Oil price shocks on shale oil supply and energy security: a case study of the United States

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Abstract

Purpose – The purpose of this study is to examine oil price shocks on US shale oil supply and energy security during the period 2000q1–2020q4.

Design/methodology/approach – In this study, the Shannon–Wiener index was used to calculate energy security, and then a structural vector autoregression (VAR) was applied to measure the effect of oil price shocks.

Findings – The results of the variance decomposition indicate that oil prices account for about 20% of changes in US shale oil production, while it explains only about 3% of changes in energy security. Finally, historical decomposition confirms the results of impulse response functions.

Originality/value – The novelty of this study is that so far, no study has examined the effect of oil price shock on shale oil production and energy security in the USA using the structural VAR model. This study also used the latest Shannon–Wiener index as a measure of energy security in the USA. The reason for selecting this index is that, in addition to considering the share of the total consumption of each primary energy, the share of energy imports from each country as well as the political risk of energy exporting countries to the USA are also included.

Keywords Unconventional oil, Energy security, Shannon–Wiener index, Structural VAR, USA

Paper type Research paper

1. Introduction

Despite the growing development of renewable energy in recent years, oil continues to be the largest source of energy consumption in the world. Oil consumption in 2020 accounts for about 31% of total primary energy consumption (BP Statistical Review of World Energy, 2021). Due to the high share of this energy, any fluctuations in oil supply can affect energy security and economic growth of energy-importing countries (Cunado *et al.*, 2015). Energy security was first addressed after the oil crisis in the 1970s (Spooner *et al.*, 2013; Sencar *et al.*, 2014; Sovacool, 2011, 2016). However, there is no single definition of energy security. In general, in most

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studies, energy security means the availability, cost-effectiveness, affordability and acceptability of energy (Ang *et al.*, 2015a; Ang *et al.*, 2015b; Sutrisno *et al.*, 2021). Energy security concerns are primarily related to oil security, because on the one hand oil is the main source of primary energy supply (31% of total primary energy consumption), and on the other hand this energy is affected by political, economic and geopolitical factors. Also, it has more price changes than other energy sources. Changes in oil prices also affect the prices of other energy sources (Bielecki, 2002; Stringer, 2008; Vivoda, 2009, 2010; Von Hippel *et al.*, 2011; BP Statistical Review of World Energy, 2021).

Oil-importing countries have focused on domestic energy development to enhance energy security while using energy diversity. Many countries pay special attention to the development of alternative sources such as renewable energy (Kousksou *et al.*, 2015; Aceleanu *et al.*, 2017; Chel and Kaushik, 2018; Østergaard *et al.*, 2020). Several other countries, such as the USA, have developed technologies for the extraction of unconventional energy sources because of the large number of unconventional energy resources (Kelsey *et al.*, 2016; Zheng *et al.*, 2017; Clarke and Evensen, 2019; Bernal *et al.*, 2019). The increase in shale oil production since 2006 is mainly due to the significant increase in oil prices, which has made extraction cost-effective and increased the profitability of shale oil production, followed by technological advances in horizontal drilling and hydraulic fracturing after 2010. This has reduced the extraction costs and increased shale oil production. Both factors have led to higher shale oil production rates in the USA (Hosseini and Shakouri, 2016; Bataa and Park, 2017; Salisu and Adediran, 2018).

Total US oil production in 2000 rose from approximately 5.9 to over 11 million barrels per day in 2020. However, this increase is largely due to shale oil production [Energy Information Administration (EIA), 2021]. Increased shale oil production may reduce US dependency on energy imports. Figure 1 shows the degree of energy dependence (ratio of total energy imports to total primary energy consumption) in the USA.

As can be seen, the rate of energy dependence has decreased from about 35% in 2010 to approximately 21% in 2020 [Energy Information Administration (EIA), 2021]. Reducing energy dependency improves energy security, creating the conditions for sustainable growth.

Numerous studies have examined the relationship between oil prices and shale oil production (Mănescu and Nuño, 2015; Su *et al.*, 2017; Bataa and Park, 2017; Kang *et al.*, 2017; Monge *et al.*, 2017; Kim, 2018; Salisu and Adediran, 2018; Lu *et al.*, 2020), while most have investigated the effects of shale oil supply on oil prices. Only a handful of studies

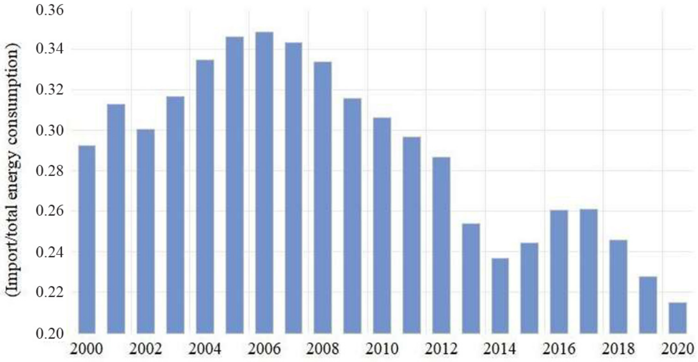

Figure 1. The ratio of total primary energy imports to total primary energy consumption in the USA

Notes:The authors created this figure with data fromthe Energy Information Administration (EIA) (2021) have looked at the effect of oil prices on unconventional oil production. Moreover, as far as we know, few studies have explored the effects of oil prices on energy security. The importance of this study is twofold: first, that the USA is the largest unconventional oil producer, and that most of its oil production comes from this source. Therefore, any increase or decrease in oil prices has a direct impact on the profitability of companies and consequently unconventional oil production. Second, given that a share of US energy consumption comes from other countries and that the bulk of the country's energy imports is oil, any fluctuations in oil prices have a direct impact on the country's energy security. For this purpose, in this study, the effect of oil price on shale oil supply and energy security is investigated. The novelty of this study is that so far, no study has examined the effect of oil price shock on shale oil production and energy security in the USA using the structural vector autoregression (VAR) (SVAR) model. This study also used the latest Shannon–Wiener index as a measure of energy security in the USA. The reason for selecting this index is that, in addition to considering the share of the total consumption of each primary energy, the share of energy imports from each country as well as the political risk of energy exporting countries to the USA are also included.

In the following, Section 2 contains the literature review, Section 3 includes the energy security methodology and the SVAR model, Section 4 presents the experimental results and discussion, and finally, Section 5 indicates the research results.

