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Original Research Article

The Impact of Exchange Rate on the Performance of Banks Listed on the Iranian Stock Exchange: An Approach Using Copula Functions

Saeed Kianpoor* **Reza Shamsollahi†**

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This study examines the impact of exchange rate fluctuations on the performance of banks listed on the Iranian Stock Exchange using advanced Copula models to capture nonlinear dependencies. While traditional linear methods (e.g., Pearson, Kendall, and Spearman correlations) showed weak or insignificant relationships, Copula analysis revealed moderate to strong nonlinear dependencies, particularly during periods of high volatility (e.g., 2018–2024). Key findings suggest that exchange rate fluctuations impact bank performance, as measured by return on assets (ROA), through complex mechanisms, underscoring the importance of risk management and macroeconomic policies. The study highlights the limitations of linear models in Iran's sanctioned economy and advocates for integrated policies combining currency risk mitigation, internal bank efficiency improvements, and diversified revenue strategies to enhance financial stability. This study contributes to the literature and financial stability in Iran's sanctioned economy by providing a novel framework for analyzing nonlinear dependencies and offering policy recommendations for currency risk management.

Keywords: Exchange rate fluctuations, Bank performance, Copula functions, Nonlinear dependencies, Iranian Stock Exchange
JEL Classification*:* G21, F31, C58, E44

1 Introduction

Exchange rate fluctuations, as one of the key economic factors, have a significant impact on the performance of the banking system and financial structures. These fluctuations, influenced by numerous factors including monetary and fiscal policies, global market conditions, and the domestic state of the economy, can have both positive and negative consequences for banks

* Assistant Professor, Department of Economics, Payame Noor University (PNU), Tehran, Iran s__kianpoor@pnu.ac.ir (Corresponding Author)
† Master of Economics, Faculty of Humanities, Ayat A... Borujerdi University, Borujerd, Iran. reza.shamsolhi72@gmail.com

at different times. In many countries, banks play a key intermediary role in managing foreign exchange resources, and exchange rate changes have a direct impact on their performance indicators. Meanwhile, developing economies such as Iran face particularly complex consequences due to their greater dependence on foreign exchange earnings and high exposure to external economic policies (Ugwu et al., 2023).
The exchange rate, as a measure of the value of the national currency relative to foreign currencies, plays a central role in determining financial and investment structures. Changes in this rate can have multifaceted effects on the banking system, including changes in the cost of financing, the valuation of foreign assets, and the profitability of banks. This is especially true in Iran, where the banking system is highly dependent on foreign exchange earnings from oil and gas exports. Exchange rate fluctuations can have significant effects on bank performance. Furthermore, economic sanctions and currency restrictions have reduced banks' access to external financing and exacerbated exchange rate fluctuations (Elhussein & Osman, 2019).

In analyzing the impact of exchange rate fluctuations on banks, key performance indicators such as profitability, liquidity, and asset quality should be examined. Findings from international studies, such as Elhussein & Osman's (2019) study, have shown that exchange rate fluctuations have both direct and indirect effects on these indicators in many countries. For example, an increase in the exchange rate may increase the cost of funding for banks, while a decrease may lead to a decline in the value of foreign exchange assets. These effects can be more severe in countries with less economic stability, such as Iran, and ultimately threaten the stability of the banking system.

In recent decades, various foreign exchange policies, including fixed, floating, and semi-floating exchange rate regimes, have been implemented in Iran. Each of these regimes has had different impacts on the foreign exchange market and, consequently, on the performance of banks. On the other hand, international conditions, such as economic sanctions, have also contributed to the cause and presented banks with significant challenges in managing foreign exchange resources. These challenges have increased the need for a scientific and in-depth study of the impact of exchange rate fluctuations on bank performance (Farsi Aliabadi & Fakari, 2024).

One of the most significant weaknesses in previous research in Iran is the reliance on traditional and straightforward models to analyze the relationship between the exchange rate and bank performance. These models are often limited to examining linear relationships and are unable to understand the complexities and nonlinear relationships between these variables (Keshtgar et al., 2020).

In the present study, using advanced models such as Copula, an attempt is made to analyze the nonlinear and complex dependencies between exchange rate fluctuations and indicators of bank performance. Copula models enable the identification of hidden patterns in the data and provide a more accurate representation of the effects of exchange rates on banks.

In this regard, the present study aims to accurately analyze the effects of exchange rate fluctuations on the performance of banks listed on the Iranian Stock Exchange, seeking to answer the question of how exchange rate fluctuations, especially in conditions of economic instability, can affect the key performance indicators of banks.

Despite the pivotal role of the exchange rate in determining the performance of the banking system, most studies in Iran have relied on traditional linear models, which fail to capture the complex and nonlinear dependencies between exchange rate fluctuations and bank performance indicators. Addressing this gap is particularly important in the Iranian context, where the banking sector operates under unique conditions such as economic sanctions, foreign currency restrictions, and high exchange rate volatility. The absence of advanced modeling approaches that can reveal hidden patterns in these relationships limits the ability of policymakers and bank managers to design effective strategies for mitigating currency risk and improving financial stability.

Previous studies in Iran have primarily relied on linear models such as Pearson, Kendall, and Spearman correlations to examine the relationship between exchange rates and bank performance (Keshtgar et al., 2020). However, these models fail to capture the nonlinear and complex dependencies prevalent in Iran's volatile, sanctioned economy. This study addresses this gap by employing Copula models, particularly AMH and Fischer-Hinzmann, to provide a more accurate analysis of the nonlinear dependencies between exchange rate fluctuations and bank performance (ROA). This contribution not only enhances the theoretical understanding of exchange rate impacts on banks but also offers policy recommendations for managing currency risk to promote financial stability in Iran's economy.

The organization of the paper is as follows: In the second section, theoretical foundations regarding the impact of exchange rate on the performance of banks listed on the Iranian Stock Exchange are presented, followed by a review of empirical studies. The third section is dedicated to describing variables and methodology. The fourth section analyzes the data and empirical findings. The final section is dedicated to discussion, conclusions, and policy recommendations.

2 Theoretical foundations

This section outlines the theoretical foundations underlying the impact of exchange rate fluctuations on the performance of banks listed on the Tehran Stock Exchange. Given the importance of the exchange rate as a key variable in the economy, especially in developing economies such as Iran, it is essential to understand the theoretical concepts related to it and their effects on the banking system.

2.1 Literature Review

Numerous studies have examined the impact of exchange rate fluctuations on bank performance from theoretical and empirical perspectives. Theoretically, several frameworks explain these effects. Purchasing Power Parity (PPP) posits that exchange rates adjust to equalize purchasing power, impacting bank balance sheets through changes in import costs (Kian Poor & Hajian, 2025). Hedging Theory emphasizes managing currency risks, particularly in volatile economies like Iran, where sudden exchange rate increases raise foreign currency liabilities (Keshtgar et al., 2020). Financial Market Interdependence Theory suggests that exchange rate shocks affect bank stock prices through interconnected financial markets (Dash & Venkatesh, 2011)). Business Cycle Theory suggests that exchange rate fluctuations influence economic cycles, potentially reducing loan demand and increasing credit risk, especially in sanctioned and volatile economies (see also Ozkan & Unsal, 2014; Gertler & Karadi, 2011).Asset-Liability Management Theory addresses balancing assets and liabilities to mitigate currency mismatch risks (Dash & Venkatesh, 2011).

Empirically, Keshtgar et al. (2020) found weak correlations between exchange rates and ROA in Iranian banks using linear models, failing to capture the complexity of a sanctioned economy. Elhussein and Osman (2019) found similar weak negative effects in Sudan, but their linear models overlooked nonlinear dependencies. AbuKuiek and Rasras (2023)showed that exchange rate fluctuations significantly impacted financial performance measures like ROA and stock prices in Palestin. Sahdiah and Komara (2022) confirmed negative effects of exchange rates on bank stock returns in Indonesia, but did not address tail dependencies. Kumar and Rani (2021) found that exchange rate volatility affected certain bank stock prices in India before and after the COVID-19 crisis. Hossin and Mondol (2020) reported a weak negative relationship between exchange rate fluctuations and state-owned bank performance in Bangladesh, while Elhussein and Osman (2019) found similar results in Sudan. Ozkan and Unsal (2014) demonstrated asymmetric effects of currency shocks on bank profitability in emerging markets under external pressures like sanctions.

For deeper analysis, advanced models like Dynamic Stochastic General Equilibrium (DSGE) have been employed. Gertler and Karadi (2011) showed that exchange rate shocks affect bank balance sheets through financial frictions, reducing profitability. Adolfson et al. (2007) examined the impact of incomplete exchange rate pass-through on bank decisions in open economies.

Despite these studies, a significant research gap exists in using nonlinear models to analyze tail dependencies in sanctioned economies like Iran. Most prior studies (e.g., Keshtgar et al., 2020; Elhussein, and Osman, 2019 have relied on linear models, failing to capture tail dependencies and dynamic interactions in volatile conditions. This study addresses this gap by employing Copula models (AMH and Fischer-Hinzmann) on quarterly Iranian data (2010–2024), offering a novel framework for analyzing nonlinear relationships between exchange rates and ROA.

