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Article

Unlocking the shale potential: examining the effects on oil prices and the potential for global adoption

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Unlocking the shale potential: examining the effects on oil prices and the potential for global adoption

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ABSTRACT

Over the last decade, a significant concern in the energy market has been the decline in the USA's oil imports and fall in energy prices. In this context, we investigate the impact of the shale revolution in the USA on oil prices and examine its potential replicability in other shale-rich countries. Employing the Auto Regressive Distributive Lag Model (ARDL), the influence of the shale energy boom on WTI oil prices has been quantified, using monthly time series data from 2008 to 2019. The results reveal that shale oil output has no effect on oil prices in the short run. However, we found a significant negative impact on oil prices in the long run, as shale development enhances the global energy supply. Additionally, we found that the shale rich countries lack the infrastructure, financing, and have limited property rights, which hampers their chances of replicating the success of shale development in USA. We recommend that countries trying to develop shale resources invest in factors that led to the shale revolution in the USA. Additionally, as low oil prices will reduce future investment in shale oil and gas exploration, the US government should offer adequate incentives for private firms to remain competitive in the energy sector and continue enjoying the benefits of the shale revolution.

IMPACT STATEMENT

The paper "Unlocking the Shale Potential: Examining the Effects on Oil Prices and the Potential for Global Adoption" offers critical insights into the transformative impact of the shale revolution on the U.S. energy landscape and global oil markets. Through the utilization of the Auto Regressive Distributive Lag (ARDL) model and an examination of more than ten years of data, this research highlights the crucial role played by U.S. crude oil output and OPEC's oil supply in driving down the global oil prices. The results draw attention to the possible financial implications associated with prolonged low oil prices, especially in terms of deterring future investments in shale oil exploration. Additionally, this study provides a roadmap for other countries with untapped shale reserves to contribute to global energy security and price stabilization by examining the possibilities for shale technology adoption on a worldwide scale.

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1. Introduction

In the last two decades, there has been a profound change in the international energy market. On these significant transformations, the International Energy Agency (IEA), commented that 'major importers are becoming exporters, large exporters are becoming large consumers, and previously small consumers are becoming the dominant source of global demand' (Publishing, OECD., & Agency, I. E 2013). The statement is in reference to the transformational changes taking place in the international energy market. For instance, the fast-growing economies of Asia have seen unprecedented growth in oil demand. These were small energy consumers earlier. Additionally, oil consumption is continuously rising in countries like Saudi Arabia, which is the largest exporter of oil, and the USA, the largest importer of oil is transforming itself into an oil and gas exporting nation.

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Significant developments in the US energy landscape have been possible due to the advent of hydraulic fracturing and fracking technology, which have been useful in the exploration of shale reserves (Salygin et al., 2019). In the US, shale oil and gas output has increased dramatically, from 2.2% in 2000 to 52.2% in 2016 (Liu and Li, 2018). In terms of volume, the production of shale gas increased from 36.2 billion cubic feet to 223.8 billion cubic feet, which is nearly a six-fold increase in gas production during the period. Consequently, the USA (687.6 billion cubic meters) surpassed Russia (604.8 billion cubic meters) and became the world's largest natural gas producer in 2009. According to the Energy Information Administration's (EIA) latest report, roughly 2.84 billion barrels (or 7.79 million barrels per day) of crude oil were produced directly from tight-oil deposits in the United States in 2022. This accounted for around 66% of total US crude oil output in 2022.

As a result of rising domestic production, the United States' net oil imports decreased, and the country became a net exporter of petroleum in 2020¹. Total petroleum exports were approximately 9.52 million barrels per day (b/d) in 2022, while total petroleum imports were approximately 8.33 million b/d. In 2020, 2021, and 2022, total petroleum exports in the United States exceeded total petroleum imports. These significant changes have been increasingly referred to as the shale revolution, which has progressively transformed the American economy (Azar, 2017; Eife, 2022; Salameh, 2012). As revealed by Figure 1, petroleum consumption in the USA is almost fully backed by its domestic production suggesting that the USA is almost sufficient for its energy needs.

The shale revolution has created a number of opportunities in the USA (Majumdar & Mittal, 2018; Wang & Krupnick, 2015). The empirical findings point to the positive effects of the gas and oil booms on the local economy, including a rise in local wages and the growth of the manufacturing sector (Allcott & Keniston, 2018). Additionally, the shale revolution has also been associated with energy security in the USA through reduced dependence on external sources (Parraguez Kobek et al., 2015). The increased production has also allowed the US to export more energy products and improve its comparative advantage in petroleum products over the years (Nadeem et al., 2021). The foreign exchange earnings from petroleum exports have reduced the strain on the country's trade balance and are likely to emerge as a more significant contributor to its economy in the near future. Various benefits have been linked to the shale revolution, but it remains to be seen whether the shale revolution has contributed to any reduction in energy prices, in which case it can truly be termed a revolution. If low energy prices can be attained due to shale development, it could provide significant incentives for countries rich in shale reserves, particularly developing nations that rely on non-renewable sources of energy for their growth.

In light of the developments mentioned in the preceding paragraphs, we propose to assess the impact of the shale revolution on the USA and its replicability. Specifically, the present study contributes to the existing literature in three ways. First, it empirically examines the effects of the shale revolution on oil prices. Second, it identifies any differences in the short and long run impact of shale on oil prices, employing the Autoregressive Distributed Lag (ARDL) methodology. The ARDL modeling is necessitated due to the non-stationary nature of time series data. Additionally, it also helps to avoid any chances of spurious regression due to a missing variable, which has been identified as the major cause of spurious regression (Ghouse et al., 2018). Third, it examines the potential of the shale revolution to spill over into other parts of the world.