2. Literature review

This section examines previous literature on the relationship between oil prices and shale oil production, energy security and economic growth.

2.1 Oil price and shale oil production

In recent years, several studies have been conducted on the relationship between oil prices and shale oil production. Most of these studies examined the effects of shale oil production on oil prices (Mănescu and Nuño, 2015; Su *et al.*, 2017; Bataa and Park, 2017; Kang *et al.*, 2017; Salisu and Adediran, 2018; Lu *et al.*, 2020; Monge *et al.*, 2017; Kim, 2018); However, only some of these studies have investigated the effect of unconventional oil production on oil prices (Umekwe and Baek, 2017; Hosseini and Shakouri, 2016).

Bataa and Park (2017) explored the effect of the shale oil revolution on crude oil prices through a SVAR model. They found that US shale oil supply shocks were significant drivers of real oil prices. In another research, Kilian (2017) stated that the price of Brent oil in mid-2014 was about 10% lower than in the absence of shale oil. Salisu and Adediran (2018) indicated that the shale oil revolution has affected not only oil prices but also energy-based goods. Su *et al.* (2017) stated that one of the factors in the decline in oil prices between June 2014 and March 2015 was an increase in shale oil in the USA. Mănescu and Nuño (2015) using an advanced general equilibrium model stated that the decline in oil prices in the second half of 2014 was mainly due to the positive oil supply shock. Lu *et al.* (2020) analyzed and forecasted crude oil prices. They indicated that the effect of US shale oil production on oil prices is gradually increasing but relatively low. Kim (2018) stated that the decline in oil prices during the period 2014–2016 was mainly due to US shale oil production. Monge *et al.* (2017) stated that US shale oil production and West Texas Intermediate (WTI) oil price behavior show a positive correlation during the period 2003–2009, but a negative correlation in the period 2014–2014.

At the same time, only a few studies have examined the effect of oil prices on shale oil production. Umekwe and Baek (2017) in a study inspected the effects of oil prices on US shale oil production using the autoregressive distributed lag (ARDL) model. The results showed that oil prices have an asymmetric effect on shale production, and shale oil production is more sensitive to oil price increases. Hosseini and Shakouri (2016) studied the future of unconventional oil production under oil price scenarios using system dynamics. The results indicated that under different oil price scenarios, the unconventional oil production rate in the world in 2025 will be between 19.6 and 25.8 million barrels per day.

2.2 Oil price and energy security

Few studies have directly dealt with the effects of oil prices on energy security (Obadi *et al.*, 2017), but given that energy security of countries is affected by energy consumption and energy prices cost-effectiveness. The effects of oil prices on energy security and energy consumption are discussed below.

According to studies, only Obadi *et al.* (2017) studied the effect of oil prices on the trade balance and energy security in the Balkans. The results showed that low oil prices had a positive effect on energy security in crude oil-importing economies, but on the other hand had a negative effect on crude oil exporting economies. Here are some other studies that have evaluated the effects of oil prices on energy consumption. Many of them have found that oil prices reduce energy consumption (Cooper, 2003; Haque, 2021), while other studies show a positive relationship between oil prices and energy consumption (Agbanike *et al.*, 2019; Nwani, 2017; Zou and Chau, 2020).

Haque (2021) probed the effect of oil price shock on energy consumption in Gulf Cooperation Council countries with the SYSTEM-GMM approach during the period 1990–2013. The results showed that the positive oil price shock reduced energy consumption. In another study, Cooper (2003) examined the effects of oil prices on oil demand in 23 countries. The results showed that the short- and long-term elasticities for US oil consumption are −0.61 and −0.453, respectively. On the other hand, Chai *et al.* (2016) in a study for China using the SVAR model found that for low energy consumption and low emissions, a 1% increase in oil prices, energy consumption decreases by 0.067%. In another study for China by Zou and Chau (2020) between 1965 and 2016, the results showed that there is a positive relationship between oil prices and oil consumption. Nwani (2017) in a study for Ecuador from 1971 to 2013 using the ARDL model found that higher oil prices in the short- and long-term increased energy consumption in Ecuador. Agbanike *et al.* (2019) examined the relationship between oil prices, energy consumption, and CO_2 emissions using the ARDL model. The results indicated that rising oil prices have boosted energy consumption in the country.

2.3 Oil price and gross domestic product

Finally, we review previous studies on the effects of oil prices on gross domestic product (GDP). In recent years, several studies have explored the relationship between oil prices and GDP growth in oil-importing and exporting countries. Here are some of these studies.

Hamilton (1983) stated that oil shocks were a contributing factor to at least a few recessions in the USA before 1972. Hamilton (1996) shows that there is a correlation between oil price shocks and recession. Kilian and Vigfusson (2011) investigated that the unexpected rise in oil prices causes a significant reduction in US GDP, but there is no response to the expected decline in oil prices. Oladosu *et al.* (2018) using a meta-analysis model stated that the estimated elasticity of US GDP is negative, but smaller than estimated a decade ago. Liu *et al.* (2020) in study of China's macroeconomics using the SVAR model implied that a positive oil price shock has negative effects on economic growth. Zhang (2008) using a nonlinear approach found that negative oil price shocks (price increases) had a greater impact on economic growth than positive shocks. Troster *et al.* (2018) in a study for the USA using Quantile and Granger causality revealed that there is a one-way causality from oil prices to economic growth. Cologni and Manera (2009) using the Markov switching model in the G-7 countries indicated that there is a negative relationship between oil prices and economic growth during the period 1980–2003. In another study for global economy, Timilsina (2015) pointed out doubling oil prices will reduce global GDP by 1.86%.

Some studies did not find a significant relationship between these two variables. Darby (1982) stated that there was no significant relationship between oil prices and actual GDP in the USA and other developed countries during the period 1957–1976. Sarwar *et al.* (2017) and Shahbaz *et al.* (2017) found a two-way relationship between oil prices and economic growth.

The difference between the current research and previous studies can be expressed in several ways. First, no studies have yet evaluated the effects of oil price shocks on shale oil production and energy security in the USA. Second, the latest Shannon–Wiener index is used to calculate the security index, here. In this index, in addition to considering the share of each primary energy consumed in the USA, the share of energy imports from each country is also considered. Because the amount of energy imports from different countries is significantly different and this can affect the energy security index. Therefore, given the diversity of countries from which the USA imports energy (especially oil) and differences in their political and economic conditions, such as some oil-exporting countries in the Middle East, it can affect US energy security. For this purpose, the political risk of energy exporting countries to the USA is also used in this index which is another advantage of the present study. Section 3 introduces the data and methodology used in this research.