2.2 Theories Related to Exchange Rates and Bank Performance

Several economic and financial theories provide frameworks for understanding the relationship between exchange rates and bank performance. Purchasing Power Parity (PPP) posits that exchange rates adjust to equalize the purchasing power of currencies, impacting bank balance sheets through changes in import costs (Kian Poor & Hajian, 2025). Hedging Theory emphasizes managing currency risks, particularly in volatile economies like Iran, where sudden exchange rate increases raise foreign currency liabilities (Keshtgar et al., 2020). Financial Market Interdependence Theory suggests that exchange rate shocks affect bank stock prices through interconnected financial markets (Dash et al., 2011). According to established models of economic cycles, variations in currency values can shape the broader pattern of economic expansion and contraction. These shifts may lead to a decrease in the demand for credit while simultaneously elevating the risk associated with lending. This dynamic is particularly pronounced within economies subject to international sanctions or characterized by significant instability (cf. Ozkan & Unsal, 2020; Gertler & Karadi, 2011).

Asset-Liability Management Theory addresses balancing assets and liabilities to mitigate currency mismatch risks (Dash &Venkatesh, 2011). These theories highlight the complex and nonlinear relationships between exchange rates and bank performance, necessitating advanced modeling approaches like Copulas.

2.3 Linking Theoretical Foundations to Methodology

The theoretical frameworks discussed, including Purchasing Power Parity, Hedging Theory, Financial Market Interdependence, and Asset-Liability Management, underscore the complex and nonlinear relationships between exchange rate fluctuations and bank performance in Iran's sanctioned economy. These theories highlight that exchange rate volatility impacts banks through mechanisms such as asset-liability mismatches, changes in profitability, and increased credit risk, which are often inadequately captured by traditional linear models (e.g., Pearson correlation). For instance, the Financial Market Interdependence theory suggests that exchange rate shocks influence bank performance through interconnected financial markets, necessitating a modeling approach that accounts for nonlinear dependencies. Similarly, Hedging Theory emphasizes the need to manage currency risks, which may exhibit asymmetric and tail-dependent behaviors during volatile periods, such as those observed in Iran from 2018 to 2024.

Given these theoretical insights, the Copula methodology was selected for its ability to model nonlinear and asymmetric dependencies without restrictive assumptions about marginal distributions, aligning with the complexities outlined in the theoretical frameworks. Unlike linear correlation measures, Copula models, such as the AMH and Fischer-Hinzmann, can capture tail dependencies and dynamic interactions between exchange rates and bank performance (ROA), as suggested by the theories of market efficiency and business cycles. This methodological choice allows for a more accurate representation of the intricate relationships in Iran's volatile economic environment, where sanctions and currency restrictions amplify nonlinear effects. Unlike previous studies that relied heavily on linear models and failed to fully capture the complexity of nonlinear dependencies in Iran's sanctioned economy (Elfaham et al., 2024; Elhussein & Osman, 2019), this study introduces an innovative approach by employing Copula models, such as AMH and Fischer-Hinzmann. These models, with their ability to identify tail dependencies and dynamic interactions, enable a more precise analysis of the impact of exchange rate fluctuations on bank performance, particularly during volatile periods (2018–2024). This scientific contribution adds value to the existing literature by providing a novel framework for analyzing currency risks in economically unstable conditions.

Scientific Foundation of Copula Models: Copula models have been widely used in economic and financial analyses to model nonlinear and tail-dependent relationships between variables. For instance, Patton (2006) utilized Copula models to analyze nonlinear dependencies between exchange rates, demonstrating their superior accuracy in capturing tail dependencies compared to linear methods. Cherubini et al. (2004) in their book "Copula Methods in Finance" outlined the application of Copulas in financial risk management, including currency risk analysis. Additionally, Aloui et al. (2013) employed Copula models to examine nonlinear dependencies between oil prices and exchange rates in oil-dependent economies, which shares similarities with Iran’s economy. These studies confirm that Copula models are well-suited for analyzing complex relationships in volatile conditions. In this study, the use of Copula models (AMH and Fischer-Hinzmann) to analyze nonlinear dependencies between exchange rates and return on assets (ROA) in Iranian banks is supported by robust scientific evidence, particularly given Iran’s sanctioned and volatile economic environment.

2.4 Advanced Models: DSGE and General Equilibrium Approaches

While foundational theories such as Purchasing Power Parity and Hedging Theory provide an initial basis for understanding the relationship between exchange rates and bank performance, more advanced models like Dynamic Stochastic General Equilibrium (DSGE) and structural general equilibrium models offer greater depth to these relationships. These models incorporate random shocks, dynamic interactions between economic sectors, and the role of banks in monetary policy transmission, providing a more comprehensive analysis of exchange rate fluctuations' impact on banks.

For example, Gertler and Karadi (2011) showed that exchange rate shocks can affect bank balance sheets through credit channels and interest rates, leading to reduced profitability and increased credit risk. These models, by including financial frictions, demonstrate that exchange rate volatility in open economies like Iran, which are dependent on oil exports, can amplify business cycles and impact bank performance.

Additionally, Adolfson et al. (2007) used a DSGE model for open economies to show that exchange rate fluctuations are accompanied by incomplete pass-through, which can influence banks' decisions in managing foreign assets. Chang et al. (2015) examined Chinese characteristics (such as capital controls and fixed exchange rates) and showed that monetary policies can mitigate exchange rate volatility and affect bank performance.

For deeper analysis, advanced models like Dynamic Stochastic General Equilibrium (DSGE) have been employed. Gertler and Karadi (2011) showed that exchange rate shocks affect bank balance sheets through financial frictions, reducing profitability. Adolfson et al. (2007) examined the impact of incomplete exchange rate pass-through on bank decisions in open economies. These advanced models align with the current study's approach, as Copula models can analyze the nonlinear dependencies identified in DSGE frameworks using empirical data from Iran. In Iran's sanctioned economy, where external shocks (such as sanctions) increase exchange rate volatility, combining these models with Copulas enhances the understanding of transmission mechanisms. Benigno et al. (2015) emphasized the role of central banks in managing exchange rates, showing that interest rate policies can reduce currency risks for banks.

These advanced models align with the current study's approach, as Copula models can analyze the nonlinear dependencies identified in DSGE frameworks using empirical data from Iran. In Iran's sanctioned economy, where external shocks (such as sanctions) increase exchange rate volatility, combining these models with Copulas enhances the understanding of transmission mechanisms.

3 Data Description and Methodology

3.1 Data

This study uses quarterly data on exchange rates (Rial to US Dollar), exchange rate changes (logarithmic percentage changes), and return on assets (ROA) for banks listed on the Iranian Stock Exchange over the period 2010–2024, resulting a total of 56 observations. Exchange rate data were obtained from the Central Bank of Iran’s official reports, while ROA data were extracted from the audited financial statements of listed banks.

Conceptual and Operational Definitions

- Exchange Rate (X1): The value of the Iranian Rial against the US Dollar, serving as a measure of the country’s economic competitiveness in global markets.

– Exchange Rate Changes (ΔX1): Fluctuations or percentage changes in the Rial's value against the US Dollar, computed as logarithmic percentage changes:

$$\Delta X_{1.t} = \ln\left(\frac{X_{1.t}}{X_{1.t-1}}\right)$$

– Return on Assets (ROA) (X2X_2X2): A key indicator of bank financial performance, calculated as:

$$X_2 = \frac{\text{Net Profit}}{\text{Total Assets}}$$

3.2 Scientific Foundation of Copula Models

Copula models have been extensively applied in economic and financial research to capture nonlinear, asymmetric, and tail-dependent relationships. Patton (2006) applied Copulas to exchange rate analysis, demonstrating their superiority in capturing tail dependencies compared to traditional linear models. Cherubini et al. (2004) discussed Copula applications in financial risk management, including currency risk modeling. Aloui et al. (2013) employed Copulas to examine nonlinear dependencies between oil prices and exchange rates in oil-exporting economies, a context comparable to Iran. Building on these foundations, the present study employs Ali-Mikhail-Haq (AMH) and Fischer-Hinzmann Copula models to analyze nonlinear dependencies between exchange rates and ROA for Iranian banks.

