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RESEARCH PAPER

Asymmetric Volatility Spillovers of Oil Price and Exchange Rate on Chemical Stocks: Fresh Results from a VAR-TBEKK-in-Mean Model for Iran

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Abstract
Investigating the dynamic relationship between markets has attracted the interest of many researchers; however; assessing the asymmetric volatility spillovers has been addressed by a few studies. In this regard, this study mainly aims to investigate the asymmetric spillovers of oil price return and exchange rate, as the key variables, on chemical industry stock returns in Iran through the lens of a VAR Triangular BEKK in mean (VAR-TBEKK-in-mean) model. Also, daily data from March 31, 2009, to June 28, 2019, was selected. The chemical industry was selected since attracted a high share of capital in the Tehran Stock Exchange (TSE) and is highly correlated with crude oil prices. The results indicated a significant volatility spillover from oil and exchange markets to the chemical industry stocks. Moreover, the result of the symmetry test indicated that global oil price shocks asymmetrically affect the conditional volatility of chemical industry stock returns. The results additionally indicate that the relationship between these markets and the extent of risk spillover between them is severely affected by the (good and bad) news and volatility of another market (particularly the oil market). Based on the results, investors are better off allocating their portfolios to chemical stocks more carefully, especially when the volatilities in the two markets (exchange and crude oil) are high. Capital market officials are advised to develop the stock market by deepening the capital market and taking into account the risk spillovers of foreign exchange and oil markets to the stock market.
Keywords: Volatility Spillover, VAR-TBEKK-in-Mean Model, Conditional Volatility, Chemical Industry, Crude Oil.
JEL Classification: G20, C24, Q32.

Introduction

Analysis of spillover between the markets has been emphasized by many researchers for decades in various practical fields. The complex environment of financial markets and relationships between these markets, as well as the necessity for forecasting future financial and economic scenarios, have motivated the researchers in financial fields to try to discover and analyze these inter-market relationships to achieve the goals of the financial and economic system effectively. Transmission between financial indicators indicates the process of information transfer among the markets. Due to the relationships between the markets, information created in a market can influence other markets. Meanwhile, modeling the relationship between the returns in different markets is of significant importance for researchers and market activists because of its suitability in the forecast of future market trends.

The global oil market is one of the important markets whose variations affect most financial markets. Oil price variations and shocks influence financial markets such as the stock market at both the macro and micro levels. Due to oil price volatility, the stocks of many companies active in stock exchanges whose performance is significantly affected by oil prices will vary, and their stock price index will be volatile according to their dependence on oil (Le and Chang, 2015).

Among the industries in Iran's stock market, the petrochemical industry (chemical products group) is of particular importance as an industry with the greatest share in Iran's non-oil exports. According to the official reports, in 2018, petrochemical industries contributed to more than 33% of the value of total non-oil exports in Iran (Figure 1). This industry also has contributed to a major part of transaction value in Iran's stock exchange[1]. Furthermore, this industry supplies the production chain of many industries and is highly associated with the energy market. These remarks motivated us to consider this industry. The issue is important because not only oil price volatilities can distinctly affect different industries, but also the impact of volatilities may be different across the countries, as implied by Park and Ratti (2008). Thus, the results cannot be generalized to another country. Besides, since a major part of petrochemical products is exported, variations in the exchange rate also have been taken into account as a factor affecting petrochemical products returns.

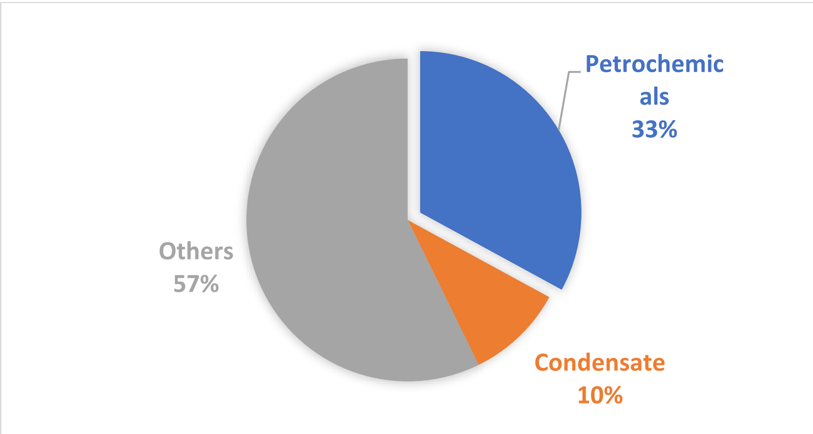


Figure 1. Share of Petrochemical Industry in Iran's Non- Crude Oil Exports
Source: CBI, 2018.

Generally, oil, exchange, and stock markets are complex economic systems affecting by various factors such as fundamental factors of supply and demand and political, psychological, and economic factors. Also, the interactions between the markets are considerable. Thus, a separate analysis for each market is rather invalid, and the researchers should carry out their analysis based on the relationships between different markets.

Regarding the above discussions, the research mainly aims to investigate the type and nature of volatility spillover between oil markets, exchange markets, and stock markets (for chemical products). For this purpose, a VAR-TBEKK-in-mean model is used for daily data from March 31, 2009, to June 28, 2019. Some studies have addressed the explanation and investigation of feedback effects between different markets. However, due to the small size of the Iranian economy, compared with the global economy, the variations in the exchange rate and chemical industry stock returns do not significantly affect the global oil market. Therefore, the research uses the triangular BEKK matrix to model the feedback effects properly. It should be noted that

[1] According to the official data by the stock exchange organization (www.tsetmc.com), chemical products have contributed to 29.8%, 12.3%, 8.6%, and 11.8% of the total market value in 2014, 2015, 2016, and 2017, respectively.

triangular BEKK helps researchers to consider feedback effects, which can be assumed zero based on the current economic realities between the markets, to achieve more reliable results.

Another point in this research is the difference between the effects of good and bad news. Indeed, the experiences of financial markets imply an asymmetric response to good and bad news. Therefore, the lack of attention to this issue can bring about misleading implications, especially in the analysis of volatility spillover and risk transmission from a market to another. This matter is considered in our model.

The rest of the research is organized as follows: Section 2 presents the theoretical foundations. Section 3 provides a review of the literature. The research methodology is presented in Section 4. The results and analysis are presented in Section 5, and Section 6 devoted to the conclusion and policy implications.

Theoretical Background

The stock price is affected by various factors such as economic and financial factors, as well as the behavior of other markets. Thus, investors need to recognize the effects of different variables and markets on stock returns to select optimal portfolios. Since global oil prices and exchange rates can significantly affect stock index, especially, for chemical products group, before the empirical analysis, the theoretical background of the impact of each variable on stock returns is investigated.