3. Data and methodology

This section consists of two subsections: Subsection 3.1 describes the data\variables, and Subsection 3.2 includes the method applied in this research.

3.1 Data

This study investigated the relationship between energy security, unconventional oil production, and oil prices quarterly from 2000q1 to 2020q4 in the USA. Given that unconventional US oil production data has been available since 2000, and oil prices have also been affected by various events during this time period (e.g. economic crisis, shale oil boom, etc.), for this purpose, this time period is considered. The data used in this study are oil prices, GDP per capita, unconventional oil production and energy security (see Table 1). In this research, energy security has been calculated by the Shannon–Wiener index. In this index, in addition to the consumption of each type of primary energy in the USA, the share of primary energy imports from each country as well as the political stability of energy exporting countries to the USA is also considered. Table 1 shows the data specifications and their sources.

3.2 Methodology approach

The methodology section is divided into two subsections. Subsection 3.2.1 includes the energy security index, and Subsection 3.2.2 contains the SVAR methodology.

3.2.1 Energy security index. In this research, the Shannon–Wiener index has been used to evaluate energy security. This index was first applied to study species diversity in ecology (Hill, 1973; Tuomisto, 2010a, 2010b). But gradually it was also used to measure the energy security index (Matsumoto *et al.*, 2018; Matsumoto and Shiraki, 2018). In energy security, it is important to pay attention to the energy source and for this purpose, the internal energy source is more secure. Primary energy diversity increases the level of energy security. The basic form of this index considers the diversity of internal primary energy of each country [equation (1)]:

Table 1.
Variable acronyms, definitions and sources

Abbreviation	Variables	Sources
OILP	West Texas Intermediate Oil Price constant 2010$	BP Statistical Review of World Energy (2021)
GDP	Gross domestic product (GDP) per capita (constant = 2010 million $)	Fred Economic Data (2021)[a]
SHALE	Unconventional oil production (thousand barrels per day)	Energy Information Administration (EIA) (2021)
ES	Energy security	Calculated by Shannon-Wiener index
	Variables used in energy security index	
P	Share of primary energy consumption (oil, gas, coal, renewable energy)	Energy Information Administration (EIA) (2021)
IM	Import primary energy from other countries to the USA	Energy Information Administration (EIA) (2021)
R	Risk index: In this study, the Political stability and absence of violence/terrorism has been used to measure this index (Given that these data are approximately −2.5 to 2.5. We converted them to a scale between 0 and 1. Zero show low political stability, and 1 is high political stability)	Worldwide Governance Indicators (WGI) (2021)

Notes: All data are quarterly over the period from 2000Q1 to 2020Q4. [a]https://fred.stlouisfed.org/. [b]https://info.worldbank.org/governance/wgi/

$$S1 = -\sum_{i=1}^{N} p_i \ln(p_i) \tag{1}$$

where i: the type of the primary energy; j: p_i: the share of primary energy i; N: the number of primary energies types.

Energy security, in addition to the diversity of each country's primary domestic energy, also depends on energy imports from other countries. For this purpose, in Model 2, energy imports from other countries are also considered [equation (2)]:

$$S2 = -\sum_{i=1}^{N} c2_i p_i \ln(p_i) \tag{2}$$

Where:

$$c2_i = \left(1 - dm_i\left(1 - \frac{IM2_i^m}{IM2_i^{max}}\right)\right)$$

$$IM2_i^m = -\sum_j^M m_{ij} ln(m_{ij})$$

$$IM2_i^{max} = -M\frac{1}{M}ln\left(\frac{1}{M}\right)$$

j: Countries from which primary energy is imported; dm_i: share of primary energy imports i; m_{ij}: share of primary energy i imports from country j; M: number of countries from which primary energy is imported.

The problem with Model 2 is that it considers the conditions for importing energy from each country to be the same. However, the political and economic risk varies from country to country. For this purpose, the third and most complete model was presented. In this model, in addition to the weight of energy imports from each country, the political risk of the countries from which energy is imported is also considered [equation (3)]:

$$S3 = -\sum_{i=1}^{N} c3_i A_j p_i \ln(p_i) \tag{3}$$

where:

$$c3_i = \left(1 - dm_i\left(1 - \frac{IM3_i^m}{IM3_i^{max}}\right)\right)$$

$$IM3_i^m = -\sum_j^M r_j m_{ij} ln(m_{ij})$$

$$IM3_i^{max} = -M\frac{1}{M}ln\left(\frac{1}{M}\right)$$

r_j: Risk index of energy imports from country j (for this index, the political stability of countries has been used, and this index is between 0 and 1). M: Number of countries from which primary energy is imported.

3.2.2 Structural VAR methodology. The SVAR model in this study includes four variables: the oil prices, the US shale oil supply, the US energy security and US GDP per capita. Based on the assumption of recursive recognition for the simultaneous relationship between variables, an SVAR model order p is proposed for the effects of oil price shock on shale oil supply, energy security and GDP per capita in the USA [equation (4)]:

$$A_0 y_t = c_0 + \sum_{i=1}^{p} A_i y_{t-i} + \varepsilon_t \tag{4}$$

where y_t = (*DLOILP*, *DLSHALE*, *DLES*, *DLGDP*) is a 4×1 vector of endogenous variables; A_0 is the 4×4 contemporaneous coefficients matrix; c_0 is a 4×1 constant component vector; A_i is the 4×4 autoregression coefficients matrix; ε_t is a 4×1 structural disturbances vector. Hence, the reduced form of the errors specified as u_t can be parsed as follows [equation (5)]:

$$u_t = A_0^{-1}\varepsilon_t = \begin{bmatrix} u_t^{DLOILP} \\ u_t^{DLSHALE} \\ u_t^{DLES} \\ u_t^{DLGDP} \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{DLOILP} \\ \varepsilon_t^{DLSHALE} \\ \varepsilon_t^{DLES} \\ \epsilon_t^{DLGDP} \end{bmatrix} \tag{5}$$

where ε_t^{DLOILP} refers to oil price shocks; $\varepsilon_t^{DLSHALE}$ shale oil supply shock; ε_t^{DLES} US energy security shock; and ε_t^{DLGDP} is the US GDP per capita shock.