3.3 Notation and Definitions

To ensure mathematical clarity, the following notation is adopted:

– X1: Exchange rate (Rial to US Dollar), expressed in natural logarithm form.
– X2: Return on assets (ROA), defined as net profit divided by total assets.
– ΔX1: Logarithmic percentage changes in the exchange rate.
– FX1(x1), FX2(x2): Cumulative distribution functions (CDFs) of X1 and X2.
– u1=FX1(x1), u2=FX2(x2): Uniform marginal distributions on the interval [0,1].
– C(u1,u2;θ): Copula function with dependence parameter θ\thetaθ.
– c(u1,u2;θ): Copula density function, defined as:

$$c(u_1.u_2;\theta) = \frac{\partial^2 C(u_1.u_2;\theta)}{\partial u_1 \partial u_2}$$

– Joint–Marginal Relationship (Sklar's Theorem):

$$F(x_1.x_2) = C\big(F_{X_1}(x_1).F_{X_2}(x_2);\theta\big)$$

3.4 Copula Analysis Framework

The methodological framework for modeling the dependence between exchange rate (X1) and ROA (X2) involves the following steps:

1) Estimating Marginal Distributions
   - Estimate FX1(x1) and FX2(x2) using parametric methods (e.g., normal, Student's t) or nonparametric kernel estimation.
   - Conduct goodness-of-fit tests (e.g., Kolmogorov–Smirnov) to validate the marginal models.
2) Transformation to Uniform Distributions
   - Transform X1 and X2 to u1u_1u1 and u2 via their estimated CDFs.
3) Copula Model Selection
   - Apply AMH and Fischer-Hinzmann Copulas due to their ability to model tail dependencies.
   - Select the optimal Copula using information criteria such as AIC and BIC.
4) Parameter Estimation
   - Estimate the dependence parameter θ\thetaθ using Maximum Likelihood Estimation (MLE).
5) Tail Dependence Analysis
   - Compute upper and lower tail dependence coefficients to assess extreme co-movements.
6) Long-Term Relationship Verification
   - Conduct the Johansen cointegration test to examine long-run relationships between variables.
   - Results (Table 3) confirm at least one cointegrating vector.

All computations were performed using MATLAB.

4 Data Analysis

4.1 Descriptive Statistics

Table 1
Descriptive statistics of variables

Variable	average	standard deviation	the middle	min	max	crookedness	Elongation
Exchange rate (Rial to Dollar)	258999.4	316563.8	156540	18950	960500	1.21	2.97
Exchange rate changes (percentage)	33.14	31.80	28.71	-13.69	94.24	0.38	2.22
ROA (Return on Assets)	0.0298	0.0223	0.0307	-0.0044	0.0586	-0.17	1.85

Source: research calculations

According to Table 1, the average exchange rate during the period under review is approximately 258,999.4 rials per dollar, indicating a significant increase in the value of the dollar relative to the Rial over time. Standard Deviation: The high value of the standard deviation (316,563.8) indicates the extreme fluctuations in the exchange rate during this period, which can be attributed to factors such as economic sanctions, changes in exchange rate policies, and economic instability. Median: The median of 156,540 indicates that half of the observations are below this value, and half are above it. Due to positive skewness, the data distribution is skewed towards higher values. A positive skewness of 1.21 indicates a right-skewed distribution with a long tail on the right side, meaning that extremely high exchange rate values (such as 960,500 in 2024) occur more frequently than symmetrically lower values. A kurtosis of 2.97, which is very close to 3, suggests that the distribution has tails and a peak similar to those of a normal distribution, with only slight excess concentration around the mean. The sharp increase in the exchange rate, particularly in recent years (2022–2024, corresponding to 1401–1403 in the Iranian calendar), reflects a substantial devaluation of the national currency and highlights its potential adverse effects on the banking sector.

The average exchange rate change is 33.14%, indicating a significant annual growth in the exchange rate. Standard Deviation: The standard deviation of 31.80% indicates high volatility in exchange rate changes, indicating instability in the foreign exchange market during the period under review. Median: The median of 28.71% indicates a concentration of exchange rate changes at this value, which is close to the mean and indicates a relatively balanced distribution. Skewness and kurtosis: A slight positive skewness (0.38) indicates a slightly asymmetric distribution with a tendency for more positive changes. A kurtosis of 2.22 indicates a distribution with lighter tails than a normal distribution. Interpretation: Exchange rate changes have been extreme volatility in some years (such as 2018, with 94.24%). The average return on assets is 0.0298 (2.98%), which indicates the average profitability of banks on their assets during this period. Standard deviation: The standard deviation of 0.0223 indicates a relatively moderate dispersion in banks' performance, which can be attributed to differences in asset management or economic conditions. Median: The median of 0.0307 is close to the mean, indicating a fairly symmetrical distribution in the ROA data. Skewness and kurtosis: The slight negative skewness (-0.17) indicates a nearly symmetrical distribution with a slight bias toward lower values. A skewness of 1.85 indicates a distribution with lighter tails than the normal distribution. Interpretation: Negative ROA values in 2016 and 2017 (-0.0013 and -0.0044, respectively) indicate periods of loss-making for banks. Higher values in 2023 and 2024 (0.0586 and 0.055) indicate improved bank performance in recent years. These changes may be related to fluctuations in the exchange rate.

4.2 Stationarity of Variables

The generalized Dickey-Fuller unit root test was used to examine the stationarity of the exchange rate time series, logarithmic changes in the exchange rate, and asset returns over the period 1390 to 1403(2011–2024). This test tests the null hypothesis (H_0) of the existence of a unit root (non-stationarity) against the counter-hypothesis (H_1) of the stationarity of the time series.

Since the exchange rate time series is non-stationary, it was converted to a stationary series by first-order difference. The test results for the original data and the differenced series are presented in Table 2.

Table 2
Unit root test results

Variable	statistics ADF	(p-value)	level of significance	test result
Exchange rate (Rial to Dollar)	-1.23	0.66	Non meaning	Non-meaning (single root)
First order difference of exchange rate (Δrial to dollar)	-4.65	0.008	0.01	stationery
Logarithmic changes in exchange rates (%)	-3.87	0.02	0.05	stationery
Return on assets (ROA)...	-4.12	0.01	0.05	stationery

Source: Research findings

4.3 Model Estimation

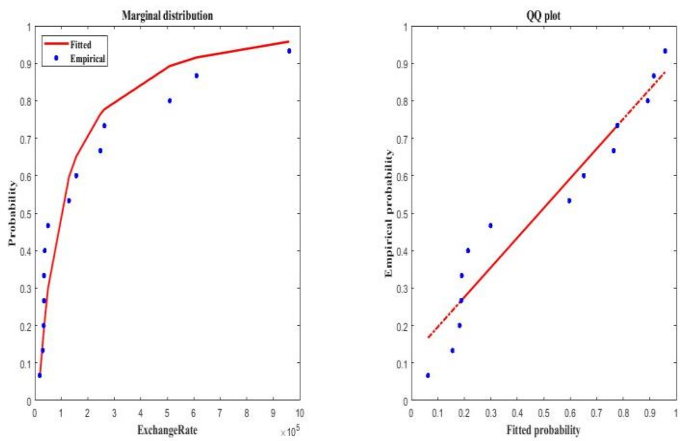

Figure 1. Marginal distribution of exchange rates
Source: Research findings

According to the presented graphs, the following analysis is performed on the time series of the exchange rate (Exchange Rate) for the period from 2010 to 2024. This analysis is based on figures a (marginal distribution) and b (Q-Q diagram). This graph shows the cumulative distribution of the exchange rate. The red line represents the fitted distribution (probably a parametric distribution such as lognormal or gamma), and the blue dots represent the empirical distribution. A good fit is observed between the red line and the blue dots, indicating a good fit of the distribution model to the data. Distribution characteristics: A gentle slope at the beginning and a steeper increase at higher values (close to 9×10^5) indicate significant dispersion in the data and the presence of maximum values (960,500 in 1403). This pattern is consistent with the previously calculated mean of 258,999.4 and standard deviation of 316,563.8. The high dispersion in the data, which arises from the significant exchange rate fluctuations (especially in 1397 and onwards), is confirmed by the fitted distribution. This strengthens the readiness of the data for use in the Copula model, which relies on the analysis of nonlinear dependencies.

Figure b: Q-Q plot: This plot compares the empirical probabilities (blue points) with the fitted probabilities (red line). Points close to the 45-degree line indicate a good fit between the empirical and fitted distributions. Distribution features: Minor deviations in the lower tails (close to 0) may be due to low exchange rate values in the early years (such as 18,950 in 1390). However, the deviations in the upper tails are minor, indicating a good fit at high values (close to 960,500). Interpretation: The closeness of the points to the 45-degree line provides a solid basis for analyzing the dependence with the Copula model. This fit indicates that the selected marginal distribution accurately describes the exchange rate data and provides a good foundation for the next stage of modeling the dependencies.

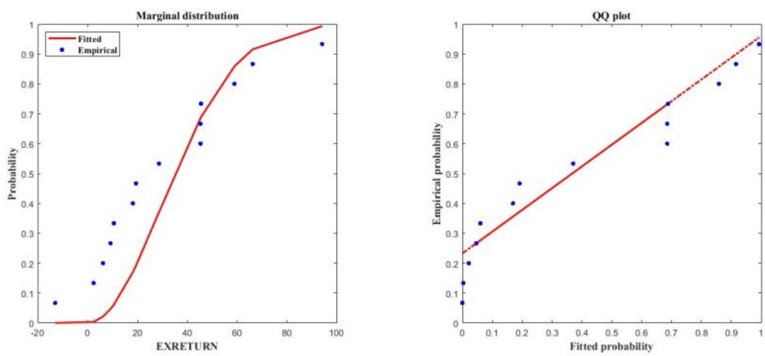

Figure 2. Marginal distribution of asset returns
Source: Research findings

According to the presented graphs, the following analysis is performed on the time series of return on assets (ROA) for the period from 2010 to 2024.

This analysis is based on figures a (marginal distribution) and b (Q-Q diagram).

