

Received: 11/05/2026

Accepted: 20/06/2026

Published: 30/06/2026

Macroeconomic Drivers of Digitalization in Türkiye: The Role of Uncertainty Nonlinear Income Effects and Financial Development

Zeliha Semra KILINÇ ¹

¹ Aydın Adnan Menderes University, Yenipazar Vocational School, Aydın, Türkiye, z.kilinc@adu.edu.tr,
ORCID: <https://orcid.org/0000-0001-9837-1587>

Abstract

Digital transformation is closely connected to the macroeconomic environment in which technological adoption takes place. Nevertheless, compared with the economic consequences of digitalization, relatively limited attention has been devoted to the macroeconomic conditions underlying its development. This study investigates the roles of uncertainty, income dynamics, and financial development in shaping digitalization in Türkiye during 1990–2023. Digitalization is represented by mobile cellular subscriptions, whereas the World Uncertainty Index is employed to capture the broader uncertainty environment. The empirical specification incorporates GDP per capita together with its squared term to assess whether the influence of income varies across income levels. After determining the integration properties of the variables through ADF and PP tests, their dynamic relationships are analyzed within an ARDL framework. The empirical evidence supports the presence of a stable long-term association among the variables. The long-run estimates reveal an adverse effect of uncertainty on digitalization. Income, by contrast, exhibits a nonlinear pattern: the positive coefficient on GDP per capita combined with the negative coefficient on its squared term implies that the contribution of income becomes progressively weaker as income rises. No statistically significant long-run effect is identified for financial development. Short-run estimates indicate persistence in changes in digitalization and a negative response to financial development, while the error-correction mechanism is negative and statistically significant. Overall, the results indicate that the advancement of digitalization in Türkiye is associated not only with income dynamics but also with macroeconomic stability and with the extent to which financial conditions support technology-related investment.

Keywords: Digitalization, World Uncertainty Index, Economic Growth, Nonlinear Income Effects, Financial Development

Introduction

Digitalization has become an increasingly important component of economic transformation, altering the way production is organized, information is exchanged, and economic agents interact. The spread of digital technologies can reduce information and transaction costs, improve access to markets, and create new opportunities for productivity gains. These changes have made digitalization relevant not only to technological progress but also to broader questions of economic growth and competitiveness (Brynjolfsson & McAfee, 2014; Goldfarb & Tucker, 2019). The pace of this transformation, however, differs considerably across countries. Such differences suggest that the diffusion of digital technologies cannot be understood independently of the economic conditions in which adoption takes place.

Income is one of the factors that may shape this process. Higher income levels can make



Kılınç, Z. S. (2026). Macroeconomic drivers of digitalization in Türkiye: The role of uncertainty nonlinear income effects and financial development. *Social Research and Education Journal*, 2(1), 69-81, <https://doi.org/10.5281/zenodo.22685062>

digital technologies more accessible to households while also expanding the capacity of firms and the public sector to invest in communication infrastructure and technological upgrading. Cross-country evidence has long pointed to substantial differences in technology adoption across levels of economic development (Chinn & Fairlie, 2010; Comin & Hobijn, 2004). At the same time, the relationship need not remain constant as income rises. Once access to basic digital technologies becomes widespread, further increases in income may generate smaller additions to adoption than they do at earlier stages of development. Differences in the intensity with which available technologies are used may also persist even after diffusion has advanced substantially (Comin & Mestieri, 2018). This possibility provides a basis for examining income and digitalization within a nonlinear framework rather than assuming a uniform effect across the entire income range.

The macroeconomic environment may also affect decisions concerning digital investment. Uncertainty is particularly relevant because investment in technology and infrastructure frequently involves costs that cannot be fully recovered once the investment has been undertaken. Under such conditions, greater uncertainty can increase the value of postponing investment until economic conditions become clearer (Bernanke, 1983; Dixit & Pindyck, 1994). Empirical research likewise shows that uncertainty can weaken investment and economic activity by encouraging firms to delay expenditure and hiring decisions (Baker et al., 2016; Bloom, 2009). Digital transformation may therefore proceed more slowly when firms and other economic agents face a less predictable economic environment.

Financial conditions constitute another potential determinant of digitalization. The adoption of new technologies often requires initial expenditures on equipment, infrastructure, software, and complementary organizational investments. Access to external finance can ease these constraints, particularly when firms cannot finance such expenditures entirely from internal resources. Financial development may consequently facilitate technological investment by broadening access to credit and improving the financing environment. However, an expansion of credit does not necessarily imply that additional financial resources will be directed toward digital activities. The relationship between financial development and digitalization may therefore depend on the structure of the financial system and the uses to which available financing is allocated (Horobet et al., 2022; Sahay et al., 2015).

These relationships are particularly relevant for Türkiye, where digital technologies have expanded substantially alongside periods of marked changes in income, financial conditions, and macroeconomic uncertainty. Existing studies concerning Türkiye have examined different aspects of uncertainty and digitalization, including the behavior of economic policy uncertainty (Jirasavetakul & Spilimbergo, 2018), the asymmetric relationship between uncertainty and consumption (Songur, 2020), and the implications of digitalization for income inequality (Akalın, 2024). Nevertheless, considerably less attention has been given to the determinants of digitalization itself and, in particular, to whether income, uncertainty, and financial development have different implications over short and long horizons.

