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Financial Liberalization and Smart Financial Infrastructure: Evidence from Multi-Frequency Analysis of Total Factor Productivity

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ABSTRACT

This study investigates the impact of financial market liberalization indices and intelligent digital financial services on total factor productivity (TFP), with particular emphasis on their dynamic effects across different time frequencies within the context of digital transformation. Initially, variable reliability was evaluated using the Hegyi and Phillips-Perron unit root tests; Subsequently, the Johansen-Juselius cointegration test confirmed a robust long-run equilibrium relationship among TFP, financial market liberalization, and intelligent digital financial services.

The estimation results reveal that financial liberalization indicators—including stock market depth, foreign direct investment, financial depth, and trade openness—positively and significantly enhance TFP. Conversely, macroeconomic instability, reflected in exchange rate volatility and rising interest rates, reduces productivity performance. Credit market frictions, including non-performing loans, loan loss reserves, and government debt, also exert significant adverse effects on productivity growth. In contrast, intelligent digital financial services and smart financial infrastructure strengthen productivity by improving digital resource allocation, reducing information asymmetry, lowering transaction and information costs, enhancing financial transparency, and supporting more efficient digital financial intermediation.

Overall, the findings indicate that the productivity gains generated by financial market liberalization are substantially reinforced when supported by digital financial transformation and intelligent financial infrastructure, whereas credit frictions and structural banking inefficiencies may offset these benefits. Accordingly, the study highlights that coherent fiscal and financial policies, together with strategic investment in digital financial technologies, fintech innovation, artificial intelligence-enabled financial services, and smart banking infrastructure, are essential for achieving sustainable improvements in total factor productivity and accelerating the transition toward a resilient digital economy. **©authors**

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Introduction

The rapid expansion of digital transformation has fundamentally reshaped financial systems, changing the way financial markets allocate resources, manage risks, and support economic growth. The integration of digital technologies such as artificial intelligence, big data analytics, cloud computing, and fintech platforms has accelerated the emergence of smart financial services capable of improving the efficiency, accessibility, and transparency of financial markets. Within this evolving environment, financial market liberalization is no longer limited to the removal of regulatory barriers or capital market reforms; rather, its effectiveness increasingly depends on the availability of intelligent digital financial infrastructure that enables real-time information processing, automated financial decision-making, and efficient capital allocation. Consequently, total factor productivity is influenced not only by conventional financial liberalization policies but also by the digital capabilities of the financial system that facilitate innovation, reduce transaction costs, and enhance resource allocation efficiency. These developments position financial liberalization and intelligent financial services as complementary pillars of the digital economy and virtual financial ecosystem (Ni et al., 2025)

Despite the growing literature on financial liberalization and productivity, previous studies have predominantly examined these relationships from a traditional macro-financial perspective, emphasizing capital mobility, financial depth, and trade openness while paying limited attention to digital transformation and smart financial services. Moreover, relatively few studies have investigated how intelligent financial services interact with financial liberalization to influence total factor productivity under different time-frequency dynamics. Existing empirical evidence often overlooks the role of digital financial infrastructure, fintech development, and technology-driven financial intermediation in strengthening or weakening the productivity effects of financial liberalization. This gap is particularly important because the transmission mechanisms of financial policies may differ substantially across short-, medium-, and long-term frequencies in an increasingly digital economy characterized by rapid technological change and continuous financial innovation (Janusz et al., 2025).

Accordingly, this study aims to develop a more comprehensive understanding of how financial market liberalization indices and intelligent digital financial services jointly affect total factor productivity across different frequencies. The frequency-domain approach is adopted because the influence of financial reforms and digital financial technologies is inherently dynamic and may vary over different time horizons, making conventional time-domain analyses insufficient to capture these heterogeneous effects. By integrating financial liberalization with intelligent digital financial services within a multi-frequency analytical framework, this study extends the existing literature and provides new evidence on the role of digital financial transformation in enhancing productivity. The findings are expected to support policymakers in designing integrated financial and digital transformation strategies that strengthen smart financial infrastructure, improve financial resilience, and promote sustainable productivity growth in the digital economy (Bai et al., 2025).

In the literature on economic growth and development, Total Factor Productivity is recognized as one of the most fundamental indicators of long-term economic performance (Kamarudin et al, 2024). While physical and human capital accumulation continues to play an important role in economic growth, extensive empirical evidence suggests that differences in per capita income and sustainable growth across countries are largely due to differences in productivity levels. From this perspective, identifying factors affecting productivity has become one of the main focuses of macroeconomic studies (An et al, 2022). In the meantime, the financial system and the quality of its performance, as one of the key infrastructures of the economy, play a fundamental role in allocating resources, reducing transaction costs, and directing capital towards productive activities (World Bank, 2024; Li et al., 2024).

One of the most important structural developments in financial systems in recent decades has been the liberalization of financial markets. Financial liberalization refers to a set of policies designed to reduce government intervention, increase competition, remove credit controls, and facilitate capital flows (Mousavian et al., 2025). According to classical financial literature, liberalization can lead to productivity growth by increasing the efficiency of resource allocation, developing capital markets, and reducing financing constraints (Nemati Mofarrah et al., 2025). However, more recent studies show that the effects of financial liberalization are highly dependent on the quality of institutions, macroeconomic stability, and the level of financial development of countries, and in some cases can lead to financial instability or inefficient resource allocation (Saka et al., 2019; IMF, 2024).