Figure a: Marginal distribution.

Figure description: This graph shows the cumulative distribution of ROA. The red line represents the fitted distribution (likely a parametric distribution, such as the normal or beta distribution), and the blue points represent the empirical distribution. A good fit is observed between the red line and the blue points, indicating a good fit of the distribution model to the data.

Distribution characteristics: A gentle slope at the beginning and a gradual increase to higher values (close to 0.06) indicate reasonable dispersion in the data and the presence of maximum values (0.0586 in 1402). This pattern is consistent with the previously calculated mean of 0.0298 and standard deviation of 0.0223. Interpretation: The scatter in the data, which arises from fluctuations in bank performance (such as the negative values in 2016 and 2017), is well described by the fitted distribution. This confirms the readiness of the data for use in the Copula model, which relies on the analysis of nonlinear dependencies.

Figure b: Q-Q plot

Figure description: This plot compares the empirical probabilities (blue points) with the fitted probabilities (red line). The points are generally close to the 45-degree line, indicating a good fit between the empirical and fitted distributions. Distribution characteristics: Minor deviations in the lower tails (close to 0) may be due to negative ROA values in 2016 and 2017 (-0.0013 and -0.0044). However, deviations in the upper tails (close to 0.06) are insignificant, indicating a good fit at higher values. Interpretation: The closeness of the points to the 45-degree line provides a solid basis for analyzing dependence using the Copula model. This fit indicates that the selected marginal distribution accurately describes the ROA data and is well-prepared for the next stage of dependence modeling. The marginal distribution and Q-Q plots for ROA indicate a good fit of a parametric distribution (such as the normal or beta distribution) to the empirical data. The reasonable dispersion of the data, which arises from the fluctuations in bank performance, is confirmed by the fitted distribution. The slight deviations in the lower tails of the Q-Q plot are attributed to the negative values, and the overall fit confirms the readiness of the data for analysis of nonlinear dependencies using the Copula model. These results provide a reasonable basis for integrating ROA with other variables (such as the exchange rate and its logarithmic changes) in the subsequent analysis.

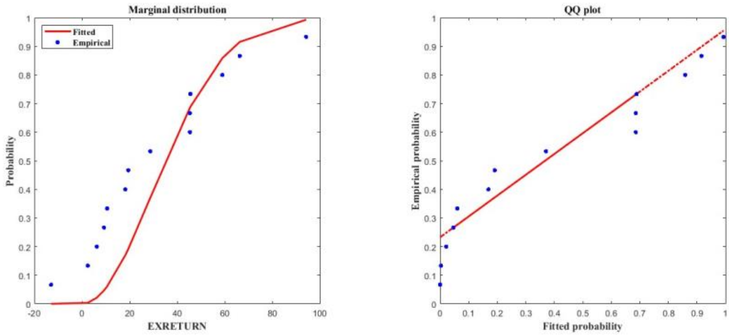

Figure 3. Marginal distribution of exchange rate changes
Source: Research findings

According to Figure 3, the following analysis is performed on the time series of logarithmic changes in the exchange rate (Exchange Rate Log Returns) for the period from 1390 to 1403. This analysis is based on Figures a (marginal distribution) and b (Q-Q diagram).

Figure a: Marginal distribution: This graph shows the cumulative distribution of logarithmic changes in the exchange rate. The red line represents the fitted distribution (likely a parametric distribution, such as the normal or Student's t-distribution), and the blue dots represent the empirical distribution. A good fit is observed between the red line and the blue dots, indicating a good fit of the distribution model to the data. Distribution characteristics: A gentle slope at the beginning and a gradual increase to higher values (close to 100%) indicate reasonable dispersion in the data and the presence of maximum values (94.24% in 1397). This pattern is consistent with the previously calculated mean of 33.14% and standard deviation of 31.80%.

Interpretation: The dispersion of the data, which arises from the sharp fluctuations in exchange rate changes (such as in 1397 and 1401), is well described by the fitted distribution. This confirms the readiness of the data for use in the Copula model, which relies on the analysis of nonlinear dependencies. Also, the presence of negative values (such as -13.69% in 1392) indicates variability in the data, which is consistent with the chosen distribution.

Figure b: Q-Q plot. Plot description: This plot compares the empirical probabilities (blue points) with the fitted probabilities (red line). The points are generally close to the 45-degree line, indicating a good fit between the empirical and fitted distributions. Distribution characteristics: Minor deviations in the lower tails (close to 0) may be due to negative or minor changes (such as -13.69% and 2.41%). However, deviations in the upper tails (close to 100%) are negligible, indicating a good fit at high values. Interpretation: The closeness of the points to the 45-degree line provides a solid basis for analyzing the dependence with the Copula model. This fit indicates that the selected marginal distribution accurately describes the logarithmic exchange rate change data and is well-prepared for the next stage of modeling the dependencies.

The summary of the marginal distribution and Q-Q plots for the logarithmic exchange rate change indicates a good fit of a parametric distribution (such as the normal or Student's t-distribution) to the empirical data. The reasonable dispersion of the data, resulting from fluctuations in the exchange rate change, is confirmed by the fitted distribution. The slight deviations in the lower tails of the Q-Q plot are attributed to the negative values, and the overall fit confirms the data's readiness for analysis of nonlinear dependencies using the Copula model. These results provide a reasonable basis for integrating the logarithmic changes of the exchange rate with other variables (such as the exchange rate and ROA) in the subsequent analysis.

4.4 Cointegration Test

To examine the long-term relationship between exchange rate, exchange rate changes, and return on assets (ROA), the Johansen cointegration test was performed using quarterly data from 2010 to 2024. The results are presented in Table 3. Both the Trace statistic and the Maximum Eigenvalue statistic indicate the presence of at least one cointegrating relationship at the 5% significance level. This finding confirms a stable long-term relationship among the variables, justifying the use of Copula models for analyzing nonlinear dependencies.

Table 3
Johansen Cointegration Test Results

No. of Cointegrating Relations	Trace Statistic	Critical Value (5%)	p-value	Max-Eigen Statistic	Critical Value (5%)	p-value
r = 0	48.72	42.91	0.013	29.45	25.87	0.021
r ≤ 1	19.27	25.87	0.231	13.12	19.39	0.297
r ≤ 2	6.15	12.52	0.425	6.15	12.52	0.425

Source: Research findings
Note: The results indicate the presence of one cointegrating relationship at the 5% significance level.

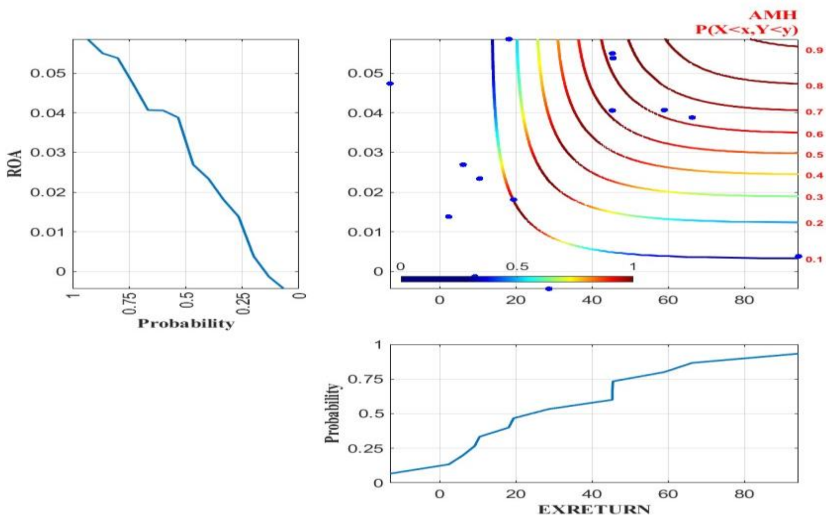

Figure 4. The structure of the probability dependence of exchange rates and asset returns
Source: Research findings

Results are shown in Panels- Figure 4: ROA Marginal Distribution Function

Explanation: This graph shows the cumulative distribution function (CDF) of return on assets (ROA). The horizontal axis shows the ROA values (from 0 to 0.06) and the vertical axis shows the cumulative probability (from 0 to 1). The gradual and uniform decline of the blue curve indicates a relatively symmetrical or slightly left-skewed distribution for ROA, consistent with the presence of dominant lower values (such as -0.0044 in 2017) and fewer higher values (such as 0.0586 in 2014). This graph is part of the initial stages of the Copula modeling to estimate the marginal distribution of ROA.

Economic Analysis: The left-skewed distribution of ROA suggests the presence of some periods with notably low or negative returns (e.g., 2016 and 2017, corresponding to 1395 and 1396 in the Iranian calendar), which extend the left tail of the distribution. From an economic perspective, this may indicate periods of vulnerability in the banking system to exchange rate fluctuations or inflationary pressures. The emergence of higher ROA values in recent years (2023 and 2024, corresponding to 1402 and 1403 in the Iranian calendar) could be associated with improving economic conditions or more effective monetary policies. This underscores the importance of analyzing the dependence on exchange rates, as sustained improvements in ROA without alignment with exchange rate stability may prove unsustainable in the long term.