Against this background, this study examines the macroeconomic determinants of digitalization in Türkiye using annual observations for 1990–2023. Digitalization is represented by mobile cellular subscriptions, while uncertainty is measured by the World Uncertainty Index (WUI). GDP per capita and its squared term are included to allow the income–digitalization relationship to vary with the level of income, and domestic credit to the private sector is used to represent financial development. The empirical analysis employs an ARDL framework to distinguish between short-run adjustments and long-run relationships. In this way, the study seeks to contribute to the literature by jointly considering uncertainty, financial development,

The remainder of the study is organized as follows. The next section reviews the relevant literature. This is followed by the presentation of the data and empirical methodology. The subsequent section reports the empirical findings, after which the results are discussed in relation to the existing literature. The final section presents the main conclusions and policy recommendations.

Literature Review

Research on digitalization has expanded alongside the growing role of digital technologies in economic activity. One of the central issues in this literature is the uneven diffusion of technology across countries. Comin and Hobijn (2004) document substantial cross-country differences in both the timing and intensity of technology adoption, showing that access to a technology does not by itself imply a similar pattern of use across economies. From a different perspective, Goldfarb and Tucker (2019) explain how digital technologies reshape economic activity by changing costs related to search, replication, transportation, tracking, and verification. These contributions suggest that the spread of digital technologies depends not only on their availability but also on the economic environment surrounding their adoption.

Income is closely connected with these differences in digital diffusion. Chinn and Fairlie (2010) show that international disparities in computer and internet penetration are associated with income as well as demographic and infrastructure-related characteristics. Myovella et al. (2020) also establish a connection between digitalization and economic development, although they find that its growth effects differ between Sub-Saharan African and OECD economies. The evidence therefore points to a strong association between income and digital development, but it does not require this association to remain constant throughout the development process.

This issue becomes particularly relevant as technological diffusion advances. At relatively lower levels of adoption, increases in income can broaden access to digital services and support the expansion of technological infrastructure. The same increase in income may produce a smaller change once a substantial share of potential users has already adopted the relevant technology. Comin and Mestieri (2018) show that important cross-country differences remain in the intensity with which technologies are used even after those technologies have become available. Their analysis draws attention to the distinction between access to technology and the intensity of its use. In the present study, this provides a rationale for allowing the relationship between income and digitalization to change with income rather than imposing a constant linear relationship.

A separate body of research provides a basis for considering uncertainty as a determinant of technology-related investment. The investment-under-uncertainty literature emphasizes that irreversibility can make the timing of investment particularly sensitive to uncertain conditions. Dixit and Pindyck (1994) show that when investment entails sunk costs, waiting may become more valuable as uncertainty increases. Firm-level evidence reported by Leahy and Whited (1996) also points to an inverse relationship between uncertainty and investment. Bloom (2009) further demonstrates that uncertainty shocks can lead firms to temporarily reduce investment and hiring. Although these studies were not developed specifically to explain digitalization, their arguments are relevant to digital transformation because expanding digital capacity often requires expenditures on technology, equipment, and infrastructure.

How uncertainty is measured is also important. Baker et al. (2016) developed the

Economic Policy Uncertainty index with a specific focus on uncertainty surrounding economic policy. The World Uncertainty Index introduced by Ahir et al. (2018, 2022) takes a broader approach by deriving country-level uncertainty measures from Economist Intelligence Unit country reports. The latter measure is particularly useful for the purpose of this study because technology-related decisions may be influenced by a wider uncertainty environment rather than by economic policy uncertainty alone. At the same time, the response to uncertainty need not be identical in every episode. Baker et al. (2020), for example, document the extraordinary increase in uncertainty associated with the COVID-19 shock. Such episodes reinforce the need to examine the relationship between uncertainty and digitalization empirically rather than presuming a uniform response.

Financial development provides a third dimension of the macroeconomic environment considered in this study. Technology adoption and infrastructure expansion can require substantial financing, making access to external funds potentially relevant to digital investment. Yet financial deepening by itself does not determine where additional financing is ultimately directed. Sahay et al. (2015) emphasize that the benefits of financial deepening depend on the broader functioning and stability of the financial system. Horobeş et al. (2022), focusing more directly on digitalization, examine its interaction with education and financial development in European countries and identify significant relationships among these dimensions. Consequently, financial development may facilitate digital transformation, but its contribution is likely to depend on the wider economic and institutional setting.

The Türkiye-specific literature has largely addressed these issues through separate research questions. Jirasavetakul and Spilimbergo (2018) examine economic policy uncertainty in Türkiye and its macroeconomic implications, whereas Songur (2020) analyzes the asymmetric relationship between uncertainty and consumption using a nonlinear framework. On the digitalization side, Akalın (2024) investigates how digitalization is related to income inequality in Türkiye. These studies provide useful evidence on uncertainty and digital transformation individually, but they leave comparatively less explored the question of how the macroeconomic environment is associated with the development of digitalization itself.

