Research Paper

 Publisher: University of Tehran

Cite this article as: Jabalameli, F., & Rahimifallah, Sh. (2023). Geoeconomic of Global Energy Transformation Exploring the Dynamic Linkages between Oil Prices, Polyethylene Costs, and Shale Gas in the United States. *Journal of World Sociopolitical Studies*, *7*(1), pp. 55-87. https://doi.org/10.22059/wsps.2023.363112.1370

Geoeconomics of Global Energy Transformation: Exploring the Dynamic Linkages between Oil Prices, Polyethylene Costs, and Shale Gas in the United States*

Farkhondeh Jabalameli[1], Shadi Rahimfallah[2]

1. Associate Professor of Economics, University of Tehran, Tehran, Iran (Corresponding Author) (fameli@ut.ac.ir) 0000-0002-4939-4034
2. PhD Student of Economics, York University, Toronto, Canada (shadirf@yorku.ca) 0009-0007-1600-9949

(Received: Jul. 01, 2022 Revised: Aug. 22, 2022 Accepted: Oct. 07, 2022)

Abstract

The Unconventional Gas Production Revolution in the US has ushered in new opportunities for American petrochemical companies, granting abundant access to gas resources and fostering business growth. Consequently, prominent global petrochemical firms have made substantial investments in the United States' petrochemical and chemical industries. Simultaneously, the surge in gas production from unconventional reserves in the US has led to considerable growth in the country's petrochemical output. To address this crucial topic, we conducted a comprehensive time series analysis, investigating the long and short-term relationships between oil and polyethylene prices in the US during the shale gas development phase. Employing an autoregressive distributed lag (ARDL) model for the period spanning from January 2013 to December 2017, our research findings reveal that, in the long run, there exists a positive and significant influence of the oil price variable on polyethylene prices. However, in the short term, no discernible impact on the polyethylene price variable was observed. Interestingly, the analysis also indicates a unidirectional causal relationship, with oil prices influencing polyethylene prices. This finding suggests that despite the divergence between oil and gas prices, oil remains a crucial determinant of petrochemical product pricing. The results underscore the significance of shale gas development and its impact on the petrochemical industry. As the US continues to experience increased gas production, comprehending the intricate relationships between oil, gas, and petrochemical prices becomes imperative for companies' strategic decision-making and policymakers alike.

Keywords: ARDL Method, Crude Oil, Energy Transformation, Natural Gas, Petrochemical Product, Time Series

---

* The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in this manuscript.

Journal of **World Sociopolitical Studies**| Vol. 7| No. 1| Winter 2023| pp. 55-87
Web Page: https://wsps.ut.ac.ir//Email: wsps@ut.ac.ir
eISSN: 2588-3127 PrintISSN: 2588-3119

1. Introduction

Over the last few decades, the world has witnessed a remarkable shift in the global energy landscape. The global energy transformation has been driven by a combination of factors, including technological advancements, environmental concerns, changing geopolitical dynamics, and evolving consumer preferences. Zou et al., (2023) express that global energy transition should be considered a multi-dimensional revolution influenced chiefly by economic and political approaches. One of the most notable trends in this transformation is the rapid rise of renewable energy sources, such as solar, wind, and hydroelectric power (Shokri & Rasoulinezhad, 2022). These clean and sustainable alternatives have gained significant momentum as countries strive to reduce greenhouse gas emissions and combat climate change. Simultaneously, advancements in energy storage technologies and smart grids have enabled better integration and utilization of renewable energy on a larger scale. Additionally, there has been increased emphasis on energy efficiency and conservation, with governments, businesses, and individuals adopting measures to reduce energy consumption and optimize resource utilization. The global energy transformation has far-reaching implications for economies, societies, and the environment, fostering opportunities for innovation, job creation, and enhanced energy security. As the world continues to grapple with energy challenges and embrace sustainable solutions, this transformation represents a pivotal step towards a more resilient, low-carbon, and inclusive energy future.

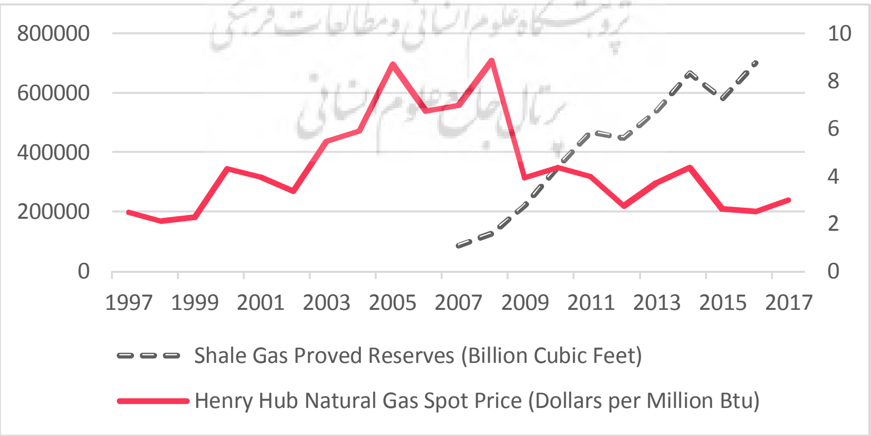
Natural gas production from shale gas began in 2000 when shale gas in the Barnett Shale became a commercial reality. Shale gas refers to natural gas trapped in shale formations[1] (EIA, 2023). In