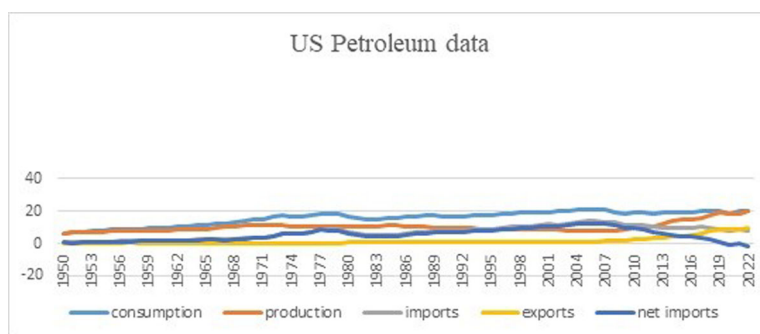


Figure 1. USA Domestic petroleum production, consumption, exports, imports and net imports.
Source: U.S. Energy Information Administration, Monthly Energy Review, September 2023.

To enhance readability, the paper has been structured in various sections. The literature review section summarizes the major findings as published in various research studies. The third section presents the strategy for constructing the model, along with variable definitions and sources of data. A discussion on the methodology and empirical findings of the ARDL analysis is reported in sections four and five. The sixth section analyzes the factors contributing to the success of the shale development program in the USA and draws comparisons with other shale rich countries to identify their prospects of replicating the shale revolution. The study has been concluded in the last section, which summarizes the results and contains recommendations based on the findings of the study.

2. Literature review

The American oil industry has its origins in the early days of oil exploration and development. Gong (2020a, 2020b) reviewed the history of the American oil industry and forecasted the future development of the oil and gas sector in the United States. He considers the recent technical advances and innovation in crude oil production and suggests that unconventional oil development has reached commercial levels in the United States, changing the energy security landscape, geopolitics, and economy. Much of this development is owed to the discovery and subsequent successful extraction of shale oil and gas, which has led to unprecedented growth in energy production in the USA.

On the question of whether the trend in the US energy market will sustain itself in the future, Solarin et al. (2020) argue that shale oil and gas output exhibit tendencies of being hysteresis and that future production would be contingent on the policies of the government. Therefore, the effectiveness and intent of the policies surrounding the development of unconventional sources of energy would, to a large extent determine the changes in the energy landscape in the USA and will also have a bearing on the international energy markets. For instance, Grinets and Kaznacheev (2014) show that a favorable tax regime, private property rights for subsoil resources, and high petrol prices in the early 2000s all contributed significantly to shale gas development in the USA. Hence, any changes in policy resulting in cutting down on tax incentives currently available or curtailing property rights would be highly detrimental to the consistent growth in oil and gas production.

A survey of the extant literature reveals a heightened interest in the shale revolution and its implications in the last decade. This interest is particularly visible in measuring the effects of shale on different countries and markets. For instance, employing a vector auto-regressive model, Wakamatsu and Aruga (2013) assert that shale gas production has substantially changed the natural gas markets of the USA and Japan and altered the underlying relationship between these markets. On a more macro level, the shale revolution has been found to contribute to an increase in production in the USA, allowing the country to better deal with negative externalities and the environment (Bilgili et al., 2016). The effect of the shale revolution on oil-producing and exporting countries has also been analyzed. For instance, Ogunyiola (2015) studied the USA shale oil development and its effect on the Nigerian economy and suggests a change in the global energy market due to the advent of horizontal drilling and hydraulic fracking, which contributed to an increase in global fuel production. This increased production led to a subsequent decline in Nigerian fuel exports translating to increased external debt. The empirical findings on the effects of shale production suggest some benefits for the producing nations, and present a gloomy picture for the conventional exporters of oil.

In the last two decades, there have been multiple works exploring the socio-economic aspects of the shale revolution in the USA. Commenting on the benefits of the shale development, Allcott and Keniston (2018) attribute the socio-economic development in the shale rich regions to shale revolution. Out of the different socio-economic indicators, Parraguez Kobek et al. (2015) argue that the most important contribution of the shale revolution has been its ability to augment energy security in the USA, through increased domestic production and reduced reliance on external sources. On the other hand, Maniloff and Mastromonaco (2014) draw our attention to the creation of huge employment opportunities in the USA due to the shale revolution, especially the highly salaried jobs in the oil and sectors (Considine et al., 2010; Weber, 2014).

On the economic front, the existing literature provides evidence for the role of shale revolution in reducing the gap in the USA's balance of trade, as well as contributing to economic growth (Moore et al., 2014).

They suggest the ban on oil exports allowed shale production to be consumed domestically, resulting in a significant decrease in the import bills on account of energy imports. However, the shale revolution has also been associated with some social and environmental costs. For instance, Raimi (2018) suggests that the surface spills and leaks of generated water, chemicals, or oil from shale fields have the potential to harm the environment and endanger people and animals. Additionally, shale development and extraction disturb the local ecosystem (Gallegos et al., 2015), enhancing the possibility of earthquakes due to much drilling and groundwater reduction (Gleeson et al., 2012; Kerr, 2012; Rivard et al., 2014).

As there are costs and benefits to any activity, shale development can only be undertaken if the benefits attached to it outweigh the cost. In this regard, Abdul Ghaffar et al. (2021) show that economic, social, and environmental benefits are ranked higher for countries like India, which have high energy demand, rely on imports to meet their demands, have high rates of unemployment, and poor air quality. Similarly, Grecu et al. (2018), conducting a cost-benefit analysis for Romania, rate the benefit of energy security as the most preferred argument for shale development. Given that the socio-economic benefits of shale development are relatively higher than its cost, countries rich in shale reserves would invest more in shale development if it affected domestic oil prices significantly.