The diagnostic constraints on the A_0^{-1} are as a lower triangle coefficients matrix in the structured VAR model. Given that in this study we consider the assumption of recursive identification for the simultaneous relationship between these variables, the limitations applied in this study are as follows. The first variable is oil prices and is known as exogenous in many studies (Li *et al.*, 2016; Adedokun, 2018; Mukhtarov *et al.*, 2021). Oil prices affect all variables of shale oil supply, energy security and GDP per capita at time *t*, but it does not affect them. The second row is shale oil production. In this study, this variable is endogenous, and it is a function of oil price is considered. According to the theory, rising oil prices will lead to cost-effectiveness and increase the profitability of shale oil production in the short run and the long run will increase investment in R&D to reduce production costs and increase production capacity (Hosseini and Shakouri, 2016). Third, as can be seen from the general definition of energy security, energy availability and cost-effectiveness are two important aspects of the energy security index (Ang *et al.*, 2015a; Ang *et al.*, 2015b; Sutrisno *et al.*, 2021). For this purpose, in this research, energy security depends not only on the oil price but also on the shale oil supply. The fourth row is GDP per capita, which depends on changes in all variables, respectively, oil prices, shale oil production and energy security. According to Cuñado and de Gracia (2003), rising oil prices cause oil-importing countries to pay more, resulting in lower aggregate demand. Based on the Keynesian framework, Hamilton (2003) states that high levels of prices reduce real wages, thereby reducing labor supply and thus negatively affecting economic growth. On the supply side, it can be said that the production function depends on energy in addition to capital and labor, and the reduction in energy supply harm on economic growth.

4. Empirical results

This section is divided into two subsections. Subsection 4.1 includes US energy security, and Subsection 4.2 presents the results of preliminary tests and SVAR model estimates.

4.1 US energy security

As described in the methodology section, this study uses the latest Shannon–Wiener index equation (3) to calculate US energy security. In addition to the share of primary energy consumption, the share of energy imports from other countries and the political risk of oil-exporting countries to the USA are also considered in this index. Figure 2 indicates the US primary energy consumption from 2000 to 2020.

As shown in Figure 2, oil consumption accounts for about 35% of primary energy consumption in 2020. Since then, natural gas consumption has risen from about 24% of total primary energy

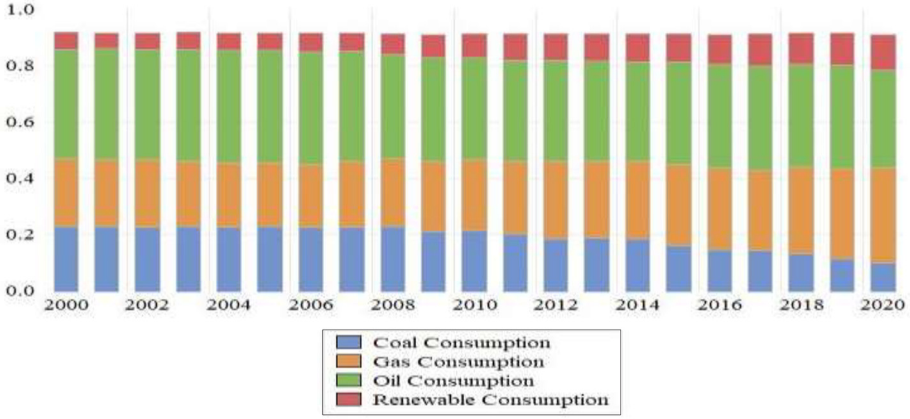

Figure 2. The share of each primary energy consumed during 2000–2020

Note: The authors created this figure with data from Energy Information Administration (EIA) (2021)

consumption in 2000 to about 34% in 2020. Renewable energy consumption, although having the lowest share, but it has had a growing trend during this period, and it increased from 6% in 2000 to about 12.5% in 2020. Meanwhile, during this period, the share of coal consumption in total energy consumption declined significantly from about 23% to about 10%.

A portion of the US energy consumption comes from imports. This can affect the energy security of this country. Figure 3 shows the share of imports of each primary energy source in the USA.

Oil imports accounted for about 85% of total US primary energy imports during this period. After that, natural gas imports during these years have varied from about 11% to 13%. Other energy sources (coal, renewable) account for a small share of energy imports. Given that oil is

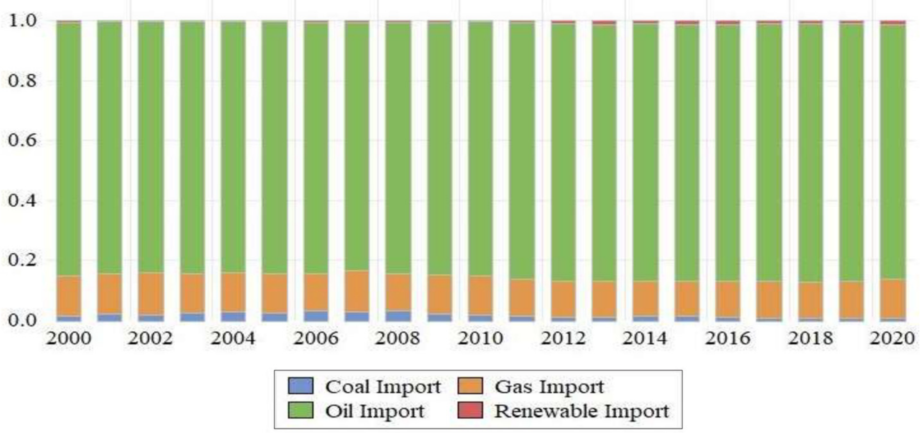

Figure 3. The share of energy imports of each of primary energy during the period 2000–2020

Note: The authors created this figure with data from Energy Information Administration (EIA) (2021) an important part of US energy imports, any change in oil prices or political turmoil in the oil market could jeopardize the country's energy security. To this end, it is better for the USA to reduce its imports from countries and regions involved in political and economic turmoil [such as Organization of the Petroleum Exporting Countries (OPEC)] as well as increase the diversity of imports from different countries. In the following, we will examine the amount of US oil imports from different countries. Figure 4 shows the number of oil imports from OPEC and non-OPEC during the period 2000–2020.

As can be seen, the USA has significantly reduced oil imports from OPEC countries between 2000 and 2020. In 2000, it imported about 5.2 million barrels per day from OPEC countries, while in 2020 this amount has reached about 885,000 barrels per day. At the same time, oil imports from non-OPEC countries in 2000 were about 6.2 million barrels per day and in 2020 it reached about 7 million barrels per day, despite fluctuations over time. Figure 5 depicts the number of oil imports from each of the OPEC countries.