Undoubtedly, the oil market, as one of the most eminent financial markets, is strongly associated with other financial markets so that fluctuations in this market affect other financial markets (Basher et al., 2018; Dutta et al., 2017; Kang et al., 2015; Liu et al., 2013; Sadorsky, 1999). Before the 1980s, due to the organizational structure of the international oil market, crude oil prices did not fluctuate significantly, thus did not involve oil agents at significant risk. From the late 1980s, after the establishment of the NYMEX stock exchange in New York and with graduate deepening of this market in the subsequent decade, the discovery of dominant oil price indexes (such as Brent and WTI) was affected by the demand and supply conditions in future markets and spot prices (Buyuksahin et al., 2013; Silverio and Szklo, 2012). With the development and financialization of the oil market and the presence of other non-fundamental effective factors, global oil prices were volatile with a wide range (Fattouh and Mahadeva, 2012). During various periods, global oil prices experience excessive volatility. For example, after a peak of 148$ per barrel in July 2008, the oil price has declined to about 40$ per barrel in late December. Another example is the decline of global oil prices from 107$ in August 2014 to about 40$ in September 2015. These price volatilities and fluctuations yield frequent market risks and lead to heavy potential losses for activists in the international oil market and other financial markets.

Investigating the impact of oil price variations on financial markets is highly important because the factors influencing this market affect other financial markets greatly. In recent decades, global oil price volatilities have been about two times the volatility of other products. The concept of excess volatility of global oil price is that trade periods, as well as other financial markets, are constantly affected by global oil price volatilities (Filis et al., 2011). Recently, investigation of the impact of oil price shocks on stock market returns has attracted the attention of many researchers (Boldanov et al., 2016; Degiannakis et al., 2013; Kilian, 2009; Ready, 2018; Soyemi et al., 2017; Zankawah and Stewart, 2019), but a small body of literature focus on emerging markets or net oil-exporters.

Although developing oil-exporting countries mostly have narrow stock markets, there is frequent evidence of the relationship between stocks and the oil market in these countries because the stock value depends on the present value of its future cash flows (Elwood, 2001; Khamis et al., 2018). Moreover, oil price volatility in oil-exporting countries can be considered as one of the most important macro factors influencing the stock market. Theoretically, the stock value equals the sum of the discounted value of the expected future cash flows (Arouri and Rault, 2010; Khamis et al., 2018; Narayan and Narayan, 2010). These cash flows can certainly be affected by macroeconomic variables such as oil shocks. An increase in oil price is expected that positively affects the currency inflow of the country, budget expenditure supply, and aggregate demand. Note that since oil-exporting countries supply a major part of their required goods from advanced and emerging countries, therefore, a rise in oil price my leads to an increase in the cost of importing consuming and capital goods for oil-exporting countries. As shown in Figure 1, global crude oil price volatility can lead to changes in stock prices in oil-exporting countries from various channels. These channels can be categorized into five groups.

In the liquidity creation channel, revenue obtained from selling oil is transferred to the central bank foreign currency account and leads to an increase in the central bank's foreign net assets and the monetary base. In the case of a decrease in oil revenues (caused by oil price declines), an increase in budget deficit compels the government to borrow from the central bank, leading to an increase in the monetary base.

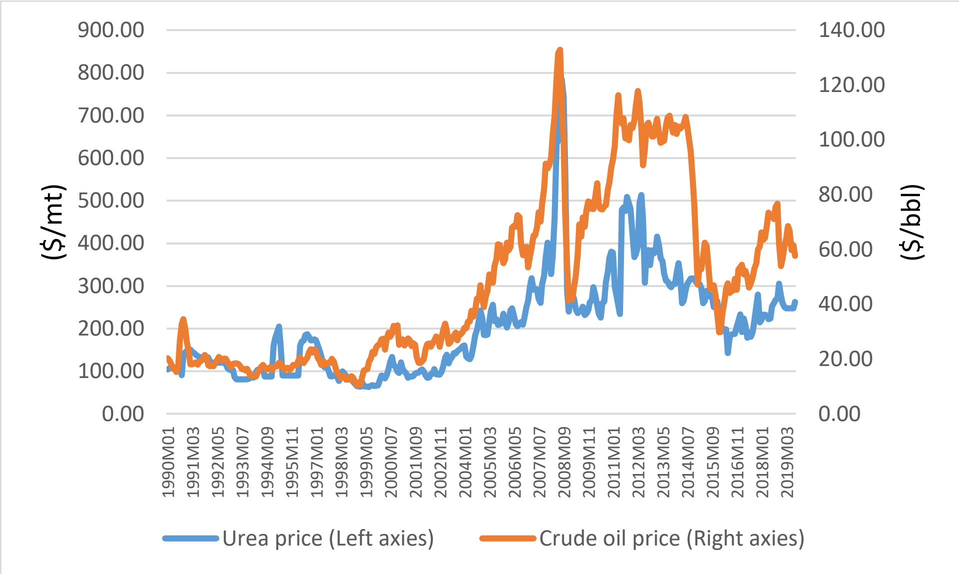


Figure 2. Crude Oil Price (Average) And Urea Price
Source: Research finding.

The second channel is the impact of oil prices on stock prices through the exchange rate channel (Morley and Pentecost, 2000; Beckmann et al., 2020). Some studies have concluded that there is a greater correlation between crude oil prices and exchange rates in oil-exporting countries than in oil-importing countries (Reboredo, 2012; Yang et al., 2017). Compared with other companies in the market, the stock price index of petrochemical companies is more affected by oil price volatilities due to its excessive dependency on oil and being directly affected by oil prices and their volatilities. From another viewpoint, although the active companies in Iran's energy sector face with internal fixed oil prices stabilized by the government, generally, changes in the global oil prices cannot significantly affect the performance of these companies. Meanwhile, due to the export-oriented nature of petrochemical industries, variations in global oil prices can directly affect the prices of exported products of these industries. Therefore, the changes in global oil prices can be reflected in the value of petrochemical industries swiftly. In Iran, regarding the controls on the prices of materials and gases required by petrochemical companies and being free of direct impacts of global prices, variations in the prices of petrochemical products affected by global markets (which can be influenced by global oil prices) play a vital role in profitability and marginal profit of petrochemical companies. For example, there is a significant co-movement between the price of Urea (one of the main petrochemical products) and global oil prices average (Figure 2).

The third channel is the impact of oil prices on stock prices through expectations effect (Byrne et al., 2019). Theoretically, variations in oil prices can affect the formation of expectations in the capital market and, consequently, the stock price index of the active companies on the stock exchange market through various channels. The result of these impacts is associated with the extent to which the companies are dependent on global oil market volatilities (Basher et al., 2012). With an increase in oil prices and revenues in oil-exporting countries, optimistic expectations are formed about the boom and raising the level of economic activities. Therefore, the increased profitability of companies active in the stock exchange and, consequently, a rise in the stock index is expected (Lu et al., 2001).

Revenue effect is the fourth channel through which global oil prices affect stock prices. Indeed, higher oil prices mean the wealth transfer from the oil-importing countries to the oil-exporting ones (Sayadi and Khosroshahi, 2020). The effect of these changes in prices depends on the performance of the government in dealing with the revenue increase. If the revenue increase is in line with the purchase of domestic goods and services, it can lead to an increase in public wealth. With an increase in the demand for labor and capital, many trading and investment opportunities have been created, affecting the future cash flows of the firms and the increase in profitability.

