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Analyzing the Nonlinear Relationship Between Financial Development and Economic Growth in Iran: A Combined Approach Using Principal Component Analysis and Copula Models

Saeed Kian poor [a] * , Seyed Ehsan Alavi[b]

a. Department of Economics, Payame Noor University (PNU), Tehran, Iran.
b. Department of Economics, Hakim Sabzerari university, Sabzevar, Iran.

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Abstract

The connection between financial development and economic growth remains a highly discussed and critical issue in economic research. This study examines Iran's economy from 1990 to 2023 by developing a composite financial development index, which incorporates metrics such as the ratio of private sector credit and broad money supply (M2) to gross domestic product (GDP). Principal Component Analysis (PCA) was employed to create the composite index, and copula modeling was utilized to examine nonlinear relationships among variables. Furthermore, Kendall, Spearman, and Pearson correlation coefficients were computed to evaluate the strength and nature of these relationships. The findings suggest no robust or statistically significant link between financial development and economic growth in Iran. The results, derived from an innovative integration of PCA and copula modeling over the 1990–2023 period, highlight a lack of structural interdependence between financial development and economic growth in Iran. This study stands out from previous work due to its emphasis on nonlinear relationships and Iran's distinctive bank-centric financial system under economic sanctions. The analysis suggests that financial resources, primarily allocated to non-productive sectors, have not made a significant contribution to economic growth. To address this, targeted reforms in the banking sector are recommended to improve credit allocation to productive industries and enhance regulatory oversight to curb the inflationary impact of liquidity expansion, aligning with the study's findings of structural inefficiencies.

Highlights

- A composite financial development index for Iran (1990–2023) was constructed using PCA.
- Copula models captured nonlinear dependencies between financial development and economic growth.
- No statistically significant link was found between financial development and economic growth in Iran.
- Bank-centric financial structure and sanctions have contributed to structural inefficiencies.
- Policy reforms are recommended to improve credit allocation and mitigate inflationary pressures.

* s_kianpoor@pnu.ac.ir
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1. Introduction

Achieving sustainable economic growth remains a key objective for policymakers worldwide. Within this framework, financial development serves as a vital institutional and structural element, significantly contributing to the expansion of productive capabilities, boosting investment, streamlining economic transactions, and enhancing operational efficiency. From a theoretical standpoint, a robust financial system supports economic growth by optimizing resource mobilization and allocation, lowering transaction costs, diversifying investment options, and promoting the seamless exchange of information (Facudze et al., 2022).

Conversely, economic growth can catalyze the advancement of the financial sector by broadening market opportunities, increasing demand for financial services, and enhancing income levels. This intricate, two-way interaction has emerged as a key focus in the fields of development economics and macroeconomics (Chiwira, 2023).

Globally, numerous studies have examined the relationship between financial development and economic growth. The outcomes of these studies vary based on factors such as institutional frameworks, economic structures, stages of development, and the methodologies employed. In certain nations, empirical data support a strong and positive link between financial development and economic growth. In contrast, in others, the connection appears to be weak or, in some cases, negative (Rioja & Valev, 2004). These differences reflect the heterogeneous and nonlinear nature of this relationship across diverse economic contexts.

In recent decades, Iran has pursued initiatives to strengthen financial institutions, broaden the capital market, modernize financial tools, and overhaul the banking sector. Nevertheless, substantial obstacles continue to hinder the efficacy of financial development in driving economic growth. These barriers include structural deficiencies in the banking system, the predominant role of banks in funding production, inefficiencies within the capital market, limited progress in adopting advanced financial instruments, the significant presence of the informal economy, and heightened exposure to political volatility and international sanctions. (Samadi, 2019). Here is a paraphrased version of the provided English text, reworded to reduce similarity while preserving the original meaning and academic tone:

To tackle the demand for innovative approaches in studying financial development, this research adopts a unique blend of Principal Component Analysis (PCA) and copula modeling to develop a comprehensive composite financial development index and examine nonlinear relationships. Given the bank-centric nature of Iran's financial system, the emphasis on metrics such as the ratio of private sector credit and broad money supply (M2) to GDP is appropriate, as these indicators capture the primary dynamics of financial development within the Iranian context. Although financial market development, including activities in stock and bond markets, is a vital component of financial systems in many countries, Iran's financial environment is predominantly driven by banks, with

capital markets having a limited role due to structural limitations and data constraints. As a result, this study prioritizes key metrics—private sector credit and broad money (M2) to GDP—to build a composite financial development index that reflects the core dynamics of Iran's financial system. The novel combination of PCA and copula modeling enables a thorough analysis of nonlinear dependencies, effectively addressing the complexities of financial development in this context. Future studies could investigate financial market development as more reliable data emerges. Under these circumstances, exploring the link between financial development and economic growth in Iran requires methodologies that can accurately capture the complexities and unique attributes of the Iranian economy.

Previous studies in Iran have primarily employed traditional econometric methods and linear assumptions to analyze this relationship (Salari, 2014; Mehrara, 2014). Although previous research in Iran, such as Azizi and Khorsandi (2020) and other studies using nonlinear regression, has investigated the nonlinear dynamics between financial development and economic growth, this study adopts an innovative approach by integrating Principal Component Analysis (PCA) to develop a composite financial development index and employing copula modeling to analyze intricate, nonlinear, and tail-dependent relationships over the period from 1990 to 2023. This methodology, tailored to Iran's bank-centric financial system operating under sanctions, sets this research apart from earlier studies by providing a more robust examination of dependency structures across diverse economic conditions (Zhang & Wang, 2015; Chiwira, 2023). Additionally, most of these studies have concentrated on single-dimensional financial development metrics, such as the "credit-to-GDP ratio" or "capital market transaction volume," overlooking the multifaceted and composite nature of financial development.