There is huge potential for developing shale reserves, but their development requires private entrepreneurship and private land and mineral ownership, apart from high oil prices (Wang & Krupnick, 2015). Given the enormity of the implications visible in the USA case, several countries are investing in the development of shale resources. The first step in that direction is to assess the economic viability of shale gas exploitation (Yuan et al., 2015). In this regard, Connors et al. (2010), Steffen and Hood (2013), and Yuan et al. (2015) have undertaken a comprehensive assessment and systematic analysis of the existing literature on technical and economic evaluation methodologies for the development of shale gas. Their aim was to offer a comprehensive overview of the present status of these techniques. They suggest that certain advancements have been achieved in current technical-economic evaluation methodologies. Nevertheless, there is a need for future enhancements in these methodologies to accurately evaluate the economic viability of shale gas development, thereby facilitating informed investment decisions. Furthermore, Steffen & Hood (2013) show that there are some risks associated with exploring oil and gas, which discourages investments in this sector. For measuring these risks, a stochastic assessment has been suggested to assess the uncertainty and productivity risk associated with shale gas wells (Steffen & Hood, 2013).

On similar lines, many studies have been conducted on the financial analysis of shale gas development projects. For instance, Banks et al. (2013) proposed a base case model to assess the profitability of producing shale gas. Similarly, to assess the economic feasibility, financial indicators such as NPV, DPI, and IRR were used for the evaluation of the Appalachian Basin with Marcellus shale (Schweitzer & Bilgesu, 2009). However, given that the shale gas sweet spot is contingent on high and sustained oil prices in the global market, improvements in the current template for shale field development are required to produce a sustainable business with operational profits (Weijermars & Van Der Linden, 2012). Additionally, Gilbert and Roberts (2020) demonstrate the existence of cost spillovers between the oil and gas markets due to common inputs. Therefore, the drilling cost for oil would increase with an increase in drilling for gas, and vice versa, making it difficult to achieve the bottom line. Furthermore, they argue that price shocks in one energy source would have consequences for the production of the other source. For instance, If gas prices witness a negative trend, drilling for oil will increase.

Although there is ample research on shale, focusing on geological, geographical, and cost benefit analysis of shale development, there is a visible gap in its effects on oil prices (See for instance, Abdul Ghaffar et al., 2021; Grecu et al., 2018; Yuan et al., 2015). However, we still lack a comprehensive study that integrates both supply and demand factors identified as drivers of oil prices. The few studies that focused on the price effects of shale have employed methodologies that are more relevant for understanding a short-run phenomenon (See for instance, Wakamatsu & Aruga, 2013). We deviate from the existing literature by employing Auto Regressive Distributed Lag (ARDL) to examine both short and long-run relationship between the variables. Moreover, the literature available has focused extensively on shale gas development in the USA only, while shale oil reserves are vastly available across the globe. Hence, this paper includes a thorough investigation of the prospects of shale development in other countries and identifies possible roadblocks for shale rich countries in replicating the success of US shale revolution.

3. Modelling strategy, data sources and variable definitions

An examination of the historical price of crude oil reveals that the fluctuations in the market have been significantly influenced by various factors, including demand, supply, political tensions, financial markets, and unpredictable events such as the COVID-19 pandemic (Aloui et al., 2018; Dey et al., 2020; Jaffe & Ellass, 2015; Kisswani, 2016; Tchatoka et al., 2019). However, the majority of the empirical works suggest that the fundamental factors that influence oil prices in the long run are demand and supply of oil, and other drivers are only relevant in explaining the short run changes (Perifanis & Dagoumas, 2019).

Following the fundamental factors thesis, we consider the demand and supply of oil to determine the effect of shale production on oil prices. Most researchers divide the supply into two primary categories: OPEC and non-OPEC supply. The OPEC countries are responsible for the world's 37 percent oil production and have 71 percent of the world's proven reserves of oil, allowing them to exert a substantial influence on the determination of oil prices by setting production targets for their members. On the other hand, non-OPEC producers are commonly perceived as price takers, meaning they mostly react to market pricing rather than actively seeking to influence prices through production management. Consequently, producers outside of OPEC often operate at or close to maximum capacity, resulting in limited surplus capacity. As a result of their limited surplus capacity, they cannot increase the market supply at will, which reduces their ability to control prices. However, assuming all other factors remain constant, reduced levels of non-OPEC supply have a tendency to exert upward pressure on prices through the reduction of overall global supply and the heightened demand for OPEC. The stronger the demand placed on OPEC, the greater its ability to exert control over pricing.

Similar to several other commodities, the prices of oil are intricately connected to the economic activity of the majority of nations. The demand for oil across all sectors rises in tandem with economic, industrial, and population expansion, whereas it declines during periods of economic slump. Oil-importing nations will augment their oil consumption due to economic expansion, ultimately resulting in elevated oil prices. According to the EIA, the demand factor can be classified into two categories: the demand originating from Organization for Economic Co-operation and Development (OECD) nations and the demand originating from non-OECD countries. When assessing demand, certain scholars utilize the Kilian global real economic activity index (Perifanis & Dagoumas, 2019), the OECD Production Industry Index (OPII), and benchmark stock indices of oil-importing nations as substitutes (Perifanis & Dagoumas, 2019). However, since the current study is undertaken to understand the price changes in the US, we employ the Index of Industrial Production (IIP) in the US as a proxy for the level of demand in the country.

3.1. Data sources and variable definitions

In order to achieve the objectives of the study, monthly time series data from 2008 to 2019 has been used to study the impact of shale oil production in the US on WTI prices. Data on US shale oil production, OPEC supply, non-OPEC supply, and WTI oil prices has been extracted from the US Energy Information Administration (Eia 2013) database. Data on the index of industrial production in the US has been obtained from the Federal Reserve Economic Database (St. Louis Fed).

The dependent variable WTI is defined by EIA as a crude stream produced in Texas and southern Oklahoma that serves as a reference or 'marker' for pricing a number of other crude streams and is traded in the domestic spot market at Cushing, Oklahoma. The variable of oil production represents the shale oil production in the US. The independent variable OPEC supply is the sum total of the oil supply of the OPEC. The non-OPEC supply, as described by EIA, is the oil production from countries outside the OPEC, which currently represents about 60 percent of world oil production. The non-OPEC supply includes key centers of oil production in North America, regions of the former Soviet Union, and the North Sea. However, pursuant to the requirements of this research, the monthly shale oil production of the US has been subtracted from the non-OPEC supply data to arrive at the figures used in the analysis. The deduction was necessitated to avoid multicollinearity and determine the true effect of shale on oil prices. Lastly, the IIP is the aggregate level of monthly industrial production in the US.