1. Shale is a fine-grained sedimentary rock that can contain rich resources of natural oil and gas.

recent decades, the combination of "horizontal drilling" and "hydraulic fracturing" has led to access to abundant shale gas resources, whereas in the past, it was not cost-effective to exploit these resources. Wood et al. (2011) argue that after a hydraulic fracturing operation, a portion of the injected fluid returns to the water flow and endangers human health and the environment. Presently, the shale revolution has bestowed significant benefits on the US economy by decreasing the prices of natural gas, reducing gas imports, and increasing employment. It has also caused the American petrochemical industry to regrow. The effect of the shale gas revolution was remarkable. The higher supply has significantly reduced domestic gas prices in the US (Figure 1). Natural gas production from shale gas has brought about a certain kind of activity in the petroleum industry in the US. Moreover, it causes petrochemical companies in the country to develop their business by having access to cheap gas.

In the petrochemical industry, ethylene is a crucial component in the production of plastic and other chemical products along with other intermediates such as propylene, butadiene, and benzene. The production of ethylene and other chemical products is based on two raw materials. The first one is naphtha produced from oil. The second one is natural gas liquids (ethane, propane, and butane). Ethane, as an almost exclusively chemical petrochemical material for the production of ethylene, is utilized in the production of plastics (EIA, 2017). The increase in ethane price and production is caused by the rise in demand for ethane in the petrochemical sector. The petrochemical industry employs ethane, naphtha, and a smaller quantity of other raw materials for ethylene production. This material is used in the production of plastics, fibers, resins, and a full scope of consumable and industrial materials (EIA, 2018). Different countries select different raw materials by considering the advantages and disadvantages of accessing raw materials. For example, in countries like the US, Canada, and the Middle East, natural gas is used for the production of petrochemicals. In North America, the low cost of raw materials caused by shale gas has led to the revival of polyethylene trade. Global polyethylene exports have become more competitive, and investments in this field have increased in the second half of this decade. The US will lead the new polyethylene capacities during the next five years in the world, owing to its acquired developments. However, profitability among exclusive producers will significantly vary based on the type of feed and geographical position. In the long run, naphtha-based facilities will lose their advantage compared to ethane cracker production because the difference in the price of crude oil and natural gas during the predicted period will increase. It is expected that in the predicted period, the increase in the difference between the prices of crude oil and natural gas would lead to the growth of capacity based on cost advantage, and intensify such competitive pressures.

Figure 1. Henry Hub Gas Price Trend and US Shale Gas Production. Billion Cubic Feet (BCF) & Dollars per Million Btu $/MMBtu.



Source: U.S. Energy Information Administration (EIA), 2017

The purpose of this study is to investigate the intricate and dynamic linkages between oil prices, polyethylene costs, and shale gas in the United States. This exploration aims to shed light on the interdependencies and relationships that exist among these critical factors in the US energy landscape. By utilizing an ARDL model and conducting a time series analysis spanning from January 2013 to December 2017, the research seeks to uncover insights into the way in which the presence and growth of shale gas production have influenced the pricing and production dynamics of petrochemical products, particularly polyethylene, in the US market. The incentive for choosing the US energy issue lies in its significance on the global stage as a major player in both oil and petrochemical production. As the shale gas revolution has reshaped the country's energy landscape, understanding the complex interactions between these key variables is essential for policymakers, industries, and investors seeking to make informed decisions, adapt to changing market conditions, and contribute to the ongoing global energy transformation towards more sustainable and efficient energy practices.

The remaining sections of the paper are structured as follows: In Section 2, we provide a comprehensive research background, delving into the context of the global energy transformation and the specific factors influencing the US energy landscape. This section will offer an in-depth overview of the shale gas revolution, its impact on the petrochemical industry, and the significance of oil prices in this context. Building on this foundation, Section 3 will present the empirical evidence gathered from the ARDL model and time series analysis conducted for the period from January 2013 to December 2017. We will analyze the long and short-run relationships between oil prices, polyethylene costs, and shale gas in the US, uncovering crucial insights into the way in which these variables interact and influence each other over time. The findings from this empirical investigation will be presented and discussed in detail. Lastly, in Section 4, we will draw comprehensive conclusions based on the research outcomes, summarizing the key findings and their implications for the US energy industry and the global energy landscape. We will explore the potential ramifications of the observed linkages between oil prices, polyethylene costs, and shale gas, offering valuable policy implications for policymakers, industry stakeholders, and investors seeking to navigate the changing dynamics of the US energy market and harness opportunities in the ongoing global energy transformation towards sustainability and efficiency.