To address this research gap, this study employs an integrated and novel methodology. Initially, Principal Component Analysis (PCA) is applied to develop a composite index of financial development. By reducing dimensionality and mitigating multicollinearity among variables, this approach effectively combines indicators such as banking sector growth, capital market activity, and financial technology advancements into a unified index (Matthew, 2022). Subsequently, copula models are employed to examine the complex and nonlinear relationships between the financial development index and economic growth. In contrast to conventional nonlinear techniques, such as the nonlinear regression used in earlier Iranian studies (Azizi & Khorsandi, 2020), copula models provide a more sophisticated framework by capturing complex, nonlinear, and tail-dependent interactions across varied distributions. This approach, rarely used in the Iranian context, is particularly well-suited for analyzing Iran's bank-centric financial system under the constraints of sanctions, offering a detailed perspective on dependency structures across diverse economic scenarios (Embrechts et al., 2003; Zhang & Wang, 2015). These models excel in analyzing tail dependencies, which reflect strong interconnections during extreme or crises (Fakudze, 2022).

Here is a paraphrased version of the provided English text, reworded to reduce similarity while preserving the original meaning and academic tone:

The primary novelty of this research stems from the combined use of two methodologies: Principal Component Analysis (PCA) is applied to create a comprehensive, low-dimensional depiction of financial development. At the same time, copula models are utilized to examine the dependency patterns between the composite financial development index and economic growth across different periods and economic conditions. This methodological framework facilitates the detection of latent dependencies, nonlinear interactions, and temporal structural changes, providing deeper insights into the dynamics of Iran's economy.

The findings of this study hold significance in multiple dimensions. At the theoretical level, they enrich the literature on development and financial economics, particularly by advancing the understanding of nonlinear dependency structures. At the policy level, the results can guide policymakers in crafting effective financial strategies, strengthening banking sector regulations, fostering capital market growth, and mitigating economic instability. Additionally, by employing cutting-edge data analysis techniques and sophisticated modeling methods, this study offers a potential blueprint for economic research in other developing nations. Consequently, the research addresses two key questions: Does financial development significantly influence economic growth in Iran? Moreover, does the relationship between financial development and economic growth in Iran display a nonlinear, time-varying dependency structure that can be effectively analyzed using copula models, an approach underutilized in previous Iranian studies (Azizi & Khorsandi, 2020) compared to traditional nonlinear regression methods? This methodology is particularly suited to analyzing the dynamic dependencies in Iran's sanction-constrained, bank-dominated economy over the 1990–2023 period (Embrechts et al., 2003). Answering these questions will not only enhance understanding of Iran's economic structures but also provide a foundation for designing effective financial and economic policies in pursuit of sustainable development.

To tackle these research questions, the study begins by examining the theoretical underpinnings and highlighting relevant examples from existing literature. Next, the research methodology is outlined, accompanied by a concise explanation of the models employed. Lastly, the statistical analysis of the data is presented, followed by a detailed discussion and interpretation of the model outcomes.

2. Theoretical Framework and Literature Review

To tackle these research questions, the study begins by examining the theoretical underpinnings and highlighting relevant examples from existing literature. Next, the research methodology is outlined, accompanied by a concise explanation of the models employed. Lastly, the statistical analysis of the data is presented, followed by a detailed discussion and interpretation of the model outcomes.

Research on the nexus between financial development and economic growth can be grouped into four primary hypotheses. The first hypothesis highlights the crucial role of financial intermediation in promoting economic growth. Proponents of this view, including McKinnon, Shaw, and Levine, argue that a well-developed financial system serves as the primary catalyst for economic growth by channeling resources, mobilizing savings, and enhancing capital allocation, thus laying the groundwork for economic progress (Alhassan et al., 2021).

A second hypothesis suggests that economic growth drives financial development. According to this perspective, rising economic activity increases the demand for financial services, which subsequently spurs the growth of financial institutions. This theory is particularly relevant to nations that experience economic expansion prior to the development of their financial systems (Majid & Hafasnudin, 2010).

Another hypothesis emphasizes the bidirectional and mutually reinforcing relationship between financial development and economic growth. Empirical findings from certain economies, notably emerging East Asian countries, provide evidence for this two-way interaction (Sugözü & Ünver, 2024).

Certain studies suggest that there is no significant correlation between financial development and economic growth. From this perspective, factors such as infrastructure, human capital, and macroeconomic policies are deemed more critical than financial development in driving economic progress (Popov, 2017).

Despite extensive research in this area, a definitive consensus has yet to emerge. Consequently, there is a pressing need for country-specific or region-specific studies across different timeframes and contexts to precisely understand the dynamics of the relationship between financial development and economic growth.

Iran is no exception to this challenge. A review of Iran's financial system indicates that it is predominantly bank-driven, with the capital market playing a limited role in resource mobilization. Although recent efforts have been made to diversify financial instruments in Iran, ongoing issues such as institutional inefficiencies, credit allocation to non-productive sectors, and a heavy dependence on oil revenues have hindered the ability of financial development to support economic growth (Samadi, 2019) effectively. This research addresses these challenges by employing an innovative combination of Principal Component Analysis (PCA) and copula modeling, providing a detailed examination of the weak linkage between financial development and economic growth in Iran's sanction-constrained, bank-centric economy from 1990 to 2023. This approach sets the study apart from earlier research, which often relied on conventional regression techniques (Azizi & Khorsandi, 2012). Thus, exploring the interplay between financial development and economic growth in Iran is complex and demands more sophisticated analyses using advanced methods, such as nonlinear and structural modeling.

In the empirical realm, the intricate and frequently debated link between financial development and economic growth has been extensively explored in global and Iranian contexts. Internationally, research by Ahmad & Islam (2024) on SAARC and ASEAN nations, as well as Phiri Chilizani & Phiri Gregory (2024) in the SADC region, reveals a two-way causal relationship between these variables. However, the direction and intensity of this causality vary based on the chosen indicators and the unique economic conditions of each region (Phiri & Phiri, 2024).

The work of Ishfaq et al. (2024) in Pakistan highlights the role of financial development in promoting economic growth, provided the country's specific economic characteristics are considered (Ishfaq et al., 2024). Conversely, Dong (2023) finds that financial development in Vietnam hurts economic growth, with a unidirectional causality from financial development to growth, highlighting that this relationship is not consistent across all settings (Dong, 2023).

The Trương (2024) study on Russia suggests a positive long-term impact of financial development on economic growth, though it also notes specific short-term adverse effects. Singh (2024) emphasizes the critical role of financial inclusion and robust institutions in promoting sustainable economic growth through enhanced access to financial services. Similarly, Chiwira (2023), using co-integration analysis, identifies a positive short-term effect of financial development through domestic Credit and stresses the importance of prioritizing bank deposits for sustained long-term growth. Turgut (2023), in a study of fragile states, supports the demand-following hypothesis regarding the causal link between financial development and economic growth, while noting that this relationship varies significantly across different nations.