As shown in Figure 5, the overall trend in oil imports from OPEC countries is declining. This amount has decreased significantly in 2019 and 2020. The largest amount of US oil imports over the period among OPEC countries come from Saudi Arabia. Imports from Venezuela fell sharply in 2019 and to almost zero in 2020. Imports from Algeria, Kuwait, Nigeria and other OPEC members also fell sharply in 2020. In the following, Figure 6 represents the number of oil imports from each of the non-OPEC countries.

Oil imports from Mexico, Norway, the UK and other non-OPEC countries have declined significantly since 2011. Meanwhile, the trend of oil imports from countries such as Canada and Russia is upward. Canada is the largest oil exporter to the USA in 2020 with about 4.1 million barrels per day.

4.2 Structural VAR results

In this section, first the statistical characteristics of the variables are given, then the results of the preliminary tests are stated, and finally the SVAR estimation results are given.

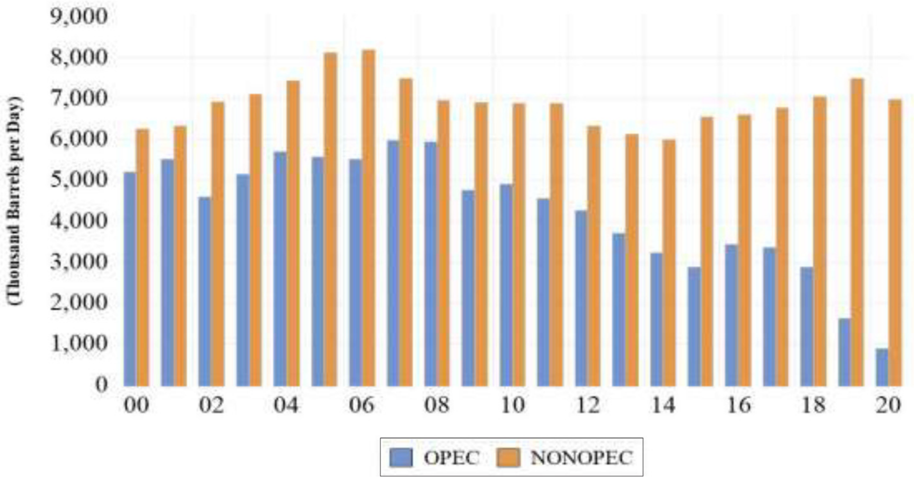

Figure 4.
Oil imports from OPEC and non-OPEC countries

Note: The authors created this figure with data from Energy Information Administration (EIA) (2021)

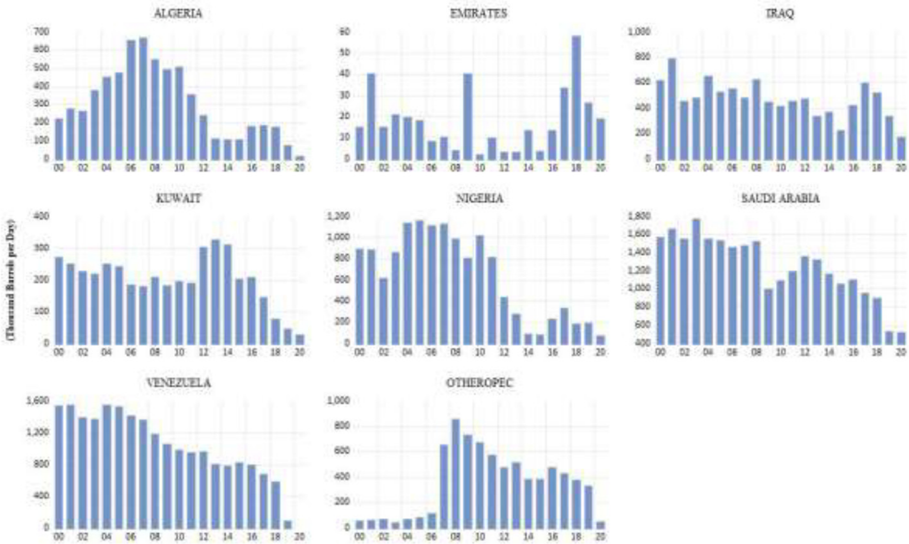

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Figure 5.
US oil imports from OPEC countries

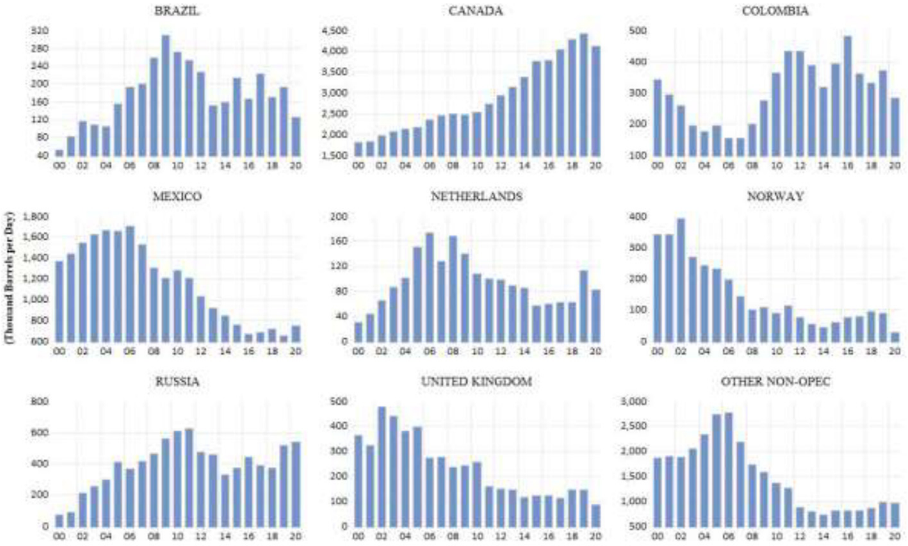

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Figure 6.
US oil imports from non-OPEC countries

Table 2 shows the results of variables statistical characteristics. The number of observations is 84, and the energy security index calculated using the Shannon–Vince index, is normalized between 0 and 1.