The fifth channel is the impact of oil prices on stock prices in oil-exporting countries through the recursive effect. Oil price increase leads to an increment in total costs of goods produced by industrial countries, causing to a rise in the monetary value of imports for oil-based countries and negative impact on future cash flows of their firms and, consequently, a decrease in stock prices (Arouri and Rault, 2010).

The net effect of oil price volatility on stock price in oil-exporting countries depends on the resultant of positive and negative impacts related to the channels mentioned.

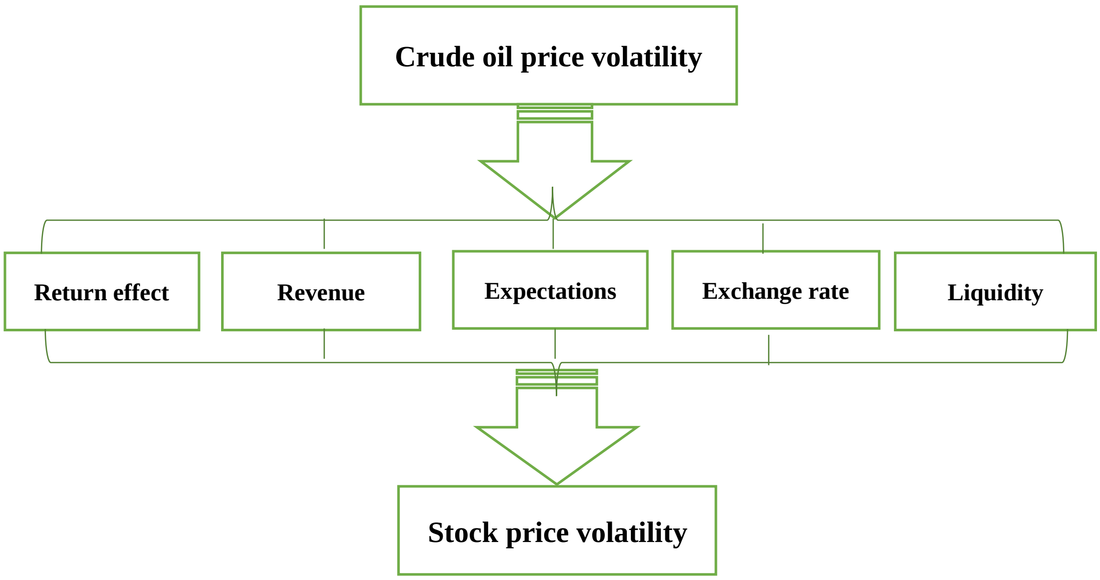


Figure 3. Crude Oil Price Volatility Impact Channels on Stock Price Volatility
Source: Research finding.

The market approach theory shows how the exchange rate affects the firm's external operation and, consequently, profit and stock prices (Yang and Doong, 2004). Based on this theory, with an increase in domestic production followed by a decline in money value, along with assuming the Marshall-Lerner Condition, the expected future cash flows are affected due to being influenced by total future internal and external demand. Consequently, present stock price, which is equivalent to the present value of future cash flows, is interacted with the level of present and future activity of the economy that is measured by factors such as industrial production, real economic growth rate, and employment rate. In their theory, Ma and Kao (1990) showed that a decrease in the exchange rate in import-based economies leads to a boom in the stock market. Therefore, the total impact of exchange rate variations on the stock market in an economy depends on the composition of the firms engaged in import and export, the degree of firms' dependency on imported raw materials, and the elasticity of demand for exported products.

Variations in petrochemical products affected by global markets (such as global oil prices) play a significant role in the profitability of the corresponding companies. For example, the price of methanol (one of the main petrochemical companies) significantly relates to global oil prices, as shown in Figure 3. Here, the average of the prices of Brent oil and WTI oil is considered for the global oil price. Finally, due to the export-oriented nature of petrochemical products, a change in the exchange rate directly affects stock prices for this group of products.

Generally, with the development of international financial markets, the dynamic relationship between the returns, transmission mechanisms, and volatility spillover between these markets is noticed increasingly in the related literature. The risk of volatility spillover between different markets is one of the risks of financial markets that compel investors and risk managers to adopt risk-minimizing policies. Moreover, the mechanisms of spillover between returns and volatilities in different assets are important for many reasons. First, an analysis of spillover mechanisms provides us with information on the efficiency of the markets. Transmission between returns on assets indicates a profitable trading strategy. A profit of this trading strategy greater than its operating cost, potentially, is evidence for the inefficiency of the market. Second, being informed of the spillover mechanisms is important because recognizing the impact of returns volatilities is of particular importance for choosing a portfolio and reducing the risk. Finally, information on assets volatility spillover can be considered in forecasting volatility.

Literature Review

Some of the main features of reviewed researches are summarized in Table 1.

Table 1. The Main Feature of Relevant Literature

Author(s)	Objective	Model and time period	Main results	Case Study
Zhao (2010)	Dynamic relationship between exchange rates and stock prices	MGARCH (1991-2009)	There is a bidirectional volatility spillover effect between the two markets.	China
Awartani and Maghyereh (2013)	Dynamic spillovers between oil and stock markets	Diebold and Yilmaz approach (2004-2009)	Return and volatility transmissions are bi-directional and asymmetric.	GCC Countries
Chang et al. (2013)	volatility spillovers and Conditional correlations between crude oil and stock index	VARMA-GARCH (2 Jan 1998 to 4 Nov 2009)	Low conditional variance between returns	US
Sahu et al. (2015)	The dynamic relationship between the exchange rate, oil prices, and stock markets	Johansen's cointegration and error correction vector (1993-2013)	The stock price volatilities in India could be explained by variations in oil prices and exchange rates.	India