2. Literature Review

The related literature can be discussed through the three following groups: The first group focuses on earlier studies and comprises articles that investigate the development of shale gas in the US and its effect on gas price as well as its relationship with international markets. For example, Mernier (2007) states that gas has not become a global product, and the regional gas market only developed in North America and the UK to a lesser degree. In North America, the gas market has achieved a complete liberalization, and the price mechanism for gas is gas on gas competition (GOG). The difference between the price mechanism of gas and oil is said to be caused by the difference in the physical property, cost of transportation, and cost of gas storage. Melling (2010) has reviewed the European gas market and stated that a major portion of the European gas depends on imports. In the majority of the European gas import contracts, the price is based on crude oil. In recent years, the market is becoming liberated gradually. But the UK has a different market because the liberalization in 1986 began by the privatization of Britannia Oil Services Ltd. In addition, they stated problems in changing from oil index to market price.

Cornot-Gandolphe (2013) conducted a report to measure the industrial effects of shale gas, which particularly focused on petrochemicals and especially ethylene. He explains that the shale gas revolution has led to a dramatic drop in energy prices, which significantly decreases raw material costs in the US. This drop in prices in the petrochemical industry of the US caused the rebirth of American petrochemicals because a major competitive advantage has been created, and its profit has increased. The competitive advantage possessed by the US in association with shale gas development is a threat to the European petrochemical industry. The industry is under international competition, especially in the Middle East. Due to the loss of competition and decreased demand, the activity of upstream European companies has become limited. This is the way in which it impacts production; no new investments and or renovation of production factories take place, and no jobs are created. On the other hand, in the US, new investments are quickly made. Ultimately, the effect on the balance of trade of ethylene and polyethylene can be remarkable. Ethane is derived from natural gas liquids (NGLs) existing in shale gas. The US petrochemical industry utilizes it as a raw material for the production of ethylene. The most important uncertainty is related to the evolution of energy prices and particularly the relative price of natural gas and oil. The competitive advantage held by the US is based on the difference in oil price in Europe and the price of ethane in the US. It seems unlikely that the naphtha price, which depends on oil, could decrease for a long period. The process of ethane price change seems unclear. Market tension for ethane leads to increased prices and decreased competitive advantage for petrochemical producers in the US. Uncertainty is associated with the US gas price level, which affects ethane production and price. Government level regulations can be increased, which will increase the costs for the US shale gas producers. The United States Environmental Protection Agency (EPA) is currently assessing the environmental impact of shale gas production and particularly its impact on water. By following a self-sufficiency policy and reducing petrochemical imports, China intensifies the competition among exporters and will probably change the current trade flow. Furthermore, China owns the largest shale gas resources in the world and participates in a program for developing these resources. If China achieves its goals and produces significant amounts of shale gas, it will immensely affect international gas trade and prices.

Wakamatsu and Aruga (2013) detected a structural break in the natural gas market of the US and Japan to estimate the exact relationship around the shale gas revolution; they investigated market data for the period of 2002 to 2012. Data analysis indicates that the breaking point of natural gas consumption happened in 2005, and before August of 2005, the natural gas market of Japan was affected by the US. However, this effect diminished or somehow disappeared after some time. This data is known to be related to the shale gas revolution, after which the US gas market changed independently. In 2011, the high production of shale gas led to high supply and rapid decrease in the prices. The US created certain regulations and exported the liquid gas of LNG to Japan to balance gas supply and demand. This could increase the domestic price of natural gas and help shale gas producers. Furthermore, the Japanese gas market is vulnerable due to foreign shocks, since it depends on imported gas. Consequently, the successful and unique development of domestic gas, such as methane hydrate will immensely affect the Japanese gas market. If the mass production level exploitation technique becomes accessible, increased natural gas supply can be an extra shock for the American and Japanese natural gas markets. According to the energy development plan of Japan, since methane hydrate reserves are located around Japan, they produce natural gas and supply it to the market, which can be profitable for Japan. The United States invests in unconventional energy sources of shale gas and oil for sustainable energy supply. Potts and Yerger (2016) have also discovered that the development of the Marcellus shale has led to the low price of natural gas in the US. Other researchers have focused on the impact of the shale gas revolution in the price mechanisms of natural gas in various markets.

Aruga (2016) states that the price of natural gas after the shale gas revolution in the US has dramatically decreased. This paper assessed the effect of the structural change of the US natural gas market after the shale revolution on the gas markets of Europe and Japan. For this purpose, the author employed the Bai-Perron Test to detect the structural break. He also utilized the Johansen co-integration test to analyze whether the shale gas revolution affected the international natural gas market. Results indicate that the increase in the supply of natural gas and the decrease in imports by the US caused by the shale gas revolution still affect international gas markets. This is because the necessary infrastructure for gas exports through a pipeline to countries with high demand has not developed, and it will take some years before the US can export its gas. The governments of countries like Japan and Europe, which are importers of gas and are not connected to the US through a pipeline, are trying to find an effective policy to strengthen their relationship with the US in the natural gas market. Finally, the supply shocks after the US shale gas revolution do not still affect the Japanese and European gas markets. Currently, the effects of the US shale gas revolution do not spread globally.