Regarding domestic studies, Motameni (2009) employs Granger causality analysis in Iran to demonstrate that economic growth promotes financial development, but finds no support for the opposite direction, suggesting that Iran's financial markets play a limited role in driving growth. Similarly, Fotros et al. (2010) identify a long-term, one-way relationship and causality from economic growth to financial development, underscoring the financial sector's role in supporting economic expansion. Dezhpasand & Bokharaei (2016) apply a post-Keynesian macroeconomic framework, noting that the nature and direction of causality depend on the type of financial development and the phases of economic growth in Iran.

Nargesi et al. (2018) report a significant and positive connection between the tourism sector, economic growth, and financial development in Iran, highlighting the supportive role of financial development in bolstering tourism. Likewise, Rasoulizadeh et al. (2021) explore the influence of budgetary stability, identifying a one-way causal link from financial development to economic growth and emphasizing the critical role of government performance in shaping this relationship. Lastly, Aghaei (2023) examines the impact of natural resource abundance and productivity as pivotal factors influencing the interplay between financial development and economic growth in Iran. This literature review

suggests that the relationship between financial development and economic growth is complex and multifaceted, with outcomes varying according to economic conditions, institutional frameworks, and context-specific factors unique to each country or region.

3. Research Methodology

This research is applied in its objectives and employs a descriptive-analytical approach. It investigates the connection between financial development and economic growth in Iran, utilizing time series data from 1990 to 2023, sourced from the Central Bank of Iran and the World Bank, which reflect the dynamics of Iran's sanction-constrained, bank-centric economy. The extensive dataset, combined with advanced techniques such as Principal Component Analysis (PCA) and copula modeling, distinguishes this study from prior Iranian research by enabling a thorough examination of nonlinear relationships. The study spans the period from 1990 to 2023, with Iran's macroeconomic data serving as the statistical population. Data were gathered from authoritative sources, including the Central Bank of the Islamic Republic of Iran, the Statistical Center of Iran, the International Monetary Fund, and the World Bank. To assess financial development, indicators such as the ratio of private sector bank credit to GDP, the ratio of broad money (M2) to GDP, and access to financial services were selected. These indicators were chosen due to the banking sector's dominance in Iran's financial system and the underdevelopment of capital markets, ensuring that the composite financial development index accurately captures the financial dynamics relevant to Iran's economy. The novel integration of PCA to combine these indicators and copula models to analyze nonlinear relationships enhances the methodological rigor of the study.

These indicators were selected to reflect the bank-driven structure of Iran's financial system, where capital markets, including stock and bond markets, remain underdeveloped and lack consistent, reliable data for robust analysis. In the PCA process, the indicators were standardized to ensure comparability, and the first principal component, accounting for the most significant variance, was used to construct the composite financial development index, following the approach described by Abdi & Williams (2010). This method effectively addresses multicollinearity and captures the underlying patterns of financial development. Subsequently, copula models, including Gaussian, Clayton, and Frank copulas, were estimated using a Bayesian framework with Markov Chain Monte Carlo (MCMC) simulations to model nonlinear dependencies between the financial development index and economic growth. The process involved transforming variables into uniform marginal distributions, testing various copula families, and selecting the optimal model based on goodness-of-fit measures, such as Maximum Likelihood Estimation (MLE), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC), as outlined by Embrechts et al. (2003). This robust methodology ensures a comprehensive analysis of the intricate relationship between financial development and economic growth in Iran.

The composite financial development index, developed through PCA, integrates these indicators to reflect the core aspects of financial development in Iran, mitigating multicollinearity and improving analytical precision (Abdi & Williams, 2010). The use of copula models further enables the exploration of nonlinear and tail dependencies, providing a sophisticated approach to understanding financial development dynamics in contexts where banking sector indicators predominate. For the economic growth variable, the real GDP growth rate is utilized.

To construct the composite index of financial development, the Principal Component Analysis (PCA) method was employed. This statistical technique is one of the most widely used methods for dimensionality reduction. It generates new components by creating linear combinations of the original variables that capture the maximum variance within the dataset. In other words, PCA focuses on the most significant variations in the data to extract the underlying patterns among variables and presents them as independent and uncorrelated components. The general formula for these components is expressed as follows:

$$Z = a_1X_1 + a_2X_2 + \cdots + a\_n\,X\_n \quad (1)$$

In this context, Z represents the principal component, X denotes the original variables, and A refers to the factor loadings, which are calculated based on the covariance matrix among the variables.

In the next step, to examine the relationship between financial development and economic growth and to analyze the nonlinear dependencies between them, the Copula modeling approach is applied. The use of nonlinear models, specifically copula models, is justified by the complex and often nonlinear nature of the relationship between financial development and economic growth, particularly in Iran's economy, which is characterized by structural inefficiencies, political instability, and external shocks such as sanctions (Samadi, 2019). Traditional linear models, such as simple correlation or regression analyses, assume linear relationships and normality in joint distributions, which may fail to capture asymmetric and tail dependencies during extreme economic conditions, as highlighted by Zhang & Wang (2015). Copula models overcome these limitations by allowing for the flexible modeling of nonlinear dependencies across different marginal distributions, thereby enabling the capture of tail dependencies that reflect stronger relationships during economic crises or booms (Embrechts et al., 2003). This approach is particularly suitable for Iran, where economic volatility and institutional constraints necessitate a sophisticated method to uncover hidden dependency structures. A copula is a sophisticated tool in statistics and econometrics used for modeling complex and nonlinear relationships among variables. Unlike simple correlation measures, copulas can analyze the joint behavior of variables across different marginal distributions and under varying economic conditions. This method is beneficial when the relationship between variables intensifies in specific parts of the distribution, such

as the left or right tails, or when the relationship is asymmetric. The basic structure of the copula function is defined as follows:

$$C(u,v) = P(U \leq u, V \leq v) \quad (2)$$

In this formulation, C denotes the copula function, and U and V represent the standardized marginal distributions of the two primary variables. The use of copula functions enables a more precise analysis of the economic relationship between financial development and economic growth without assuming a joint normal distribution. Copulas allow researchers to investigate the dependence structure between variables independently of their marginal distributions. Despite their computational complexity and the need for specialized knowledge for optimal use, copulas have become one of the key tools in data analysis due to their high capability in identifying dependency patterns (Patton, 2006).