Author(s)	Objective	Model and time period	Main results	Case Study
Salma (2015)	volatility spillover between crude oil prices the stock markets	VAR-GARCH Copula (2005-2012)	moderate cross-market volatility transmission and shocks between the markets	GCC Countries
Ewing and Malik (2016)	volatility spillover between oil prices and stock markets	Univariate and bivariate GARCH (July 1, 1996- June 30, 2013)	By including structural breaks in the model, strong volatility spillover effects were observed.	US
Jain and Biswal (2016)	Dynamic relationship between oil price, exchange rate, gold price, and stock market	DCC-GARCH (2006–2015)	fall in gold prices and crude oil prices cause to fall in the value of the benchmark stock index	India
Raza et al. (2016)	Asymmetric impacts of gold and oil prices, and their volatilities on stock prices	NARDL (January 2008 - June 2015)	Oil prices also had a negative impact on the stock prices of all emerging economies.	Emerging economies (BRICS, Mexico, Thailand, Chile, and Indonesia)
Liu et al. (2017)	spillover effects between the price of WTI crude oil and Russian stock markets	GARCH model and wavelet transformation (Dec 2003 – Dec 2014)	different spillover effects in different wavelet scales	Russia, Brazil
de Oliveira et al. (2018)	volatility spillover effects from several channels to the Brazilian stock market	DCC, MGARCH-BEKK, and t-Copulas models (2014 to 2016)	US monetary policy and rebalancing of portfolios generate volatility to Brazil	Brazil
Ashfaq et al. (2019)	Effect of oil prices on leading Asian energy exporting and importing economies’ stock returns	MGARCH Models (1 Sept 2009 to Aug 31, 2018)	A various level of correlation with oil but the influence of oil shock is more pronounced on oil exporting countries.	Net-oil exporting countries (Saudi Arabia, United Arab Emirates, Iraq) and net-oil importing countries (China, Japan, India, South Korea)
Zankawah and Stewart (2019)	volatility spillover effects from crude oil to exchange rate and stock markets	MGARCH BEKK (Jan 1991 to Dec 2015)	The relationship between oil prices and stock markets depends on whether oil prices are endogenous or exogenous.	Ghana
Yu et al. (2019)	dependence and spillover effects between WTI and US-China stock markets	Copula and MGARCH (1991–2016)	Different volatility spillovers with varying directionality, in response to the structural changes. Also, the oil market stimulates sharp and continual fluctuations in market dependences.	US and China
Kumar et al. (2019)	time-varying volatility and correlations between crude oil, natural gas, and stock prices	VARMA-DCC-GARCH	Implications for portfolio selection dealing with the Indian stock market and energy commodity futures for forecasting potential market risk exposure.	India
Sarwar et al. (2020)	volatility spillover of the oil market and stock market returns	bivariate BEKK-GARCH (1997 to 2014)	Volatility spillover varies across data frequencies (daily, weekly, and monthly) used.	Bombay, Karachi, and Shanghai
Liu et al.	volatility relationships	DCC, BEKK-	a significant bidirectional	US

Author(s)	Objective	Model and time period	Main results	Case Study
(2020)	between crude oil and the U.S. stock markets	GARCH (10 May 2007 to 11 June 2018)	implied volatility spillover and a positive time-varying correlation between the oil and stock markets	
Morema et al. (2020)	Volatility spillovers of oil and gold price fluctuations on equity market	VAR- ADCC-GARCH (January 3, 2006 to April 23, 2020)	There is significant volatility spillover between the gold and stock markets, and the oil and stock markets.	South Africa
Liu and Gong (2020)	time-varying volatility spillovers between the crude oil markets	TVP-VAR-SV (November 29, 2002 to July 13, 2018)	volatility and volatility spillovers are positively correlated and are two-way Granger causality	Crude oil markets
Urom et al. (2020)	Regime dependent effects and cyclical volatility spillover between crude oil price movements and stock returns	MS-EGARCH (August 2002 to January 2018)	Stock returns in all the markets exhibit regime switching behavior with the bull market regime dominating most of the period except for Russia.	major oil exporting countries: UAE, Qatar, Saudi Arabia, Russia, Venezuela and Kuwait
Çatık et al. (2020)	Time-varying impact of oil prices on sectoral stock returns	state-space model (January 3, 1997 and August 9, 2018)	Impact of oil price returns differ markedly over time and generally have a smaller impact on sectoral returns compared with exchange rate returns.	Turkey
Liu and Jiang (2020)	examine the multi-scale feature of volatility spillover in the energy stock market	GARCH-BEKK (2014-2019)	volatility spillover effects are more fragmented in the short term, while the volatility changes will be only transmitted by a small number of important stock prices in the long term.	China

The literature review implies that despite extensive attention to investigating interactions between different markets and recognizing the structure of their relationships, the results are controversial. Some studies consider the topic concerning the oil market, and some others take into account financial markets with different objectives. Emphasizing the oil market and in line with the relationship between three markets of oil, exchange, and petrochemical industry stock in a net oil-exporting country, the present study addresses the investigations of volatility spillover among the three markets, relationships among the returns, and risk volatility between the markets using working daily data over the period 2008-2018. The innovations of the paper, compared with previous studies, can be listed as follows.

- Using VAR-TBEKK-in-mean approach along with the modeling of feedback effects by the triangular BEKK matrix to investigate average spillover effect and volatility spillover between the oil, exchange, and stock markets (chemical products stock)
- Taking into account the difference between good and bad news or incorporating the asymmetry effects of good and bad news into the model
- Considering chemical industry stock rather than the overall stock index (because the main material of all chemical products is oil, these products are affected by variations in global oil prices and exchange rates due to their export-oriented nature)

Methodology

From the economic view, the average price volatility transmission effects between several markets reflect the fact that price at a market not only is affected by volatilities in previous periods but also is impressed by price volatilities in other relevant markets. Accordingly, in line with Jain and Biswal (2016) and Zankawah and Stewart (2019), a VAR-TBEKK-in-mean model is used to estimate volatility spillover between oil price returns, exchange returns, and chemical industry stock returns over the period 2008-2018 with daily data. The present approach enables us not only to examine mean volatility spillover between the three markets but also to analyze the effect of information asymmetry from a market to another by incorporating asymmetry effects in conditional variance equations. In this model, the first variable represents the exchange rate return denoted by r_t^1; the second variable indicates chemical industry stock returns series denoted by r_t^2, and the third variable stands for oil price returns denoted by r_t^3. The return for each variable is calculated as follows.

$$r_t^i = \log\left(\frac{p_{i,t}}{p_{i,t-1}}\right) \times 100; \quad i = 1,2,3 \tag{1}$$

where $p_{1,t}$ is the ratio of the US dollar value to IRR value (exchange rate with the number 1), $p_{2,t}$ represents the chemical industry stock price (with number 2), and $p_{3,t}$ is the oil price (with number 3). As mentioned, the variable sequence is daily.

Equation (2) specifies the mean equation for the research model. In this equation, h_t represents the matrix of the market risk of each variable on the market returns of other variables. The reason for incorporating matrix h_t in the model is to include the risk effect of a market on the returns of other markets (returns effects). Indeed, the equation turns into a VAR(3)-in-mean model.

$$r_t = \mu + \Gamma_1 r_{t-1} + \Gamma_2 r_{t-2} + \Gamma_3 r_{t-3} + \psi\sqrt{h_t} + \varepsilon_t \tag{2}$$

Note that the optimal lag is selected based on information standards, herein assumed to be 3 in line with empirical results. This point is greatly important in estimating the conditional variance-covariance matrix h_t because if it does not hold, the estimation of the parameters of the conditional variance-covariance matrix is biased. Regarding the order of the variables, the vectors and matrices related to Equation (2) used in the estimation model are as follows.

