Systemic Risk Assessment of the Capital Market: Based on the Decomposition of Oil Shock Effects in the SVAR-Copula-GARCH Framework

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Abstract

The specific oil shocks also exhibited the lowest Akaike criterion values under a normal distribution. Analyzing the results of the copula model under the Student's t-distribution revealed that significant risk spillovers exist between the two markets during all three types of shocks. However, regarding oil supply shocks, the results confirm the presence of spillover effects from oil supply shocks to the stock market, and the 95% Value at Risk (VaR) is higher than the corresponding conditional CoVaR at the same probability level. This indicates that risk spillover from the oil market supply is associated with lower levels of value at risk in the stock market. Regarding demand-side shocks and specific oil shocks, it was also observed that significant and asymmetric risk spillover effects from the oil market to stock returns are statistically significant and confirmable. The Expected Shortfall (ES) results, except for supply shocks, were consistent with the conditional Value at Risk calculations. In fact, for all three types of oil supply shocks, the ES value is higher at the 95% level, but at the 5% level, the conditional expected shortfall is greater. This, despite confirming the existence of risk spillover effects, suggests that the spillover of oil supply shocks to the stock market is not symmetric. The spillover effects have varied across different levels of market risk exposure, indicating a long-term interpretation of shock spillover effects. Additionally, increasing and decreasing values of supply shocks have not had the same impact on stock returns.

Keywords: *systemic risk, capital market, oil shock, SVAR-Copula-GARCH framework*

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1. Introduction

The significance of oil in Iran's economy is undeniable. Meanwhile, in recent years, there has been a rapid expansion in futures trading, options, and other derivatives, making oil market fluctuations increasingly financial in nature and more integrated into the global financial system [1, 2]. Institutional investors have increased their share of investments in commodities such as oil [3, 4]. Consequently, identifying the dynamics of inter-market relationships to determine the extent to which the capital market is influenced by other markets, particularly following the 2008 financial crisis, has garnered significant attention. Understanding economic-financial relationships and adopting a systemic perspective on various dimensions of the financial-economic system are essential for policymaking in any country. However, analyzing the relationship between changes in energy prices and macroeconomic variables is somewhat complex [5, 6].

Changes in oil prices and oil price risks have significant effects on economic variables. Numerous studies have examined the impact of persistent and temporary fluctuations in OPEC oil prices on investment, production, and unemployment rates in Iran's economy. The findings of these studies indicate that persistent fluctuations in oil prices lead to reduced production and investment while increasing unemployment, with long-term effects on all three variables. Additionally, temporary uncertainty in oil prices results in decreased investment and production while increasing unemployment [7-9].

The literature on the impact of oil shocks on financial markets highlights various dimensions of risk transmission and market interactions. Baki-Hasko'I and Samadi focused on conditional variance modeling in investment portfolios using the Copula-GARCH framework, demonstrating the necessity of proper variance heterogeneity modeling for portfolio risk assessmen [10]t. Abbasi-Nejad and Ebrahimi analyzed the impact of oil price fluctuations on stock returns, revealing that while price increases have no significant effect on stock returns, higher-scale fluctuations can positively affect returns in bullish markets [11]. Homayounifar et al. used the DCC-GARCH model to assess dynamic correlations between assets, indicating that financial crises significantly alter inter-asset conditional correlations [12]. Bot Shekan et al. (2017) examined volatility spillovers in capital markets, confirming a positive correlation between stock index returns, exchange rates, and real estate returns, while dismissing significant spillovers between stock and real estate markets [13].

Some studies modeled volatility spillovers, asset allocation, and portfolio adjustments between the USD/EUR exchange rate and energy prices in six spot oil markets across different global regions using the DCC-GARCH model from 1998 to 2012. Their findings confirmed the existence of significant asymmetric exchange rate spillovers to the oil market [14-17]. Peng et al. investigated extreme oil risk spillovers into stock returns for 529 companies listed on the Shanghai Stock Exchange's A-share market using a nonparametric kernel-based method for quantile-on-quantile Granger causality testing from crude oil to company stock returns. The empirical results provided strong evidence of asymmetry in the transmission of extreme oil price movements to stock returns, indicating that the positive risk spillover is more pronounced than the negative risk spillover. Specifically, the most severe case was the spillover of lower risks to lower stock returns [18]. Other studies analyzed the impact of oil price volatility on stock markets using quantile regression and quantile-quantile regression in France, the United States, China, the United Kingdom, Germany, South Korea, Italy, and Japan. These findings reveal that when stock market returns and volatility are low, oil price volatility has a negative spillover effect on these countries' financial markets. However, when stock returns are high and oil price volatility is low, an increase in oil price volatility leads to higher stock market returns [11, 19-22].