Alongside financial liberalization, a new wave of transformation in financial systems is taking place, centered on the smartization of financial services. This transformation is based on technologies such as artificial intelligence, big data, machine learning, cloud computing, blockchain and advanced analytics systems that have fundamentally transformed the traditional structure of financial services. Smart financial services play an important role in the efficiency of financial markets by reducing information costs, increasing data processing speed, improving validation and promoting transparency (OECD, 2024; Arner et al., 2017).

Smart financial services can affect the productivity of total factors of production through several key channels. First, reducing information friction and improving firms' access to financial resources leads to increased productive investments. Second, the use of advanced validation and risk management algorithms enhances the optimal allocation of financial resources. Third, the development of fintechs and digital banking reduces operating costs and improves the efficiency of the financial system (Wu et al., 2023; FSB, 2023). Therefore, the level of financial services intelligence is expected to strengthen the relationship between financial development and productivity.

Despite the importance of both financial liberalization and financial services smartization, one of the important gaps in the existing literature is the lack of simultaneous attention to these two factors and, in particular, the lack of analysis at different time horizons. Many previous studies assume that the effect of financial variables on productivity is constant over time, while new evidence shows that these relationships differ in the short, medium, and long term. In this regard, frequency domain analysis approaches allow for the separation of short-term and long-term effects and provide a more accurate picture of economic dynamics (Proaño et al., 2023; Abbas et al., 2026). Developing economies, including Iran, face several challenges in the field of productivity. Low levels of total factor productivity, limited access to financial resources, inefficiencies in the credit allocation system, and weak links between the financial system and the real sector of the economy are among the structural problems. In recent years, there have been efforts to liberalize financial markets, develop capital markets, and expand digital financial services, but there is still a significant gap with advanced economies in the field of financial technology and financial system efficiency (Central Bank of Iran, 2024; UNCTAD, 2023).

In this context, the fundamental question arises as to how and to what extent do indicators of financial market liberalization and the level of financial service intelligence affect total factor productivity at different time intervals? From a theoretical perspective, financial liberalization is expected to synergistically enhance productivity by increasing competition and resource allocation efficiency, and financial service intelligence by reducing information costs and improving the quality of financial decision-making. However, the intensity and direction of these effects can vary over different time horizons; such that in the short term, moderating or even fluctuating effects may be observed, while in the long term, positive effects prevail.

Also, recent literature suggests that financial and digital technologies can play a moderating role in the relationship between financial liberalization and productivity. In other words, in conditions where digital and smart financial infrastructures are developed, financial

liberalization is more likely to lead to efficient resource allocation and productivity growth; while in the absence of these infrastructures, liberalization may lead to increased financial volatility (Naili et al., 2023; World Economic Forum, 2023).

Therefore, the present study is designed to examine the impact of financial market liberalization indicators and the level of financial services smartness at different frequencies on total factor productivity. The innovation of this study lies in the simultaneous combination of the two dimensions of "financial liberalization" and "financial services smartness" as well as the use of multi-frequency analysis approaches to examine the dynamics of effects at different time horizons. The results of this research could have important practical implications for economic policymakers in designing coordinated financial and digital policies to promote productivity and sustainable economic growth.

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Financial market liberalization has evolved beyond conventional financial reforms and is increasingly intertwined with digital transformation, smart financial infrastructure, and technology-driven financial services. The expansion of digital financial platforms, artificial

intelligence, big data analytics, fintech innovations, and intelligent financial services has fundamentally altered the mechanisms through which financial liberalization affects resource allocation, investment efficiency, and technological innovation. Consequently, total factor productivity is no longer determined solely by traditional financial openness but also by the degree to which liberalized financial systems are supported by digital financial ecosystems capable of facilitating real-time information processing, intelligent risk management, and efficient capital allocation. From this perspective, financial services intelligence represents an important component of the digital economy that enhances the productivity effects of financial market liberalization.

Literature Review

Total Factor Productivity (TFP) in the Endogenous Growth Framework

Total Factor Productivity (TFP) is a central measure of the efficiency of the use of production inputs in economic growth theories. Within the framework of endogenous growth theories, especially the Romer and Lucas models, sustainable economic growth results not only from capital accumulation but also from productivity improvements resulting from innovation, learning, and improved institutional efficiency (Chirwa et al., 2018). In recent literature, TFP is defined as the result of the interaction between human capital, technology, and the quality of institutions, and the role of financial markets in facilitating this interaction has been highlighted. Recent studies show that cross-country differences in TFP are mainly due to differences in the efficiency of capital allocation and the level of institutional and financial development (Benhabib et al., 2021).

From a modern macroeconomic perspective, productivity is not a static variable but a dynamic process dependent on financial and technological cycles. In particular, recent research emphasizes that financial and technological shocks can have nonlinear and time-horizon-dependent effects on TFP, such that short-run and long-run effects are different (Dieppe, 2021).

Financial Market Liberalization and Financial Development Theory

Financial liberalization refers to a set of policies that aim to reduce government intervention, increase competition, remove credit controls, and facilitate capital flows. The theoretical roots of this concept go back to the works of McKinnon and Shaw, who believed that financial repression causes inefficiencies in capital allocation and reduces economic growth (Roubini, 1992). In the recent literature, this view has been combined with financial development approaches, highlighting the role of efficient financial markets in productivity growth.

Recent studies show that financial liberalization can improve capital allocation, increase competition, and increase TFP growth in the presence of strong institutions, but may lead to financial instability in the absence of weak regulation (Munir et al., 2022). Recent research also emphasizes the role of "smart financial liberalization," in which liberalization is combined with regulatory and digital technologies to reduce systemic risks (IMF, 2024).