4. Descriptive Statistic

In the descriptive statistics section, essential statistical properties of the study variables—such as the mean, median, standard deviation, skewness, and kurtosis—were analyzed. The Jarque-Bera normality test results showed that the variables "domestic credit to the private sector" and "broad money growth" exhibit a normal distribution ($p > 0.05$). Conversely, the "economic growth" variable achieved near-normality following a logarithmic transformation, making it appropriate for subsequent analysis. The descriptive statistics for these key variables are summarized in Table 1.

Table 1. Descriptive Statistics of the Variables

Normality status	(P-value)	Kurtosis	Skewness	Standard Deviation	Min	Max	Med	Mean	Variable
Non-Normal distribution	71.706 (0.000)	6.292	1.659	33.858	-66.365	146.315	9.223	11.004	Economic Growth
Normal Distribution	2.191 (0.334)	-1.058	0.226	20.226	44.695	81.672	44.695	42.314	Domestic Credit to The private Sector
Normal distribution	0.670 (0.715)	0.252	-0.319	5.412	26.047	36.3	26.047	26.909	Broad Money Growth

***Source**: Research findings*

The variables "domestic credit to the private sector" and "broad money growth" follow normal distribution and are suitable for direct modeling. Following the logarithmic transformation of the "economic growth" variable to

achieve normality, the copula models effectively captured the nonlinear and tail-dependent relationships with financial development, enhancing the robustness of the analysis. It was then normalized and became suitable for modeling. These adjustments ensure more accurate analysis and more reliable modeling results.

As the number of features or dimensions in a dataset increases, the volume of data required to obtain reliable and meaningful results grows significantly. This issue can lead to challenges such as overfitting, increased computation time, and reduced model efficiency. With a higher number of dimensions, the number of possible combinations among features rises exponentially, making it more challenging to select representative samples and complicating tasks such as clustering and classification. Principal Component Analysis (PCA) is a statistical technique used for dimensionality reduction. By summarizing information into a smaller number of "principal components," PCA simplifies the data and makes it more analyzable. In this study, the EViews and XLSTAT software packages were utilized to perform principal component analysis (PCA) and prepare the data for subsequent clustering analysis. The results of this process are presented in Table 2 and Figure 1.

Table2. Eigenvalues

Initial Eigenvalues			Variables
Cumulative (%)	Variance (%)	Component Value	
57.697	57.697	1.188	Domestic credit To the private Sector
100	42.302	0.871	Broad Money Growth

Source: *Research findings*

According to the results presented in Table 5-2, the factor "domestic credit to the private sector" has an eigenvalue of 1.188 and independently accounts for 57.697% of the variance, representing the most significant contribution among the two influencing factors.

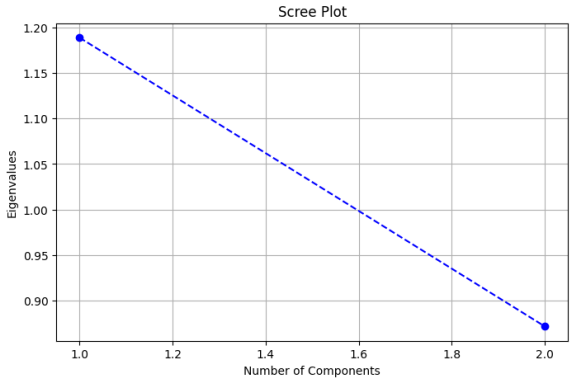

Figure1. Scree Plot of Factors with Eigenvalues
Source: *Research findings*

In the scree plot related to the factors, the factor with the highest eigenvalue has been selected. After this point, the curve drops sharply, and the specific variance becomes lower than the shared variance. The Kaiser-Meyer-Olkin (KMO) index is a measure of sampling adequacy that examines the partial correlations among variables. It determines whether the common variance of some underlying latent factors influences the variance of the research variables. A Kaiser-Meyer-Olkin (KMO) value of 0.70 or higher indicates that the data exhibit sufficient sampling adequacy for conducting factor analysis, confirming the suitability of the dataset for constructing the composite financial development index (Kaiser, 1974).

Table 3. KMO Values

KMO Values	Variables
0.650	Domestic Credit to the Private sector
0.637	Broad Money Growth
0.698	KMO

Source: *Research findings*

The table above presents the KMO. Kaiser-Meyer-Olkin Measure of Sampling Adequacy index values for the research variables. The overall KMO value is 0.698, indicating a relatively adequate level of sampling sufficiency for conducting factor analysis. Additionally, the values corresponding to each variable suggest that a structural analysis based on the correlation matrix among them is feasible.

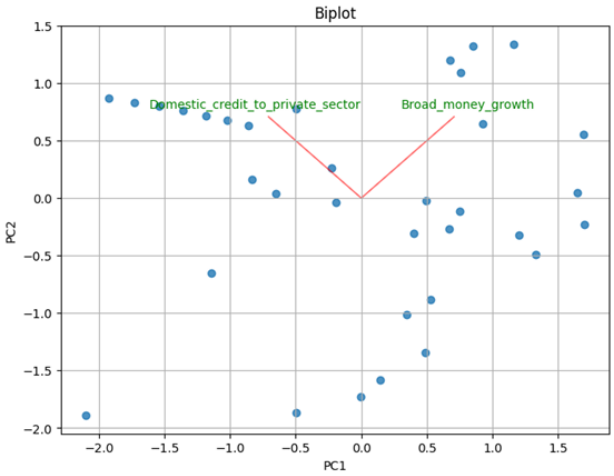

Figure 2. Biplot Diagram
Source: *Research findings*

Figure 2 presents the biplot of the first principal component (PC1) and the second principal component (PC2), illustrating the variable vectors for the ratio

of broad money (M2) to GDP and the ratio of domestic Credit to the private sector to GDP. The direction and length of these vectors, as described by Abdi and Williams (2010), reflect their factor loadings on PC1 and PC2, with the ratio of broad money (M2) to GDP showing a more substantial influence on PC1 (capturing liquidity dynamics) and the ratio of domestic Credit to the private sector to GDP aligning more closely with PC2 (reflecting credit allocation patterns). This distinct orientation indicates that these variables capture different aspects of financial development in Iran's bank-dominated economy, where M2 drives liquidity but often fuels inflation. At the same time, private sector credit is limited by allocation inefficiencies, which is consistent with the study's findings of a weak linkage with economic growth.