Le (2018) investigated the shale gas revolution and its effect on crude oil. By using a structural vector autoregressive model, the effect of natural gas production on the real price of oil may be discovered. The results revealed that after the spread of shale gas production, the real oil price of West Texas Intermediate (WTI) droped by an average of $10.22 per barrel from 2007 to 2017 and this amount increases over time. This estimated price gap of oil over 2007-2017 can be attributed to the shale gas revolution. It states that the shale gas revolution in the US has occurred in the 21st century and significantly affected the US and global economies. In addition to the US, other countries European countries as well as China are searching for shale gas. However, the conditions for the development of these resources among regions and countries vary significantly. On the other hand, based on the complicated issues that have increased about its extraction, and because its effects are not completely identified, there are some doubts, discussions and even strong oppositions for shale gas development. In this paper, the potential of shale gas in China and Europe are investigated based on fundamental conditions that are considered to be important in the success of the shale gas industry in the US. Several ideal factors, including natural and geological, proper and transparent policies for the encouragement of shale gas investment, environment protection policies, and public trust and acceptance were influential in the US shale gas development. Furthermore, shale gas development needs a developed and free-market that provides a competitive system with a suitable price. In the following, it states that developed infrastructure like natural gas transportation and distribution pipeline networks help decrease costs. Analyses have shown that no other region enjoys these ideal conditions, and this is probably the reason for which the US shale gas development has been alone in its success. It seems impossible that the US shale gas revolution will be repeated in China and Europe. Unclear resource potential, imperfect political system, environmental problems, and underground infrastructure are the main threats and weaknesses that China and Europe must encounter in discovery and development. Furthermore, it shows that China and European countries will face major challenges that need to be solved. For example, in a comparative mode, the US has a free market, and the price system is competitive. However, even though Europe moves towards liberalization, the oil price index is still dominant. China is moving from an exclusive system to a competitive one.

The Second group of literature comprises papers that display the relationship between the price of oil and petroleum products. For example, Gormus and Atinc (2016) investigated the relationship between oil price shocks and macroeconomic variables in the US. They showed that Brent Crude Oil price and West Texas Intermediate oil prices contain much information for macroeconomic variable prediction. They used measurement methods to show that not only oil price, but also oil price fluctuations have a major effect on macroeconomic variables. Ederington et al. (2019) discovered that studies relating to the relationship between petroleum products and oil price mainly indicate that crude oil price is the cause of changes in petroleum products prices. However, there is limited evidence for the effect of the price of petroleum product on oil price. In the majority of studies relating to oil, the oil price in the US-based on the WTI oil price and the price of oil outside the US (mainly in Western Europe) are based on Brent oil price.

Moreover, in studies relating to the effect of oil price on petrol price, they discovered that there are different conclusions. But they realized that most studies show that the response of petroleum products price to the oil price increase and decrease varies and more quickly mitigated about the oil price increase. It usually called as the asymmetric phenomenon of “rockets and feathers”.

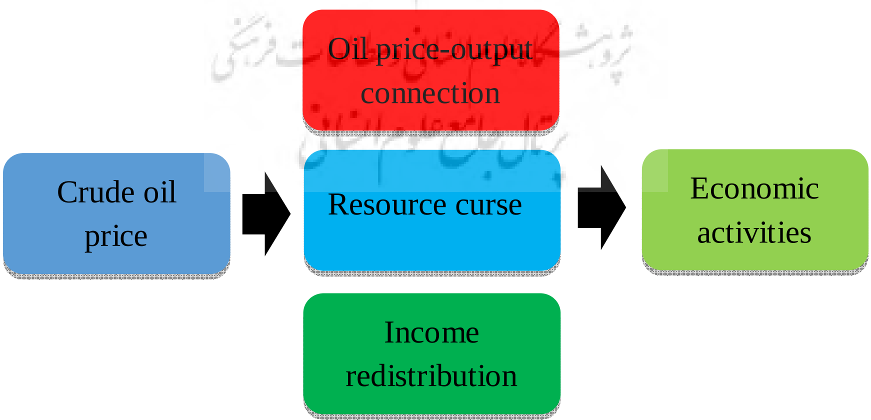
The third group of earlier studies are papers that focus on the relationship between oil, gas and petrochemicals. Several studies establish that crude oil and natural gas prices are co-integrated. However other studies indicate that the two price series have “decoupled”. Ramberg and Parsons (2012) state that, there is not yet any evidence that the relationship between the two price series has severed. There is an enormous amount of unexplained fluctuation in natural gas prices at short horizons. Oil price is a crucial determinant of natural gas price. Jadidzadeh and Serletis (2017) declare that almost 45% of the variation in the real price of natural gas can be attributed to structural supply and demand shocks in the global crude oil market relationship between oil and gas prices. Erdős and Ormos (2012) believe that there exists a strong relationship between oil and gas market between 1992 and 2001, but after that, the relationship between them gradually weakens. Geng et al. (2016) showed that the relationship between oil and gas has been affected by shale gas revolutionary; for this search, they divided time to before and after the North American shale gas revolution. They found that before the North American shale gas revolution, WTI crude oil prices had a significant positive impact on Henry Hub prices. However, this effect has weakened since the North American shale gas revolution.