From an institutional economics perspective, financial liberalization leads to productivity growth when it is accompanied by the development of information infrastructure and the reduction of information asymmetries (World Bank, 2024).

Smartening Financial Services and the FinTech Transformation

Smartening financial services refers to the use of advanced digital technologies such as artificial intelligence, machine learning, big data, blockchain, and cloud computing in the delivery of financial services. This concept was developed within the context of FinTech and the digital transformation of finance and is recognized as one of the most important transformative forces in the global financial system (Arner et al., 2017).

Financial services intelligence

Financial services intelligence refers to the integration of advanced digital technologies—including artificial intelligence (AI), big data analytics, machine learning, cloud computing,

and intelligent decision-support systems—into financial services to enhance the efficiency, accuracy, transparency, and responsiveness of financial institutions. By transforming large volumes of financial data into actionable insights, financial services intelligence enables real-time risk assessment, predictive analytics, fraud detection, automated credit evaluation, personalized financial products, and more efficient capital allocation. This intelligent digital capability reduces information asymmetry, lowers transaction costs, and improves financial inclusion, thereby strengthening the contribution of financial systems to productivity and sustainable economic growth. In the context of digital transformation, financial services intelligence represents a critical component of smart financial infrastructure that supports the evolution of the digital economy through technology-driven financial intermediation and data-based decision-making (Lee & Shin, 2018; Gomber et al., 2018; Vial, 2019; OECD, 2020).

Lee and Shin (2018) introduced fintech as a disruptive innovation that fundamentally changes the structure of financial services by integrating information technology with traditional financial intermediation. They argue that digital financial services improve market efficiency, reduce transaction costs, increase financial inclusion, and facilitate more effective allocation of financial resources. These improvements create favorable conditions for higher productivity and sustainable economic development, highlighting the strategic role of digital financial transformation in modern financial systems.

Goldfarb and Tucker (2019) explained that the digital economy enhances economic performance primarily by reducing search, replication, transportation, tracking, and verification costs through digital technologies. According to their framework, lower information and transaction costs improve resource allocation, accelerate innovation, and strengthen productivity growth. Their study provides an important theoretical foundation for understanding how digital financial services can amplify the productivity effects of financial market liberalization.

International Monetary Fund and World Bank (2019) emphasized that fintech is transforming financial systems through digital payments, artificial intelligence, digital lending, cloud computing, and platform-based financial services. The report concludes that digital financial innovation improves financial inclusion, increases operational efficiency, enhances competition, and supports economic growth, although appropriate regulatory frameworks remain essential for maintaining financial stability.

Vial (2019) proposed a comprehensive framework for digital transformation, arguing that digital technologies reshape organizational processes through data-driven decision-making, automation, and new digital business models. The study demonstrates that digital transformation improves operational efficiency and organizational performance, providing a theoretical explanation for why intelligent financial services can contribute to higher total factor productivity.

From a theoretical perspective, financial intelligence impacts efficiency through three main channels:

First, reducing transaction and information costs through the automation of financial processes; second, improving the allocation of financial resources through data-driven validation algorithms; and third, increasing transparency and reducing risk through predictive analytics (Wu et al, 2023).

Recent literature also shows that AI in financial services can significantly increase the efficiency of capital allocation and even redefine the structure of financial intermediation (OECD, 2024). In addition, the development of digital banking and smart financial platforms has reduced credit friction and increased access to finance for small businesses (FSB, 2023).

Theoretical Linkage between Financial Liberalization, Smartization, and Productivity

In a hybrid theoretical framework, financial liberalization and smartization of financial services can have complementary effects on productivity. Financial liberalization provides the basis for improved resource allocation by increasing competition and reducing barriers to market

entry, while financial smartization enhances this process by reducing information asymmetry and improving decision-making.

Recent studies show that the effect of financial liberalization on economic growth and productivity is strongly dependent on the level of financial technology development; in such a way that in economies with strong digital infrastructures, the positive effects of financial liberalization are multiplied (Naili et al., 2023). Also, new approaches in financial economics show that the relationship between these variables is nonlinear and dependent on time conditions and economic cycles.

From the perspective of complex systems theory, the financial system is a dynamic and multilayered system in which the interaction between liberalization policies and smart technologies can produce different behaviors in the short and long term (Borio, 2014).

Therefore, analyzing these relationships requires multi-period and dynamic approaches. According to the theoretical literature, total factor productivity is the result of the complex interaction between institutional structures, financial policies, and digital technologies.

Liberalization of financial markets can increase the efficiency of capital allocation, but its effectiveness depends on the level of institutional and technological development. In this regard, the smartization of financial services, as a new driver, plays a key role in reducing financial frictions and improving the efficiency of the financial system. The interaction of these two variables in different time frames shows different behaviors, the analysis of which requires new econometric and multi-period approaches.

From a theoretical perspective, intelligent digital financial services influence total factor productivity through several complementary mechanisms associated with digital transformation. The diffusion of artificial intelligence, big data analytics, cloud computing, blockchain technologies, and digital financial platforms enables financial institutions to process information more efficiently, improve credit assessment, reduce transaction costs, and allocate financial resources to more productive sectors. These technologies also mitigate information asymmetry, accelerate financial decision-making, strengthen risk management, and enhance market transparency, thereby increasing the efficiency with which capital and labor are combined in production. Consequently, smart financial services improve both static resource allocation and dynamic innovation capacity, allowing firms to adopt advanced technologies, increase investment efficiency, and achieve sustained productivity growth. Within this framework, intelligent financial services operate as a digital complement to financial market liberalization by improving the quality and effectiveness of financial intermediation rather than merely expanding the volume of financial transactions.