$$r_t = \begin{bmatrix} r_t^1 \\ r_t^2 \\ r_t^3 \end{bmatrix}, \sqrt{h_t} = \begin{bmatrix} \sqrt{h_{11,t}} \\ \sqrt{h_{22,t}} \\ \sqrt{h_{33,t}} \end{bmatrix}, \varepsilon_t = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{bmatrix}, \mu = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{bmatrix}, \psi = \begin{bmatrix} \psi_{11} & \psi_{12} & \psi_{13} \\ \psi_{21} & \psi_{22} & \psi_{23} \\ \psi_{31} & \psi_{32} & \psi_{33} \end{bmatrix}$$

$$\Gamma_1 = \begin{bmatrix} \gamma_{11}^1 & \gamma_{12}^1 & \gamma_{13}^1 \\ \gamma_{21}^1 & \gamma_{22}^1 & \gamma_{23}^1 \\ \gamma_{31}^1 & \gamma_{32}^1 & \gamma_{33}^1 \end{bmatrix}, \Gamma_2 = \begin{bmatrix} \gamma_{11}^2 & \gamma_{12}^2 & \gamma_{13}^2 \\ \gamma_{21}^2 & \gamma_{22}^2 & \gamma_{23}^2 \\ \gamma_{31}^2 & \gamma_{32}^2 & \gamma_{33}^2 \end{bmatrix}, \Gamma_3 = \begin{bmatrix} \gamma_{11}^3 & \gamma_{12}^3 & \gamma_{13}^3 \\ \gamma_{21}^3 & \gamma_{22}^3 & \gamma_{23}^3 \\ \gamma_{31}^3 & \gamma_{32}^3 & \gamma_{33}^3 \end{bmatrix} \tag{3}$$

where r_t represents the returns of the index i; ij used for market i to market j; ψ stands for the coefficients of the 3×3 matrix of risk and indicates the effect of risk of asset i on return on asset j; ε_t denotes a 3×1 matrix of noise, and Γ_t shows a 3×3 matrix of returns of market i.

Risk effects are relevant to the mean equation or VAR-in-mean model. These effects are analyzed on the main diagonal of the matrix, and other elements are assumed zero. In the TBEKK approach, a diagonal lower triangular matrix appears. Spillover effects also are considered for the variance-covariance matrix or BEKK. Indeed, since both exchange risks and stock risks do not have spillover on global oil price returns, the triangular BEKK matrix is used to regard this fact. Therefore, all the elements above the main diagonal of the 3×3 matrix of mean equation (only the elements above the main diagonal of the matrix of risks on returns) are assumed zero.

$$hhs(i,j) = \begin{bmatrix} hhs(1,1) & 0 & 0 \\ hhs(2,1) & hhs(2,2) & 0 \\ hhs(3,1) & hhs(3,20 & hhs(3,3) \end{bmatrix} \tag{4}$$

On the other hand, the conditional variance-covariance matrix should be specified. This matrix is specified by the asymmetric BEKK(1,1) method, as follows.

$$H_t = \acute{C}C + \acute{A}\varepsilon_{t-1}\acute{\varepsilon}_{t-1}A + \acute{B}H_{t-1}B + \acute{D}e_{t-1}D, \quad e_{t-1} >< 0 \tag{5}$$

Where ($e_{t-1} >< 0$) is the effect of good and bad news. This approach ensures that the conditional variance-covariance matrix H_t is positive definite for all values of ε_t in the sample. This condition is necessary for model estimation by the maximum likelihood method.

$$H_t = \begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix}, \varepsilon_{t-1} = \begin{bmatrix} \varepsilon_{1,t-1} \\ \varepsilon_{2,t-1} \\ \varepsilon_{3,t-1} \end{bmatrix}, e_{t-1} = \begin{bmatrix} e_{1,t-1} \\ e_{2,t-1} \\ e_{3,t-1} \end{bmatrix},$$
$$C = \begin{bmatrix} C_{11} & 0 & 0 \\ C_{21} & C_{22} & 0 \\ C_{31} & C_{32} & C_{33} \end{bmatrix}, A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}, B = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix},$$
$$D = \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \tag{6}$$

Therefore

$$\begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix} = \begin{bmatrix} C_{11} & \acute{0} & 0 \\ C_{21} & C_{22} & 0 \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} C_{11} & 0 & 0 \\ C_{21} & C_{22} & 0 \\ C_{31} & C_{32} & C_{33} \end{bmatrix} + \begin{bmatrix} a_{11} & \acute{a_{12}} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$
$$\times \begin{bmatrix} \varepsilon_{1,t-1} \\ \varepsilon_{2,t-1} \\ \varepsilon_{3,t-1} \end{bmatrix} \begin{bmatrix} e_{1,\acute{t}-1} \\ e_{2,t-1} \\ e_{3,t-1} \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} + \begin{bmatrix} b_{11} & \acute{b_{12}} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix}$$
$$\times \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} + \begin{bmatrix} d_{11} & \acute{d_{12}} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \begin{bmatrix} e_{1,t-1} \\ e_{2,t-1} \\ e_{3,t-1} \end{bmatrix} \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \tag{7}$$

where H_t is of the order 3×3 representing the conditional variance-covariance, which always is positive definite; ε_{t-1} is the 3×1 vector of noise; C is a 3×3 diagonal constant matrix; A is the coefficient matrix of ARCH; B is the coefficient matrix of GARCH, and D is the matrix representing the asymmetry of good and bad news. Furthermore, $h_{32,t}$ is the conditional covariance of oil prices and chemical industry stock prices; $h_{21,t}$ is the conditional covariance of exchange rates and chemical industry stocks, and $h_{31,t}$ is the conditional covariance of chemical industry stock and oil prices. Finally, $h_{11,t}$, $h_{22,t}$, and $h_{23,t}$ are the conditional variance of the residuals for exchange rates, chemical industry stocks, and oil prices in time t, respectively. All the elements above the main diagonal of the 3×3 lower triangular matrix in the mean equation (herein, only the elements above the main diagonal of risk on returns matrix) should be considered zero. The conditional variance-covariance matrix is specified by the TBEKK(1,1) method, as follows.

$$\begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix} = \begin{bmatrix} C_{11} & \acute{0} & 0 \\ C_{21} & C_{22} & 0 \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} C_{11} & 0 & 0 \\ C_{21} & C_{22} & 0 \\ C_{31} & C_{32} & C_{33} \end{bmatrix} + \begin{bmatrix} a_{11} & \acute{0} & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$
$$\times \begin{bmatrix} \varepsilon_{1,t-1} \\ \varepsilon_{2,t-1} \\ \varepsilon_{3,t-1} \end{bmatrix} \begin{bmatrix} e_{1,\acute{t}-1} \\ e_{2,t-1} \\ e_{3,t-1} \end{bmatrix} \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} + \begin{bmatrix} b_{11} & \acute{0} & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{21,t} & h_{22,t} & h_{23,t} \\ h_{31,t} & h_{32,t} & h_{33,t} \end{bmatrix}$$

$$\times \begin{bmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{bmatrix} + \begin{bmatrix} d_{11} & \acute{0} & 0 \\ d_{21} & d_{22} & 0 \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \begin{bmatrix} e_{1,t-1} \\ e_{2,t-1} \\ e_{3,t-1} \end{bmatrix} \begin{bmatrix} d_{11} & 0 & 0 \\ d_{21} & d_{22} & 0 \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \tag{8}$$

Therefore, according to the conditional variance-covariance model, 24 parameters should be estimated for the equation of H_t. Consequently, 57 parameters are required to carry out the estimation.

Empirical Results

In this section, the empirical findings are analyzed.

Data

The variables include crude oil prices, exchange rates, and chemical industry stock prices are defined in Table 2.