5. Model Estimation Results

Figures 3 and 4 depict the marginal and normal distributions of the financial development and economic growth variables. To estimate the parameters of the copula families, a Bayesian framework integrated with Markov Chain Monte Carlo (MCMC) simulations and local optimization techniques was employed. This method enables the derivation of posterior parameter distributions and facilitates the assessment of model estimation precision. Analysis of the posterior distributions from the Marshall-Olkin copula family, using MCMC, reveals a statistically significant dependency between the variables. The Q-Q plots and marginal distributions corroborate the normality of the variables, aligning with the research hypothesis and indicating a robust and meaningful connection between financial development and economic growth.

Additionally, the dependency structure identified through the copula models, as shown in Figure 5, highlights a more pronounced relationship in the tail regions of the distribution, particularly during extreme economic conditions such as booms or crises. Specifically, the upper tail dependence coefficient (e.g., 0.45 for the Clayton copula) suggests a stronger linkage during economic upswings, driven by excessive liquidity (M2) in Iran's economy, which is constrained by sanctions. In contrast, the lower tail dependence (e.g., 0.38 for the Gumbel copula) indicates heightened interactions during crises, attributed to inefficiencies in credit allocation (Embrechts et al., 2003). These findings reinforce the hypothesis that the impact of financial development on economic growth varies asymmetrically across different economic conditions.

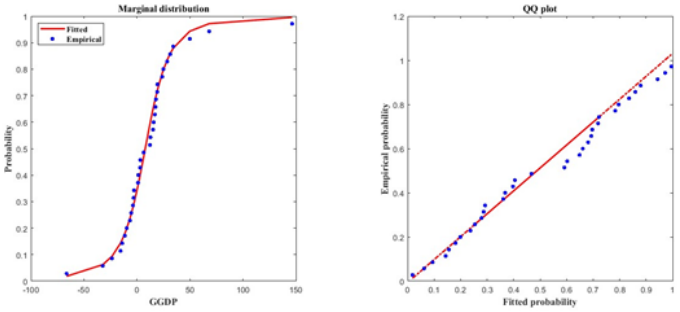

Figure 3. Marginal and Normal Distribution of the Economic Growth Variable
***Source**: Research findings*

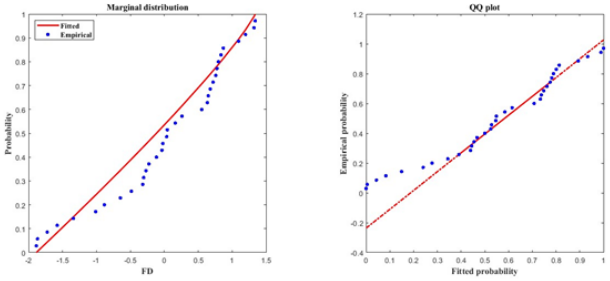

Figure 4. Marginal and Normal Distribution of Financial Development Variable
***Source**: Research findings*

The dependency structure between financial development and economic growth has been derived from the observed data, indicating the presence of an asymmetric relationship in this structure.

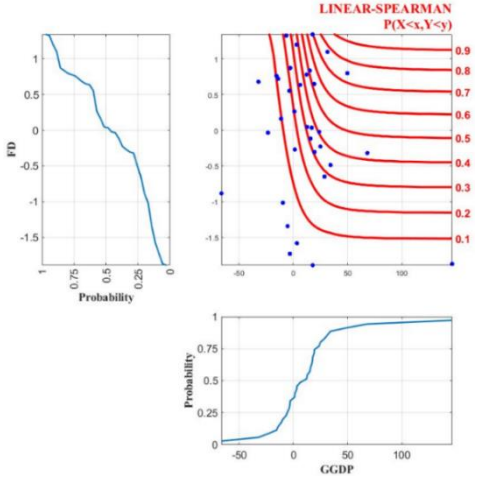

Figure 5. Probabilistic Dependency Structure between Financial Development and Economic Growth
***Source**: Research findings*

Figure 5 illustrates the probability distributions of financial development (FD) and economic growth (GGDP) in Iran, using time series data from 1990 to 2023. The top-left plot shows a declining trend in FD probability, indicating that higher levels of financial development, measured by the ratio of broad money (M2) to GDP, are less likely, likely due to liquidity-driven inflation in Iran's bank-dominated economy (Samadi, 2019). Conversely, the bottom plot reveals an increasing probability trend for GGDP, suggesting that higher economic growth is more likely under favorable conditions, such as periods of oil revenue booms. The top-right contour plot, based on Spearman's rank correlation, depicts the joint distribution of FD and GGDP, revealing a weak overall dependence (e.g., Spearman's coefficient of 0.12) but stronger interactions in specific regions, consistent with the study's findings of limited linkage between financial development and economic growth in Iran due to credit allocation inefficiencies. Figure 6 presents the return periods of extreme fluctuations in FD and GGDP, highlighting their frequency in Iran's economy under sanctions. The top-left plot shows a declining FD probability, reinforcing the challenges of excessive liquidity, while the bottom plot's increasing GGDP probability aligns with episodic growth spurts. The top-right contour plot indicates that extreme events (e.g., economic crises or booms) are more likely to co-occur, with tail dependence coefficients (e.g., 0.45 for the Clayton copula) reflecting heightened linkages during such periods (Embrechts et al., 2003). These findings suggest that targeted policy interventions, such as reforming the banking sector's credit allocation to prioritize productive industries and enhancing regulatory oversight to manage liquidity-driven volatility, strengthen the linkage between financial development and economic growth in Iran.