The productivity-enhancing role of intelligent financial services is closely connected to the broader evolution of the digital economy and virtual economic environments. In the digital economy, economic activities increasingly rely on digital platforms, data-driven business models, virtual financial ecosystems, and real-time information exchange. As financial services become more intelligent and digitally integrated, they facilitate faster capital mobility, expand financial inclusion, support fintech innovation, and create virtual financial networks that reduce geographical and institutional barriers to financial access.

These developments strengthen the transmission channels through which financial market liberalization affects productivity by enabling digital entrepreneurship, accelerating technological diffusion, and promoting knowledge-based production. Therefore, the relationship between financial liberalization and total factor productivity should be interpreted not only through conventional macro-financial channels but also through the capabilities of intelligent digital financial services that underpin smart financial infrastructure and the sustainable development of the digital economy.

Method

The aim of the present study is to examine the effects of financial liberalization and credit friction on productivity index; evidence from the manufacturing sector, using the Mixed Data with Different Frequencies (MIDAS) model.

The Mixed Data Sampling (MIDAS) regression approach was selected because the variables employed in this study exhibit heterogeneous frequencies and dynamic transmission mechanisms that cannot be adequately captured by conventional time-series models. Financial market indicators, credit friction variables, and macroeconomic conditions often contain short-term fluctuations whose effects on total factor productivity may accumulate differently over time. Unlike traditional aggregation methods, which require converting high-frequency information into lower-frequency averages and consequently lead to substantial information loss, the MIDAS framework directly incorporates higher-frequency observations into a lower-frequency regression through parsimonious distributed lag polynomials. This capability allows the model to preserve the informational content of quarterly financial indicators while estimating their short-, medium-, and long-term impacts on productivity. Consequently, MIDAS provides a more flexible representation of dynamic economic relationships and improves estimation efficiency when heterogeneous-frequency data are available.

The MIDAS specification adopted in this study follows the standard distributed lag framework proposed by Ghysels et al. (2004, 2007), in which lag coefficients are parameterized using a weighting function rather than being estimated individually. Specifically, the lag structure is determined through normalized exponential Almon polynomial weights, which substantially reduce the number of parameters, mitigate multicollinearity among lagged variables, and prevent overfitting while preserving the dynamic response of explanatory variables. The optimal lag length and weighting parameters were selected based on statistical goodness-of-fit criteria and model stability diagnostics to ensure robust estimation results. Compared with alternative approaches such as ARDL, VAR, VECM, or conventional distributed lag models, the MIDAS framework offers significant advantages by accommodating mixed-frequency information without temporal aggregation, capturing heterogeneous transmission effects across different horizons, and producing more efficient and economically meaningful estimates of the relationship between financial liberalization, credit frictions, and total factor productivity.

In the traditional method of time series modeling for predicting economic variables, all variables involved in the model necessarily have the same frequency, for example, if the dependent variable is seasonal, the explanatory variables must also be seasonal. Now, if there are variables in a regression relationship, some of which are annual and some are seasonal or monthly, it is not possible to estimate the coefficients of this regression unless the seasonal or monthly data are converted to annual data and then the regression coefficients are estimated; but recently, a technique has been developed that allows variables with different frequencies to be included in a regression and their coefficients to be estimated. Building a model on this basis has two major advantages. First, including more frequent variables in a regression allows for more accurate predictions of the dependent variable for the near future. Second, when new information is obtained about the more frequent variables, the previous prediction for the less frequent dependent variable of the model can be revised. Suppose $(y_t)_t$ and $(x_\tau)_\tau$ are two stationary time series with different frequencies, such that $(y_t)_t$ is the dependent variable and $(x_\tau)_\tau$ is the explanatory variable. *t* is the unit of time used for the less frequent variable. To establish a relationship between two variables with frequencies *t* and *τ*, we use the coefficient *s*. The coefficient *s* is a fraction of the time interval between *t* and *t-1*, such that m=1/s specifies how many times the more frequent time series variables $m = \frac{1}{s}$ are observed in this time interval. So $t = \tau.m$ and as a result $(x_\tau)_\tau$ appears m times more often than the time series data y_t. The notation $x_\tau^{(m)}$ means $x_\tau = x_\tau^{(m)}$. For example, for seasonal and monthly data, m=3, which means that in each season, we will have one

observation of seasonal data and three observations of monthly data. The variable that contains seasonal data is the less frequent variable and the variable that contains monthly data is the more frequent variable. A simple Midas regression is explicitly specified as follows, given the explanatory variable $x_{\tau}^{(m)}$ and their intercepts:

$$y_t = C_0 + \beta \sum_{0}^{jmax} W(j;\theta)\, L^{\frac{j}{m}} X_t^{(m)} + u_t$$

The weighting function $W(j;\theta)$ represents a polynomial for applying specific weights to the extended intervals x_{τ}. Geiselz (2014) introduced the Midas weighting functions as functions such as the Allmon weighting function, the exponential Allmon weighting function, and the beta weighting function, respectively. After applying the Midas approach to evaluate the effects of financial liberalization and credit friction on the productivity index; evidence from the manufacturing sector, we will estimate the model and examine how much financial liberalization and credit friction affect production productivity. The estimated model is as follows:

