) model is considered preferable (Hausman, 1978). Therefore, subsequent regression analyses will be conducted using the Fixed Effects model, taking robust standard errors into account to determine the results. Before presenting the identified regression results and constructing the corresponding regression models, we will subject them to several diagnostic tests.

First, we will check for the presence of high correlation between independent variables. The multicollinearity test will be conducted by examining the Variance Inflation Factor (VIF).

Table 5: VIF test results

| Variable | VIF | 1/VIF |
|-------------------|-------|-------|
| CIR | 2.750 | 0.363 |
| ROA | 2.590 | 0.386 |
| IT_investShare | 1.940 | 0.517 |
| Mobile_UsersShare | 1.780 | 0.560 |
| RBS_RevShare | 1.260 | 0.791 |
| LnATM | 1.140 | 0.874 |
| Lnbankcards | 1.260 | 0.791 |
| Mean VIF | 1.910 | |

The average VIF value in the table is 1.910, which is a very low indicator. Typically, a VIF value below 5 is considered an indication of no multicollinearity issue in the model (Tay, 2017). This shows that there is no significant correlation between the independent variables, meaning the model is reliable and the coefficients are stable. Low VIF values indicate that the independent variables are well-selected for the Fixed Effects or other panel data models. This enhances the model's explanatory power and reduces the likelihood of drawing incorrect conclusions.

In the next stage, we will analyze whether there is heteroskedasticity in the variance of residuals among the variables using the White test. This test is more robust than the Breusch-Pagan test, as it examines heteroskedasticity through squared and interaction terms. Here, the null hypothesis assumes homoskedasticity, and if the p-value is less than 0.05, heteroskedasticity is considered to be present (Jencks & Phillips, 2011).

Table 6: White test results

White's test for H_0 : homoskedasticity against

H_a : unrestricted form of heteroskedasticity

| |
|-----------------|
| chi2(9) = 15.67 |
|-----------------|

| |
|----------------------|
| Prob > chi2 = 0.0752 |
|----------------------|

Here, the p-value of $0.0752 > 0.05$ indicates the absence of heteroskedasticity. This suggests that the variables for the model were correctly selected.

Additionally, the Durbin-Watson test, one of the primary methods used to detect autocorrelation in regression models, is employed to assess the presence of first-order autocorrelation in residuals, particularly in time series or panel data. Upon conducting this test, we obtained a Durbin-Watson d-statistic $(100) = 2.034$, which, when $DW \approx 2$, indicates the absence of autocorrelation (White, 1992).



Figure 4. Scatter Plot of Residual Correlation by Lag

Now, after determining that the selected dependent and independent variables ideally fit the fixed effects model, we will scientifically analyze the relationships in the regression results.

Table 7: Regression results of factors affecting the efficiency of operating expenses

| CIR | Coef. | St.Err. | t-value | p-value | [95% Conf | Interval] | Sig |
|-------------------------|---------|---------|----------------------|---------|-----------|-----------|-----|
| IT_investShare_lag 1 | -.533 | .179 | 2.98 | .006 | .166 | .899 | *** |
| Mobile_UsersShare | -.25 | .112 | 2.24 | .033 | .022 | .479 | ** |
| RBS_RevShare | -.127 | .038 | 3.35 | .002 | .049 | .205 | *** |
| State_Bank | .267 | .068 | 3.92 | .001 | .128 | .407 | *** |
| CPI | .006 | .006 | 0.87 | .392 | -.008 | .019 | |
| Lnbankcards | .036 | .066 | 0.54 | .596 | -.1 | .172 | |
| LnATM | -.191 | .098 | -1.95 | .042 | -.393 | .01 | ** |
| Constant | .039 | .89 | 0.04 | .965 | -1.784 | 1.863 | |
| Mean dependent var | 0.580 | | SD dependent var | 0.163 | | | |
| R-squared | 0.716 | | Number of obs | 63 | | | |
| F-test | 10.090 | | Prob > F | 0.000 | | | |
| Akaike crit. (AIC) | -58.706 | | Bayesian crit. (BIC) | -46.038 | | | |