4. Research methodology

We employ the following Equation (1), which shows West Texas Intermediate (WTI) as a dependent variable and US oil production, OPEC oil supply, non-OPEC oil supply, and the Index of Industrial Production (IIP) as independent variables.

$$WTI_t = \alpha_0 + \beta_1 Oilproduction_t + \beta_2 OPECoilsupply_t + \beta_3 nonOPECoilsuuply_t + \beta_4 IIP_t + \varepsilon_t \quad (1)$$

Where, t stand for time and ε_t is an idiosyncratic term that follows a normal distribution with a mean of zero and standard deviation of one.

The first step of any regression analysis consists of testing for stationarity, which is one of the assumptions of OLS estimation and must be fulfilled to avoid the chances of spurious results (Naeem & Akhtar, 2024). The assumption is verified with the help of unit root tests, which specify the order of integration of a data series. New developments in econometrics show that most macro-economic time series are non-stationary. Hence, over time, some variables may diverge from their mean, while others may converge to their mean. Those time series that diverge from their mean over time are said to be non-stationary. The presence of a unit root in a series indicates that the series is non-stationary and cannot be modeled in a regular regression model. As non-stationary series violates the assumptions of constant mean and variance in OLS, the results from the analysis may be considered spurious. This can lead to incorrect inferences about the relationship between independent variables and oil prices, suggesting a strong connection where there may be none or incorrect conclusions about the magnitude and direction of the impact of independent variables on oil prices. One way to overcome this problem of spurious regression is a test of cointegration, which signifies whether two or more series move together over time (Azmi et al., 2023).

We adopt the ARDL methodology to examine the long-run equilibrium between the variables as well as understand the short-run dynamics. Although, there are multiple methods for examining long-run relationships (for instance, Johansen cointegration, Engle-Granger test, etc.), ARDL offers two primary advantages (Nkoro & Uko, 2016). First, it gives efficient results for shorter samples. Second, it works with variables having different orders of integration, as long as the order of integration of the variables under study is less than two. In order to ensure that our variables satisfy the conditions for running an ARDL analysis, we use Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests for investigating the presence of a unit root in the series.²

From Equation (1), the empirical version of the ARDL model to determine the long-run relationship among variables can be represented as:

$$\begin{aligned} \Delta WTI_t = & \beta_0 + \sum_{i=1}^p \beta_0 \Delta WTI_{t-i} + \sum_{i=1}^q \beta_1 \Delta oilproduction_{t-i} + \sum_{i=1}^q \beta_2 \Delta OPECoilsupply_{t-i} \\ & + \sum_{i=1}^q \beta_4 \Delta nonOPECoilsupply_{t-i} + \sum_{i=1}^q \beta_5 \Delta IIP_{t-i} + \gamma_0 WTI_{t-1} + \gamma_1 oilproduction_{t-1} + \gamma_2 OPECoilsupply_{t-1} \\ & + \gamma_3 nonoilsupply_{t-1} + \gamma_4 IIP_{t-1} + v_t \end{aligned} \quad (2)$$

Where, Δ is the first difference operator, p and q is the optimal lag length, $\beta_0, \beta_1, \dots, \beta_5$ are the short-run coefficients while as $\gamma_0, \gamma_2, \dots, \gamma_4$ represent the long-run coefficients, and v_t is the error term. The error correction model of the Equation 3 is expressed as follows:

$$\begin{aligned} \Delta WTI_t = & \alpha_0 + \sum_{i=1}^p \alpha_0 \Delta WTI_{t-i} + \sum_{i=1}^q \alpha_1 \Delta oilproduction_{t-i} + \sum_{i=1}^q \alpha_2 \Delta OPECoilsupply_{t-i} \\ & + \sum_{i=1}^q \alpha_3 \Delta nonOPECoilsupply_{t-i} + \sum_{i=1}^q \alpha_4 \Delta IIP_{t-i} + \partial_0 ECT_{t-1} + \mu_t \end{aligned} \quad (3)$$

Where, ECT is the error correction term with one period lag and ∂_0 is the coefficient of the error correction term. To determine the existence of a long-run relationship in Equation (1), the bounds test is used. The null hypothesis of the nonexistence of a cointegrating relationship among the variables is tested using the F-statistics of the F-bounds test. The specified ARDL model must satisfy the condition

that the variables are $I(0)$ or $I(1)$, as the ARDL procedure crashes in the presence of variables integrated of an order higher than one. The ARDL bounds test approach is recommended in cases of different orders of integration of variables.

For the robustness of the empirical results, we employed a series of residual diagnostic and stability diagnostic tests. A serial correlation test (LM Test) was performed to examine the problem of serial correlation in residuals. Additionally, a heteroscedasticity test (Breusch-Pagan-Godfrey test) was undertaken to identify whether the residuals were homoscedastic. Lastly, a normality test (Jarque-Bera test) was employed to ensure the residuals were normally distributed. We further performed CUSUM and CUSUMQ tests as stability parameters for the model.

5. Results and discussion

5.1. Unit root results

The stationarity of the variables has been tested using Augmented Dickey Fuller (ADF) and Philips-Perron (PP) test. The ADF test is generally considered to be superior over other tests due to its wide applicability (Azmi & Khan, 2024). The test adjusts the DF test, which takes care of the possibility of autocorrelation in the error term as it adds a lagged term to the dependent variable. The PP test take care of the autocorrelation in the error term, and its asymptotic distribution is the same as the ADF test statistic. Both tests have been performed under two conditions, first with the assumption of only an intercept and then with the assumption of both a trend and an intercept. The null hypothesis of both tests is that there is a unit root in the time series with the alternate hypothesis of stationary series.