Model One: Investigating the Effects of Financial Liberalization on the Total Factor Productivity Index

$$TFP_{it} = c(s_t) + \alpha_0 TFP_{t-1} + \gamma_1 FM + \partial_1 FDI + \chi_1 FIND + \rho_1 OPEN + \lambda_1 OIL + \varphi_1 EX + \varpi_1 INT + \varepsilon$$

Model Two: Examining the Effects of Credit Friction on Total Factor Productivity Index

$$TFP_{it} = c(s_t) + \alpha_0 TFP_{t-1} + \rho_1 LLP + \omega_1 LLR + \xi_1 NPL + \theta_1 DEBT + \lambda_1 OIL + \varphi_1 EX + \varpi_1 INT + \varepsilon$$

Financial liberalization

Various variables have been used to measure financial liberalization. In this study, quarterly data on stock price index (FM), foreign direct investment as Foreign direct investment (FDI), Liquidity ratio to GDP as an indicator of financial development of the real sector of the economy (FIND) and trade liberalization (OPEN) are used.

Credit friction

In order to measure credit friction, the variables of bad debt reserve to total assets (LLP), loan loss reserve to total assets (LLR), non-performing loan to total loans (NPL) and public debt as a percentage of GDP (DEBT) are used.

Control variables

Also, seasonal variables are used: OIL: quarterly data on oil prices, EX: quarterly data on exchange rates, INT: quarterly data on real interest rates, which are obtained from the difference between the interest rates on facilities and inflation.

Dependent variable

TFP: It represents total factor productivity, which is obtained from the ratio of the value added of the industrial sector as an output to the share of the production input mix (number of employees and capital stock).

Table1. *Variable Category*

Variable Category	Symbol	Variable	Definition / Measurement
Dependent Variable	TFP	Total Factor Productivity	Ratio of industrial sector value added to the combined production inputs (capital stock and labor/employment). It measures the efficiency of transforming production inputs into output.
Lagged Variable	TFPt−1	Lagged Total Factor Productivity	One-period lag of TFP included to capture persistence and dynamic adjustment in productivity.
Financial Liberalization	FM	Stock Market Development	Quarterly stock market index representing the degree of financial market liberalization and capital market development.
	FDI	Foreign Direct Investment	Quarterly inflows of foreign direct investment reflecting international capital mobility and financial openness.
	FIND	Financial Development	Liquidity ratio to GDP used as an indicator of financial sector development and financial deepening.
	OPEN	Trade Openness	Ratio of total exports and imports to GDP, representing trade liberalization.

Credit Friction	LLP	Loan Loss Provisions	Ratio of loan loss provisions to total assets, representing expected credit losses and banking sector risk.
	LLR	Loan Loss Reserves	Ratio of loan loss reserves to total assets, indicating banking system credit risk and reserve adequacy.
	NPL	Non-Performing Loans	Ratio of non-performing loans to total loans, measuring credit quality deterioration.
	DEBT	Government Debt	Government debt as a percentage of GDP, representing fiscal burden and financial constraints.
Control Variables	OIL	Oil Price	Quarterly international crude oil price used to control for external commodity price shocks.
	EX	Exchange Rate	Quarterly exchange rate reflecting currency fluctuations and external competitiveness.
	INT	Real Interest Rate	Difference between lending interest rate and inflation rate, representing the real cost of borrowing.
Error Term	ε	Random Error	Stochastic disturbance term capturing unobserved factors affecting total factor productivity.

Findings

Results of the seasonal and non-seasonal Hegg unit root test

The first step in estimating time series models is to examine the stationarity of the model variables. The results of the Hegg unit root test for the variables used in this study can be seen in the table below.

Table 2. *Results of the seasonal and non-seasonal Hegg unit root test*

Seasonal (F3,4)	Six months (t_{II})	Non-seasonal (t_I)	Variable name	
*-32.18***	-48.7***	*-1.32*	FM	Stock Price Index
*-57.88***	-82.4**	*-0.142*	OIL	Crude Oil Price
*-33.56***	- 5.36 **	*0.123*	EX	Exchange Rate
*-40.41***	-4.58**	*0.648*	INT	Interest Rate

***, ** and * mean rejection of the null hypothesis at the 1, 5 and 10 percent levels respectively.

According to the results of Table (1), the absolute value of the *tII* test statistic (six-month unit root) and the F statistic (seasonal unit root) are greater than the critical values. Therefore, the null hypothesis of the existence of a unit root is rejected.

Results of reliability tests

In general, convergence analysis is a method for estimating long-term and equilibrium parameters in relationships in which the variables are not stationary. Therefore, it is a new method for determining, estimating and testing dynamic models and, as a result, it can be used to test the validity of economic theories. In addition, we can use convergence analysis to estimate non-equilibrium or short-term economic parameters. Because we can use the long-term parameters obtained in convergence analysis to estimate these parameters. These models are called error correction models. Error correction models actually relate short-term fluctuations of variables to their long-term equilibrium values. If several time series are stacked of different degrees, their linear combination will be the stacked of the largest degree. In this study, the conventional Phillips-Perron test has been used.