Thus, the present study seeks to answer the following research questions:

Do different types of oil shocks have identical effects on systemic risk in Iran's capital market?

Among various asymmetric spillover models, which model, considering the Value at Risk (VaR) criterion, provides the best explanatory capability in relation to observed realities?

2. Methodology

In the present study, data collection was conducted using library research and document analysis, and quantitative analysis methods were employed for data evaluation. The software programs EViews and R (primarily through coding and relevant packages) were used for data analysis. In the case of equations related to CoES, since no specific software package was available for the required computations, customized coding was developed specifically for this study.

In this study, the real price of oil, based on monthly data from January 2009 to June 2024, is decomposed into three components: supply, demand, and oil-specific shocks. Global oil production and global oil supply data were obtained from the U.S. Energy Information Administration (EIA). The Kilian index, which serves as an indicator of global economic activity, was sourced from Kilian's personal website with updates extending to 2024. Stock returns were collected from the database of the Securities and Exchange Organization, and crude oil purchase prices were adjusted for inflation using the Consumer Price Index (CPI) from U.S. statistics.

Accordingly, the impact pattern of various oil shocks on systemic risk in the capital market was analyzed using the integrated SVAR-Copula-GARCH model. Based on Kilian's (2009) classification of oil shock types, the Value at Risk (VaR) was calculated using two methods: CoES and CoVaR. The results were then computed for different integrated SVAR models under Gaussian, Student's t, Clayton, and Gumbel copulas. The characteristics of each copula model and the corresponding results are presented in the subsequent sections of this article.

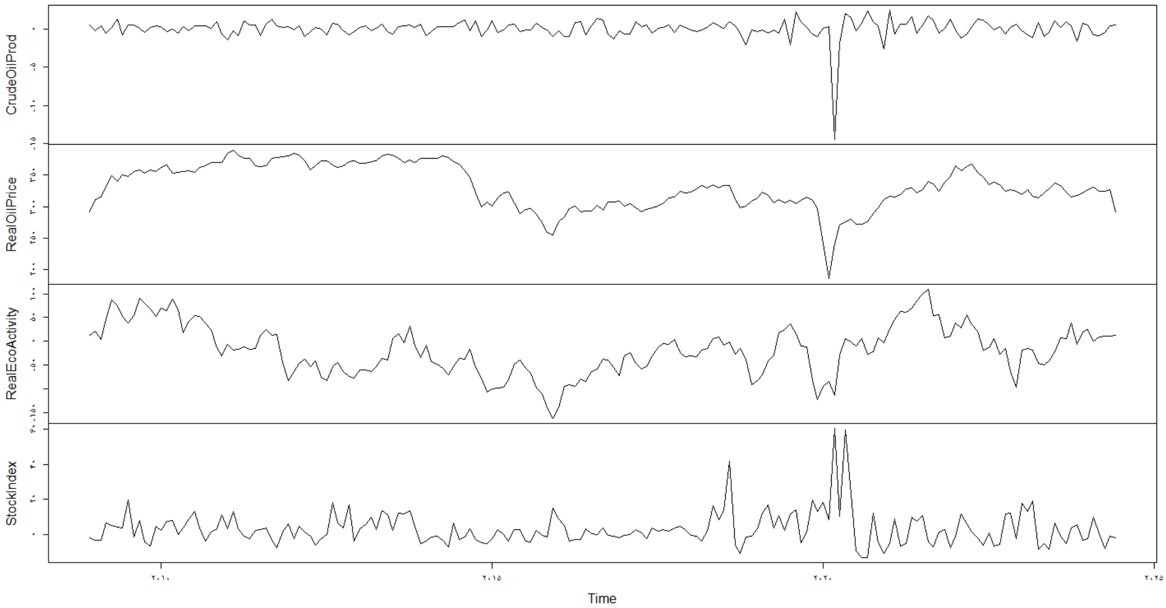

Figure 1. Crude Oil Production, Global Economic Activity Index, Real OPEC Crude Oil Price, Tehran Stock Exchange Index Returns

To examine the dynamic dependency structure between oil shocks and the Iranian stock market index, Value at Risk (VaR) was utilized, which measures the risk arising from capital movement from the oil market to stock markets. This section is primarily divided into two parts. In the first part, the real price of oil is decomposed into three components. Subsequently, by determining Value at Risk (VaR), Conditional Value at Risk (CoVaR), and Expected Shortfall (ES), which is considered an innovative aspect of this study, we assess the risk and the symmetric and asymmetric effects of the three oil shocks on the Tehran Stock Exchange market index.