Tiwari et al. (2019) examine a time-series econometric relationship between U.S. natural gas and crude oil prices by applying wavelet methodology. They found that during the shale gas revolution oil, and natural gas prices were procyclical, and oil prices were leading natural gas prices. Delavari and Gandali Alikhani (2012) concentrated on the short-run relationship between Iranian crude oil and methanol price in Iran using a vector error correction model (VECM). Results indicated that in the long run, there is a significant relationship between Iranian crude oil price and methanol price. This is while there is no meaningful relationship between the variables in the short run. Hence, under these circumstances, petrochemical companies must continuously follow up on oil price fluctuations to control the market of their products. This is because, with increased oil price fluctuations, the stability of foreign exchange earnings obtained from methanol exports as a non-oil export item will become ambiguous.

3. Theoretical Framework

In this Section, several economic theories are discussed to explore the relationship between oil price and its impact on economic activities. The first theory is oil price-output relationship, which posits that higher oil prices can lead to increased production costs for businesses as well as higher consumer prices for goods and services. As a result, firms may reduce output, leading to a slowdown in economic growth. On the other hand, lower oil prices can have a positive impact on the economy by reducing production costs and consumer expenses, thereby boosting economic activity. The second related theory is resource curse, suggesting that economies that are heavily dependent on oil exports can face negative consequences, such as economic instability, corruption, and inequality. This is because a heavy reliance on oil revenues may lead to a lack of diversification in the economy, making it vulnerable to fluctuations in oil prices. In addition, income redistribution can be addressed as another theoretical part of oil price- economic activities interconnections. Changes in oil prices can also impact income distribution. For oil-importing countries, higher oil prices may lead to increased energy costs, reducing disposable income for households and businesses. In contrast, oil-exporting countries may benefit from higher oil prices, leading to increased government revenues. Figure 2 demonstrates the transmission channels of impacting oil price on economic activities in a country.

Figure 2. Theoretical Framework



Source: Authors

4. Empirical Evidences

First, we investigated the co-integration relationship and Granger causality relationship to determine the pricing relationship between oil and gas during the shale gas production.

4.1. Testing the Co-Integration Relationship and Granger Causality Relationship of Oil and Gas

To assess the co-integration of the variables, the maximum likelihood (ML) method invented by Johansen and Juselius (1990) utilized to determine the long-run relationship. For this purpose, we employ the effect size test and maximum-high value test. In the maximum-eigenvalue test, "a null hypothesis indicating the absence of a co-integration relationship versus the presence of a co-integration relationship" and "the presence of one or less co-integration relationship versus two co-integration relationships" etc. will be tested, respectively. The effect size test will be the same. If the test statistics relating to these variables are greater than critical values at an error level of 5%, the opposite hypothesis will be accepted. This is how the number of co-integration vectors will be acquired. According to the results obtained in Table 1 (Appendix), there is a co-integration relationship between oil and gas prices in the US (Johansen & Juselius, 1990).

Results in Table 2 (Appendix) reveal that there is a co-integration relationship between the prices of gas and oil in the US. Regarding the Granger causality test results (Engle & Granger, 1987), despite the production of shale gas and reduction of the pricing relationship between oil and gas compared to the time before shale gas production, oil is still the cause of gas price change. In the US, due to the market liberalization and the high volume of gas and gas trade, its price is determined on the spot market. The most important spot market in Louisiana and North America is Henry Hub, where some pipelines intersect; this is where gas price is determined. Competitive gas price is based on supply and demand as well as future market development and spot price. Moreover, in spot markets, the prices vary based on transport costs. Consequently, there is a significant one-way causality from oil price to gas price.

To examine the correlation between oil and gas prices, we also analyzed data over three periods. In the period 2000–2019, we observed that the correlation relationship decreased over time. Before the shale gas revolution of 1999-2006, the correlation between prices was high, although the relationship between oil and gas prices has declined since the shale gas revolution between 2006-2019. Moreover, petroleum and natural gas products are interchangeable; as a result, the dependency of the price of these two variables is confirmed, and crude oil is the primary driver of gas price.

Therefore, in this research, the pricing relationship of polyethylene product, a high percentage of which is produced using ethane feed (gas), will be evaluated using an ARDL model. Furthermore, despite the reduction in the relationship between gas price and oil price, the oil price will be assessed utilizing an ARDL model.