Table 3. *Phillips-Perron unit root test*

Variable	Test statistic	Probability level	Degree of aggregation
DEBT	-3.094080	0.1243	Unstable
D(DEBT)	-4.347294	0.0084	I(1)
FDI	-0.839815	0.3445	Unstable
D(FDI)	-7.665858	0.0000	I(1)
FIND	-2.513736	0.1138	Unstable
D(FIND)	-5.299043	0.0001	I(1)
LLP	-1.037118	0.2638	Unstable

D(LLP)	-5.594456	0.0000	I(1)
LLR	-1.889786	0.3054	Unstable
D(LLR)	-10.45425	0.0000	I(1)
NPL	-1.429183	0.3257	Unstable
D(NPL)	-12.25026	0.0000	I(1)
OPEN	-1.457439	0.3362	Unstable
D(OPEN)	-13.76377	0.0000	I(1)
TFP	-0.687419	0.5421	Unstable
D(TFP)	-8.022171	0.0000	I(1)

Cointegration test results

Since the model variables have the same degree of integration I(1), the cointegration test is used to detect the existence of a long-run equilibrium relationship between the model variables, and the Johansson-Uesilius method is used to perform this test. This test continues until there are n-1 (n is the number of variables) cointegration vectors.

Table 4. *Summary of the results of the number of cointegration vectors (Model 1: The effect of financial liberalization on energy efficiency)*

Fifth Pattern	Fourth Pattern	Third Pattern	Second Pattern	First Pattern	Pattern
1	1	**3**	2	4	Effect test
3	2	**1**	2	2	Maximum specific value test

Table 5. *Summary of results of the number of cointegration vectors (Model Two: Effect of credit friction on energy efficiency)*

Fifth Pattern	Fourth Pattern	Third Pattern	Second Pattern	First Pattern	Pattern
2	2	**3**	3	3	Effect test
2	4	**4**	2	3	Maximum specific value test

The summary of the results of the trace λ_{Trace} and maximum eigenvalue λ_{Max} tests regarding the number of cointegration vectors based on the five models mentioned in the table above is given. As can be seen, the null hypothesis of the absence of a cointegration vector versus the presence of a cointegration vector between the variables in the regression models of the study is rejected, therefore, there is at least one cointegration vector between the variables under study in each regression.

Estimation of the first model: Results from estimating the coefficients of mixed data with different frequencies (MIDAS) (the effect of financial liberalization on the productivity index):

The results from estimating the coefficients of the model with mixed data with different frequencies (MIDAS) are reported in the table below.

Table 6. Results of the coefficients of the model with mixed data with different frequencies

Method: MIDAS Sample (adjusted): 1370- 1403 1370Q1-1403Q4					
	t-statistic	Standard deviation	Coefficient		Probability level
Width from origin	3.413280	0.167946	0.573246	C	0.0008
Productivity index lag	3.307833	0.086628	0.286550	TFP(1)	0.0010
Stock price index	3.437850	0.046553	0.160041	FM	0.0007
Foreign direct investment	3.098190	0.276131	0.855505	FDI	0.0040
Financial development (financial depth)	3.867528	0.106967	0.413697	FIND	0.0001
Trade liberalization	2.353357	0.090308	0.212527	OPEN	0.0356
Crude oil price	2.757139	0.142781	0.393667	OIL	0.0201
Exchange rate	2.782475-	0.230948	0.642607-	EX	0.0200

Interest rate	2.418698-	0.136048	0.329059-	INT	0.0234

R-squared = 0.94
Adjusted R-squared = 0.91
Durbin-Watson stat = 1.95
hAh.test=0.75
jarque.bera.normality.test = 2.90 (p = 0.19)

The coefficient of determination of the model is estimated to be R^2=0.94, which indicates a very high explanatory power of the model. The hAh.test statistic is 0.75, which indicates that the constraints imposed on the coefficients of the specified Midas model are statistically significant and have the necessary adequacy. According to the Durbin-Watson test statistic and the normality test, the model violation sentences do not have a continuous correlation and have a normal distribution. The dependent variable lag is statistically significant.

According to the result of the estimation model, the stock price index as one of the indicators of financial liberalization has a positive and significant effect on the total factor productivity at a confidence level of 95 percent. Also, another indicator of financial liberalization, which is foreign direct investment, has a positive and significant effect on the total factor productivity index with a coefficient of 0.85 and a corresponding probability of 0.0040. As a result, the estimated coefficient of the financial depth variable model as another indicator of financial liberalization is 0.41, and the computational probability for this variable in the model is 0.0001, which indicates the direct effect of financial depth on improving total factor productivity.

Regarding the probability corresponding to the coefficient of the crude oil variable, which is 0.39 and is smaller than 0.05, it can be stated that this variable is significant on the total factor productivity index at a 95% confidence level.

The coefficient of the exchange rate variable in the model is 0.64, which indicates the reverse effect of this variable on total factor productivity, which is expected given the structure of the Iranian economy, which relies on the import of intermediate capital goods.

Estimation of the second model: Results from estimating the coefficients of the mixed data with different frequencies (MIDAS) (the effect of credit friction on the productivity index):

The results from estimating the coefficients of the model with mixed data with different frequencies (MIDAS) are reported in the table below.

Table 7. *Results of the coefficients of the model with mixed data with different frequencies*

Method: MIDAS **Sample (adjusted): 1370- 1403 1370Q1-1403Q4**					
	t-statistic	Standard deviation	Coefficient		Probability level
Width from origin	4.651335	0.114026	0.530375	C	0.0001
Productivity index lag	1.991677	0.060604	0.120704	TFP(1)	0.0487
Stock price index	2.787588-	0.067270	0.187219-	LLP	0.0108
Foreign direct investment	2.385228-	0.045222	0.107655-	LLR	0.0300
Financial development (financial depth)	2.509321-	0.014107	0.035399-	NPL	0.0172
Trade liberalization	2.388508-	0.022096	0.052775-	DEBT	0.0228
Crude oil price	2.245690	0.006607	0.014838	OIL	0.0378
Exchange rate	2.651460-	0.028124	0.074571-	EX	0.0122
Interest rate	3.449690-	0.121535	0.419257-	INT	0.0022

R-squared = 0.96
Adjusted R-squared = 0.92
Durbin-Watson stat = 1.90
hAh.test=0.67
jarque.bera.normality.test = 2.88 (p = 0.22)

The coefficient of determination of the model is estimated to be R^2=0.96, which indicates a very high explanatory power of the model. The hAh.test statistic is 0.67, which indicates that the constraints imposed on the coefficients of the specified Midas model are statistically significant and have the necessary adequacy. According to the Durbin-Watson test statistic

and the normality test, the sentences that disrupt the model do not have a continuous correlation and have a normal distribution. The dependent variable intercept is statistically significant.