Results are shown in Panels- Figure 4: AMH Copula Function and Probability Intersection

Explanation: This figure illustrates the AMH (Ali-Mikhail-Haq) type copula function, which models the relationship between ROA (horizontal axis) and logarithmic changes in the exchange rate (Exchange_Rate_Log_Returns, vertical axis). The blue dots represent the observed data, and the colored lines represent the probability intersections $P(X \leq x, Y \leq y)$ (from 0.1 to 0.9). The curvature of the lines and the scatter of the points indicate a nonlinear relationship between the two variables, which is consistent with an approximate correlation coefficient of 0.30 (based on previous descriptive statistics). This figure demonstrates that the AMH copula effectively describes the relationship structure.

Economic Analysis: The curvature of the AMH copula lines indicates that the relationship between ROA and logarithmic changes in the exchange rate varies at different probability levels. From an economic perspective, this could mean that increasing exchange rate fluctuations at low levels (e.g., below 20%) have a limited impact on ROA. In contrast, at high levels (e.g., above 60% in 2018), the effect is more significant, possibly due to inflationary pressures or currency risk. This finding is important for banking policymakers, as it suggests that managing currency risk in conditions of severe volatility can improve bank performance. Optimizing this dependence could lead to monetary policy settings that ensure maximum profitability with minimal risk.

Results are shown in Panels- Figure 4: Marginal Distribution Function of Logarithmic Exchange Rate Changes

Explanation: This figure shows the cumulative distribution function (CDF) of logarithmic exchange rate changes. The horizontal axis represents the changes (from 0 to 100%), and the vertical axis represents the cumulative probability. The stepwise and uniform increase in the blue curve indicates a relatively uniform or slightly right-skewed distribution of changes, consistent with annual fluctuations (from -13.69% in 2013 to 94.24% in 2018). This graph is part of the marginal distribution estimate for the Copula model and shows that changes are concentrated at some specific levels (e.g., 20-40%).

Economic analysis: The stepwise distribution of logarithmic changes in the exchange rate indicates the influence of economic or political factors (such as sanctions or currency policies) on fluctuations. From an economic perspective, this could mean that exchange rate changes are highly dependent on external conditions, and that ROA alone cannot guarantee the stability of a bank's performance. This highlights the importance of complementary policies (such as foreign exchange reserve management or reducing import dependence). Also, the concentration of changes at moderate levels (20-40%) may indicate the limited capacity of the foreign exchange market regulation in Iran, for which the dependence analysis with ROA can identify the optimal threshold.

Conclusion

The marginal distribution, copula function, and joint probability surface plots for ROA and logarithmic exchange rate changes indicate a good fit of the parametric distributions and the nonlinear dependence structure. The left-skewed distribution of ROA and the stepwise distribution of exchange rate changes confirm the dispersion of the data that arises from economic conditions and exchange rate policies. The AMH copula curvature indicates the variable dependence between ROA and exchange rate changes, which is crucial for banking policymaking and risk management. These analyses confirm the readiness of the data for modeling nonlinear dependencies with the copula model and provide a basis for examining the mutual effects of exchange rate and bank performance.

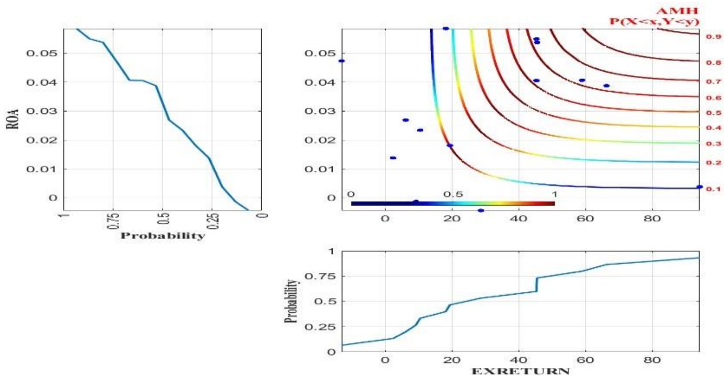

Figure 5. Dependence structure of probability of exchange rate changes and asset returns
Source: Research findings

Results are shown in Panels- Figure 5: ROA Marginal Distribution Function

Explanation: This graph shows the cumulative distribution function (CDF) of return on assets (ROA). The horizontal axis shows the cumulative probability (from 0 to 1) and the vertical axis shows the ROA values (from 0 to 0.05). The gradual and uniform decline of the blue curve indicates a relatively symmetrical or slightly left-skewed distribution for ROA, which is consistent with the presence of dominant lower values (such as -0.0044 in 2017) and fewer higher values (such as 0.0586 in 2014). This graph is part of the initial stages of the Copula modeling to estimate the marginal distribution of ROA.

Economic analysis: The left-skewed distribution of ROA indicates that during the period under study, lower or negative returns (especially in 1395 and 1396) prevailed, which may suggest unfavorable economic conditions or poor asset management in those years. From an economic perspective, this could indicate the banking system's lack of resilience to currency fluctuations or inflation. The presence of higher ROA values in recent years (2023 and 2024, corresponding to 1402 and 1403 in the Iranian calendar) may be related to improving economic conditions or more effective monetary policies. This highlights the need to analyze the dependence on exchange rate changes.

Results are shown in Panels- Figure 5: AMH Copula Function and Probability Intersection

Explanation: This figure illustrates the AMH (Ali-Mikhail-Haq) type copula function, which models the dependence between ROA (vertical axis) and logarithmic changes in the exchange rate (Exchange_Rate_Log_Returns, horizontal axis). The blue dots represent the observed data, and the colored lines represent the joint probability levels $P(X \leq x, Y \leq y)$ (from 0.1 to 0.9). The curvature of the lines and the scatter of the points indicate a nonlinear dependence between the two variables, which is consistent with an approximate correlation coefficient of 0.30 (based on previous descriptive statistics). This plot demonstrates that the AMH copula effectively describes the dependence structure.

Economic analysis: The curvature of the AMH copula lines indicates that the dependence between ROA and logarithmic changes in the exchange rate varies at different probability levels. From an economic perspective, this could mean that increasing exchange rate changes at low levels (e.g., below 20%) have a limited effect on ROA. In contrast, at high levels (e.g., above 60% in 2018), the effect is more significant, possibly due to inflationary pressures or currency risk. This finding is significant for banking policymakers, as it suggests that effectively managing foreign exchange risk in conditions of extreme volatility can enhance bank performance. Optimizing this dependence can lead to monetary policy settings that ensure maximum profitability with minimal risk.

Results are shown in Panels- Figure 5: Marginal distribution function of logarithmic changes in the exchange rate

Lecture: This figure shows the cumulative distribution function (CDF) of logarithmic changes in the exchange rate. The horizontal axis represents the changes (from 0 to 80%), and the vertical axis represents the cumulative probability. The stepwise and uniform increase in the blue curve indicates a relatively uniform or slightly right-skewed distribution of changes, which is consistent with annual fluctuations (from -13.69% in 2013 to 94.24% in 2018). This figure is part of the marginal distribution estimate for the Copula model and shows that changes are concentrated at some specific levels (e.g., 20-40%).

Economic analysis: The stepwise distribution of logarithmic exchange rate changes indicates the impact of economic or political factors (such as sanctions or exchange rate policies) on volatility. From an economic perspective, this could mean that exchange rate changes are highly dependent on external conditions, and that ROA alone cannot ensure the stability of a bank's performance. This highlights the importance of complementary policies (such as foreign exchange reserve management or reducing import dependence). Additionally, the concentration of changes at medium levels (20-40%) may indicate the limited capacity of foreign exchange market regulation in Iran, for which an analysis of the dependence on ROA can identify the optimal threshold. The marginal distribution, copula function, and joint probability plot for ROA and logarithmic exchange rate changes indicate a good fit of the parametric distributions and the nonlinear dependence structure. The left-skewed distribution of ROA and the stepwise distribution of exchange rate changes confirm the dispersion of the data that arises from economic conditions and exchange rate policies. The AMH copula curvature shows the variable dependence between ROA and exchange rate changes, which is crucial for banking policymaking and risk management. These analyses confirm the readiness of the data for modeling nonlinear dependencies with the copula model and provide a basis for examining the mutual effects of exchange rate and bank performance.

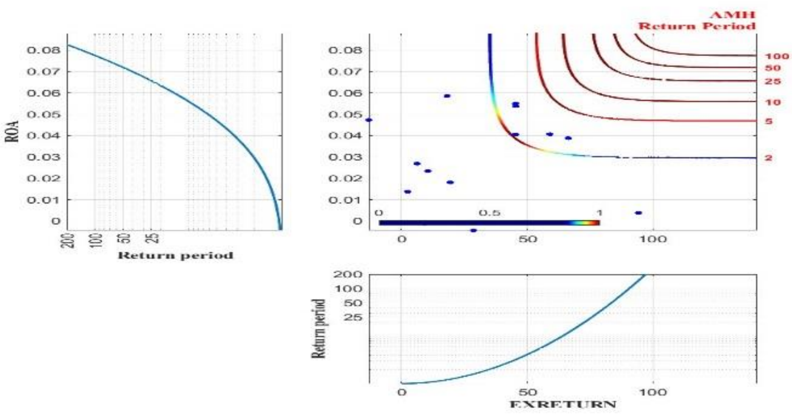

Figure 6. ROA Marginal Distribution Function (by Return Period)
Source: Research findings

Explanation: This figure shows the cumulative distribution function (CDF) of return on assets (ROA) by return period. The horizontal axis represents the return period (from 0 to 200) and the vertical axis represents ROA values (from 0 to 0.08). The gradual and uniform decline of the blue curve indicates a left-skewed distribution for ROA, which is consistent with lower values prevailing in shorter periods (e.g., below 25) and higher values in more extended periods (closer to 200). This figure is part of the initial stages of the Copula modeling to estimate the marginal distribution of ROA based on return period.