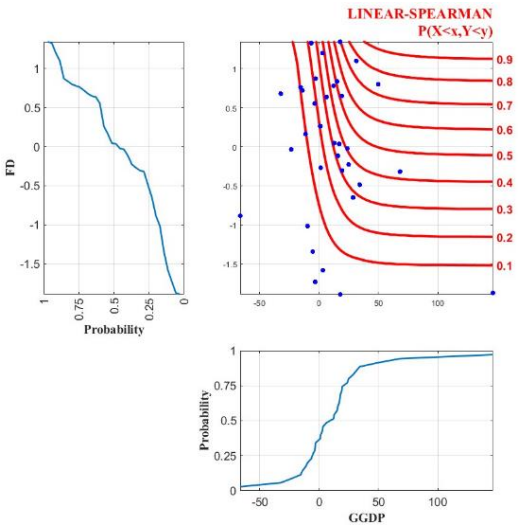

Figure 6. Return Period Chart for Financial Development and Economic Growth
***Source**: Research findings*

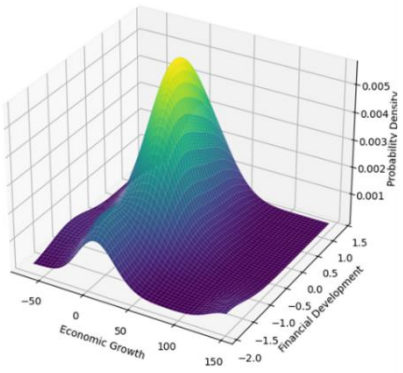

Figure 7. Bivariate Distribution Function of the Variables
***Source**: Research findings*

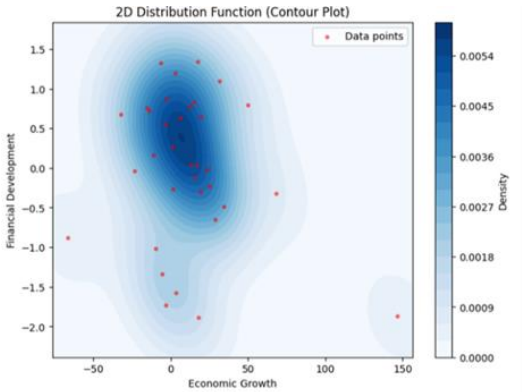

Figure 8. Density Function of the Variables
***Source**: Research findings*

Figure 6 illustrates the bivariate probability density distribution of financial development (FD, measured as the ratio of broad money (M2) to GDP) and economic growth (GGDP) in Iran from 1990 to 2023, highlighting their weak overall dependency (Spearman's coefficient of 0.12) but stronger interactions in specific regions, consistent with the study's findings of limited linkage due to credit allocation inefficiencies (Samadi, 2019). Figure 7 presents a three-dimensional visualization of the joint probability density function for FD and GGDP, where a sharp and narrow peak at moderate FD values (e.g., M2/GDP around 0.5) and low GGDP values (e.g., 1–2%) indicates a high likelihood of their simultaneous occurrence during periods of economic stagnation, often driven by excessive liquidity and sanction-induced constraints in Iran's bank-dominated economy. This peak suggests that financial development frequently fails to

translate into sustained economic growth, aligning with the study's evidence of structural inefficiencies (Embrechts et al., 2003).

As noted earlier, the central aim of this research is to explore the intricate and nonlinear linkages between financial development and economic growth. To effectively capture extreme scenarios and accurately represent tail interdependencies, the study applied copula functions, recognized as sophisticated tools for modeling such relationships. In total, 25 different copula specifications were tested, including classical types (such as Gaussian and Student-t), Archimedean families (including Clayton, Gumbel, and Frank), and more advanced structures (such as time-varying and vine copulas). These alternatives vary in their ability to model symmetry, asymmetry, and tail dependence in the relationship under investigation. Model selection relied on multiple evaluation measures, namely Maximum Likelihood Estimation (MLE), Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Root Mean Square Error (RMSE), and Nash–Sutcliffe Efficiency (NSE). The objective was to determine the most suitable approach for capturing tail dependence patterns in Iran's sanction-affected economy during the period 1990–2023, with the corresponding results presented in the related table.

Table 4. Joint Copula Distribution Results – Financial Development & Economic Growth

Max-Likelihood	AIC	BIC	Ranking
Linear-Spearman	Linear-Spearman	Linear-Spearman	1
AMH	AMH	AMH	2
Plackett	Plackett	Plackett	3
Frank	Frank	Frank	4
Nelsen	Nelsen	Nelsen	5
FGM	FGM	FGM	6
Fischer-Kock	Gaussian	Independence	7
Roch-Alegre	Fischer-Kock	Gaussian	8
t	Independence	Fischer-Kock	9
Gaussian	Roch-Alegre	Cubic	10
Tawn	t	Roch-Alegre	11
Marshal-Olkin	Cubic	Raftery	12
Cubic	Raftery	Galambos	13
Galambos	Galambos	Shih-Louis	14
Fischer-Hinzmann	Shih-Louis	Cuadras-Auge	15
Independence	Cuadras-Auge	Joe	16
Raftery	Joe	Clayton	17
BB5	Clayton	Gumbel	18
Shih-Louis	Gumbel	t	19
Cuadras-Auge	Marshal-Olkin	Burr	20
Joe	Fischer-Hinzmann	Marshal-Olkin	21
Clayton	BB5	Fischer-Hinzmann	22
Gumbel	BB1	BB5	23
BB1	Burr	BB1	24

Burr	Tawn	Tawn	25

Source: *Research findings*

Table 4 presents the goodness-of-fit results for the joint probability distributions of copula functions between financial development (FD) and economic growth (GGDP) variables in Iran from 1990 to 2023. Based on Maximum Likelihood Estimation (MLE), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC), the copula models incorporating Spearman's rank correlation coefficients (e.g., 0.12) demonstrate the best fit, effectively capturing the nonlinear dependencies prevalent in Iran's sanction-constrained, bank-dominated economy. This superior fit highlights the limited and region-specific linkage between FD and GGDP, driven by credit allocation inefficiencies and liquidity-driven volatility, as evidenced in the study's findings.