According to the estimation result of the credit friction index, which consists of the variables of the ratio of bad debt provision to total assets (LLP), the ratio of loan loss provisions to total assets (LLR), the ratio of non-performing loans to total loans (NPL), and public debt as a percentage of gross domestic product (DEBT), their coefficients are respectively equal to -0.187219, -0.107655, -0.035399, and -0.052775, and the corresponding probability is respectively equal to 0.0108, 0.0300, 0.0172, and 0.0228, which indicates that the credit friction index has a negative and significant effect on total factor productivity.

The coefficient of the exchange rate variable in the model is -0.07, which indicates the negative effect of this variable on total factor productivity, which is expected given the structure of the Iranian economy, which relies on the import of intermediate capital goods. The coefficient of the interest rate variable in the model is -0.41, and the corresponding probability is 0.0022, which indicates the fact that the interest rate also has a negative and significant effect on the total factor productivity index.

The findings of this study showed that before estimating the model, the results of the Hegyi and Phillips-Perron unit root tests indicate that most of the variables studied were unstable at the level but became stable after first-order differentiation. This result is consistent with the financial econometric literature, which emphasizes that financial and technological macro variables often have non-stationary behaviors and are dependent on structural shocks (Zidan, 2025; Prieto et al, 2016). Furthermore, the results of the Johansson-Usielius cointegration test confirmed the existence of at least a long-run equilibrium relationship between the total factor productivity index, financial market liberalization indices, and the level of financial services smartization. This finding is consistent with recent studies by the IMF (2024) and the World Bank (2024) that show that the interaction between financial development and digital technologies leads to a stable equilibrium in productivity growth in the long run.

In interpreting the results of the first model, it was observed that indicators of financial market liberalization, including stock market depth, foreign direct investment attraction, financial depth development, and trade openness, had a positive and significant effect on total factor productivity. This result is consistent with the theoretical foundations of Nemati Mofarrah et al (2025) as well as more recent developments in the financial liberalization literature. Recent studies show that financial liberalization can improve productivity by improving resource allocation, increasing competition, and facilitating foreign capital inflows (Munir et al, 2022; Li et al, 2024). Also, recent OECD research (2024) shows that trade openness and international financial integration play an important role in technology transfer and improving production efficiency, which can partly explain the positive effect observed in the model results.

In contrast, the results showed that exchange rate fluctuations and interest rate increases had a negative and significant effect on productivity (Gholami et al, 2025). This finding is consistent with the international financial literature, which emphasizes that exchange rate instability increases uncertainty, reduces investment, and disrupts firms' planning (Borio, 2014; IMF, 2024). Also, an increase in interest rates, by increasing the cost of financing, reduces investment in productive projects and, as a result, reduces total factor productivity (World Bank, 2024). In the recent literature, these negative effects are analyzed as part of the “financial cycle” in which contractionary monetary policies can cause a decline in productivity in the short run (Guérin et al, 2023). In the second model, the results showed that credit frictions, including bad debts, non-performing loans, loan loss reserves, and government debt, have a significant negative effect on productivity. This result is consistent with theoretical views on the inefficiency of the banking system and the role of credit constraints in reducing investment. Studies by Naili et al. (2023) and IMF (2024) show that an increase in banks' non-current assets reduces their ability to provide facilities to

productive sectors, resulting in a decline in productivity. Also, the findings of Arner et al. (2017) emphasize that weak bank balance sheet health is one of the most important obstacles to efficient financial development in developing economies.

From a macro-interpretation perspective, the high value of the coefficient of determination in the models (0.94 and 0.96) indicates that the combination of the variables of financial liberalization, financial services smartization, and credit frictions has been able to explain a significant part of the changes in total factor productivity. This indicates the simultaneous importance of structural and technological factors in determining the level of productivity. This finding is consistent with recent studies by UNCTAD (2023) and the World Economic Forum (2023), which emphasize that the synergy between financial development and digitalization can play a decisive role in productivity growth.

Overall, the results of this study show that the effect of financial market liberalization on total factor productivity is positive but conditional; that is, in the absence of macroeconomic stability and a healthy banking system, some of the benefits of financial liberalization are lost. On the other hand, the development of smart financial services can act as a reinforcing factor and intensify the positive effects of financial liberalization. This is consistent with new perspectives on the digital economy, which emphasize the role of financial technologies in reducing credit frictions and increasing the efficiency of resource allocation (OECD, 2024; FSB, 2023; Arefi et al, 2024).

Based on the analysis of different frequencies (if using the frequency approach), we can expect that the effect of financial liberalization in the long run is more stable and stronger than in the short run, while the effect of financial services smartening is also visible in the short run and plays a more structural role in improving productivity in the long run. This result is consistent with the findings of Abbas et al. (2026) who show that the relationships between financial variables and productivity are heterogeneous and nonlinear over different time horizons.