Oil Shock: Oil shock refers to sudden changes in oil prices. Various definitions and measurement methods are proposed for assessing its impact on macroeconomic variables. Based on the theoretical framework of this study, the oil shock variable is measured according to the model proposed by Kilian (2009). Kilian constructs a three-variable structural VAR model to decompose the real price of oil. Based on the standard VAR model, structural shocks and impulse response functions are obtained using the Cholesky decomposition. This allows for the estimation of the three shocks, represented as $\hat{\boldsymbol{\varepsilon}}_t = (\hat{\varepsilon}_t^{SS}, \hat{\varepsilon}_t^{DS}, \hat{\varepsilon}_t^{OS})'$, and the derivation of the instantaneous response function $I_q = \frac{\partial p_{t+q}}{\partial \varepsilon_t} = (\frac{\partial p_{t+q}}{\partial \varepsilon_t^{S}}, \frac{\partial p_{t+q}}{\partial \varepsilon_t^{DS}}, \frac{\partial p_{t+q}}{\partial \varepsilon_t^{OS}})\ for\ q = 0,1,2,$ using the Cholesky decomposition. The cumulative effects of these three shocks are historically represented in the equation $p_t = c + p_t^{SS} + p_t^{DS} + p_t^{OS}$, where the components of real oil prices include supply shocks, demand shocks, and oil-specific shocks. The differential values of these shocks will be used for risk spillover analysis ($, p_t^{SS}, p_t^{DS}, p_t^{OS}$).

The dependent variable in this study is the systemic risk of the stock market, which pertains to the entire market. This type of risk, also known as "non-diversifiable risk" or "market risk," affects the overall market rather than just a specific company's or industry's stock. It is both unpredictable and unavoidable. Systematic risk in the stock market cannot be eliminated through diversification; rather, it can only be mitigated through risk-hedging strategies or asset allocation strategies.

To further analyze risk spillovers, this study employs CoVaR, introduced by Adrian and Brunnermeier (2016), to examine the transmission of risk from oil shocks to the stock market. CoVaR is widely used to assess systemic risk spillovers in financial markets. The significance of spillover effects and their asymmetry is tested using the Kolmogorov-Smirnov test. In this study, systemic market risk is evaluated using the Conditional Value at Risk (CoVaR) measure, which is defined as follows:

Value at Risk (VaR): Conditional Value at Risk for a market is the value at risk of that market, given that another variable is under financial distress (in the VaR region). In other words, conditional VaR at time t and a given confidence level ($1-\beta$) can be defined as the β-th quantile of the conditional distribution of market return prices:

$\Pr(x1t \leq CoVaR\beta;t1 \mid x2t \leq VaR\alpha;t2;\ x3t) = \beta$

where CoVaR represents the conditional value at risk of the market, and VaR represents the value at risk of the variable under analysis. Similarly, the upward price spillover is defined as:

$\Pr(x1t \leq CoVaR\beta;t1 \mid x2t \geq VaR\alpha;t2;\ x3t) = \beta$.

In this study, Value at Risk (VaR) is computed using two methods: Conditional Expected Shortfall (ES) and CoVaR. ES, or Entropic Value at Risk, is based on Kullback-Leibler divergence and measures the distance between two similar points in different distributions, enabling an asymmetric examination of relationships. The key distinguishing feature of this paper compared to previous studies is the computation of Conditional ES using two variables, which is based on the integration of relevant probability distributions. This approach allows for an understanding of the asymmetric relationships between stock return risk and oil prices.

Research Model

For each type of copula model, correlation parameters are estimated. First, a time-varying conditional copula model is formulated for the two variables of return and risk. Then, bivariate normal, Clayton, Student-t, and Gumbel distributions are derived based on Kilian (2009) and Patton (2006, 2009) through the integration of relevant probability functions, and the time-varying correlation coefficient ρt is extracted.