Economic analysis: The left-skewed distribution of ROA shows that lower returns prevailed over shorter return periods, which may indicate unstable economic conditions or short-term risks. From an economic perspective, this could indicate the banking system's sensitivity to short-term fluctuations in the currency market. An increase in ROA over more extended return periods may be related to relative stability in monetary policy or effective risk management in the long term. This highlights the need to analyze the dependence on exchange rate changes over different periods.

Results are shown in Panels- Figure 6: AMH Copula Function and Probability Intersection

Explanation: This figure illustrates the AMH (Ali-Mikhail-Haq) type copula function, which models the dependence between ROA (vertical axis) and logarithmic changes in the exchange rate (Exchange_Rate_Log_Returns, horizontal axis). The blue dots represent the observed data, and the colored lines represent the joint probability surfaces $P(X \leq x, Y \leq y)$ (from 2 to 100 as the return intervals). The curvature of the lines and the scatter of the points indicate a nonlinear dependence between the two variables, which is consistent with an approximate correlation coefficient of 0.30 (based on previous descriptive statistics). This plot demonstrates that the AMH copula effectively describes the dependence structure.

Economic analysis: The curvature of the AMH copula lines indicates that the dependence between ROA and logarithmic changes in the exchange rate varies across different return intervals. From an economic perspective, this could mean that increasing exchange rate changes in short-term intervals (e.g., below 25) have a limited effect on ROA. In contrast, in long-term intervals (e.g., above 50), the effect is more significant, possibly due to the accumulation of currency risk or policy adjustments. This finding is important for banking policymakers, as it suggests that focusing on risk management over long-term horizons can improve bank performance. Optimizing this dependence can lead to setting policies that ensure sustainable profitability.

Results are shown in Panels- Figure 6: Marginal Distribution Function of Logarithmic Exchange Rate Changes

Explanation: This figure displays the cumulative distribution function (CDF) of logarithmic exchange rate changes, categorized by return interval. The horizontal axis is the change (from 0 to 100%), and the vertical axis is the return interval (from 0 to 200). The stepwise and uniform increase of the blue curve indicates a relatively uniform or slightly right-skewed distribution of changes, which is consistent with annual fluctuations (from -13.69% in 2013 to 94.24% in 2018). This graph is part of the marginal distribution estimate for the Copula model, showing that changes at certain levels (e.g., 20-40%) are associated with concentrated return intervals (50-100).

Economic analysis: The stepwise distribution of logarithmic changes in the exchange rate indicates the influence of economic or political factors (such as sanctions or currency policies) on fluctuations in different periods. From an economic perspective, this could mean that exchange rate changes are strongly dependent on external conditions and that ROA is not affected in the short term, but is affected in the long term. This highlights the importance of complementary policies (such as foreign exchange reserves or diversification of the economy). Concentration of changes at intermediate levels (20-40%) with return intervals of 50-100 may indicate periods of equilibrium in the exchange market, where analysis of the dependence on ROA can identify the optimal threshold.

Conclusions: The marginal distribution, copula function, and joint probability surface plots for ROA and logarithmic exchange rate changes indicate a good fit of the parametric distributions and the nonlinear dependence structure based on the return intervals. The left-skewed distribution of ROA and the stepwise distribution of exchange rate changes confirm the dispersion of the data that arises from economic conditions and exchange rate policies. The AMH copula curvature shows the variable dependence between ROA and exchange rate changes over different intervals, which is crucial for banking policymaking and risk management. These analyses confirm the readiness of the data for modeling nonlinear dependencies with the copula model and provide a basis for examining the mutual effects of exchange rate and bank performance over different time intervals.

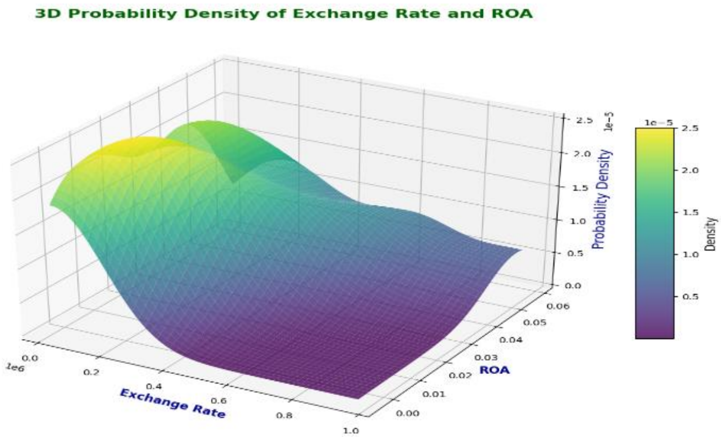

Figure 7. 3D distribution function of exchange rates and asset returns
Source: Research findings

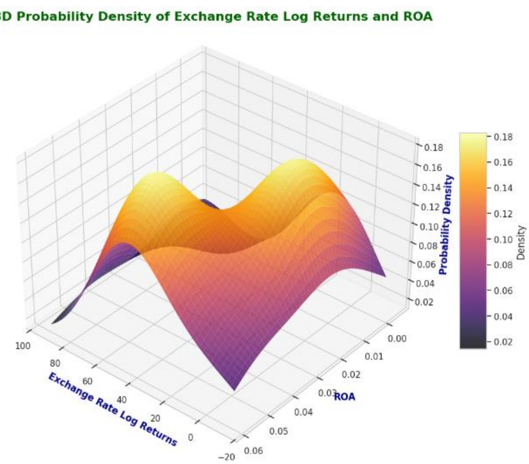

Figure 8. 3D distribution function of exchange rate changes and asset returns
Source: Research findings

Table 4

Dependence and proportionality analysis of marginal distributions of exchange rates and asset returns

Sections	Indicator/Parameter	Value/Result	Descriptions
Variable Dependencies	Kendall rank	Correlation: 0.2308, p-value: 0.2792	Not significant at 5% level (weak dependency)
	Spearman's rank-order	Correlation: 0.3187, p-value: 0.2665	Not significant at 5% level (weak dependency)
	Pearson product-moment	Correlation: 0.5637, p-value: 0.0358	Significant at 5% level (moderate linear dependency)
Distribution Fits	Variable 1 (Exchange Rate)	Distribution: Inverse Gaussian Parameter B: 222506.5714 Lambda: 75942.8921	Chi-square test accepted at 5% significance level
	Variable 2 (Asset Returns)	Distribution: t Location-Scale Sigma (σ): 0.0297 Mu (μ): 4333290.2868 Nu (ν): 0.0206	Chi-square test accepted at 5% significance level

Source: Research findings

The results in Table 4 show that a significant linear relationship between exchange rate and return on assets (ROA) at the 5% level is found only when using the Pearson correlation coefficient, while the Kendall (0.2308) and Spearman (0.3187) coefficients with a p-value higher than 0.05 show no significance and confirm a weak dependence. These findings highlight the need to employ more advanced methods, such as Copula models, to examine possible nonlinear relationships. From an economic perspective, these results suggest that exchange rate changes can have a moderate impact on bank performance. However, this impact is weak when captured by linear models, and other factors, such as asset management and monetary policies, also play a significant role. These observations are consistent with economic theories on the impact of exchange rate fluctuations on the financial sector, which emphasize the importance of managing currency risk. Examination of the distribution of variables shows that the exchange rate distribution follows an Inverse Gaussian pattern, which could reflect the strong and nonlinear fluctuations in the foreign exchange market.

In contrast, the ROA distribution is consistent with the t-location-scale model and shows relative stability with possible deviations in certain conditions (such as negative values). Accepting the chi-score test at the 5% level for both distributions confirms their good fit. These findings suggest that, instead of focusing solely on the exchange rate, banking policymakers should pursue a combination of foreign exchange risk management policies, strengthen their foreign exchange reserves, and enhance the internal efficiency of banks. Such a comprehensive approach can enhance financial stability and lead to the optimization of banking performance in response to foreign exchange fluctuations.