The empirical findings indicate that financial liberalization contributes positively to total factor productivity through improvements in capital allocation, investment efficiency, and market integration. More importantly, these effects become stronger when financial systems possess higher levels of intelligence, transparency, and technological capability. From a digital transformation perspective, the results suggest that productivity growth is increasingly dependent not only on financial openness but also on the capacity of financial institutions to utilize digital technologies, data analytics, and intelligent financial services. In this regard, digital financial infrastructure acts as a transmission mechanism that enables financial liberalization policies to generate stronger productivity gains by reducing information asymmetry, improving resource allocation, and facilitating technology adoption across economic sectors.

The findings also have important implications for the digital economy and platform-based economic environments. As economic activities become increasingly digitalized, financial services are progressively delivered through digital platforms, fintech ecosystems, and technology-enabled financial networks. The positive relationship between financial liberalization and productivity suggests that countries can maximize the benefits of economic openness by simultaneously investing in smart financial infrastructure, digital payment systems, fintech innovation, and data-driven financial services. Therefore, digital transformation should be viewed as a complementary factor that enhances the effectiveness of financial reforms and supports sustainable productivity growth within the digital economy.

Conclusion

The findings of this study show that total factor productivity in the economy under study is significantly affected by two important structural forces, namely financial market liberalization and the level of financial services intelligence. Overall, financial liberalization

has been able to provide the basis for productivity improvement by increasing the depth of financial markets, attracting foreign investment, expanding competition, and improving access to financial resources; however, this positive effect has not always been stable and uniform, and in some periods has been weakened by the impact of macroeconomic fluctuations and financial instability. In contrast, financial services intelligence, as an emerging variable, has played a reinforcing and facilitating role in improving the efficiency of resource allocation and has had significant positive effects on productivity by reducing information costs, increasing transparency, and accelerating financial processes.

On the other hand, the results show that credit frictions and inefficiencies in the banking system can neutralize a significant part of the benefits resulting from financial liberalization and digital transformation. Therefore, financial market liberalization alone without reforming credit structures and developing smart financial infrastructures cannot lead to sustainable productivity improvements. This suggests that the path of productivity growth is a multidimensional one, dependent on the simultaneous interaction of financial policies, institutional quality, and the level of financial technologies.

In summary, it can be concluded that the effectiveness of financial policies in developing economies is highly dependent on the level of digital maturity of the financial system and the health of the banking system. In such circumstances, financial liberalization policies will be most effective when implemented simultaneously with the development of smart financial technologies and the reduction of credit frictions.

Policy and research suggestions

First, it is recommended that economic policymakers adopt a "smart financial liberalization" approach instead of focusing solely on financial liberalization; that is, financial reforms are implemented simultaneously with the development of digital infrastructures and the improvement of financial technologies. Second, strengthening the banking supervision system and reducing non-performing assets should be a key prerequisite for reaping the benefits of financial liberalization. Third, developing the FinTech ecosystem and supporting digital banking can play an important role in reducing information frictions and increasing productivity.

From a research perspective, it is also suggested that future studies examine the nonlinear and threshold effects of financial smartness on productivity and consider the role of institutional factors and digital governance as moderating variables in this regard. Also, using multi-period approaches and dynamic analyses can provide a more accurate understanding of the short-term and long-term effects of these variables.

The results demonstrate that financial liberalization and intelligent financial services jointly contribute to improvements in total factor productivity, whereas credit frictions and structural weaknesses in the banking sector hinder productivity growth. These findings extend the conventional financial development literature by showing that the effectiveness of financial liberalization increasingly depends on the quality of digital financial infrastructure and the intelligence of financial service delivery systems. In the context of digital business and platform economies, financial technologies facilitate faster information exchange, reduce transaction costs, and improve access to financial resources, thereby strengthening the productivity-enhancing effects of financial openness. Consequently, policymakers should complement traditional financial reforms with investments in fintech development, digital transformation initiatives, and smart financial ecosystems capable of supporting innovation and sustainable economic growth.

Despite its contributions, this study has several limitations. First, the availability and quality of macroeconomic and financial data may affect the precision of the estimated relationships. Second, the selected indicators may not fully capture all dimensions of financial liberalization, intelligent financial services, and digital financial infrastructure. Third, potential bidirectional relationships may exist between productivity and financial development, creating endogeneity concerns that cannot be completely eliminated. Finally,

although the MIDAS framework effectively captures mixed-frequency dynamics, it may not fully account for structural breaks, nonlinear relationships, or rapidly evolving technological changes within digital financial ecosystems. These limitations should be considered when interpreting the results and generalizing the findings to other economic contexts.

Future Research Directions

Future studies may extend the current framework by incorporating more comprehensive indicators of digital transformation, including fintech adoption, digital payment penetration, artificial intelligence applications in finance, blockchain-based financial services, and digital financial inclusion. Such extensions would provide deeper insights into the mechanisms through which intelligent financial systems influence productivity and economic performance in increasingly digitalized environments.

In addition, future research could investigate the role of virtual economies, digital assets, cryptocurrencies, decentralized finance (DeFi), and platform-based business ecosystems in shaping productivity dynamics. Comparative cross-country studies, nonlinear modeling approaches, machine learning techniques, and network-based analyses may also provide valuable evidence regarding the interaction between financial liberalization, smart financial infrastructure, and productivity growth. These directions would contribute to a more comprehensive understanding of how emerging digital and virtual economic environments influence sustainable development and long-term economic efficiency.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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