Subsequently, these steps are repeated using the Conditional Entropic Value at Risk (CoES), which is interpreted through Kullback-Leibler loss function divergence and is computed through the integration of relevant probability functions.

C$t(u1, u2;\ \theta c \mid \mathscr{F}t-1) = Ct(u1, u2;\ \vartheta t),\ ui = Fi,t(xi;\ \theta i \mid \mathscr{F}t-1),\ i = 1,2,$

$$D_{KL}\left(p(x)\,||\,q(x)\right) = \int_{-\infty}^{+\infty} p(x)\ln\frac{p(x)}{q(x)}d(x)$$

$$CES(X) = E\left(X \middle| X > \gamma_p(X), \boldsymbol{X} = X\right) = \int_{\gamma_p(X)}^{+\infty} yf(y|X)\,d(y)/p$$

Finally, to determine the statistical significance of risk differences, the Kolmogorov-Smirnov test is applied. Additionally, information criteria tests (Akaike, Adjusted Akaike, and Log-Likelihood Ratio) are employed to select the most suitable model, rank the models, and interpret the results.

3. Findings and Results

Major events such as wars and uprisings like the Arab Spring, global economic crises such as the 2008 financial crisis, political events like Iran's nuclear case, or oil market-specific incidents such as the BP oil spill or OPEC oil disputes, are all considered different types of shocks. According to the theoretical framework of this article, each of these events has had a distinct impact on risk spillovers between financial and oil markets, and Iran's economy has not been immune to these effects.

After conducting normality tests, ARCH effects, and heteroscedasticity tests, it was determined that both time series exhibit ARCH effects and variance heterogeneity. The next step involved estimating the SVAR model based on research model and calculating the A matrix to determine the three types of oil shocks.

Table 1. Descriptive Statistics of Research Variables

	Crude Oil Production	Real Oil Price	Global Economic Activity	Stock Market Index
Min.	-14.4643	185.8	-161.74	-13.13
1st Qu.	-0.4051	306.9	-53.56	-2.57
Median	0.2318	327.1	-17.45	2.13
Mean	0.0672	330.9	-17.85	3.36
3rd Qu.	0.5995	363.9	14.10	7.18
Max.	2.4945	389.9	109.68	60.34

Table 2. Estimated Parameters of the Reduced-Form SVAR Model

	Crude Oil Production	Real Oil Price	Global Economic Activity
Estimation of the A Matrix			
Crude Oil Production	0.772	0	0
Real Oil Price	0.275	0.093	0
Global Economic Activity	-0.282	-0.012	0.043
Estimation of the Beta (β) Matrix			
Crude Oil Production	1	0	0
Real Oil Price	0	1	0
Global Economic Activity	0	0	1
Covariance Matrix of Residuals			
Crude Oil Production	167.8	-497.7	954.9
Real Oil Price	-497.7	13092.7	371.2
Global Economic Activity	954.9	371.2	59456.3

After computing the A matrix values, the SVAR model's impulse shocks were estimated using bootstrap resampling with 1000 iterations. The left panel of Figure 2 shows that shocks originating from the global economy have a persistent but very gradual and minimal effect on real oil prices. In the middle panel, it is evident that shocks in real oil prices have a much greater effect on the global economy, with a strong impact lasting for at least four consecutive months before gradually declining after the fourth month. The right panel illustrates the effects of oil supply shocks on oil prices and the global economy, showing that supply shocks have a significantly larger impact on the global economy, with observable effects lasting for at least three months.