After describing the variables statistical characteristics, the stationary of the data should be examined. Augmented Dickey–Fuller (ADF) (Dickey and Fuller, 1979), Phillips–Perron (PP) (Phillips and Perron, 1988), Kwiatkowski–Phillips–Schmidt–Shin (KPSS) (Kwiatkowski *et al.*, 1992) and Elliott–Rothenberg–Stock (ERS) (Elliott *et al.*, 1992) tests were used to evaluate the data stationary. Null hypothesis is the existence of a unit root in all tests except KPSS. As Table 3 shows, **LOLIP** in the KPSS test cannot reject the null hypothesis, and shows that this variable is stationary at 1%. But other variables **LGDP**, **LES**, and **LSHALE** confirm the existence of a unit root. The results of the unit root test for the first-order difference of the variables show that all variables **DLOILP**, **DLGDP**, **DLES** reject the hypothesis of the unit root existence. This indicates that the stationary of all variables is confirmed.

After examining the stationary of the variables, in the SVAR model, we must first obtain the optimal lags. For this purpose, we used the likelihood ratio (LR) statistics provided by Hatemi-j (2003), final predict error (FPE) developed by Hsiao (1979), Akaike information criteria (AIC) introduced by Akaike (1998), Schwarz information criteria (SC) provided by Schwarz (1978) and Hannan–Quinn information criteria (HQ) presented by Hannan and Quinn (1979). The results of Table 4 show that the statistics of LR, FPE and AIC consider the third lags is optimal, while SC indicates the first lag and HQ the second lags. For this purpose, in this research, third lags are used as the optimal lag.

Table 2.
Descriptive statistics

			Descriptive statistics		
Variables	Obs.	Mean	SD	Min.	Max.
OILP	84	63.48483	25.15929	24.85495	131.3050
GDP	84	51.65092	3.324410	45.98318	58.33271
ES	84	0.946661	0.027353	0.903168	1
SHALE	84	7370.523	7584.607	1110.427	24726.32

Note: Obs. is the number of observations in the model, SD is the standard deviation, Min and Max are the minimum and maximum, respectively

Table 3.
ADF, PP, KPSS and ERS unit root tests

Variables	ADF	PP	KPSS	ERS
LOILP	−1.848608	−1.905147	0.299767***	6.134086
LGDP	−1.264840	−1.095721	1.035096	44.56386
LES	−1.671853	−1.308756	0.882361	16.27459
LSHALE	−0.434506	0.296504	1.085196	77.79861
DLOILP	−8.070610***	−8.069973***	0.203632***	0.595966***
DLGDP	−11.15630***	−11.63585***	0.068535***	0.926819***
DLES	−6.76094***	−8.442531***	0.286834***	0.465612***
DLSHALE	−2.92669**	−4.061459***	0.299364***	2.463576**

Note: ***, ** and * denote statistical significance at 1, 5 and 10% level, respectively

Lag	LR	FPE	AIC	SC	HQ
0	NA	1.24e-12	−16.06212	−15.94036	−16.01342
1	106.0873	4.32e-13	−17.11997	−16.51119*	−16.87646
2	55.65395	2.90e-13	−17.52282	−16.42702	−17.08451*
3	35.68909*	2.54e-13*	−17.66488*	−16.08205	−17.03176
4	9.964522	3.31e-13	−17.41537	−15.34552	−16.58745
5	17.27977	3.78e-13	−17.30836	−14.75148	−16.28563
6	9.881296	4.94e-13	−17.08280	−14.03889	−15.86526

Notes: LR: sequentially modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan–Quinn information criterion

Table 4.
Lag-order selection criteria

After determining the optimal lag, we examine the stability conditions. This test assumes that the infinite-order vector moving-average and reversible (Abrigo and Love, 2016). We check out the stability conditions concerning the three lags. As shown in Figure 7, all modulus is less than 1 and all 12 eigenvalues are within the circle, which confirms the existence of stability conditions.

4.2.1 Impulse response functions. After examining the stability conditions and estimating the SVAR model, the results of impulse response functions (IRFs) are investigated. This section indicates the effect of oil price shocks on shale oil production, energy security and economic growth in the USA.

As shown in Figure 8, the results of oil price shocks on US shale oil production exhibit that they positively affect shale oil production at all periods. This effect is very high in the first 5 periods (seasons) and then gradually diminishes. This result indicates that higher oil prices will make shale oil production more cost-effective at certain oil wells, as well as increase investment in further shale oil extraction in the country. Due to the short extraction time for shale oil production, the shale oil supply increases rapidly in a short time. The results of the study are confirmed by the findings of Umekwe and Baek (2017) on the impact of oil prices on US shale oil production estimated by the ARDL model.

Eigenvalue	
Root	Modulus
-0.906559	0.906559
0.888681	0.888681
0.178269 - 0.815094i	0.834361
0.178269 + 0.815094i	0.834361
-0.162271 - 0.705043i	0.723476
-0.162271 +0.705043i	0.723476
-0.308017 - 0.542260i	0.623635
-0.308017 + 0.542260i	0.623635
-0.552589	0.552589
0.144988 - 0.491389i	0.512333
0.144988 + 0.491389i	0.512333
0.358318	0.358318