4. 2. Introducing the First Autoregressive Distributed Lag (ARDL) Model

The advantage of the ARDL model presented by Pesaran & Shin (1998) is that this model is applicable without considering whether the model variables are static or become static with one differencing operation. In other words, in this approach, there is no need to divide variables to correlations of 0 and 1. This econometric model is designed to evaluate the long-run relationship between time series and error correction model (ECM) in the short-run. In time-series studies, whenever a set of desired variables has a dual-type behavior based on unit root tests such that some of them are at the static level and some others become static after one differencing operation, the following happens. The use of normal co-integration tests, including the Engle-Granger test for investigating the existence of long-run relationships between variables will not be applicable. In such cases, the employment of an ARDL model is proposed. To answer the question, the US time-series data for 2013 to 2017 will be used with a monthly basis in the ARDL model. The ARDL model for the assessment of long-run relationships at the level with general form is as Equation 1:

$$(1) \quad y_t=\alpha. +\sum_{i=1}^{P} \beta_i y_{t-i}+\sum_{i=0}^{q} \theta_i x_{t-i} + u_t$$

Where x_t represents a vector of descriptive variables affecting the dependent variable of y_t. In this model, it assumed that the time series of the descriptive variables and the dependent variable are co-integrated. The regression equation has an autoregressive dynamic form, with lag in the descriptive variables. In this equation, the estimated coefficient matrix of Θ represents the long-run effect of the descriptive variables on the dependent variable. In the short run, the error correction model (ECM) will be as Equation 2:

$$(2) \quad t\text{-}1 + u_t \ \ ECM + \sum_{i=1}^{P} \beta_i \Delta y_{t-i}+\sum_{i=0}^{q} \theta_i \Delta x_{t-i+} {}_0\Delta y_t=\alpha$$

Equation (2) displays a short-run relationship. Δ represents the lag operator. In this regression equation, ξ represents the error correction coefficient. ξ is a negative value and indicates what percentage of the disequilibrium will be eliminated in every period that if a deviation from long-run equilibrium occurs. In fact, it represents the long-run equilibrium speed.

The short-run fluctuation error correction model relates variables to long-run equilibrium values. These models are a type of partial equilibrium model. In such models, by entering the stationary residual from a long-run relationship, the forces effective in the short run and the rate of reaching long-run equilibrium value are measured (Pesaran & Shin, 1998).

In the first model, a time series analysis will be conducted on the pricing relationship between WTI oil price and American high-density polythene. In this model, however, the WTI oil price is the independent variable, and polyethylene (PE) is the dependent variable. Furthermore, an extensive shale gas production virtual dummy variable equaling one for 201610 and zero for the other months is considered. The model is defined as Equations 3-4:

The ARDL model and the ECM are used to investigate the long and short-run relationships, respectively.

$$(3)\quad PE_t = \Upsilon_0 + \sum_{i=1}^{P} \Upsilon_1 PE_{t-i} + \sum_{i=0}^{q1} \Upsilon_2 Wti_{t-i} + dummy + v_t$$

$$(4)\quad \Delta PE_t = \omega_0 + \sum_{i=1}^{P} \omega_1 \Delta PE_{t-i} + \sum_{i=0}^{q1} \omega_2 \Delta Wti_{t-i} + \xi ecm_{t-1} + dummy$$

Equation (3) is a particular type of the ARDL model presented for the relationship between oil price and polyethylene price. Equation (4) is an absolute representation of the proposed ECM.

4. 3. Unit Root Test

One of the important features of time series data and panel data that provide useful information about data series creation is the unit root test. For this purpose, an augmented Dickey-Fuller test (ADF) has been used. In this regard, to determine the number of lags, the Schwarz-Bayesian Information Criterion (SBIC) has been utilized. The results are presented in Table 3 (Appendix).

Although the ARDL model is not sensitive to the static state of a variable, the static variable must be proven not to be a second-order variable. The results in Table 3, indicate that the variables of polyethylene (PE) price and (WTI) oil price are at the nonstationary level. To measure the co-integration degree of the variables, we used the ADF test with the first-order difference of the variables. As illustrated in Table 4, all variables have become static with one round of differencing, which means that they are co-integrated of order one I (1).

4. 4. Model Definition

In this model, the WTI oil price has been selected to be the independent variable. High-density polyethylene (HDPE) price has been chosen to be the criterion for American polyethylene price, which was determined to be the dependent variable. These variables were selected in the form of time series from 2013 to 2017 with a monthly basis. The ARDL (3.0) model was selected using the SBIC.

4. 5. Bounds Testing

To investigate the existence of co-integration vectors, in other words, the existence of long-run relationships between the study variables, bounds testing approach developed by Pesaran et al. (2001) was used. This technique enjoys remarkable advantages compared to other co-integration methods, especially the Johansen and Juselius co-integration tests that has been used in previous studies. First, bounds testing is suitable for small-sized samples. The least-squares estimator has normal distribution asymptotically. In small-sized samples, it has bias and more compatibility. In time-series studies, whenever a set of desired variables have a dual-type behavior based on unit root tests, in a way that some of them are at the static level I(0) and others become static after one differencing operation I(1), the following happens: The use of normal co-integration tests, including the Engle-Granger test for investigating the existence of long-run relationships between variables will not be applicable. In such cases, the employment of an ARDL model is proposed. The importance of this characteristic becomes more evident when different unit root tests offer different results and lead to uncertainty in determining the co-integration degree of the variables.