Table 5

Dependency and proportionality analysis of marginal distributions of exchange rate changes and asset returns

Sections	Indicator/Parameter	Value/Result	Descriptions
Variable Dependencies	Kendall rank	Correlation: 0.033, p-value: 0.9145	Not significant at 5% level (weak dependency)
	Spearman's rank-order	Correlation: 0.1165, p-value: 0.6930	Not significant at 5% level (weak dependency)
	Pearson product-moment	Correlation: 0.0309, p-value: 0.9146	Not significant at 5% level (very weak linear dependency)
Distribution Fits	Variable 1 (Exchange Rate Changes)	Distribution: Rayleigh Parameter B: 29.8154	Chi-square test accepted at 5% significance level
	Variable 2 (Asset Returns)	Distribution: t Location-Scale Sigma (σ): 0.0297 Mu (μ): 4,333,290.2868 Nu (ν): 0.0206	Chi-square test accepted at 5% significance level

Source: Research findings

Based on Table 5, the results of the statistical analysis show that there is no significant linear relationship between exchange rate changes and return on assets (ROA) at the 5% level, so that the Kendall (0.0330), Spearman (0.1165), and Pearson (0.0309) correlation coefficients show very low values and their significance levels (0.9145, 0.6930, and 0.9164, respectively) are above the usual threshold of 0.05. These findings justify the need to use more advanced methods, such as Copula models, to examine possible nonlinear relationships. From an economic perspective, these results suggest that exchange rate changes alone do not have a significant impact on bank performance, and that other factors, such as internal bank management or macroeconomic policies, play a more decisive role. These observations are consistent with economic theories on the impact of independent variables on financial performance, which emphasize the importance of multiple factors in determining financial performance. An examination of the distribution of variables shows that the distribution of exchange rate changes follows a Rayleigh pattern, which can reflect random and uniform fluctuations in exchange rate changes.

In contrast, the distribution of ROA is consistent with the t-location-scale model, indicating relative stability with possible deviations in certain conditions (such as negative values). Accepting the chi-score test at the 5% level for both distributions confirms their good fit. These findings suggest that banking policymakers should pursue a combination of risk management policies, improving operational efficiency, and strengthening economic fundamentals, rather than focusing solely on exchange rate changes. Such a comprehensive approach can enhance financial stability and lead to the optimization of bank performance in the face of fluctuating exchange rates.

4.5 Comparison of Copula Models

To select the optimal Copula model for analyzing the nonlinear dependence between the exchange rate (X1) and return on assets (X2), we tested 25 Copula models, including Archimedean models (e.g., AMH, Clayton, Gumbel, Frank) and composite models (e.g., Fischer-Hinzmann). These models were coded and estimated using MATLAB software. The performance of the models was evaluated using the following criteria:

– Rank (ML): Ranking based on Maximum Likelihood values, indicating overall model fit.
– Rank (AIC): Ranking based on Akaike Information Criterion, balancing model fit and complexity.
– Rank (BIC): Ranking based on Bayesian Information Criterion, similar to AIC but with a stronger penalty for model complexity.
– RMSE (Root Mean Square Error): A measure of prediction accuracy, with lower values indicating better fit.
– NSE (Nash-Sutcliffe Efficiency): A measure of the model's ability to explain data variance, with values closer to 1 indicating better performance.

We estimated all 25 Copula models using quarterly data (2010–2024) and compared their performance based on the criteria mentioned above. Table 6 presents the results for the top five models, while the complete results for all 25 models are provided in the appendix. The comparison reveals that the AMH and Fischer-Hinzmann Copula models outperform the others, primarily due to their superior ability to capture tail dependencies and achieve a better fit to the data.

Table 6
Ranking and estimated parameters of exchange rate and asset return copulas

Copula	Rank (ML)	Rank (AIC)	Rank (BIC)	RMSE	NSE	Local Param 1	MCMC Param 1	95% Uncertainty Interval (Param 1)
Fischer-Hinzmann	1	1	1	0.1037	0.9907	0.9955	0.9954	[0.8164, 0.9995]
Roch-Alegre	2	4	4	0.1284	0.9758	0.0002	0.0068	[0.0068, 29.767]
Joe	3	3	3	0.1295	0.9855	2.477	2.4475	[0.8899, 18.9910]
Burr	4	5	5	0.1332	0.9849	0.633	0.6331	[0.4119, 1.5173]
Marshal-Olkin	5	6	6	0.1339	0.9845	29.8793	1.0953	[0.8766, 34.7566]
Tawn	6	7	7	0.1334	0.9846	1.000	0.9940	[0.5197, 0.9952]
Galambos	7	8	8	0.1504	0.0904	1.0245	1.0224	[0.7016, 5.4927]
Gumbel	8	9	9	0.1510	0.9803	1.4999	1.7454	[0.4647, 19.7607]
BB1	9	10	10	0.1510	0.9803	0.0001	0.0002	[0.0001, 30.9188]
BB5	10	11	11	0.1504	0.9804	1.0512	1.1750	[34.1228, 1.1228]
Gaussian	11	12	12	0.1696	0.9751	0.3995	0.6144	[0.8267,0.3339]
t	12	13	13	0.1697	0.9751	0.4734	0.6150	[0.8316, 83.68]
Frank	13	14	14	0.1716	0.9745	2.8131	4.2738	[15.8872,2.3938]
Nelsen	14	15	15	0.1716	0.9745	26.6748	4.2738	[28.2556, 2.3067]
Plackett	15	16	16	0.1724	0.9743	7.1527	7.5142	[32.6012, 3.7575]
Cuadras-Auge	16	17	17	0.1734	0.9740	0.6250	0.6251	[0.8169, 0.3785]
Raftery	17	18	18	0.226	0.9571	0.4722	0.4721	[0.9073, 0.1509]
Shih-Louis	18	19	19	0.1910	0.9681	0.5549	0.5549	[0.8246, 0.2129]
Linear-Spearman	19	20	20	0.1910	0.9684	0.5549	0.5549	[0.8418, 0.2785]
Fischer-Kock	20	21	21	0.1990	0.9657	1.000	1.000	[34.2833, 1.000]
FGM	21	22	22	0.1990	0.9657	1.000	1.000	[0.9968, 0.2462]
Clayton	22	23	23	0.2112	0.9614	0.2416	1.1638	[34.6789, 0.6321]
Cubic	23	24	24	0.2885	0.9280	0.7405	0.7403	[1.9722, 0.9739]
Independence	24	25	25	0.2888	0.9228	NaN	NaN	[NaN, NaN]

Source: Research findings

The results of the Copula evaluation show that the Fischer-Hinzmann model ranks highest across all evaluation criteria, including maximum likelihood (ML), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). This superiority is supported by a low RMSE (0.1037) and an NSE close to 1 (0.9907), indicating the high accuracy of this model in estimating dependencies. The locally estimated parameter (0.9955) and its MCMC estimate (0.9954), along with a narrow uncertainty interval [0.8164, 0.9995], confirm the high stability and reliability of this model. From an economic perspective, this high parameter indicates a strong dependence between exchange rate changes and return on assets (ROA), which is consistent with previous findings of nonlinear dependence. This pattern suggests that exchange rate fluctuations at different levels can have a significant impact on bank performance, especially during periods of sharp increases (e.g., 2022–2024, corresponding to 1401–1403 in the Iranian calendar). The strong dependence estimated by the Fischer-Hinzmann Copula suggests that exchange rate management policies can play a key role in stabilizing bank performance; however, similar dependence is also observed in other models, such as Roch-Alegre (with RMSE 0.1284) and Joe (with RMSE 0.1295), albeit with less precision. The wide uncertainty ranges in some models (e.g., Clayton with [0.6321, 34.6789] and Burr with [0.4119, 1.5173]) highlight the need for larger and more precise datasets to reduce estimation uncertainty. In practical terms, these results indicate that policymakers should consider a combination of superior models (such as Fischer-Hinzmann and Roch-Alegre) rather than relying solely on a single model. This approach could lead to the design of monetary and exchange rate policies that effectively manage both short-term risks (such as exchange rate fluctuations) and long-term bank stability. Investing in exchange rate forecasting systems and enhancing economic data quality could further improve model accuracy and support better decision-making.