Building on these strands of research, the present study considers income, uncertainty, and financial development simultaneously rather than examining them in isolation. Two aspects distinguish the empirical specification. First, uncertainty is represented by the WUI, allowing the analysis to capture a broader uncertainty environment. Second, income enters the model both in level and squared form, making it possible to test whether its association with digitalization changes as income rises. Financial development is incorporated alongside these variables to account for the financing dimension of technological transformation. The resulting framework is intended to provide evidence on how these macroeconomic factors are related to Türkiye's digitalization process over both short and long horizons.

Method

This study uses annual observations for Türkiye covering the period 1990–2023. The time span is determined by the availability of consistent data for all variables included in the model. Digitalization is treated as the dependent variable and is represented by mobile cellular subscriptions. The explanatory variables consist of the World Uncertainty Index (WUI), GDP per capita, the squared term of GDP per capita, and financial development measured by domestic credit to the private sector.

The empirical specification is designed to capture both linear and nonlinear effects. GDP

per capita enters the model together with its squared term so that the relationship between income and digitalization is allowed to vary across income levels. WUI is included to represent the broader uncertainty environment, while financial development is used to account for the financing conditions that may influence technology-related investment.

Before estimating the dynamic model, the time-series properties of the variables are examined using the Augmented Dickey–Fuller and Phillips–Perron unit root tests. These tests are applied to determine whether the variables are stationary in levels or after first differencing. Since the series are found to consist of a combination of $I(0)$ and $I(1)$ variables, the ARDL bounds-testing framework is adopted. This approach is appropriate in the present setting because it permits the joint analysis of variables with different integration orders, provided that none is $I(2)$, and it enables the short-run adjustment process and the long-run relationship to be evaluated within the same specification.

The empirical model can be written as follows:

$$LMAS_t = \beta_0 + \beta_1 WUI_t + \beta_2 LGDP_t + \beta_3 LGDP_t^2 + \beta_4 LFD_t + \varepsilon_t \quad (1)$$

Table 1. Variable Definitions and Data Sources

Variable	Definition	Unit /Conversion	Source
LMAS	Mobile Cellular Subscriptions	Logarithmic	World Bank (n.d.-c)
WUI	World Uncertainty Index	Original index value	Ahir et al. (2018)
LGDP	GDP per capita (constant 2015 US\$)	Logarithmic	World Bank (n.d.-b)
LGDP ²	Squared term of log GDP per capita	Squared logarithmic term	Author's calculation
LFD	Domestic credit to private sector by banks (% of GDP)	Logarithmic	World Bank (n.d.-a)

Source: World Bank (n.d.-a, n.d.-b, n.d.-c) and Ahir et al. (2018).

Table 1 summarizes the variables, their transformations, and the corresponding data sources. LMAS denotes the natural logarithm of mobile cellular subscriptions and is used as the proxy for digitalization. WUI enters the model in its original index form and captures the broader uncertainty environment. Income is represented by the natural logarithm of GDP per capita, while $LGDP^2$ is constructed by squaring the logarithmic income variable in order to allow for a nonlinear income effect. Financial development is measured by the natural logarithm of domestic credit to the private sector as a percentage of GDP.

Table 2. Descriptive Statistics

	LMAS	WUI	LGDP	LFD
Mean	16.342968	0.2865335	9.0001328	3.371053
Median	17.859769	0.2633566	8.9873894	3.265088
Maximum	18.339470	0.7221146	9.6113211	4.242940
Minimum	10.367504	0.0369879	8.5437216	2.590505
Std. Dev.	2.5983290	0.1328406	0.3352448	0.597396
Skewness	-1.2368582	1.0516369	0.2583494	0.186556
Kurtosis	3.0004179	4.8721634	1.7272841	1.362033
Jarque-Bera	8.6682876	11.232405	2.6729431	3.998042
Probability	0.0131130	0.0036384	0.2627711	0.135467
Observations	34	34	34	34

Table 2 provides an overview of the distributional properties of the variables. Among the variables, LMAS displays the largest dispersion, with a standard deviation of 2.598 around a mean of 16.343. WUI has an average value of 0.287 and is positively skewed, indicating a

distribution with relatively more observations toward the upper end. LMAS, in contrast, is negatively skewed, while the skewness values of LGDP and LFD are comparatively small and positive. The Jarque–Bera statistics also reveal differences across the series. Normality is rejected for LMAS and WUI at the 5% level, whereas the corresponding null hypothesis cannot be rejected for LGDP and LFD. These statistics provide an initial view of the characteristics of the series before their time-series properties are examined.

Empirical Analysis

The integration properties of the series are examined before estimating the ARDL model. Both the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are applied for this purpose, with the results reported in Table 3. Using both tests provides a basis for determining whether each variable enters the analysis as a level-stationary series or becomes stationary after first differencing.