Table 2. Variable Descriptions and Data Sources

Variable	Description	Data Frequency	Data Source
RPOIL	Return of the Brent crude oil price	Daily	International Energy Agency (IEA) (https://www.iea.org/)
REXR	Return of the Iran exchange rate against the US dollar	Daily	https://www.tgju.org/currency
RCHEM	Return of the chemical industry stock price	Daily	Tehran Securities Exchange Technology Management Co. (www.tsetmc.com)

Table 3 presents some main descriptive statistics of daily returns of the variables oil price (RPOIL), exchange rate (REXR), and chemical industry stock prices (RCHEM) in the Tehran Stock Exchange for the period from March 31, 2009, to June 28, 2019 (including 1239 observations). From this table, the average daily return on variables oil price, exchange rate, and chemical industry stock prices are 2.1%, 0.001%, and 0.002%, respectively, in the period studied.

Table 3. Descriptive Statistics

Descriptive Statistics	RPOIL	REXR	RCHEM
Mean	-0.00002	0.0010	0.0023
Median	- 0.0003	0.0002	0.0004
Max	0.1772	0.6757	0.7945
Min	-0.1494	-0.7631	-0.7782
Std. Dev.	0.0257	0.0632	0.1312
Skewness	0.3521	0.0413	-0.0016
kurtosis	9.5717	84.476	24.008
Jarque-Bera	2229.69	33883.6	22526.6
(Prob)	(0.0000)***	(0.0000)***	(0.0000)***
ARCH-LM	25.58	247.35	270.22
(Prob)	(0.0000)***	(0.0000)***	(0.0000)***
Observations	1239	1239	1239

Source: Research finding.
Note: *** denotes the significance at the 1% level.

The coefficients of skewness and kurtosis for unconditional distribution of returns series indicate high deviations of distributions of the three series from the normal distribution. The

Jarque-Bera statistic also implies that the hypothesis of normal distributions for all three return series is rejected at 1% significance level. Thus, not all return series have a normal distribution. Positive skewness statistic implies that the series have longer right tails than that of the normal distribution. The values of the skewness coefficient indicate asymmetry of distributions of studied returns series. Moreover, the values of the kurtosis coefficient imply that the studied distributions have fatter tails than the normal distribution. The time process of the variables, i.e., oil prices, exchange rates, and chemical industries stocks, is shown in Figure 4.

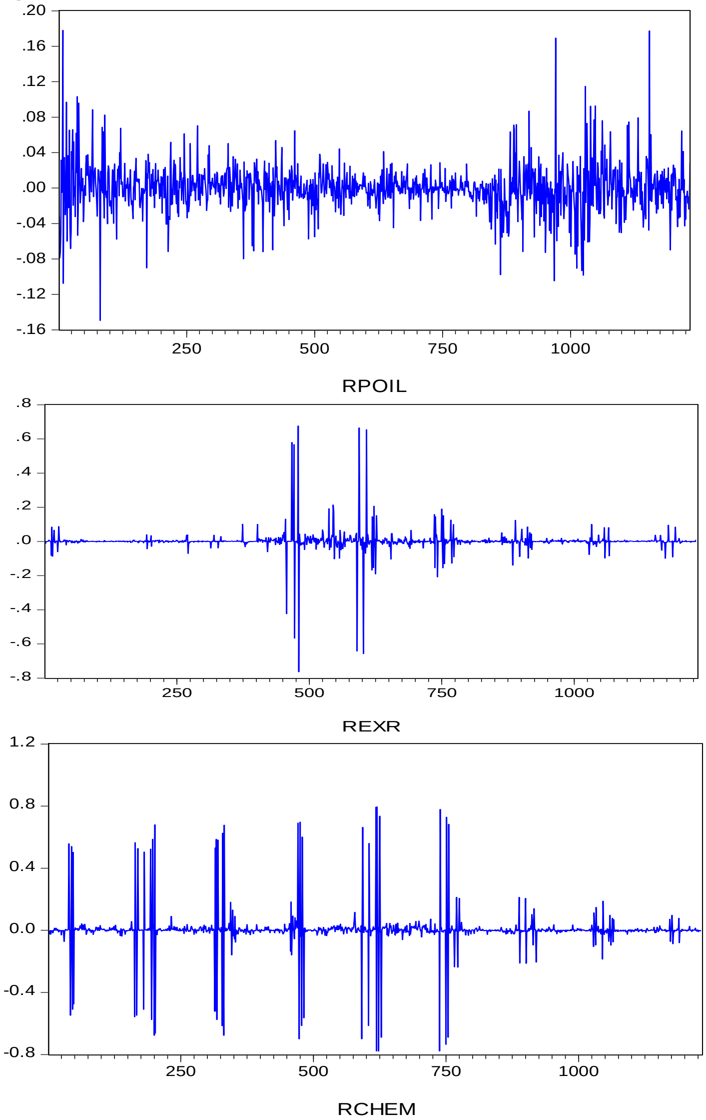


Figure 4. Returns of Crude Oil Prices (RPOIL), Exchange Rates (REXR), and Chemical Industries Stocks (RCHEM)
Source: Research finding.

A review of the return process of the variables intuitively reflects clustered volatilities in each series so that high volatility periods are close to each other, and low volatility periods are sequenced. This situation shows ARCH effects in the series.

Stationary Test

Table 4 presents the results of the augmented Dickey-Fuller (ADF) method to test the stationary of the variables. The results of the ADF test indicate that the returns of variables oil price, exchange rate, and chemical industry stock prices with the presence of intercepts are stationary at 1% level. In other words, all the time series variables are stationary at level (I(0)).

Table 4. Results of Unit Root Test based on ADF

Variable	Statistic	Prob	Result
RPOIL	-33.3774	0.0000	I(0)
REXR	-17.5337	0.0000	I(0)
RCHEM	-15.2016	0.0000	I(0)

Source: Research finding.

Lag selection

After ensuring the stationarity of the variables, the optimal order of the VAR model (mean equation) is determined. For this purpose, we use the Schwarz-Bayesian Information Criterion (SIC). Meanwhile, based on the Hannan-Quinn Information Criterion (HQIC), the optimal number of lags is determined 3, as shown in Table 5.

Table 5. Optimal Lag of the VAR Model (Mean Equation)

RPOIL-REXR- RCHEM		
Information Criterion		Lags
SIC	HQIC	
-8.3811	-8.3889	0
-8.5430	-8.5743	1
-8.5984	-8.6531	2
*-8.6853	*-8.7634	*3

Source: Research finding.
Note: (*) optimal lag.