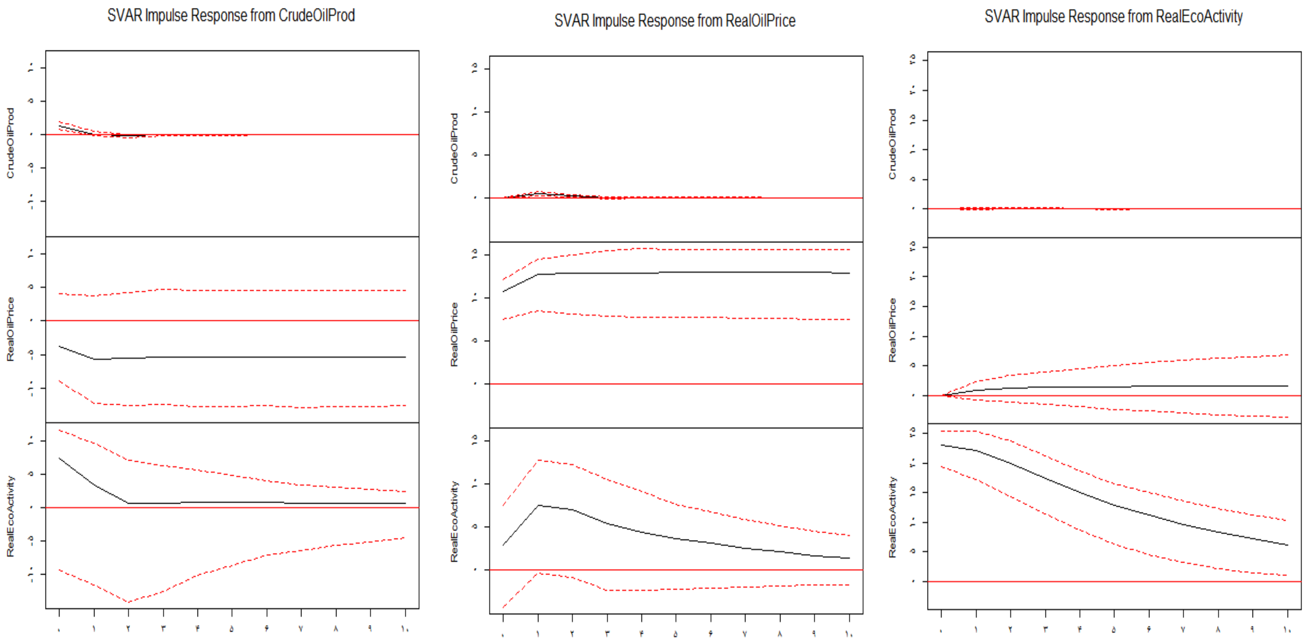

Figure 2. Impulse Shock Results Derived from AR Matrix Estimation for the Structural Model

Next, the SVAR model residuals were examined, and the results confirmed the presence of ARCH effects, as shown in Figure 3.