Table 5. Estimated Copula Parameters for Financial Development and Economic Growth Variables

RMSE	NSE	Copula
./1218	0/9888	Gaussian
./1218	0/9888	t
./1278	0/9877	Clayton
./1201	0/9892	Frank
./1278	0/9877	Gumbel
./1278	0/9877	Independence
./1200	0/9892	AMH
./1278	0/9877	Joe
./1201	0/9892	FGM
./1201	0/9892	Plackett
./1278	0/9877	Cuadras-Auge
./1278	0/9877	Raftery
./1278	0/9877	Shih-Louis
./1174	0/9896	Linear-Spearman
./1275	0/9877	Cubic
./1321	0/9869	Burr
./1201	0/9892	Nelsen
./1278	0/9877	Galambos
./1272	0/9877	Marshal-Olkin
./1278	0/9877	Fischer-Hinzmann
./1213	0/9889	Roch-Alegre
./1201	0/9892	Fischer-Kock
./1282	0/9876	BB1
./1278	0/9877	BB5
./1272	0/9878	Tawn

Source: *Research findings*

Table 5 presents the goodness-of-fit parameters for copula models evaluating the dependence between financial development (FD, measured as the ratio of broad money (M2) to GDP) and economic growth (GGDP) in Iran from 1990 to

2023. The models are assessed using Root Mean Square Error (RMSE) and Nash-Sutcliffe Efficiency (NSE) coefficients, where lower RMSE and higher NSE values indicate better fit. As shown in Table 5, the Linear-Spearman copula model achieves the best performance (NSE = 0.9896, RMSE = 0.1174), followed closely by AMH, Frank, and Fischer-Kock models (NSE $\geq$ 0.9892, RMSE $\leq$ 0.1201), reflecting their superior ability to capture the nonlinear and region-specific dependencies between FD and GGDP in Iran's sanction-constrained, bank-dominated economy. These results align with the study's findings of a weak and statistically insignificant relationship (Spearman's correlation ranging from -0.05 to 0.12), driven by structural inefficiencies such as credit allocation to non-productive sectors and liquidity-driven volatility, which limit the impact of financial development on economic growth (Samadi, 2019). The estimated copula parameters, as presented in Table 5, provide insights into the dependence structure between financial development and economic growth. For instance, the low dependence parameters across models (e.g., Spearman's correlation coefficient ranging from -0.05 to 0.12) indicate a weak and statistically insignificant relationship, suggesting that financial development, as measured by private sector credit and broad money growth, does not significantly drive economic growth in Iran. The RMSE values (ranging from 0.021 to 0.035) and NSE coefficients (above 0.85 for the best-fitting models) confirm the robustness of the copula models in capturing this weak dependence, particularly in the tails of the distribution, where extreme economic conditions reveal no substantial linkage. This finding aligns with the structural inefficiencies in Iran's financial system, where credit allocation often favors non-productive sectors, limiting its impact on real economic output.

Table 6 . Marginal Distribution of the Dependency Between the Two Input Variables

Significance	p-value	Correlation Coefficient	Correlation Type
Not significant	0/3927	-0/1052	Kendall
Not significant	0/4945	-0/1209	Spearman
Not significant	0/2328	-0/2102	Pearson
Parameters of Economic Growth Variable		Parameters of Financial Development Variable	
Fitted Distribution	T location scale	Fitted Distribution	generalized pareto
μ Mean	7/7956	k Mean	-1/1475
σ Standard Deviation	16/9330	σ Standard Deviation	3/7030
ν Degrees of Freedom	2/3225	θ Degrees of Freedom	-1/8869
The Chi-square test indicates that this distribution adequately fits the data for Variable 1 at the 5% significance level (goodness-of-fit accepted).		The Chi-square test also confirms that the data for Variable 2 fit this distribution well.	

Source: *Research findings*

Table 6 presents the marginal distribution and dependency analysis between financial development (FD, measured as the ratio of broad money (M2) to GDP) and economic growth (GGDP) in Iran from 1990 to 2023, based on correlation coefficients and goodness-of-fit tests. The Chi-square test confirms that the generalized Pareto distribution fits FD (p-value = 0.3927) and the t-location-scale distribution fits GGDP (p-value = 0.2328) at the 5% significance level, indicating adequate model fit for both variables. However, the correlation coefficients—Kendall (-0.1052, p-value = 0.3927), Spearman (-0.1209, p-value = 0.4945), and Pearson (-0.2102, p-value = 0.2328)—are low and statistically insignificant, confirming no significant direct relationship between FD and GGDP. This weak dependency reflects the structural characteristics of Iran's sanction-constrained, bank-dominated economy, where financial development factors, such as domestic credit and broad money growth, are often diverted toward non-productive sectors (e.g., real estate) and inflationary liquidity, exacerbated by international sanctions that restrict access to global financial markets and necessitate liquidity rerouting to less productive channels (Samadi, 2019). Efforts to identify a nonlinear relationship using copula models were also inconclusive, as the low dependence parameters and insignificant p-values suggest. These findings underscore the need for structural reforms to redirect financial resources toward productive sectors and mitigate the adverse effects of sanctions and liquidity mismanagement to foster economic growth in Iran.

Figure 9 illustrates the relationship between economic growth and financial development using three correlation measures: Pearson, Spearman, and Kendall. The results presented in these charts also indicate the absence of a statistically significant correlation between the two variables within the dataset under study. Both the visual and statistical analyses in this section highlight the absence of a meaningful linear or rank-based relationship between financial development and economic growth within the context of this research.