Table 3. Unit Root Test Results

		Variables	ADF	PP
Level	Constant	LMAS	-5.2190 (7)***	-4.0038 (3)***
		WUI	-4.0442 (0)***	-4.0137 (2)***
		LGDP	0.7348 (0)	2.0756 (8)
		LGDP ²	0.8907 (0)	2.3979 (8)
		LFD	-1.3700 (3)	-0.9087 (3)
	Constant Trend	LMAS	-6.6753 (8)***	-1.2028 (3)
		WUI	-4.4559 (0)***	-4.4559 (0)***
		LGDP	-2.4567 (0)	-2.3322 (5)
		LGDP ²	-2.2804 (2)	-2.1533 (5)
		LFD	-1.9923 (3)	-1.3881 (3)
First Difference	Constant	LMAS	-2.3186 (6)	-1.3387 (6)
		WUI	-6.7249 (1)***	-14.188 (12)***
		LGDP	-5.7710 (0)***	-6.4386 (7)***
		LGDP ²	-5.6676 (0)***	-6.1452 (7)***
		LFD	-3.4173 (0)	-3.4173 (0)
	Constant Trend	LMAS	-0.9421 (6)	-2.3092 (5)
		WUI	-6.6061 (1)***	-13.9738 (12)***
		LGDP	-5.8414 (0)***	-7.7738 (10)***
		LGDP ²	-5.7958 (0)***	-7.7759 (10)***
		LFD	-3.3795 (0)***	-3.3795 (0)***

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

The unit root results indicate different integration properties across the variables. LMAS and WUI are stationary at level under the relevant specifications and are therefore treated as I(0). In contrast, the level statistics for LGDP, LGDP², and LFD do not provide sufficient evidence of stationarity, whereas stationarity is obtained after first differencing. These three variables are consequently classified as I(1). Most importantly for the subsequent estimation, none of the series is found to be integrated of order two. The coexistence of I(0) and I(1) variables therefore supports the use of the ARDL bounds-testing framework for investigating the relationship among the variables.

ARDL Bounds Test

Given the integration results, the next step is to test whether the variables share a long-run relationship. The ARDL bounds test of Pesaran and Shin (1999) and Pesaran et al. (2001) is used for this purpose. The null hypothesis of the test states that no level relationship exists

Macroeconomic Drivers of Digitalization in Türkiye: The Role of Uncertainty Nonlinear Income Effects and Financial Development among the variables. Evidence of cointegration is obtained when the calculated F-statistic exceeds the relevant upper-bound critical value.

In this context, the general form of the ARDL model employed in the study can be expressed as follows:

$$\Delta LMAS_t = \alpha_0 + \sum_{i=1}^p \alpha_{(1i)} \Delta LMAS_{t-i} + \sum_{i=0}^{q_1} \alpha_{(2i)} \Delta WUI_{t-i} + \sum_{i=0}^{q_2} \alpha_{(3i)} \Delta LGDP_{t-i} + \sum_{i=0}^{q_3} \alpha_{(4i)} \Delta LGDP^2_{t-i} + \sum_{i=0}^{q_4} \alpha_{(5i)} \Delta LFD_{t-i} + \beta_1 LMAS_{t-1} + \beta_2 WUI_{t-1} + \beta_3 LGDP_{t-1} + \beta_4 LGDP^2_{t-1} + \beta_5 LFD_{t-1} + \varepsilon_t \quad (2)$$

The results of the bounds test and diagnostic tests are presented in Table 4.

Table 4. ARDL Bounds Test and Diagnostic Tests

	F-Statistic	Critical Value	
k	4	Lower Bound	Upper Bound
F-statistic	6.433832	3.058	4.22
Diagnostic Test			
	Test Statistic	Probability Value	
Breusch Pagan Godfrey	1.273981	0.305443	
Ramsey RESET	1.326490	0.327089	
Breusch Godfrey	1.561742	0.235532	
Jarque-Bera	0.859947	0.650526	
R ²	0.999335		
Adjusted R ²	0.998969		

Table 4 reports the bounds test together with the diagnostic statistics of the estimated model. The F-statistic is 6.433832, which is above the upper-bound critical value of 4.22 at the 5% level. The null hypothesis of no level relationship is therefore rejected, providing evidence that the variables are cointegrated over the sample period.

The diagnostic results do not point to problems that would undermine the estimated specification. The Breusch–Pagan–Godfrey test produces a probability value of 0.305, while the probability associated with the Breusch–Godfrey test is 0.235. Thus, the residual diagnostics provide no evidence of heteroskedasticity or serial correlation at the 5% level. The Ramsey RESET result (p = 0.327) does not indicate functional-form misspecification, and the Jarque–Bera statistic (p = 0.650) does not reject residual normality. The model also records an R² of 0.999 and an adjusted R² of 0.998. Taken together, these diagnostic outcomes provide no indication of a major specification or residual problem in the estimated ARDL model.

Following the identification of cointegration, the long-run coefficients are estimated and reported in Table 5, while the short-run dynamics are presented in Table 6.