Unit root tests are generally considered weak to determine stationarity; therefore, PP test for unit root has been used to check the robustness of ADF results, following Azmi and Akhtar (2022). ADF and PP unit root tests are summarized in Table 1, which shows that in most cases, the null hypothesis cannot be rejected at levels. However, after differencing the variables, all the series become stationary. The results of both the ADF and PP tests are identical, suggesting that only non-OPEC supply can be deemed to be stationary at levels under the assumption of intercept and trend. Since most of the variables are integrated of order one, or $I(1)$, simple linear regression cannot be used to study the long-term impacts of the explanatory variables on the dependent variable. This necessitates the use of cointegration to study the relationship among the variables of interest. Furthermore, the different order of integration of variables demands the use of the ARDL bounds test approach. As both ADF and PP unit root tests indicate that none of the variables in the model are integrated of an order higher than one, the assumption of ARDL methodology is satisfied. Complete results of the ADF and PP unit root tests can be obtained from the corresponding author on reasonable request.

6. ARDL results

After the stationarity test, the lag order of the regressors has been checked. The lag structure of the model was selected on the basis of Akaike's Information Criteria (AIC), which suggested ARDL (2,2,0,0) as the optimum model. The computed F statistic, t statistic, and the long and short run coefficients have been reported separately in Tables 2, 3, and 4, respectively.

As evident from Table 2, the computed test statistic is greater than the upper bound critical values at the 5 percent level of significance. Hence, the null hypothesis of a no levels relationship is rejected for

Table 1. Summary of unit root test results.

Variables	Identified order of integration			
	ADF		PP	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend
WTI	$I(1)$	$I(1)$	$I(1)$	$I(1)$
Oil Production	$I(1)$	$I(1)$	$I(1)$	$I(1)$
OPEC Supply	$I(1)$	$I(1)$	$I(1)$	$I(1)$
Non-OPEC Supply	$I(1)$	$I(0)$	$I(1)$	$I(0)$
IIP	$I(1)$	$I(1)$	$I(1)$	$I(1)$

Source: Author's Own Calculation.

Table 2. Results of F bounds test.

Variables	F Statistics	Result
WTI Oil Price/US crude oil production, OPEC oil supply, Non-OPEC supply, IIP US	4.297991	Cointegration
Critical values	Lower-bound critical values	Upper-bound critical values
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Source: Author's Own Calculation.

Table 3. Results of T-Bounds Test.

T-Bounds test		Null hypothesis: No levels relationship		
Test statistic	Value	Signif.	I(0)	I(1)
t-statistic	−4.720019	10%	−2.57	−3.66
		5%	−2.86	−3.99
		2.5%	−3.13	−4.26
		1%	−3.43	−4.6

Source: Author's Own Calculation.

Table 4. Estimated short and long-run coefficients.

Regressors	Short run coefficients	p value	Long run coefficients	p value
US oil production	0.244619	0.9468	−13.87743	0.0006
OPEC oil supply	−6.153423	0.1279	−1.176797	0.0638
Non-OPEC supply	−1.798955	0.2235	−9.406663	0.2276
IIP_US	0.821720	0.0359	4.296739	0.0006
ECT	−0.191243	0.0000		

Source: Author's Own Calculation.

this model. Consequently, the F-bounds test suggests that the variables in the model share a long-run relationship.

In order to validate the results of the F-bounds test, the researcher also carried out the t-bounds test. The results of the *t-bounds* test are presented in Table 3. As the test statistic (absolute value) is greater than the upper bounds critical values at the 1 percent level of significance, the null hypothesis of a no-level relationship is rejected. Therefore, the t-bounds test validates the results of the F-bounds test and establishes that the long relationship between the variables suggested by F-bounds test is not non-sensical.

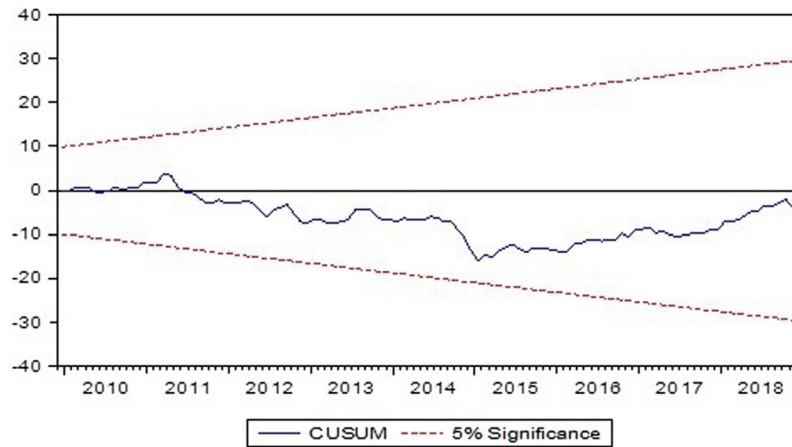
Both F and T bounds tests suggest that the variables in the model are in long-run equilibrium. Therefore, the long-run coefficients have been estimated along with the short-run dynamics. The estimation results are reported in Table 4.

Table 4 shows the long- and short-run coefficients of the explanatory variables. In the short run, IIP is significant, while other variables are insignificant. As the capacity to produce is given in the short run, an increase in economic activity leads to a rise in demand for oil and hence drives the oil price upward. However, in the long run, three of the four variables are found to be significant, namely, US crude oil production, OPEC supply, and IIP. In line with economic theory, all variables have appropriate signs. The results show that non-OPEC supply is the only variable that has no significant impact on WTI oil prices in the long run. Specifically, an increase of one unit in US crude oil production leads to a 13-unit decrease in WTI oil prices, indicating that energy expansion caused by the shale gas revolution has a large negative effect on WTI oil prices. However, an increase in OPEC oil supply causes a decline in WTI prices, with a coefficient estimate of -1.17 units. The magnitude of the US oil production coefficient can be attributed to the earlier restrictions placed on the export of crude oil and the lack of infrastructure to process light oil, which has created a glut at storage and refineries, resulting in a downward spiral of WTI prices. These findings are supported by Aguilera and Radetzki (2016), who claim that the shale revolution has exerted greater downward pressure on WTI prices in comparison to other international benchmarks like Brent. The excess supply has greatly benefited the downstream oil industry by making available oil at lower costs and allowing them to augment their processing capacity. However, the present findings should be interpreted with caution, given the inability of the ARDL framework to deal with

Table 5. Residual diagnostics.