Estimation and Spillover Effect Test

After examining the stationary and optimal lag numbers and estimating the VAR-TBEKK-in-mean model, in this section, the volatility spillover effects between oil price returns and chemical industry stock price returns are tested using the hypothesis $H_0 = a_{32} = b_{32} = 0$. The volatility spillover effect of oil price returns on exchange rate returns also is examined using the hypothesis $H_0 = a_{31} = b_{31} = 0$, and volatility spillover effects of chemical industry stock price returns on exchange rate returns are tested by the hypothesis $H_0 = a_{21} = b_{21} = 0$. Additionally, according to the assumptions of the TBEKK model, volatility spillover effects of exchange rate returns on chemical industry stock price returns and oil price returns, as well as volatility spillover effects of chemical industry stock price returns on oil price returns, are assumed zero. According to the characteristics of the research methodology used, if no direct relationship exists between two tested variables, the conditional variances of the variables are calculated only for their previous values. Therefore, all non-diagonal elements of the matrix are zero, meaning that no null hypothesis is rejected. Therefore, we have:

$$\begin{aligned} &H_0 = a_{32} = b_{32} = 0 \\ &H_0 = a_{31} = b_{31} = 0 \\ &H_0 = a_{21} = b_{21} = 0 \end{aligned} \tag{9}$$

The VAR-TBEKK-in-mean introduced in the methodology can be estimated by the Quasi Maximum Likelihood (QML) method proposed by Bollerslev and Wooldridge (1992). The reason for using this estimation method is to avoid specifying a distribution function for the noise term. Having T observations of $r_t^i = [r_t^1, r_t^2, r_t^3]$, the following maximization problem is considered.

$$maxlogL(\theta)_t = \sum_{t=1}^{T} L(\theta)_t \tag{10}$$

where L_T is the likelihood function of the sample parameter vectors.

$$L(\theta)_t = log(2\pi) - log|H_t| - \frac{1}{2}\acute{\varepsilon}_t H_t^{-1} \varepsilon_t \tag{11}$$

Here, l_t is the conditional log-likelihood function.[1] Table 6 shows the results of testing risk effects of asset i on returns of asset j in the mean equation.[2]

Table 6. Testing the Risk Effects of Asset i on Returns of Asset j

Mean Equation	REXR	RCHEM	RPOIL
HHS(1,1)	$-0.0016^{(***)}$ 0.0010	-	-
HHS(2,2)	-	-0.0006^{***} (0.0003)	-
HHS(3,3)	-	-	0.0013 (0.0065)

Source: Research finding.
Note: *, **, and *** denotes significance at the 1%, 5%, and 10% levels respectively.
Numbers in parenthesis indicate the standard deviation of the coefficient.

Note that ψ or $hhs(i, j)$ examines the risk effects of asset i on returns on asset j. The null hypothesis for testing the existence of variance heteroscedasticity was rejected at the 0.01 significance level, according to the results. The null hypothesis for examining the significance of the coefficients also was tested. The effect of exchange rate risks on exchange rate returns is significant at 10% significance level (the null hypothesis was rejected), meaning that risks and volatilities caused by exchange rates lead to decreasing the exchange rate returns. Finally, the effect of stock price risks on stock price returns is significant at the 10% significance level, and the effect of oil price return risks on oil price returns is not significant.

Table 7 represents the results of estimating the variance-covariance (V-C) equation, where C_{ij} denotes the intercept, A_{ij} is the ARCH effects, B_{ij} is the GARCH effects, and D_{ij} is the symmetry matrix.

Table 7. Results of V-C Equation of the TBEKK Model and Volatility Spillover Between Returns

V-C Equation	Volatility Spillover		
	REXR	RCHEM	RPOIL
C(1,1)	0.4628^{*} (0.02557)	-	-
C(2,1)	0.1009^{***} (0.0592)	-	-
C(2,2)	-	0.1229 (0.0984)	-
C(3,1)	$-0.0504^{(***)}$ (0.0330)	-	-
C(3,2)	-	0.1752^{*}	-

1 In this study, the asymptotic-Newton method and RATS software were used for model estimation, maximization, and convergence in equations.

2 Regarding the main purpose of the research and due to avoiding more computational results, the output for the mean equation is not reported.

V-C Equation	Volatility Spillover		
	REXR	RCHEM	RPOIL
		(0.03030)	
C(3,3)	-	-	0.0211 (0.0290)
A(1,1)	0.9279* (0.0445)	-	-
A(2,1)	-0.1719* (0.0447)	-	-
A(2,2)	-	0.9497* (0.0385)	-
A(3,1)	0.0142(***) (0.0092)	-	-
A(3,2)	-	-0.0106** (0.0051)	-
A(3,3)	-	-	-0.1610* (0.0143)
B(1,1)	0.8131* (0.0077)	-	-
B(2,1)	0.0534* (0.0191)	-	-
B(2,2)	-	0.8716* (0.0052)	-
B(3,1)	-0.0025 (0.0019)	-	-
B(3,2)	-	0.0015** (0.0007)	-
B(3,3)	-	-	0.9830* (0.0017)
A(2,1)=B(2,1)=0	-	14.764601*	-
A(3,1)=B(3,1)=0	-	-	3.206927
A(3,2)=B(3,2)=0	-	-	4.408584(***)

Source: Research finding.
Note: *, **, and *** denotes significance at the 1%, 5%, and 10% levels respectively.
Numbers in parenthesis indicate the standard deviation of the coefficient.

In matrices A and B, the elements on the main diagonal $(i = j)$ indicate the conditional variance, and off-diagonal elements $(i \neq j)$ represent the conditional covariance between the returns of the variables studied. The null and alternative hypotheses for simultaneously examining ARCH and GARCH spillover effects are as follows:

H_0: No heteroscedasticity or absence of spillover effect ($A_{32} = B_{32} = 0$)

H_1: Heteroscedasticity or presence of spillover effect ($A_{32} = B_{32} \neq 0$)

According to the results provided in Table 8, the null hypothesis for testing the significance of volatility transmission from chemical industry stock returns to exchange rate returns is rejected. Regarding that a major part of chemical industry products is exported, volatility in the stock market of these products is expected to cause volatility in exchange rate returns.

The null hypothesis for testing the significance of volatility transmission from oil price returns to chemical industry stock price returns is also rejected, meaning that there is volatility transmission from oil price returns to chemical industry stock price returns. Since the raw material of all chemical products is oil, this result was expected to be the case.

The null hypothesis for testing the significance of volatility transmission from oil price returns to exchange rate returns is also rejected. Therefore, volatility in oil price returns affects exchange rate returns in Iran. This result is not far from the expectation because a major part of Iran's exchange revenues depends on oil. Now, the effects of volatility transmission from oil markets to chemical industry stock markets are inspected. According to the results, the null hypothesis is rejected at the 11% significant level, meaning that volatility spillover is from oil price returns to chemical industry stock price returns ($a_{32} = b_{32} = 0$). Therefore, summarily, when there is volatility spillover from the oil market to the chemical industry stock market through the GARCH and ARCH effects simultaneously, a spillover effect exists from the oil market to the chemical industry stock market.

For a more precise specification, we diagonalize the matrix according to equation (5) and add the symmetry part (the similar effects of good and bad news) or matrix $\acute{D}D$ to the variance equation. The results of estimating the variance-covariance equation for the TBEKK model with the symmetry assumption is as follows.