Table 5. Long-Run Coefficient Estimates

Variable	Coefficient	Standard Error	t-statistic	Probability
WUI	-4.389548	1.851084	-2.371339	0.025115
LGDP (-1)	420.2092	55.12391	7.622993	0.000000
LGDP ² (-1)	-22.87449	3.069578	-7.452000	0.000000
LFD (-1)	-1.095910	0.936259	-1.170520	0.252019
C	-1905.059	248.0681	-7.679584	0.000000

The long-run estimates are presented in Table 5. WUI carries a negative and statistically

significant coefficient, indicating an inverse long-run association between uncertainty and digitalization. The coefficient of LGDP is positive and statistically significant, whereas the coefficient attached to LGDP² is negative and significant. Since the income variable enters the specification in both linear and squared form, these coefficients should be interpreted jointly rather than separately. Their opposite signs provide evidence of an inverted U-shaped relationship between income and digitalization.

The turning point calculated from the estimated income coefficients is approximately 9.185 in logarithmic GDP per capita. This value falls within the observed LGDP range of 8.544 to 9.611, indicating that the estimated turning point is located within the sample rather than outside the range of the data. Accordingly, the marginal association between income and digitalization is positive below the estimated threshold, becomes progressively weaker as income approaches the turning point, and turns negative beyond it within the fitted relationship.

In contrast, the long-run coefficient of LFD is not statistically significant. The estimates therefore do not provide sufficient evidence of a systematic long-run relationship between the financial development measure used in the model and digitalization over the period examined.

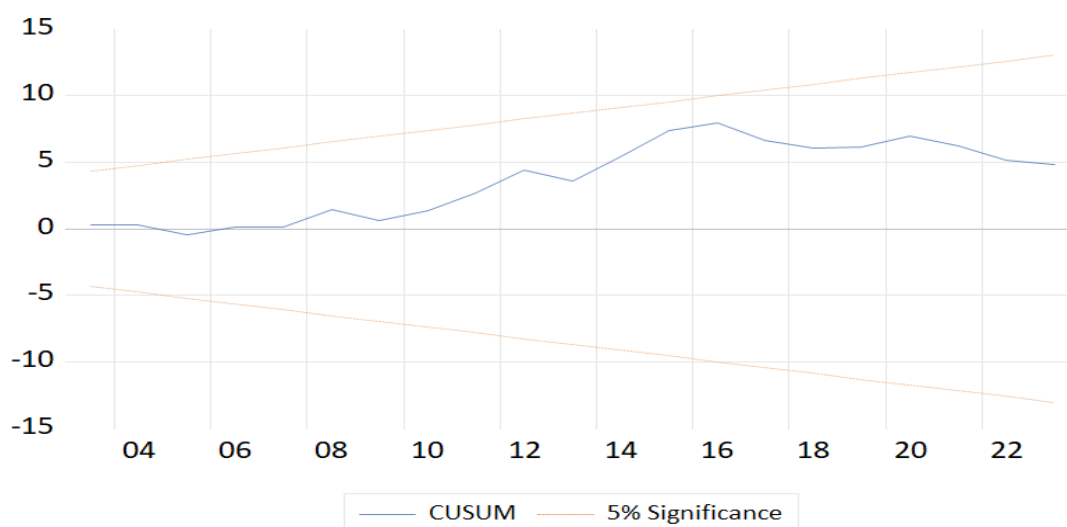
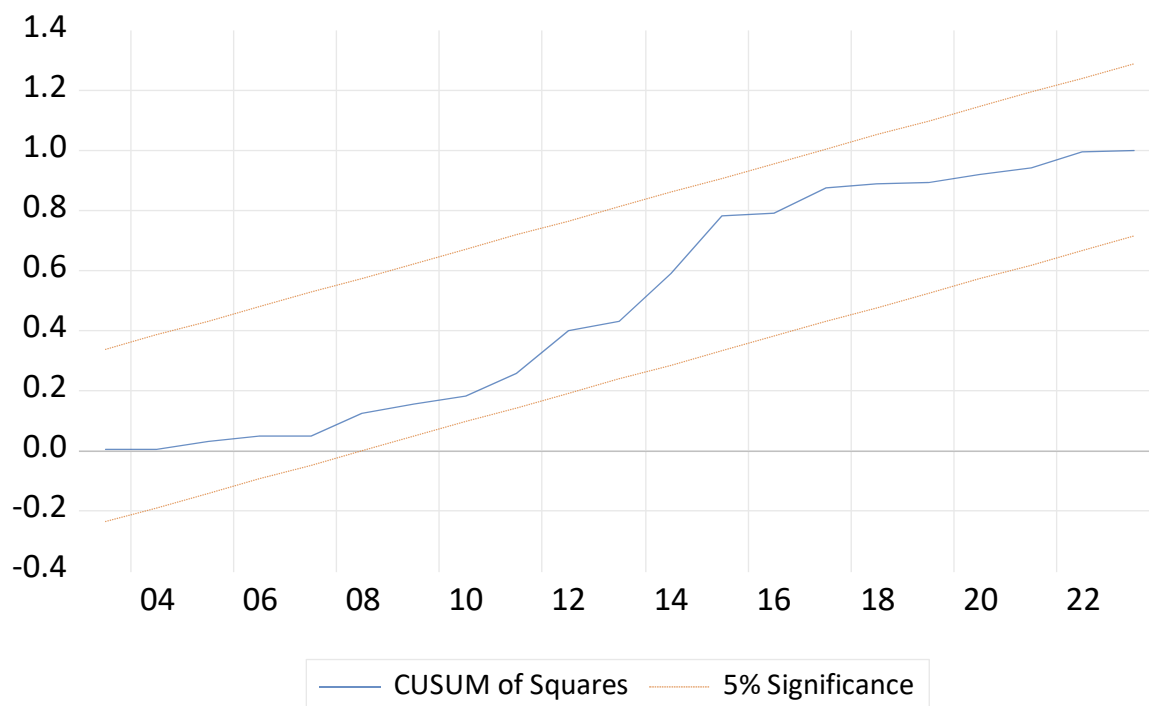
Table 6. Short-Run (ECM) Results