According to the results in Table 5, assuming there are different 1000, 60, and 55-member samples, the value of the F statistic is higher than the upper bound limit of the table. The value is an indicator of the presence of long-run relationships between the variables. For this reason, despite the existence of confirmed long-run relationships, in the next stage, these coefficients will be estimated.

Table 5. Bounds Testing Results for the ARDL (3.0) Model

Test Statistic	Value	Signif.	I(0)	I(1)
			Finite Sample: n=1000	
F-statistic	7.200196	10%	3.02	3.51
K	1	5%	3.62	4.16
		2.5%	4.18	4.79
		1%	4.94	5.58
Actual Sample Size	57		Finite Sample: n=60	
		10%	3.127	3.65
		5%	3.803	4.363
		1%	5.383	6.033
			Finite Sample: n=55	
		10%	3.143	3.67
		5%	3.79	4.393
		1%	5.377	6.047

Source: Authors' Findings

4. 6. Long-Run Relationships between the Variables

The estimated coefficient indicates that oil price significantly affects polyethylene price (Table 6). One unit of increase in oil price, with the other factors remaining unchanged, will cause polyethylene price to increase by 8.9 units. The equation obtained from the long run estimation of the model is as follows:

$$(5) \quad PE = 772.21 + 8.90*WTI$$

Table 6. The First Model – The Long-Run Relationship between Oil Price and Polyethylene Price for the ARDL (3.0) Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
WTI	8.905301	1.106318	8.049497	0.00000
C	772.2154	78.37047	9.853397	0.00000

Source: Authors' Findings

4. 7. The Short-Run Error Correction Model

Error correction models (ECM) are a type of partial equilibrium model. In such models, by entering the stationary residual from a long-run relationship, the forces effective in the short run and the rate of reaching the long-run equilibrium value are measured. In these models, if the error correction coefficient appears with a negative sign, it indicates the error correction speed and inclination towards long-run equilibrium. The error correction coefficient reveals what percentage of the dependent variable's disequilibrium in every period has become adjusted towards a long-run relationship. Model estimation is also conducted using error correction, and the error correction coefficient equals -0.20, which is significant. Accordingly, the speed of adjustment towards equilibrium from the short run to the long-run period due to changes in practical factors is approximately 20%. The process of adjustment from the short run to long run will take almost five years. The crude oil price does not affect polyethylene price in the short term.

Table 7. Error Correction Test Results for the ARDL (3.0) Model

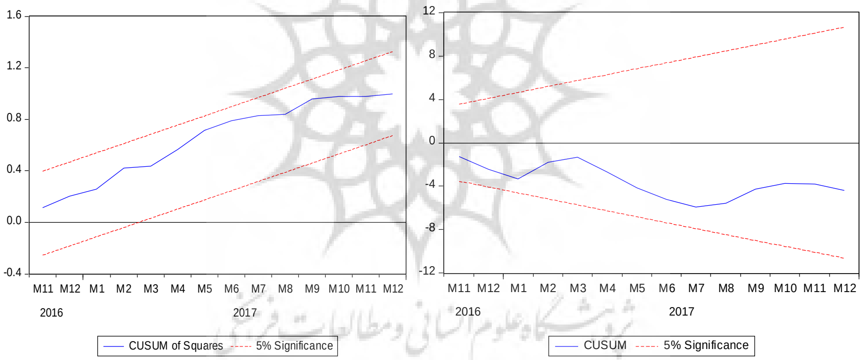
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(PE(-1))	0.578131	0.107761	5.364945	0.000000
D(PE(-2))	-0.342623	0.100946	-3.394115	0.001300
DUM	-79.326790	40.135300	-1.976484	0.053500
CointEq(-1)*	-0.207075	0.043706	-4.7379	0.000000

Source: Authors' Compilation

4. 8. Stability Test

Stability test has been known as the approximate compatibility test of regression coefficients over time. One way to test the stability of estimated coefficients is to use the CUSUM and the CUSUMSQ tests. These tests, developed by Brown, Durbin, and Evans (1975), are based on the cumulative sum of residuals. One important advantage of this test is that it can be used under conditions with uncertainty about the occurrence of structural change. Pesaran proposes that the above-mentioned tests be used to determine the stability of short and long-run coefficients in the ECM. The confidence interval in these two tests consists of two straight lines that show a confidence level of 95%. If the test statistic is placed between these two lines, it will not be possible to reject the null hypothesis, which states the stability of the coefficients.