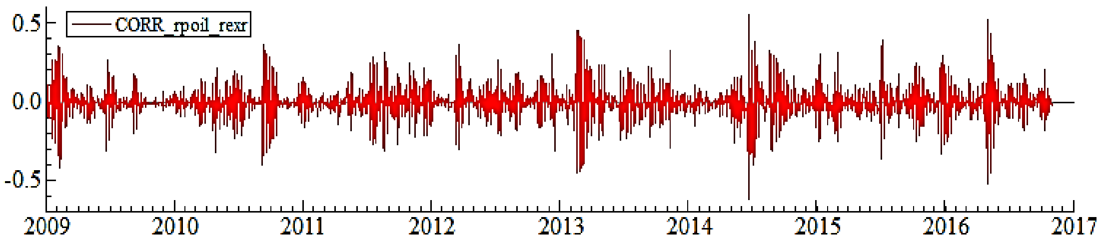
Table 8. The Variance-Covariance Equation in TBEKK Model and Volatility Spillover (With Symmetry Assumption)

Variance equation	Volatility Spillover		
	REXR	**RCHEM**	**RPOIL**
D(1,1)	-0.3625 (0.0512)	-	
D(2,1)	–	0.3423 (0.0450)	–
D(2,2)	–	-0.0786 (0.0363)	–
D(3,1)	–	–	-1.1826 (0.0412)
D(3,2)	–	–	0.0008 (0.0076)
D(3,3)	–	–	0.79020 (0.0527)

Source: Research finding.
Note: Numbers in parenthesis indicate the standard deviation of the coefficient.

In this table, the null hypothesis indicates asymmetry ($D_{ij} = 0$). Regarding the significance of D_{31} and rejection of the null hypothesis $A_{31} = D_{31} = 0$ at the 5% significance level, it can be said that global oil price shocks asymmetrically affect conditional exchange rate return volatilities. Also, since D_{32} is significant and the null hypothesis $A_{31} = D_{31} = 0$ is rejected, it can be claimed that global oil price shocks asymmetrically affect the conditional volatility of chemical industry stock price returns.

Finally, Figure 5 presents the process of dynamic conditional correlation between daily returns of oil prices, exchange rates, and chemical industry stocks. Accordingly, the conditional correlation between the returns is negative in some periods and positive in other periods.



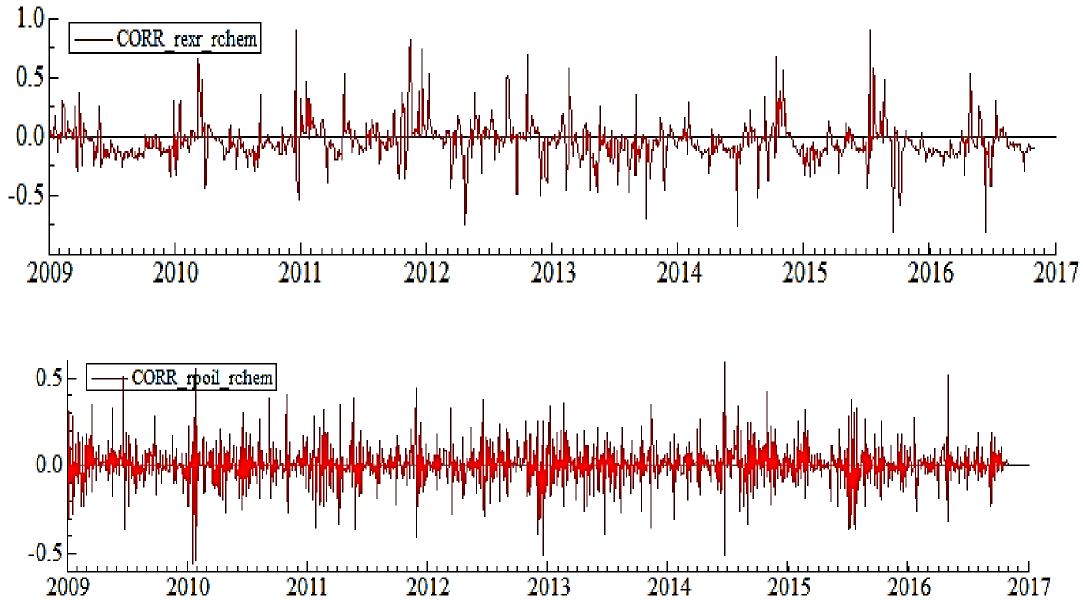


Figure 5. Dynamic Conditional Correlation between Returns of Oil Prices, Exchange Rates, and Chemical Industry Stocks
Source: Research finding.

Conclusion

Regarding the importance of investigating volatility spillover effects of the global oil market and exchange rate on chemical industry stock market (as the representative of capital markets), this research mainly aimed to investigate the type and the process of volatility spillover between oil markets, exchange markets, and chemical industry stock markets using a VAR-TBEKK-in-mean model. According to the research methodology, a triangular BEKK (TBEKK) matrix was used that enabled us to explain feedback effects between the market volatilities more correctly. The results of the research can be listed as follows:

According to the results, the insignificance of the volatility transmission from oil price returns to chemical industry stock price returns was rejected, meaning that there is a volatility transmission from oil price returns to chemical industry stock price returns. This result is in the line with Waheed et al. (2018) and Çatık et al. (2020). Since a major part of chemical products is exported, this volatility in the chemical industry stock returns is expected to make the exchange rate returns volatile.

The null hypothesis, testing the spillover from oil price returns to exchange rates, was rejected. Thus, oil price returns volatilities affect exchange rates volatility. Further, the null hypothesis indicating the insignificance of volatility spillover from the chemical industry spillover to exchange rate returns was rejected.

At 95% confidence level, global oil price shocks have an asymmetric effect on conditional volatility of exchange rate returns. This finding support the result of Aedy et al. (2020). Moreover, global oil price shocks asymmetrically affect the conditional volatility of chemical industry stock returns. According to the results, the symmetry in the response of the conditional variances of the markets to the good and bad news of other markets was rejected, meaning that the market (particularly, chemical industry stock market) do not respond to the positive and negative shocks of other markets (specifically, the oil market and exchange market) similarly. Therefore, the acceptance of the hypothesis of asymmetric effects of good and bad news of oil and exchange markets can be impressive in boosting the intensity of risk spillover between the markets.

The results verified that the relationship between the markets and the extent of risk spillover between them is severely affected by the news and volatility or stability of another market (particularly the oil market).

Generally, the findings imply the presence of volatility spillover from the oil and exchange markets to chemical industry stocks in Iran. Nevertheless, the intensity of spillovers between the markets is not the same, and in some instances, the spillover is more intense.

Our results lead to important implications from investors' and policy makers' perspective. According to the findings, the stock market index (particularly, the chemical industry stock market) is significantly affected by volatilities in oil and exchange markets. These results indicate that the authorities at the capital market should monitor the behavior of other markets such as oil and exchange markets. In this way, besides trying to increase the market depth, Capital market officials are advised to develop the stock market by taking into account the risk spillovers of foreign exchange and oil markets to the stock market. Moreover, investors are better off allocating their portfolio in the chemical stocks more carefully, especially when the volatilities in the two markets (exchange and crude oil) are high. Managing their risk exposures to exchange rate and oil price fluctuations and on taking advantages of potential diversification opportunities that may arise due to lowered dependence among the exchange rates and crude oil is suggested.

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