Variable	Coefficient	Standard Error	t-statistic	Probability
Cointeq*	-0.123998	0.017936	-6.913333	0.000000
$\Delta\text{LMAS}(-1)$	0.764231	0.047002	16.25952	0.000000
ΔLGDP	6.076538	9.640119	0.630338	0.533974
ΔLGDP^2	-0.249127	0.532991	-0.467413	0.644097
ΔLFD	-0.707220	0.163583	-4.323306	0.000200
$\Delta\text{LFD}(-1)$	-0.617152	0.182011	-3.390742	0.002236

Table 6 presents the short-run estimates obtained from the error-correction representation of the model. The error-correction coefficient is -0.124 and statistically significant. Its negative sign is consistent with convergence toward the estimated long-run relationship, while its magnitude implies that approximately 12.4% of a deviation from equilibrium is corrected within one year.

Among the short-run coefficients, $\Delta\text{LMAS}(-1)$ is positive and statistically significant, indicating persistence in changes in digitalization from one period to the next. Neither ΔLGDP nor ΔLGDP^2 is statistically significant, so the nonlinear income pattern identified in the long-run estimates is not observed in the short-run dynamics. Financial development shows a different short-run pattern: both ΔLFD and $\Delta\text{LFD}(-1)$ have negative and statistically significant coefficients. The short-run estimates therefore indicate a negative contemporaneous and lagged association between changes in financial development and changes in digitalization.

To assess the stability of the estimated parameters, the CUSUM and CUSUMSQ tests are employed. The results are presented in Figures 1 and 2, respectively.

Figure 1. CUSUM Test**Figure 2.** CUSUM of Squares (CUSUMSQ) Test

Figures 1 and 2 report the CUSUM and CUSUMSQ stability tests, respectively. In both cases, the plotted statistics stay inside the 5% critical boundaries over the sample period. Although some movement is visible in the CUSUMSQ path, it remains within the corresponding limits. The two tests therefore provide no evidence of parameter instability in the estimated model.

Discussion

The findings point to distinct roles for uncertainty, income, and financial development in

Türkiye's digitalization process. The negative long-run association between WUI and digitalization suggests that a more uncertain macroeconomic environment may be unfavorable to the expansion of digital activity. This result is consistent with the broader investment literature, in which uncertainty is associated with postponed or reduced investment when decisions involve irreversible costs (Baker et al., 2016; Bloom, 2009). In the context of digitalization, this mechanism is particularly relevant because technological transformation often requires commitments to infrastructure, equipment, and complementary organizational investments. The result obtained for Türkiye therefore extends the uncertainty argument to the development of digitalization over the period examined.

The income results provide a different perspective. Rather than indicating a uniform relationship between income and digitalization, the estimates support an inverted U-shaped pattern. This finding is consistent with the view that the diffusion and use of technology evolve as economies develop. Previous research has documented a close association between income and access to digital technologies (Chinn & Fairlie, 2010; Myovella et al., 2020), while Comin and Mestieri (2018) show that substantial differences in the intensity of technology use can persist even when technologies have become broadly available. In this respect, the turning point identified for Türkiye may reflect a transition from an earlier phase in which rising income facilitates wider access toward a stage in which additional income alone produces progressively smaller gains in the digitalization indicator.

This interpretation should also be considered in relation to the measure of digitalization employed in the study. Mobile cellular subscriptions primarily capture the diffusion of a relatively mature communication technology. As penetration increases, further income growth need not generate proportional increases in the number of subscriptions. The inverted U-shaped relationship found here should therefore not be interpreted as evidence that higher income generally reduces technological development. Rather, it indicates that the relationship between income and the particular digitalization measure used in this study changes across the observed income range. This distinction is important because more advanced dimensions of digital transformation may follow different patterns.

Financial development presents a less uniform relationship with digitalization. The absence of a statistically significant long-run coefficient indicates that domestic credit to the private sector, as measured in this study, is not systematically associated with digitalization over the longer horizon. This differs from evidence suggesting that financial development can accompany digital transformation in other settings (Horobeş et al., 2022). One reason for such differences may be that the availability of credit does not by itself determine whether financing supports technology-related expenditure. As emphasized more broadly in the financial development literature, the effects of financial deepening depend on how effectively financial systems perform their economic functions (Sahay et al., 2015).