Graph

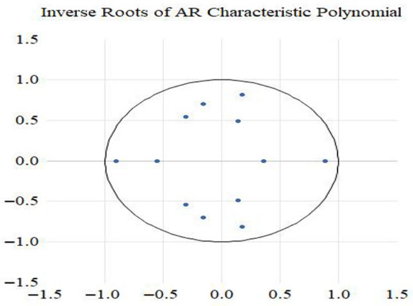


Figure 7.
Eigenvalue stability condition

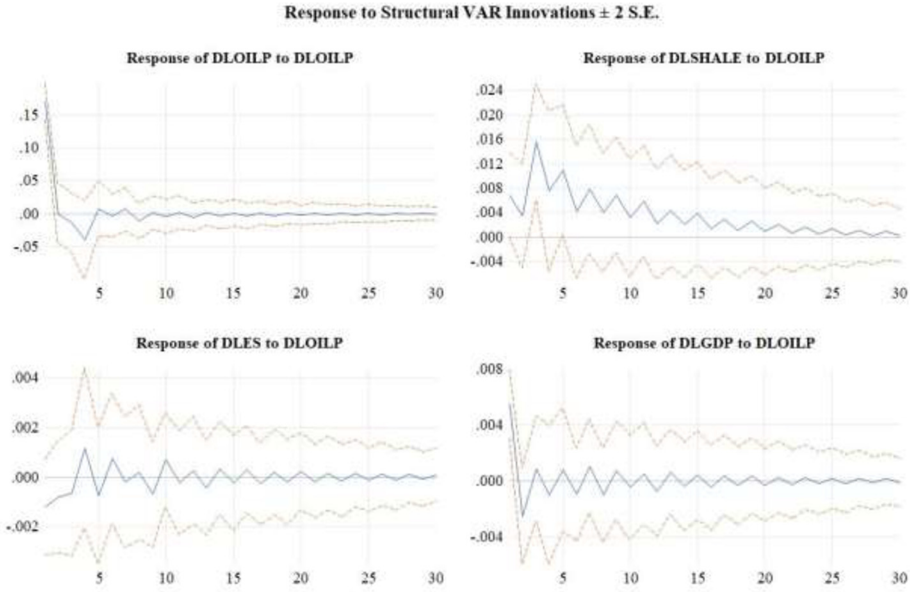


Figure 8.
Results of impulse response functions

The results of the oil price shock on US energy security show that the rise of oil prices causes a negative shock on US energy security. This shock in the first 3 periods has negative effects on US energy security, then continues oscillating until period 10 and gradually stabilizes. Thus, it can be argued that rising oil prices increase the cost of oil imports, which in turn mitigates oil imports and thus jeopardizes US energy security in the short term. Rising oil prices, on the other hand, increase investment in shale oil production, and after a while, energy security in the USA increases as domestic shale oil production increases. Obadi *et al.* (2017) in a study for Balkan countries confirmed that rising oil prices reduce the energy security of oil-importing countries, but lead to increased energy security of oil-exporting countries.

Finally, the effects of the oil price shocks on US economic growth suggest that the response of economic growth to rising oil prices in the first periods is very large and negative, but this reaction diminishes after three periods and gradually reaches equilibrium. This reaction implies that positive shocks of oil prices could significantly reduce US economic growth in the short term. Kilian and Vigfusson (2011) in a study for the USA confirmed that unexpected positive shocks in oil prices cause a significant reduction in GDP. Liu *et al.* (2020) in a study for China using the SVAR model and Timilsina (2015) in another survey for the global economy using the general equilibrium model corroborated the research results.

After checking the IRF, the results of the forecast error variance decomposition (FEVD) are calculated in Table 5. This table shows the extent to which the unpredictable changes in each variable can be explained by shocks of the other variables. The results of shale oil production (**DLSHALE**) variance decomposition exhibit that in the first period 95% of the changes in this variable are explained by itself, and about 5% of the changes are explained by the oil price. In the second period, **DLGDP** of about 15%, oil prices of about 4.95% and energy security of about 4.7% explain the changes in shale oil production. After five periods, 26% of its changes are due to **DLGDP**, 20% due to oil prices and 9.7% due to energy security. And finally, in the tenth period, about 33% was explained by **DLGDP**, 20% by oil prices and 11% by energy security.

The results of energy security of DLES variance decomposition in the first period indicate that **DLOILP** and **DLSHALE** explain 1.92% and 1.52% of energy security changes, respectively. The findings of the second period show that **DLGDP** had more explanatory effects than **DLSHALE**, and **DLOILP**, and explained 3.7%, 2.8% and 2.5% of energy security changes, respectively. After five periods, the **DLGDP** describes energy security changes by about 21%, followed by the **DLSHALE** and **DLOILP** variables with 7.34% and 3.3% of US energy security changes, respectively. Ultimately, in the tenth period, 24.7% of the changes are explained by **DLGDP**, 9% by **DLSHALE** and 3.3% of the changes by **DLOILP**.

In the main model, the WTI oil price was used to estimate the SVAR model. The following, brent oil price is considered to robustness check. The results of FEVD and IRF are given in Appendix (Table A1, Figure A1). As can be seen from Table A1 and Figure A1, the model robustness is confirmed.

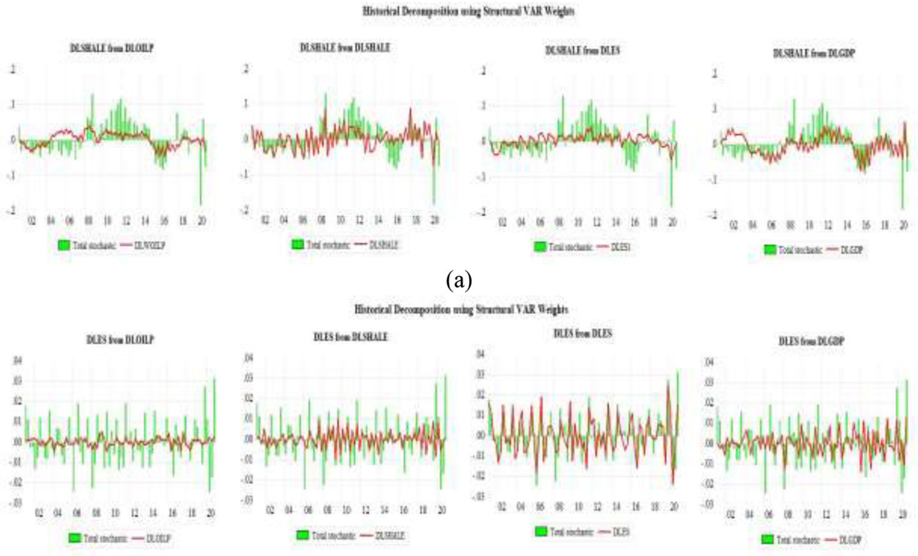
4.2.2 Historical decomposition. After variance decomposition, we finally examine the historical decomposition of each of the shocks on shale oil production and energy security over the study period.

Figure 9(a) presents a historical decomposition of the contribution of each of shale oil production, oil prices and energy security structural shocks to fluctuations in shale oil production over time. As can be witnessed (see Figure 9(a)), rising oil prices before the 2008 financial crisis were one of the drivers of increasing shale oil production. Because it made shale oil production cost-effective and increased investment in this industry. In addition, the significant drop in oil prices after the oil crisis has had a negative effect on US shale oil production. Oil prices from 2010 to early 2014 had little effect on shale oil production because, as mentioned earlier, the increase in shale oil production during this period was largely due to advances in horizontal drilling technology and hydraulic fracturing. But as you can see, part of the decline in US shale oil production after June 2014 was due to lower oil prices. The results of historical decomposition show that energy security has had little effect on shale oil production. However, economic growth has been one of the variables affecting shale oil production in this period, as shown in Figure 9(a), the increases and decreases in US economic growth, especially since 2011, may have led to changes in the US shale oil production.