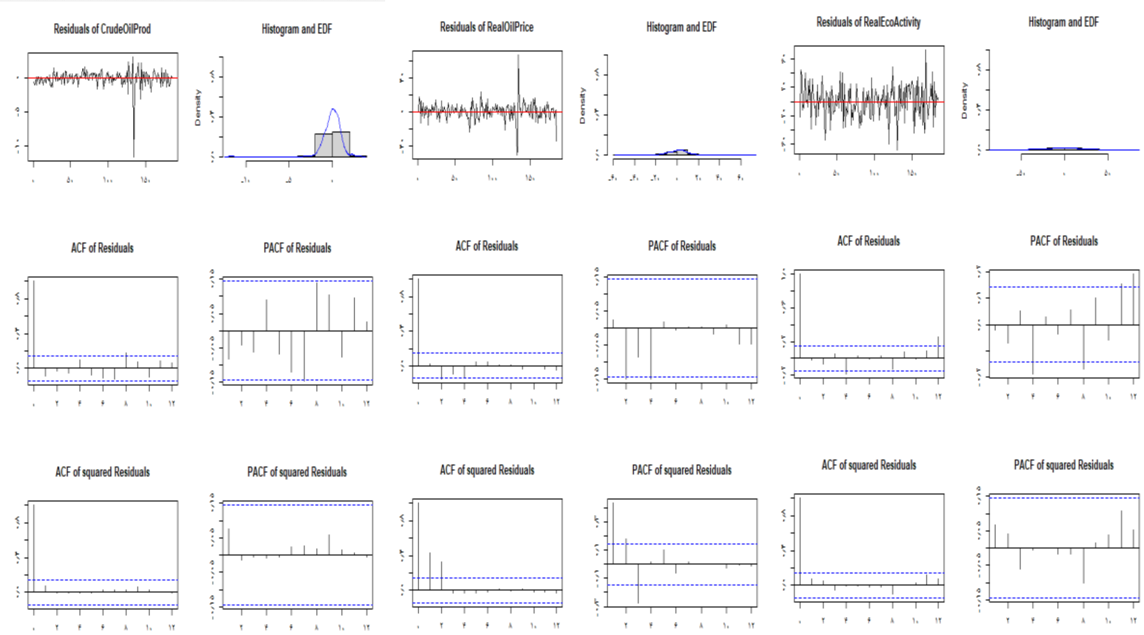

Figure 3. Correlation Tests on Estimated Structural Model Residuals

Following this, the Cholesky decomposition was applied to calculate the simple and cumulative effects of the three-variable shocks on oil prices. Based on these results, Equation 2 was estimated, and the three time series related to shocks $\hat{\boldsymbol{\varepsilon}}t = ([\![\hat{\varepsilon}]\!]\_t^{SS}, [\![\hat{\varepsilon}]\!]\_t^{DS}, [\![\hat{\varepsilon}]\!]\_t^{0S})$ were obtained, as depicted in Figure 4.

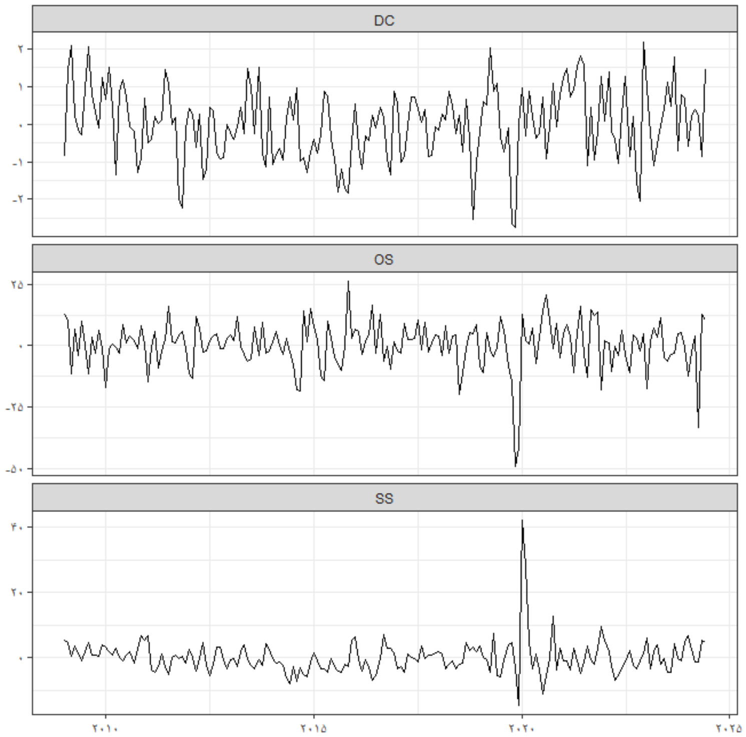

Figure 4. Cholesky Decomposition Results and Time Series of the Three Oil Shocks

The next step involved identifying the most appropriate ARMA-GARCH model for the OS, SS, DC, and Stock Index time series. Among the candidate models—sGARCH, eGARCH, gjrGARCH, apARCH, and csGARCH—the best distributions were selected based on the Akaike criterion after standardization. The relationship between the standardized variable values and stock returns was also examined.

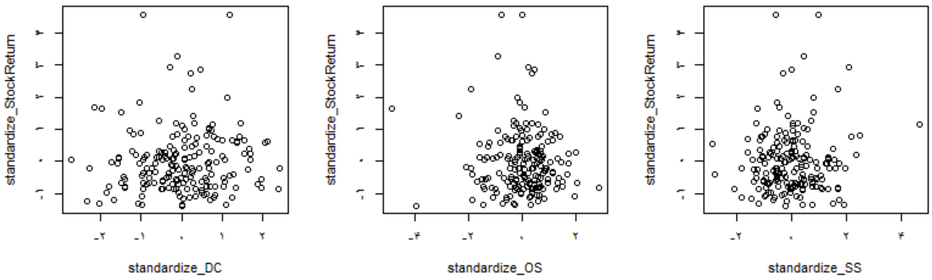

Figure 5. Standardized Residuals of Stock Returns on Cholesky Decomposition Results of the Three Oil Shock Time Series

4. Discussion and Conclusion

The findings of this study indicate that oil shocks exert significant yet asymmetric influences on the systemic risk of Iran's capital market. The results demonstrate that supply shocks have a notable spillover effect on stock market risk, with CoVaR values consistently exceeding VaR values at the 5% probability level, suggesting that risk spillovers originating from the oil supply side contribute to systemic market risk. In contrast, at the 95% probability level, VaR exceeds CoVaR, indicating that systemic risk is less sensitive to supply-side shocks under normal market conditions. Moreover, specific oil shocks and demand-side shocks exhibit asymmetric spillovers, with CoVaR(95%) being lower than VaR(95%), but CoVaR(5%) exceeding VaR(5%), implying that under extreme financial stress, oil demand fluctuations exacerbate stock market risk. These findings align with previous literature emphasizing the long-term asymmetric effects of oil price shocks on financial markets [11].