Test	Null hypothesis	Test statistics	<i>p</i> Value
Serial correlation (LM test)	No serial correlation	0.724542	0.4869
Heteroscedasticity test (Breusch-Pagan-Godfrey Test)	No heteroscedasticity	1.866460	0.726
Normality test (Jarque-Bera Test)	Normal distribution	1.039857	0.594563

Source: Authors own calculations.

**Figure 2.** Results of CUSUM Test.

the issues of simultaneity and reverse causality, which might have contributed to a larger coefficient of independent variables³. Furthermore, the effect of non-OPEC oil supply exerts a negative but insignificant effect on WTI prices.

The error correction term is found to be negative and significant at the 1% level of significance. ECT depicts the speed of adjustment, or how fast the variables will return to long-run equilibrium if there is a shock in the short run. The coefficient of the ECT shows that 19% deviations will be corrected in the succeeding period (month in this case).

7. Residual and stability Diagnostics

Table 5 reports the test results of various residual diagnostics along with the probability values. These tests are carried out to detect serial correlation and heteroscedasticity in the residuals and ensure that the residuals are normally distributed. The null hypothesis for all three residual diagnostics could not be rejected, confirming the robustness of the results.

Furthermore, in order to examine the stability of the short- and long-run coefficients, the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of recursive residuals squared (CUSUMQ) are employed. These tests evaluate the stability of the regression coefficients and ensure that the regression equation is stable over the study period. The CUSUM and CUSUMQ statistics are plotted against the upper and lower bound critical values at the 5% significance level. If the CUSUM and CUSUMQ statistics plots lie within the critical bound of the 5% significance level, then the null hypothesis cannot be rejected (the coefficients are stable). Examination of Figures 2 and 3 suggests that the estimated long- and short-run coefficients of the ARDL model are stable over the study period.

8. Prospects of shale revolution in other countries

The shale gas reserves are vastly spread across different regions of the world. The success story of the USA's shale gas revolution has prompted many countries to explore the possibility of replicating the US model (Gong, 2020b) (UNCTAD 2018a). A study by EIA/ARI (2013) assessed the shale formations in 41 countries, which comprised 137 gas basins. The report suggests that 32 percent of the global natural gas reserves and 10 percent of the estimated oil resources are concentrated in shale formations. In 2015, the EIA estimated around 7,576.6 trillion cubic feet (tcf) of technically recoverable resources of shale gas. In the

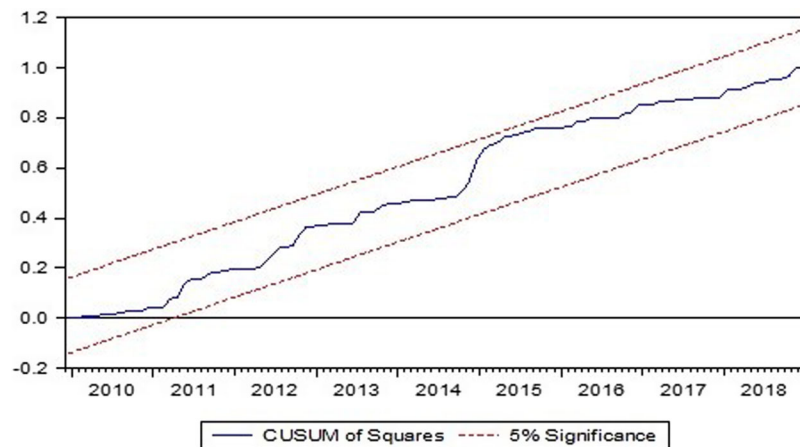


Figure 3. Results of CUSUMQ Test.

Table 6. Top 10 countries with technically recoverable shale oil resources.

Rank	Country	Shale oil (billion barrels)
1	RUSSIA	75
2	US	58
3	CHINA	32
4	ARGENTINA	27
5	LIBYA	26
6	AUSTRALIA	18
7	VENENZUELA	13
8	MEXICO	13
9	PALISTAN	9
10	CANADA	9

Source: EIA.

list of the top leading countries with technically recoverable shale gas, China topped the list with 1,115 trillion cubic feet, followed by Argentina, Algeria, the USA, Canada, Mexico, South Africa, Russia, and Brazil with 802, 707, 665, 573, 545, 390, 285, and 245 trillion cubic feet, respectively. This makes their combined reserves account for three-quarters of the world's technically recoverable shale resource.

Countries like Turkey, Poland, South Africa, France, Morocco, Chile, and Ukraine also possess shale gas reserves. These countries are highly dependent on oil imports, but their import status could change in the future as they have the basic infrastructure for the exploration and production of shale gas. There is a possibility that they can easily fulfill their domestic consumption with the shale reserves they possess and can also be future exporters (Abaas et al., 2018). Countries around the world are at different stages of shale development, with relatively lower levels of production than the USA.

Empirical results from our study suggest role of shale revolution in declining domestic oil prices, apart from its other macro-economic benefits, such as a reduction in energy imports. In light of the economic benefits of shale development, other countries would like to replicate the success of shale development. Successful development of shale in other countries would provide these countries with low energy prices, improved energy security, and relatively less pollution (Chong, 2014). On a more macro level, it can also provide energy importing countries with more sources of supply, eventually changing the dynamics of the world energy market, as visible in the case of the USA. Table 6 presents the top 10 countries in terms of the most technically recoverable shale resources. However, it should be taken into consideration that reserve estimates from organizations such as the EIA almost always underestimate ultimate cumulative reserves as they apply relatively strict parameters as to what is considered recoverable (Aguilera & Radetzki, 2016). Therefore, the current levels of technically recoverable shale reserves are likely to increase in the future and possibly alter the list of countries with most reserves. For the purpose of our study, we chose the first five countries in Table 6, excluding the US, to examine the replicability of the shale revolution.