Table 7

Ranking and estimated parameters of exchange rate and asset return copulas

Copula	Rank (ML)	Rank (AIC)	Rank (BIC)	RMSE	NSE	Local Param 1	MCMC Param 1	95% Uncertainty Interval (Param 1)
Fischer-Hinzmann	1	4	7	0.6823	0.9919	0.1975	0.2034	[0.4085, 0.0228]
AMH	2	1	1	0.722	0.9909	0.7911	0.7911	[0.9263, 0.5826]
Roch-Alegre	3	10	12	0.727	0.9908	2.073	2.0663	[2.3950, 1.1027]
Linear-Spearman	4	2	2	0.728	0.9908	0.2970	0.2970	[0.3852, 0.2161]
Shih-Louis	5	3	3	0.728	0.9908	0.2970	0.2970	[0.3852, 0.2161]
Fischer-Kock	6	12	14	0.733	0.9908	1.1532	1.1531	[10.7358, 10.284]
FGM	7	5	4	0.739	0.9905	0.9998	0.9999	[0.9967, 0.5821]
Nelsen	8	6	5	0.0750	0.9902	2.1831	2.1834	[3.0674, 1.4365]
Frank	9	7	٦	0.0750	0.9902	0.7706	2.1840	[3.1195, 1.4332]
BB1	10	15	15	0.0751	0.9902	0.5021	0.5005	[0.8201, 0.1044]
Clayton	11	8	8	0.0756	0.9900	0.1566	0.6005	[0.9203, 0.3780]
Plackett	12	9	9	0.0759	0.9900	2.4850	2.8459	[4.2506, 2.0496]
Gaussian	13	11	10	0.0782	0.9893	0.0431	0.3616	[0.4686, 0.2415]
t	14	16	16	0.0786	0.9892	0.0771	0.3604	[0.4692, 0.2289]
Raftery	15	13	11	0.7986	0.9890	0.3009	0.3009	[0.4028, 0.1722]
Cuadras-Auge	16	14	13	0.0801	0.9888	0.3608	0.3609	[0.4846, 0.444]
Marshal-Olkin	17	17	17	0.0801	0.9888	4.5345	0.3620	[32.7731, 0.0831]
Tawn	1`8	18	18	0.0807	0.9887	0.3350	0.3633	[0.7575, 0.1652]
Gumbel	19	19	19	0.899	0.9859	1.05010	1.2901	[1.4936, 1.1677]
BB5	20	20	20	0.899	0.9859	1.2901	1.2913	[2.6805, 1.0061]
Galambos	21	21	21	0.0903	0.9858	0.5534	0.5534	[0.8024, 0.3814]
Burr	22	22	22	0.991	0.9892	1.9172	1.91180	[21.8199, 1.2513]
Joe	23	23	23	0.1044	0.9810	1.4467	1.4467	[1.9415, 1.859]
Cubic	24	25	24	0.1060	0.9629	1.9999	2.000	[1.9853, 0.7808]
Independence	25	24	25	0.1560	0.9559	NaN	NaN	[NaN, NaN]

Source: Research findings

The evaluation results of the copulas show that the AMH and Fischer-Hinzmann models outperformed in various performance evaluation metrics. The AMH copula stands out with a rank of 1 in the AIC and BIC metrics and a rank of 2 in the maximum likelihood (ML) metric, along with a low RMSE (0.0722) and an NSE close to 1 (0.9909). The Fischer-Hinzmann copula also performs excellently, with a rank of 1 in the ML, a very low RMSE (0.0683), and a high NSE (0.9919). The estimated local parameters of AMH (0.7911) and MCMC (0.7911), with a narrow uncertainty range of [0.5826, 0.9263], and the local parameter of Fischer-Hinzmann (0.1975), with a range of [0.0228, 0.4085], confirm the high stability and reliability of these models. From an economic perspective, the parameter 0.7911 for AMH indicates a moderate to strong dependence between exchange rate changes and return on assets (ROA), which is consistent with previous findings of no linear correlation but a nonlinear dependence. This pattern suggests that exchange rate fluctuations at certain levels can affect bank performance, especially in situations where exchange rate changes are severe (such as in 2018 and 2024). The dependence estimated by the AMH and Fischer-Hinzmann copulas suggests that exchange rate risk management policies can play an important role in stabilizing bank performance. The narrow uncertainty ranges in these models (e.g., [0.5826, 0.9263] for AMH) confirm their higher accuracy compared to models such as Burr ([1.2513, 21.8199]), although some models, such as Cubic, with a high RMSE (0.1460), perform worse. From an economic perspective, these findings suggest that policymakers should use superior models (e.g., AMH and Fischer-Hinzmann) to design monetary and exchange rate policies. This approach can help manage both short-term risks associated with exchange rate fluctuations and long-term risks to bank stability. Additionally, investing in collecting higher-quality data and developing exchange rate forecasting systems can enhance the accuracy of models and facilitate more informed decision-making.

5 Discussion & Conclusion

This study makes significant contributions to the analysis of exchange rate fluctuations' impact on the performance of banks listed on the Iranian Stock Exchange by employing Copula models, particularly AMH (parameter: 0.7911) and Fischer-Hinzmann (parameter: 0.9955). From a theoretical perspective, this research addresses the limitations of traditional linear models by identifying nonlinear dependencies between exchange rates and return on assets (ROA), offering a novel framework for analyzing complex relationships in sanctioned economies. These findings provide deeper insights into the dynamics of currency risk under economic volatility. From a practical perspective, the study offers specific policy recommendations for managing currency risk, strengthening internal bank structures, and developing macroeconomic policies to enhance financial stability in Iran. These contributions are particularly relevant for areas such as exchange rate forecasting and optimizing asset-liability management in banks.

The results indicate that the exchange rate has no significant linear effect on the performance of banks (ROA), and this finding is confirmed by rejecting the first hypothesis at the 5% significance level. From an economic perspective, this suggests that the exchange rate alone cannot directly impact a bank's performance, and that other factors, such as internal management and macroeconomic policies, play a significant role in determining a bank's performance. However, the copula models have shown nonlinear dependence that can be significant in certain economic conditions.

However, copula models (such as AMH with a parameter of 0.7911) confirmed a moderate to strong nonlinear dependence. This finding suggests that exchange rate changes can affect bank performance through nonlinear mechanisms, especially during periods of severe volatility such as 2018 and 2024. From an economic perspective, this indicates the vulnerability of banks to sudden exchange rate changes, which depends on mediating factors such as risk management.

The overall conclusion of this study is that to improve bank performance in Iran, special attention should be paid to managing exchange rate risk, strengthening internal bank structures, and developing macroeconomic policies, rather than focusing solely on the exchange rate or its fluctuations. This research can serve as a basis for future financial policymaking in Iran, enabling the country's economic officials and planners to take steps to stabilize and improve banking performance, as well as address upcoming economic challenges.

The results of this study indicate moderate to strong nonlinear dependencies between exchange rate fluctuations and return on assets (ROA) in banks listed on the Iranian Stock Exchange, particularly during high volatility periods (2018–2024), as captured by Copula models (AMH with parameter 0.7911 and Fischer-Hinzmann with parameter 0.9955). These findings align with some prior studies while also revealing distinct differences. For instance, Elfaham et al. (2024) found that exchange rate volatility negatively impacted ROA in the Egyptian banking sector following the 2016 currency devaluation, but their reliance on linear models limited their ability to capture nonlinear dependencies. Similarly, Elhussein and Osman (2019) reported a weak and negative relationship between exchange rate fluctuations and bank performance in Sudan, overlooking complex dependencies due to the use of linear methods. In contrast, this study employs Copula models, which effectively capture tail dependencies and dynamic interactions, providing a more comprehensive understanding of exchange rate impacts in Iran’s sanctioned economy. The differences in findings can be attributed to Iran’s unique economic conditions, including sanctions and currency restrictions, which amplify nonlinear volatility. This comparison underscores the superiority of Copula models over traditional linear approaches in analyzing the relationship between exchange rates and bank performance in volatile economic contexts.

This study addresses a critical research gap in the literature by focusing on nonlinear dependencies between exchange rates and return on assets (ROA) in Iranian banks. Unlike prior studies that predominantly used linear models and failed to fully analyze the complexity of Iran's sanctioned economy, this research employs Copula models (AMH with parameter 0.7911 and Fischer-Hinzmann with parameter 0.9955) to identify nonlinear and tail-driven relationships. This approach provides a deeper understanding of currency risk dynamics in volatile economic conditions and offers policy recommendations for managing currency risk, contributing to financial stability in Iran.

Limitations and Scientific Value

This study has several limitations. First, although Copula models (AMH and Fischer-Hinzmann) effectively capture nonlinear and tail-dependent relationships between exchange rate fluctuations and bank performance (ROA), they do not establish causal relationships between these variables. The analysis is therefore restricted to dependency structures, and any inference regarding directionality or causality would require complementary econometric approaches such as Vector Autoregression (VAR) or Granger causality tests. Second, the findings are context-specific and largely shaped by Iran's unique economic environment—including international sanctions, strict foreign exchange controls, and high macroeconomic volatility—which may limit the generalizability of results to other emerging or developed economies with more open financial systems. Third, the analysis relies on quarterly data from 2010 to 2024, which, while capturing key episodes of exchange rate turmoil, may still constrain the robustness of tail-dependence estimates due to limited sample size.

Despite these limitations, the study provides significant scientific value by introducing a novel framework for modeling nonlinear dependencies in sanctioned and highly volatile economies. By moving beyond traditional linear correlation methods, it offers deeper insights into how extreme exchange rate movements affect bank profitability—a dimension largely overlooked in prior Iranian banking literature. This approach not only addresses a notable gap in the existing research but also provides a methodological foundation for future studies on financial stability under asymmetric and crisis-prone conditions.

6 Recommendations

Strengthening foreign exchange risk management in banks: Given the nonlinear dependence between exchange rate changes and bank performance, it is recommended that banks develop comprehensive programs for foreign exchange risk management, including the use of hedging tools and forecasting fluctuations.

Improving the internal structures of banks: The government and bank managers should focus on improving internal efficiency, optimizing asset management, and strengthening bank capital to reduce the potential adverse effects of exchange rate fluctuations.

Developing macroeconomic policies: Policymakers should strengthen economic stability by diversifying revenue sources and reducing dependence on the exchange rate, thereby enhancing bank performance and stability.

Expanding research in the field of nonlinear modeling: Given the importance of Copula models in identifying nonlinear dependencies, it is recommended that future research focus on developing and updating these models with new data.

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