The explanation for this asymmetry lies in investor sentiment and market expectations, as upward oil price shocks are often associated with economic growth in oil-exporting economies like Iran, boosting investor confidence and increasing stock valuations. However, oil price declines do not always translate into equivalent losses, as investors anticipate government intervention to stabilize the economy. This behavioral tendency further validates the prospect theory, where losses and gains are perceived differently by investors [23-27].

Furthermore, the SVAR-Copula-GARCH framework effectively captures the structural dependencies between oil market shocks and stock market risk, demonstrating that supply shocks exert the most prolonged effects on stock returns. An additional contribution of this study is its demonstration of the superior explanatory power of the Student's t-Copula distribution in modeling oil supply and specific oil shocks, as evidenced by the lowest Akaike Information Criterion (AIC) values. This suggests that heavy-tailed distributions better capture the tail dependency between oil and stock markets, in contrast to normal distributions, which underestimate extreme risk spillovers. The observed nonlinear and asymmetric transmission of risk is also in line with previous studies [4, 28-31] which found that while short-term fluctuations in oil prices have minimal effects on stock returns, larger-scale fluctuations exert significant influence. The results suggest that demand-side and specific oil shocks have more pronounced impacts during financial downturns, whereas supply-side shocks influence both normal and extreme market conditions. This implies that policymakers and investors should prioritize supply-side risk mitigation strategies, as their effects are more persistent.

Another critical insight is that systemic risk cannot be fully diversified away, as indicated by the significant CoVaR values across all scenarios. This finding aligns with Homayounifar et al. (2013), who noted that financial crises induce structural changes in asset correlations, making risk diversification less effective [12]. Moreover, the inability of diversification to eliminate systemic risk reinforces the importance of risk-hedging strategies, such as derivative instruments and sovereign wealth fund reserves, to mitigate financial instability resulting from oil price fluctuations.

Despite its contributions, this study has certain limitations. First, the dataset spans from January 2009 to June 2024, meaning that results are contingent on recent oil market conditions and may not fully generalize to earlier historical periods with different geopolitical and economic structures. Additionally, the study focuses solely on Iran's capital market, limiting the applicability of its findings to other oil-exporting economies. The reliance on the SVAR-Copula-GARCH model, while robust, assumes structural stability over time, which may not fully capture evolving market conditions. Another limitation is that exogenous policy interventions, such as government subsidies and foreign exchange interventions, were not explicitly modeled, despite their potential influence on stock market dynamics.

Future research should explore cross-country comparisons by analyzing systemic risk spillovers in other oil-dependent economies, such as Saudi Arabia, Russia, and Venezuela, to assess whether similar asymmetric effects are observed. Expanding the dataset to include a broader historical period would help validate the robustness of the findings. Additionally, incorporating alternative volatility modeling techniques, such as Markov-Switching GARCH models, could provide deeper insights into nonlinear regime shifts in financial risk transmission. Another promising avenue is investigating the role of macroeconomic policy measures, such as interest rate adjustments, fiscal policies, and exchange rate regimes, in moderating the impact of oil shocks on stock market risk.

For investors and portfolio managers, hedging strategies should prioritize supply-side oil shocks, as they have the most prolonged and pronounced effects on stock market risk. Derivatives, such as oil futures and options, can be employed to hedge against extreme downside risk. Policymakers should strengthen financial resilience mechanisms, including foreign exchange reserves and sovereign wealth funds, to buffer against oil-induced market volatility. Additionally, risk management frameworks in the Tehran Stock Exchange should incorporate dynamic spillover assessments, integrating time-varying copula dependencies to account for nonlinear correlations between the oil and financial markets. By implementing these strategies, investors and policymakers can better mitigate the adverse effects of oil market fluctuations on systemic financial risk.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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