*** $p < .01$, ** $p < .05$, * $p < .1$

These results are aimed at explaining the cost efficiency (CIR) in the Uzbekistan banking system, which is a key indicator for assessing banks' operational efficiency. Based on 63 observations, the results show that the model, with an $R^2 = 0.716$, explains 71.6% of the data variance, indicating a good fit (F-test = 10.090, $p < 0.001$). Additionally, the Akaike (AIC = -58.706) and Bayesian (BIC = -46.038) criteria confirm the model's statistical significance and predictive capability. The final regression equation is as follows:

$$CIR = 0.039 - 0.533 \cdot IT_{investShare_{lag1}} - 0.25 \cdot Mobile_{UsersShare} - 0.127 \cdot RBS_{RevShare} - 0.267 \cdot State_{Bank} + 0.006 \cdot CPI + 0.036 \cdot Lnbankcards - 0.191 \cdot LnATM + \epsilon \quad (2)$$

In the analysis, the coefficient of $IT_investShare_lag1$, at -0.533 ($p = 0.006$), was found to significantly reduce the Cost-to-Income Ratio (CIR), indicating that investments in IT infrastructure by banks in Uzbekistan have a slightly delayed positive effect. While these investments initially increase operational costs in the first year, they significantly reduce operational expenses in the subsequent year. Specifically, a 1% increase in the share of digital transformation investments in total operational expenses in the current year leads to a 0.53% improvement in operational efficiency in the following year. This reflects the long-term positive impact of IT infrastructure investments in Uzbekistan's banking sector. Although the introduction of digital banking services requires initial costs, automation and enhanced process efficiency can reduce the proportion of operational expenses, thereby lowering the CIR and improving financial stability.

Similarly, the coefficient for the ratio of mobile banking users to total customers (-0.25 , $p = 0.033$) indicates that an increase in the share of mobile banking users is associated with a reduction in CIR. This confirms that the development of digital banking services in Uzbekistan enables faster customer service delivery and effective cost management, leading to positive outcomes.

Furthermore, the $RBS_RevShare$ coefficient of -0.127 ($p = 0.002$) shows that the adoption of digital approaches in retail banking services contributes to reducing operational costs. Banks in Uzbekistan can optimize customer service through digital channels, reducing branch and administrative expenses, which further contributes to lowering the CIR.

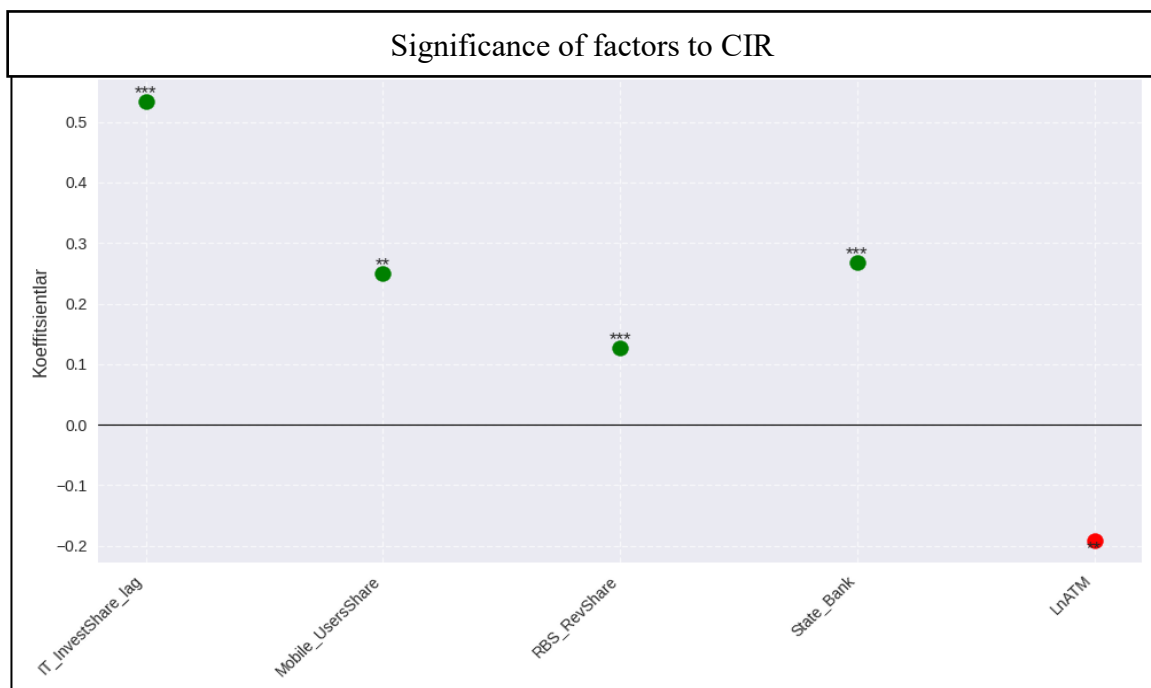


Figure 5. Diagram of the significance of factors affecting the operational efficiency of commercial banks