In order to answer, if the success of the shale revolution can be replicated outside the USA, we first identify reasons that have helped the USA in the development of shale resources. A careful examination

reveals that the successful shale development program in the USA is not only because of the size of the reserves or the technological advancements, but also due to a number of other factors that worked in synchronization. We rely on the seminal works of Maugeri (2013) and Andreasson (2018), who identified the key factors for the success of the shale development program in the USA. These factors are as follows:

- I. Property Rights
- II. Concentration of Shale Formations
- III. Financing
- IV. Technology and Infrastructure
- V. Water Resources

In the United States, private resource rights are held by landowners and enterprises, rather than by the state (Wang & Krupnick, 2015). The proprietor is free to explore his property as he wishes, as long as he adheres to the basic norms and follows established precedents. The land ownership system in the US has allowed entrepreneurs and private corporations operating independent businesses to lead the development of the shale gas industry. We compare the property rights in the USA to those in select countries. The results presented in Table 7 show that most countries have state-owned enterprises that are involved in shale exploration due to limited property rights. On the other hand, Argentina and Australia have highly regulated property ownership systems, where property laws are regulated at both the provincial and national level. The dual regulatory oversight on property rights in these countries would act as a deterrent for investors in shale development.

The concentration of shale resources is identified as another reason for the flourishing of the shale industry in the USA. Concentrated reserves allow countries to exploit shale reserves with lower capital investments for extraction as well as transportation. The USA has a substantial amount of shale resources, mainly concentrated in areas like the Permian Basin, Marcellus Shale, and Eagle Ford Shale. The United States stands out from most nations when concentration of resources is concerned, which has

Table 7. Summary of comparisons between US and other shale oil rich countries.

Criteria	United States	Russia	China	Argentina	Libya	Australia
Property rights	Individuals and companies may possess property rights to mineral resources (Maugeri, 2013)	state-owned enterprises (Jinjolia et al., 2015)	state-owned enterprises (Wan et al., 2014)	Subsurface ownership is provincial (Gomes & Brandt, 2016)	state-owned enterprise ⁴	Regulation in Australia is controlled at the national and state level. (Blythe et al., 2016)
Concentration of resources	Yes (Maugeri, 2013)	Yes (EIA/ARI, 2013)	Widely distributed (Zhai et al., 2018)	Widely distributed (EIA/ARI, 2013)	Yes (EIA/ARI, 2013)	Widely Distributed (EIA/ARI, 2013)
Financing	Private financing available (Maugeri, 2013)	High governmental financial support (Feng, 2019)	High governmental financial support (Salygin et al., 2019)	High governmental financial support ⁵	Insufficient access to finance (Financing Landscape Analysis Libya, 2023)	Private financing available ⁶
Technology and Infrastructure	High technical innovation and infrastructure (Weijermars & Van Der Linden, 2012).	Technological backwardness. (Kropatcheva, 2014)	Lacks infrastructure (Zeng et al., 2014)	Infrastructure exists (Mares, 2012)	Technology and Infrastructure exist already (Khalifa & Shalhi, 2021)	Lack of infrastructure in most areas (Warner, 2011) Lacks Technology (Stevens et al., 2013) (Salygin et al., 2019)
Average exposure to baseline water stress over shale play area	Medium to high (Blythe et al., 2016)		High (Blythe et al., 2016)	Low to medium (Blythe et al., 2016)	Arid and low-water use (Blythe et al., 2016)	Low (Blythe et al., 2016)

Source: Author's Compilation.

permitted the country to develop shale resources at a lower break-even point (UNCTAD 2018b). A perusal view of Table 7 elucidates that the countries under study have concentrated shale resources, with the exception of China and Australia, where they are widely distributed. Reserves that are well distributed across the geography of a country cause operational issues, pushing the cost of producing and distributing the oil.

Finance is another factor that has allowed the development of shale reserves in the USA. As finance has been termed the bloodline for business, access to finance forms the bedrock of the development of any industry. For instance, Wan et al. (2014) argue that the energy market in the USA would not have witnessed such dramatic changes without the involvement of small companies, which depend more on external sources of finance. The USA has a vibrant financial system that enables private financiers to offer a streamlined and expedited procedure for funding independent enterprises, accelerating investments, and supporting exploration projects. A comparison of the private financing avenues in other shale-rich countries, shows that countries like China and Russia provide a lot of government finance for shale exploration and development, indicating the unwillingness of the private sector to lend support to such projects. Conversely, we see a lack of availability of finance in Argentina and Libya (see Table 7). In the absence of a well-developed financial system, replicating the shale revolution would be difficult, given the huge capital requirements for developing oil fields. Additionally, private financing is also required to make shale development more efficient and market-oriented.

Additionally, infrastructure availability significantly impacts the capital costs of shale gas exploration. Several crucial elements influencing the cost and speed of shale gas production include the quantity of drilling rigs, the scope and scale of the pipeline network, processing facilities, and the presence of LNG terminals (for internal markets).

Drilling equipment is more readily available in the United States than in other regions worldwide. Moreover, the pipeline network in the USA consists of approximately 500,000 kilometers of transmission pipelines connecting natural gas-producing sites and storage facilities to customers. A comparison of the infrastructure in the USA with that of other shale-rich countries reveals that most countries lack the infrastructure to propel a shale revolution and need to undertake huge infrastructure investments to overcome this shortcoming (see Table 7).

Another key aspect of the shale revolution is the extensive use of hydraulic fracturing, sometimes known as fracking, which entails pumping chemicals, sand, and water into shale formations under high pressure to extract trapped hydrocarbons. Fracking has increased energy production, but its high water demands raise questions about the sustainable use of clean water supplies. Fracking operations can use large amounts of water, which may compete with other uses like agriculture and towns, especially in water-scarce areas. Additionally, the disposal of wastewater from fracking presents environmental hazards, such as groundwater and surface water contamination. Countries with high demand for fresh water supply would struggle to meet the requirements for shale development. There are two essential requirements that need to be met in regards to water supply for a successful shale project. First, the areas with shale reserves should have fresh water sources. Second, the demand for fresh water in those areas can be met even after extensive usage for shale development.