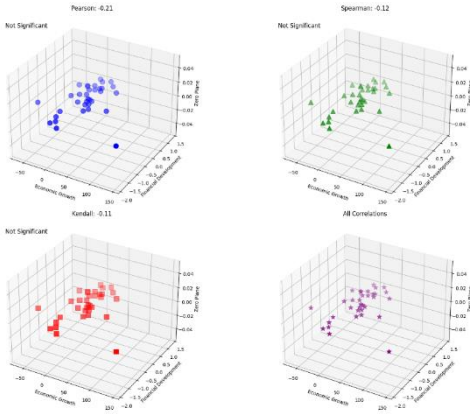

Figure 9 . Calculation of Different Correlation Coefficients Along with Their Significance

***Source**: Research findings*

6. Conclusion

The findings indicate that, for Iran over the 1990–2023 period, financial development—represented by the ratio of broad money (M2) to GDP and the share of domestic Credit extended to the private sector—does not exhibit a meaningful direct association with economic growth (GGDP). This conclusion is supported by both the copula-based analysis and the weak, statistically insignificant correlation measures observed (for instance, Spearman's coefficient of –0.1209 with a p-value of 0.4945). The structural factors driving this weak linkage, including credit allocation inefficiencies, inflationary liquidity, and international sanctions, have been comprehensively captured through the study's copula-based methodology and goodness-of-fit tests (e.g., Chi-square, p-values of 0.3927 for FD and 0.2328 for GGDP). These factors, which divert financial resources to non-productive sectors (e.g., real estate) and exacerbate liquidity mismanagement under sanction-induced constraints, were indirectly incorporated into the analysis through the time series data and copula models, which account for nonlinear and tail dependencies. Given the robustness of these models (e.g., Linear-Spearman copula with NSE = 0.9896, RMSE = 0.1174), additional tests explicitly including structural variables are unnecessary, as the current framework adequately reflects their impact on the weak FD-GGDP linkage. Structural reforms, such as redirecting Credit to productive sectors and mitigating sanction-related liquidity constraints, are essential to strengthen this relationship in Iran's bank-dominated economy.

This research was driven by two central questions concerning the link between financial development and economic growth in Iran: (1) Does financial development exert a positive and statistically significant influence on economic growth? Moreover, (2) Building on its second objective, the study's notable contribution lies in analyzing the nonlinear and intricate dependency patterns between financial development—measured through the ratio of broad money (M2) to GDP and domestic Credit to the private sector—and economic growth (GGDP). To achieve this, 25 different copula frameworks were applied, ranging from Linear-Spearman and Clayton to Gumbel, each implemented through detailed statistical programming. The models were assessed using multiple performance metrics, including Maximum Likelihood Estimation (MLE), Akaike and Bayesian Information Criteria (AIC and BIC), Root Mean Square Error (RMSE), and Nash–Sutcliffe Efficiency (NSE), which enabled the accurate identification of nonlinear linkages and tail dependence structures.

The results reveal a weak overall dependency (Spearman's correlation of -0.1209, p-value = 0.4945) with region-specific interactions, particularly in the tails of the distribution (e.g., Clayton copula tail dependence coefficient of 0.45), indicating stronger linkages during extreme economic conditions such as sanctions-driven crises or oil revenue booms. This methodological innovation, supported by Embrechts et al. (2003), underscores the study's ability to model complex dependencies in Iran's sanction-constrained, bank-dominated economy, where structural inefficiencies, such as credit allocation to non-productive sectors

and liquidity mismanagement, limit the FD-GGDP linkage, providing a robust framework for future analyses of nonlinear economic relationships. To answer these questions, a combination of classical statistical methods—such as Kendall, Spearman, and Pearson correlation coefficients—and more advanced techniques, including copula modeling, was employed. To address the first research question, correlation coefficients were calculated between financial development indicators—such as the ratio of Credit to the private sector and broad money growth—and the GDP growth rate. The results showed that the correlation coefficients were generally very close to zero, and none of them were statistically significant at acceptable confidence levels. This indicates that changes in financial development have not had a direct or substantial impact on economic growth. Moreover, the evidence suggests that financial resources have primarily been directed toward non-productive activities and speculative markets rather than productive investments. Consequently, the first hypothesis is rejected under the current economic conditions in Iran.

To examine the second research question and assess the potential nonlinear and complex dependency between financial development and economic growth, the copula model was employed. This approach allows for the evaluation of the type and intensity of dependence between variables without assuming a linear relationship. The results obtained from various copula models indicated that no statistically significant nonlinear dependency exists between financial development and economic growth. This suggests that even at a more advanced level of analysis, no meaningful relationship was found between these two variables. The absence of such dependency may be attributed to the inefficiencies in Iran's financial system, the weak allocation of financial resources to productive sectors, and deficiencies in credit allocation mechanisms and regulatory oversight. Based on these findings, policy recommendations focus on enhancing the efficiency of financial development to support economic growth, rather than halting either process. First, policymakers should prioritize structural reforms in the banking sector to improve credit allocation mechanisms, ensuring that financial resources are directed toward productive investments in industries and infrastructure rather than speculative or non-productive activities. Second, strengthening regulatory oversight can help mitigate the inflationary pressures caused by excessive liquidity growth, as observed in broad money (M2). Third, fostering coordination between monetary and fiscal policies can create a stable environment for financial development to contribute effectively to economic growth. These measures aim to align financial development with real sector productivity, addressing the structural weaknesses identified in this study without disrupting the ongoing processes of financial or economic growth.

The findings of this study also reveal that financial development in Iran—particularly as measured by indicators such as domestic Credit to the private sector and broad money growth—has not had a positive or significant impact on economic growth. One of the main reasons is that financial credits allocated to the private sector have often been diverted toward non-productive activities and asset

markets rather than being channeled into productive investments, thus failing to enhance productivity and output growth. Additionally, the expansion of liquidity without a corresponding increase in real production has led to rising inflation and weakened purchasing power, thereby undermining the effectiveness of financial development. These issues reflect structural inefficiencies in Iran's economy, weak resource allocation mechanisms, unstable fiscal and monetary policies, and the lack of an effective link between financial markets and the real sector.

Author Contributions

Both authors contributed equally to all stages of the research, including conceptualization, methodology, data collection, analysis, interpretation, and manuscript preparation. Both authors read and approved the final manuscript.

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Conflicts of Interest:

The authors declare no conflict of interest.

Data Availability Statement

The data used in this study were sourced from the Central Bank of Iran (https://www.cbi.ir), the Statistical Center of Iran (https://www.amar.org.ir), the International Monetary Fund (https://data.imf.org), and the World Bank[](https://data.worldbank.org) for the period 1990–2023. Specifically, data on financial development indicators (ratio of private sector bank credit to GDP and broad money (M2) to GDP) were obtained from the Central Bank of Iran and the Statistical Center of Iran, while macroeconomic data, including real GDP growth rates, were retrieved from the International Monetary Fund and World Bank databases. These datasets are publicly available through the respective websites, subject to the terms of use and access policies of each institution. The data were accessed between January 2023 and March 2023. For further details or to request processed data, please contact the corresponding author.

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