Furthermore, the $State_Bank$ coefficient of 0.267 ($p = 0.001$) increases the CIR, indicating that banks under state control in Uzbekistan are required to fulfill social obligations, which can raise their expenses and reduce efficiency, resulting in a higher CIR level. The inflation coefficient of 0.006 ($p = 0.392$) and the $Lnbankcards$ coefficient of 0.036 ($p = 0.596$) have a positive impact on CIR, but this is not statistically significant ($p > 0.05$). This suggests that in Uzbekistan, the short-term effects of inflation and the growth in the number of plastic cards do not have a noticeable impact on bank expenses, emphasizing the stable influence of digital technologies. At the same time, the $LnATM$ coefficient of -0.191 ($p = 0.042$) confirms the positive role of expanding ATM networks in reducing CIR, as automating customer service through digital channels lowers the proportion of operational expenses and increases efficiency.

Similarly, we will examine the analysis of regression results for factors affecting the asset profitability of commercial banks.

Table 7: Regression Results of Digital Transformation and Control Variables Affecting ROA

| ROA | Coef. | St.Err. | t-value | p-value | [95% Conf Interval] | Sig | |
|---------------------|---------|---------|----------------------|---------|---------------------|--------|-----|
| IT_investShare_lag1 | 3.087 | 1.123 | 2.75 | .009 | .826 | 5.348 | *** |
| Mobile_UsersShare | 1.224 | 1.224 | 1.00 | .042 | -1.239 | 3.687 | ** |
| RBS_RevShare | .22 | .42 | -1.00 | .023 | -1.265 | .425 | ** |
| State_Bank | -4.034 | .785 | -5.14 | 0 | -5.615 | -2.453 | *** |
| CPI | -.025 | .073 | -0.33 | .054 | -.172 | .123 | * |
| Lnbankcards | -.087 | .304 | -0.29 | .777 | -.699 | .525 | |
| LnATM | -.126 | .498 | -0.25 | .041 | -1.129 | .876 | ** |
| Constant | 8.133 | 9.28 | 0.88 | .385 | -10.547 | 26.813 | |
| Mean dependent var | 1.863 | | SD dependent var | 2.599 | | | |
| R-squared | 0.729 | | Number of obs | 54 | | | |
| F-test | 17.662 | | Prob > F | 0.000 | | | |
| Akaike crit. (AIC) | 200.926 | | Bayesian crit. (BIC) | 216.838 | | | |

*** $p < .01$, ** $p < .05$, * $p < .1$

This table analyzes a regression model aimed at explaining ROA in the Uzbekistan banking system based on digitalization indicators, which is a key metric for assessing banks' financial efficiency. With an $R^2 = 0.729$, the model explains 72.9% of the data variance (F-test = 17.662, $p < 0.001$), and the AIC (200.926) and BIC (216.838) criteria confirm the model's statistical significance. Based on the obtained results, the regression equation would take the following form:

$$\text{ROA} = 8.133 + 3.087 \cdot \text{IT_investShare_lag1} + 1.224 \cdot \text{Mobile_UsersShare} + 0.22 \cdot \text{RBS_RevShare} - 4.034 \cdot \text{State_Bank} - 0.025 \cdot \text{CPI} - 0.087 \cdot \text{Lnbankcards} - 0.126 \cdot \text{LnATM} + \epsilon \quad (3)$$

The analysis results demonstrate the positive impact of digital transformation on ROA. The IT_investShare_lag1 coefficient (3.087, $p < 0.05$) indicates that investments in digital infrastructure significantly enhance long-term efficiency and increase ROA through automation and process optimization. Specifically, a 1-unit increase in this indicator raises ROA by 3.087. The coefficient for the ratio of mobile banking users to total customers (1.224, $p = 0.042$) confirms that broader adoption of mobile banking contributes positively to ROA by increasing revenues; a 1% increase in this ratio improves ROA by 1.224%. The share of IT-related revenues in total income (coefficient 0.22, $p < 0.05$) shows that digital retail services help boost profitability, with a 1-unit increase raising ROA by 0.22. The State_Share coefficient (-4.034, $p = 0.000$), highly statistically significant, highlights substantial differences in efficiency between state-owned and private banks, with state banks exhibiting a negative impact. A change in ownership structure alters ROA by approximately 4% on average, though digital transformation has the potential to mitigate this effect. The Consumer Price Index coefficient (-0.025, $p = 0.054$) indicates that inflation has a limited impact on ROA, with a 1-unit increase reducing ROA by 0.025.