The negative short-run coefficients of financial development require particular caution. One possible interpretation is that increases in available financing do not immediately translate into expenditure on digital technologies because financial resources may initially respond to other financing needs. This mechanism is not directly tested by the present model, however, since the financial development indicator measures the amount of private-sector credit relative to GDP rather than the sectoral allocation or purpose of that credit. The short-run result should therefore be interpreted as evidence of a negative statistical association rather than as direct evidence that credit is diverted away from digital investment. Further research using more detailed information on the composition and destination of financing would be required to examine this mechanism directly.

The difference between the short- and long-run findings also highlights the importance of the time horizon. Income displays a nonlinear relationship with digitalization over the long run but no statistically significant short-run effect, whereas financial development is significant in the short run but not over the longer horizon. These differences suggest that the macroeconomic conditions associated with digitalization do not operate at the same speed. Some relationships may emerge gradually as technological adoption and infrastructure adjust, while others may be more closely related to temporary changes in economic and financial conditions.

Conclusion and Recommendations

This study examines the macroeconomic factors associated with digitalization in Türkiye over the period 1990–2023, focusing on uncertainty, income dynamics, and financial development. Using the ARDL bounds-testing framework, the analysis identifies a long-run relationship among the variables and shows that their associations with digitalization differ across time horizons.

A central finding is the nonlinear role of income. The long-run estimates support an inverted U-shaped relationship, with the estimated turning point lying within the observed income range. This indicates that increases in income are associated with stronger digitalization up to a certain point, but the strength of this relationship diminishes as income rises. The finding is particularly relevant given that digitalization is represented by mobile cellular subscriptions, a technology for which further expansion may naturally become more limited as penetration increases. Accordingly, sustained digital transformation at more advanced stages cannot be expected to depend on income growth alone.

Uncertainty also emerges as an important long-run factor. Its negative association with digitalization suggests that a less predictable macroeconomic environment may weaken the conditions under which long-term technology-related decisions are made. From a policy perspective, this finding underlines the relevance of macroeconomic stability for digital transformation. Improving predictability in the economic environment may support investment decisions that require longer planning horizons, including those involving digital infrastructure and technological upgrading.

The results for financial development call for a more differentiated policy interpretation. The lack of a statistically significant long-run effect and the negative short-run coefficients indicate that greater private-sector credit is not automatically accompanied by stronger digitalization. Consequently, policies aimed solely at expanding the volume of finance may be insufficient to support digital transformation. Greater attention could instead be given to improving firms' access to financing instruments designed for technological upgrading, digital infrastructure, innovation, and related investment. Such measures would provide a more direct link between financial conditions and the financing needs associated with digital transformation.

Several limitations should be considered when interpreting the findings. First, mobile cellular subscriptions are used as the digitalization proxy because they provide a sufficiently long and consistent annual series for the period examined. Although this measure captures an important dimension of technological diffusion, it does not encompass the full scope of contemporary digital transformation. Second, domestic credit to the private sector measures the overall depth of credit provision but does not reveal how financing is distributed across sectors or investment purposes. Finally, the empirical specification focuses on a selected group of macroeconomic determinants and therefore does not incorporate every structural or institutional factor that may influence digitalization.

Future research could address these limitations by employing broader indicators of digital development as sufficiently long time series become available. Measures related to broadband access, internet use, digital services, cloud technologies, and artificial intelligence could provide additional insight into more advanced stages of digital transformation. Similarly, incorporating variables related to human capital, innovation capacity, institutional quality, and the composition of financial resources could help identify the channels through which macroeconomic conditions interact with technological adoption.

Taken together, the findings show that Türkiye's digitalization process is associated with more than the expansion of income alone. The nonlinear income pattern, the adverse long-run association with uncertainty, and the differing short- and long-run results for financial development indicate that digital transformation is embedded in a broader macroeconomic environment. Policies that combine economic stability with targeted support for technological investment and access to appropriate financing may therefore provide a stronger basis for sustaining digital transformation over time.

Declarations

Authors' contributions: The author was solely responsible for the conceptualization, data collection, analysis, and preparation of the manuscript.

Competing interests: The author declares no competing interests.

Funding: This research received no external funding.

Ethics approval and consent to participate: Not applicable. This study did not involve human participants or animals and therefore did not require ethics committee approval.