Table 5.
Forecast error variance decomposition (FEVD)

		Impulse variables			
Response variables	Forecast horizon	DLOILP	DLSHALE	DLES	DLGDP
DLSHALE	1	4.988746	95.01125	0	0
	2	4.951461	75.36626	4.701535	14.98075
	5	20.02558	43.44328	9.861702	26.66944
	10	20.13585	35.46693	11.27924	33.11799
DLES	1	1.923797	1.526411	96.54979	0
	2	2.495549	2.866020	90.91036	3.728069
	5	2.727806	7.345645	68.81378	21.11277
	10	3.323738	9.018421	62.91865	24.73919

Note: FEVD followed the variance decomposition and was performed using 200 Monte Carlo simulations for ten periods



(a)

(b)

Figure 9. Historical decomposition using SVAR weights: (a) DLSHALE and (b) DLES

Figure 9 shows the results of a historical decomposition of US energy security. Economic growth has been one of the factors influencing US energy security in the period under study. Then there is shale oil production, which has been able to explain fluctuations in energy security over time. As can be seen, increasing (decreasing) shale oil fluctuations have a positive (negative) effect on US energy security. Oil prices have had less impact on US energy security over time than other variables. As Figure 9(b) represents, the largest impact of oil prices on US energy security during this period was between 2008 and 2009, and around 2015–2018.

5. Conclusion

In this study, we examine the effects of oil price shocks on shale oil production and energy security in the USA during the period 2000q1–2020q4 using the SVAR model. Therefore, we first calculate the US energy security using the latest Shannon–Wiener index. This index considers the share of energy imports from different countries as well as the political risk of these countries. Because the share of US energy imports varies from country to country, and each of these energy-exporting countries to the USA has different political and economic conditions. Then, after performing preliminary tests and finding the optimal lags, we estimate the SVAR model, and the results of IRF, variance decomposition and historical decomposition are given.

The results of the US energy import analysis show that oil accounts for about 85% of US energy imports, and it is indicated that it is necessary to develop US shale oil production to reduce dependence on oil imports. On the other hand, due to political and economic unrest in some oil-exporting countries, such as OPEC, the USA has reduced oil imports from these countries over time, which it is mainly due to shale oil production and can help to increase US energy security.

The results of the IRF of oil price on shale oil production show that the positive oil price shock has a significant positive effect, especially in the short run, on shale oil production, and this effect gradually stabilizes over time. It can be stated that the increase in oil prices will increase the profitability of shale oil production and investment in this industry will also increase, and this is a strong stimulus to increase production. On the other hand, the effects of the oil price shock on energy security suggest that rising oil prices in the short-term endanger US energy security. But in the long run, this increase could lead to higher US shale oil production and increase energy security for the country, because the oil price increase can rise shale oil production. The results of variance decomposition implied that the oil price (tenth period) was able to explain about 20% of changes in shale oil production. While oil prices account for only 3% of energy security changes, the country's economic growth with about 24% has been the most important factor, and then shale oil production has been able to explain about 9% of changes in energy security. Finally, the historical decomposition also confirms the impulse response results.

The government and policymakers must pursue incentive policies to optimize the energy structure to maintain energy diversity and increase energy sustainability and security. The USA must also increase the conditions for private investment and incentives to develop and extract unconventional oil and gas resources alongside available renewable sources. Paying attention to unconventional resources production causes that in addition to supplying energy from domestic sources and reducing dependence on energy imports, the risk of energy security is minimized and can be protected from unexpected fluctuations in oil prices. For future studies, researchers could examine the relationship between unconventional oil production, the environment and energy security.

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Further reading

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Appendix

Table A1. Forecast error variance decomposition (FEVD) (robustness check)

Response variables	Forecast horizon	Impulse variables DLBOILP	DLSHALE	DLES	DLGDP
DLSHALE	1	3.740278	96.25972	0	0
	2	4.080643	77.83663	3.792097	14.29063
	5	22.53715	41.10217	8.003061	28.35762
	10	23.54985	32.29180	9.378098	34.78025
DLES	1	1.186601	2.434662	96.37874	0
	2	3.866192	3.890400	87.35222	4.891188
	5	3.369290	6.991406	68.38878	21.25052
	10	3.604849	8.431320	63.31302	24.65082

Note: FEVD followed the variance decomposition and was performed using 200 Monte Carlo simulations for ten periods

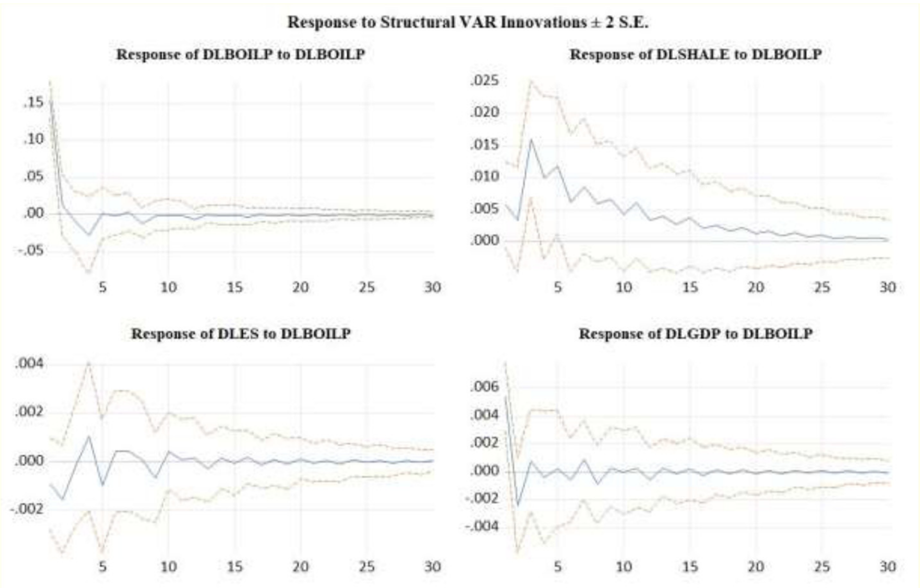

Figure A1. Results of impulse response functions (robustness check)

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