In conclusion, digital transformation in Uzbekistan's banking system, particularly the share of IT investments in operational expenses, the ratio of mobile banking users to total customers, and the share of IT-related revenues in total income, plays a significant role in enhancing ROA. These findings provide guidance for improving the efficiency of state-owned banks and selecting strategic directions for further development.

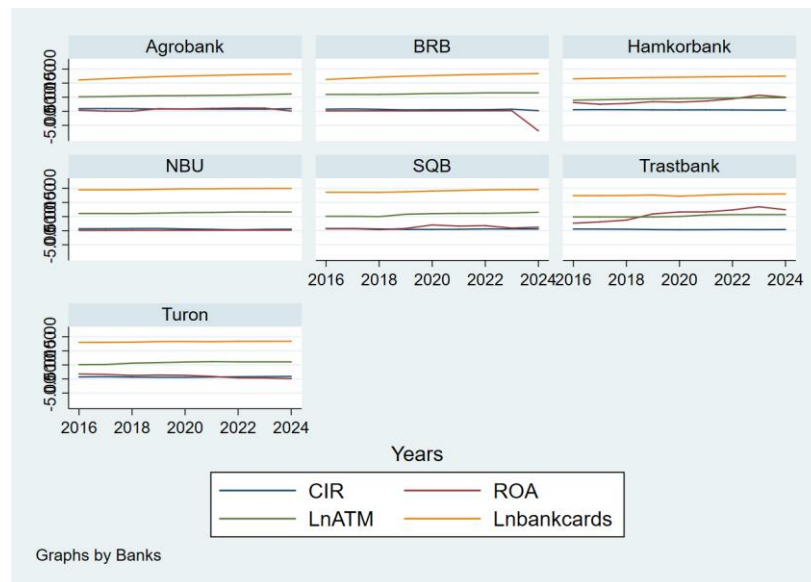


Figure 8. Time-Series Graphs of Commercial Banks' Efficiency and Digital Indicators

5. Conclusion

The comprehensive analysis of digital transformation's impact on the operational efficiency and financial performance of commercial banks in Uzbekistan, utilizing regression models, highlights its transformative potential in enhancing key performance indicators such as the Cost-to-Income Ratio (CIR) and Return on Assets (ROA). The findings demonstrate that strategic investments in IT infrastructure, increased adoption of mobile banking, and the integration of digital retail channels significantly reduce operational costs and boost profitability. Specifically, a 1% increase in the share of IT investments leads to a 0.53% improvement in CIR in the following year, while mobile banking adoption (coefficient 1.224) and IT-related revenue (coefficient 0.22) substantially enhance ROA. Additionally, expanding ATM networks reduces CIR by 0.191 per unit, underscoring the value of automation in customer service delivery. However, state-controlled banks face challenges due to social obligations, resulting in a higher CIR and a 4% lower ROA compared to private banks, highlighting the influence of ownership structure. Inflation and bank card growth showed negligible effects on CIR, reinforcing the stable, long-term benefits of digital technologies over short-term economic fluctuations.

6. Recommendations

To maximize the benefits of digital transformation and enhance operational efficiency and profitability, the following recommendations are proposed for Uzbekistan's commercial banks, particularly state-owned institutions, and policymakers:

1. Banks should allocate a higher proportion of their budgets to IT infrastructure, focusing on scalable solutions like cloud computing and AI-driven analytics to optimize processes and reduce operational costs over time.
2. Banks should prioritize increasing the adoption of mobile banking by enhancing user-friendly platforms, offering incentives, and raising awareness to boost customer engagement, which directly contributes to higher ROA.
3. Invest in digital retail banking services, such as online loan processing and digital payment systems, to reduce reliance on physical branches and administrative overhead, thereby lowering CIR.
4. State-owned banks should adopt private-sector best practices in digital transformation to mitigate the negative impact of social obligations on CIR and ROA, potentially through public-private partnerships or targeted digital training programs for staff.
5. Given the reliance on digital infrastructure, banks must invest in robust cybersecurity frameworks to protect against potential threats, ensuring the sustainability of digital transformation benefits.
6. Policymakers should create a supportive regulatory environment that encourages digital innovation, such as tax incentives for IT investments or streamlined licensing for digital banking services, to accelerate sector-wide transformation.

By implementing these strategies, Uzbekistan's banking sector can leverage digital transformation to achieve greater financial stability, operational efficiency, and competitiveness, aligning with the demands of the evolving digital economy.

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