References

- Ahir, H., Bloom, N., & Furceri, D. (2018). *The world uncertainty index* [Unpublished manuscript].
- Ahir, H., Bloom, N., & Furceri, D. (2022). *The world uncertainty index* (NBER Working Paper No. 29763). National Bureau of Economic Research. <https://doi.org/10.3386/w29763>
- Akalın, G. (2024). Dijitalleşme Türkiye’de gelir eşitsizliğini nasıl etkilemektedir? [How does digitalization affect income inequality in Türkiye?]. *Dumlupınar Üniversitesi Sosyal Bilimler Dergisi*, (81), 60–71. <https://doi.org/10.51290/dpusbe.1429793>
- Baker, S. R., Bloom, N., & Davis, S. J. (2016). Measuring economic policy uncertainty. *The Quarterly Journal of Economics*, 131(4), 1593–1636. <https://doi.org/10.1093/qje/qjw024>
- Baker, S. R., Bloom, N., Davis, S. J., & Terry, S. J. (2020). *COVID-induced economic uncertainty* (NBER Working Paper No. 26983). National Bureau of Economic Research. <https://doi.org/10.3386/w26983>
- Bernanke, B. S. (1983). Irreversibility, uncertainty, and cyclical investment. *The Quarterly Journal of Economics*, 98(1), 85–106. <https://doi.org/10.2307/1885568>
- Bloom, N. (2009). The impact of uncertainty shocks. *Econometrica*, 77(3), 623–685. <https://doi.org/10.3982/ECTA6248>
- Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. W. W. Norton & Company.
- Chinn, M. D., & Fairlie, R. W. (2010). ICT use in the developing world: An analysis of differences in computer and internet penetration. *Review of International Economics*, 18(1), 153–167. <https://doi.org/10.1111/j.1467-9396.2009.00861.x>

- Macroeconomic Drivers of Digitalization in Türkiye: The Role of Uncertainty Nonlinear Income Effects and Financial Development
Comin, D., & Hobijn, B. (2004). Cross-country technology adoption: Making the theories face the facts. *Journal of Monetary Economics*, 51(1), 39–83. <https://doi.org/10.1016/j.jmoneco.2003.07.003>
- Comin, D., & Mestieri, M. (2018). If technology has arrived everywhere, why has income diverged? *American Economic Journal: Macroeconomics*, 10(3), 137–178. <https://doi.org/10.1257/mac.20150175>
- Dixit, A. K., & Pindyck, R. S. (1994). *Investment under uncertainty*. Princeton University Press.
- Goldfarb, A., & Tucker, C. (2019). Digital economics. *Journal of Economic Literature*, 57(1), 3–43. <https://doi.org/10.1257/jel.20171452>
- Horobeţ, A., Mnohoghitnei, I., Zlatea, E. M. L., & Belaşcu, L. (2022). The interplay between digitalization, education, and financial development: A European case study. *Journal of Risk and Financial Management*, 15(3), Article 135. <https://doi.org/10.3390/jrfm15030135>
- Jirasavetakul, L. B. F., & Spilimbergo, A. (2018). *Economic policy uncertainty in Turkey* (IMF Working Paper No. 18/272). International Monetary Fund. <https://doi.org/10.5089/9781484387740.001>
- Leahy, J. V., & Whited, T. M. (1996). The effect of uncertainty on investment: Some stylized facts. *Journal of Money, Credit and Banking*, 28(1), 64–83. <https://doi.org/10.2307/2077967>
- Myovella, G., Karacuka, M., & Haucap, J. (2020). Digitalization and economic growth: A comparative analysis of Sub-Saharan Africa and OECD economies. *Telecommunications Policy*, 44(2), Article 101856. <https://doi.org/10.1016/j.telpol.2019.101856>
- Pesaran, M. H., & Shin, Y. (1999). An autoregressive distributed-lag modelling approach to cointegration analysis. In S. Strøm (Ed.), *Econometrics and economic theory in the 20th century: The Ragnar Frisch centennial symposium* (pp. 371–413). Cambridge University Press. <https://doi.org/10.1017/CCOL521633230.011>
- Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289–326. <https://doi.org/10.1002/jae.616>
- Sahay, R., Čihák, M., N'Diaye, P., Barajas, A., Bi, R., Ayala, D., Gao, Y., Kyobe, A., Nguyen, L., Saborowski, C., Sviryzdenka, K., & Yousefi, S. R. (2015). *Rethinking financial deepening: Stability and growth in emerging markets* (IMF Staff Discussion Note No. 15/08). International Monetary Fund. <https://doi.org/10.5089/9781498312615.006>
- Songur, M. (2020). Türkiye’de tüketim ile belirsizlik arasındaki asimetrik ilişki: Doğrusal olmayan ARDL yaklaşımı [The asymmetric relationship between consumption and uncertainty in Türkiye: A nonlinear ARDL approach]. *Maliye Dergisi*, (179), 71–84.
- World Bank. (n.d.-a). *Domestic credit to private sector by banks (% of GDP)* [Data set]. World Development Indicators. Retrieved August 10, 2026, from <https://data.worldbank.org/indicator/FD.AST.PRVT.GD.ZS>
- World Bank. (n.d.-b). *GDP per capita (constant 2015 US\$)* [Data set]. World Development Indicators. Retrieved August 10, 2026, from <https://data.worldbank.org/indicator/NY.GDP.PCAP.KD>
- World Bank. (n.d.-c). *Mobile cellular subscriptions* [Data set]. World Development Indicators. Retrieved August 10, 2026, from <https://data.worldbank.org/indicator/IT.CEL.SETS>