In the USA, property rights, the abundance of shale gas resources, private funding, technology, and the presence of necessary transportation infrastructure are the primary factors contributing to the successful commercialization of shale gas. A comparative analysis of the top five countries with abundant shale reserves is presented in Table 7.

Examining the potential for shale gas projects in the top five countries indicates several geological, operational, technological, and regulatory challenges that need to be addressed. Technology and infrastructural enhancements are necessary to achieve the same success as U.S. shale gas development, along with crucial policy and regulatory changes. For instance, Russia needs to liberalize property rights and allow individuals and companies to enjoy land resources more freely. Additionally, Russia needs a more developed financial sector where private players are able to support shale exploration and development. Moreover, Russia needs to develop a more robust research and development environment, resulting in the reduction of the exploration and extraction costs associated with shale.

9. Discussion and conclusion

This article provides a comprehensive analysis of the profound effects of the shale revolution on the energy landscape of the United States. The aforementioned transition has not just resulted in the transformation of the nation's energy economy within the past decade, but it has also yielded significant consequences for the global energy market. The United States, which was historically heavily reliant on oil and gas imports, has witnessed a stunning transition into a leading participant in natural gas production and export, signifying a fundamental shift in its energy status. The empirical analysis conducted in this paper aims to identify the linkages between the shale revolution and the WTI oil prices. The result highlights the considerable influence of crude oil production in the United States, primarily attributed to the shale revolution, and its significant adverse effect on oil prices. Additionally, the study underscores the considerable adverse influence of OPEC's oil supply on oil prices, demonstrating that an escalation in production from this influential entity results in a decrease in oil prices. On the contrary, the data reveals that industrial activity in the United States exerts a relatively positive and significant influence on oil prices. This finding implies that, under the assumption of other factors remaining constant, a rise in economic activity in the United States has the potential to elevate oil prices. This observation sheds light on the intricate relationship between economic expansion and energy expenditures. In contrast, the impact of non-OPEC oil supply seems to be less substantial, exhibiting a statistically negligible negative effect.

The shale revolution and subsequent decline in oil prices have had a positive impact on consumers by making available, more affordable energy. The need for cheap energy for consumers has been the central argument of proponents of a ban on crude exports. However, their reservations about lifting the ban have been found lacking. On the contrary, the lifting of the ban has resulted in increased production of oil and other associated gases, lower prices of oil products, net GDP and trade balance additions.⁷ Nevertheless, the current terrain poses greater challenges for oil corporations, specifically those engaged in the discovery of shale oil and gas. Decreased oil prices have the potential to diminish profit margins and curtail the inclination to further participate in this particular sector. It is imperative for the United States government to provide adequate incentives in order to foster the sustainability and competitiveness of private entities within the energy sector. Such policies may promote innovation, keep the energy sector humming, and solidify the United States' newfound role as a significant energy producer and exporter on the world stage. The shale revolution has significantly transformed the energy sector in the United States and worldwide, giving rise to a range of opportunities and challenges that necessitate proactive engagement from policymakers and business stakeholders.

Aguilera and Radetzki (2016) posit that the shale reserves would continue to rise globally, and the technology for extracting oil and gas from such reserves would become more efficient and spread to other nations, allowing the shale revolution to sustain itself in the future and spillover to other countries. Furthermore, they contend that the countries that are already big producers of oil are more likely to witness a shale revolution than small producers, as they would already have the existing infrastructure to make such a revolution possible. However, in order to avail themselves of the benefits of shale development, countries rich in shale resources should invest in research and development, along with planned investments in infrastructure. Investment in research should also be undertaken to minimize the social and environmental costs attached to shale development. In order to solicit investments from private enterprises, governments can offer tax benefits and subsidies in the initial years. Moreover, a relook at the financial system is necessitated, and policies aimed at ensuring a robust financial sector for easy and cheap access to finance are required. Furthermore, regulations on property rights need to be liberalized to incentivize the exploration and development of shale resources. Lastly, shale rich countries should evaluate water availability and create plans to guarantee sustainable water management techniques in regions designated for shale development. This involves implementing water recycling and reuse technologies, investigating alternate water sources, and creating regulatory procedures to safeguard water quality and quantity.

Notes

1. <https://www.eia.gov/energyexplained/oil-and-petroleum-products/imports-and-exports.php#:~:text=Total%20petroleum%20net%20exports%20were,about%2020.01%20million%20b/d.>

2. For a detailed understanding of the ARDL model and unit root tests, refer to Pesaran et al. (2001), Said and Dickey (1984), and Phillips and Perron (1988).
3. The problem of simultaneity and reverse causality is unlikely to significantly mislead the results as long as the errors are serially uncorrelated (as shown in Table 5). Furthermore, the variables under investigation are found to be cointegrated, which makes OLS-based ARDL approach super-consistent.
4. <https://noc.ly/index.php/en/about-us-2>.
5. <https://www.in-vr.co/post/the-argentinian-shale-gas-industry>.
6. <https://ieefa.org/articles/billions-oil-and-gas-investments-undermine-macquaries-net-zero-commitments>.
7. <https://www.api.org/~media/Files/News/2022/07/25/Economic-Benefits-of-Crude-Oil-Exports-Retrospective>.

Author contributions statement

Conceptualization – M.R.N.
 Methodology – M.R.N. and S.N.A.
 Investigation – M.R.N.
 Analysis and interpretation of the data – M.R.N. and S.N.A.
 Writing - Original Draft – M.R.N.
 Review and Editing – S.N.A.
 Final approval – S.N.A.
 All authors agree to be accountable for all aspects of the work.

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Data availability statement

The data used in the present study can be obtained from the corresponding author on reasonable request.

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