Figure 3. CUSUM of Residuals and CUSUMSQ of Residuals



Source: Authors' Compilation

4. 9. Granger Causality Test

Table 8 illustrates the Granger causality test results of the variables of oil and polyethylene. There is a one-way causality relationship between the variables, which indicates that oil is the cause of change in the price of polyethylene. A significant portion of the product of polyethylene in the US is produced using ethane gas feed. Despite the reduction of the pricing relationship between gas and oil after the development of shale gas, the price of polyethylene is still indirectly subject to oil price. Polyethylene price can be subject to various factors. For example, with increased polyethylene product demand, the demand for ethane as well as the price of ethane will increase. However, oil price does not increase because raw materials are mainly produced from gas. Therefore, one-way causality is accepted. However, when the oil price goes higher, the prices of gas and polyethylene will follow.

Oil price can affect polyethylene price in two ways: First, by directly affecting the gas price as a result of the indirect effect on ethane price. However, due to the spread of shale gas, this susceptibility has been dramatically reduced. Second, through the market, because oil price as a fundamental product causes changes in different macroeconomic sectors (Lee, 2018). In the US, polyethylene is mainly produced from ethane. In spite of the effective relationship between oil price and polyethylene product, as well as the one-way causality, there is a profit margin for American polyethylene producers.

Table 8. Causality Test Results for the ARDL (3.0) Model

Null Hypothesis	F-Statistic	Prob	Result
WTI does not Granger Cause PE	9.32949	0.0003	Oil price is the cause of the polyethylene price
PE does not Granger Cause WTI	1.71286	0.1902	

Source: Author Findings

5. Conclusion and Policy Implications

5. 1. Concluding Remarks

In this study, we have investigated the intricate relationships between oil and polyethylene prices in the US during the period of shale gas development. By using an ARDL model in the time series from January 2013 to December 2017, we uncovered compelling insights that hold crucial implications for policy and decision-making. Our findings indicate that despite the widespread adoption of shale gas in the US and the reduced connection between oil and gas prices, the price of oil remains a fundamental determinant of polyethylene prices. This implies that the American petrochemical industry relies significantly on oil price dynamics, even in the presence of abundant shale gas resources.

A key observation from our research is the US petrochemical sector's strategic use of cheap feed inputs, particularly ethane, which plays a critical role in the production of polyethylene. This practice allows the US to leverage its access to inexpensive raw materials and link the pricing of its petrochemical products to oil prices. This cost advantage contributes to the short-term dynamics of production costs, directly influenced by shale gas. However, in the long run, our analysis suggests that the US is poised to substantially increase its shale gas production, particularly in the extraction of ethane. This ongoing trend is expected to solidify the US's position as a primary hub for polyethylene production. With its advantageous access to cost-effective feed and advanced production technologies, the US is likely to bolster its competitive edge in the ethylene production chain and bolster exports of downstream products, such as polyethylene. As a result, we anticipate that the increasing dominance of the US in the global polyethylene market will have far-reaching effects on product prices in the long term. Policymakers and stakeholders in the petrochemical industry need organize such developments to devise effective strategies for fostering competitiveness and securing their positions in the evolving global energy landscape.

In conclusion, our study highlights the vital role of oil prices in shaping the US petrochemical industry, even amidst the shale gas boom. By understanding the long-term implications of shale gas development, the US can capitalize on its cost advantage, enhance its competitiveness, and fortify its position as a major player in the international polyethylene market. Policymakers must carefully consider these findings to formulate measures that support sustainable growth and maximize the benefits of the ongoing global energy transformation.

5. 2. Policy Implications and Recommendations for Future Research

Based on the intricate relationships between oil and polyethylene prices during the US shale gas development phase, we propose practical policies to foster competitiveness and sustainability in the petrochemical industry. Policymakers should encourage feedstock diversification, invest in research and development, prioritize energy security and sustainability, devise trade and export strategies, ensure policy coordination, and engage in long-term planning. By leveraging the cost advantages of shale gas, promoting innovation, and anticipating market dynamics, the US can strengthen its position as a leading player in the global polyethylene market, ensuring continued growth and aligning with broader sustainability and energy transition goals.

To expand future research in this domain, several recommendations can be considered. Firstly, conducting a comparative analysis of other petrochemical markets globally can offer valuable insights into the specificities of the US petrochemical industry's relationship between oil and polyethylene prices. Examining the factors influencing pricing dynamics in different regions and their implications on competitiveness can provide a broader perspective for policymakers and industry stakeholders. Secondly, integrating environmental and climate change considerations in the analysis may enhance the sustainability aspect of the research. Investigating the environmental impact of shale gas development and its influence on petrochemical product pricing will aid in developing eco-friendly strategies for the industry's future growth. Additionally, exploring the role of technological advancements and digitalization in the petrochemical sector can shed light on how disruptive technologies can reshape pricing dynamics and supply chain management. Moreover, future research should encompass a more extended time frame to capture the industry's evolving trends beyond the shale gas development phase. Analyzing the long-term implications of shale gas production and its effect on petrochemical pricing will provide a more comprehensive understanding of the industry's trajectory. Finally, conducting case studies on specific petrochemical companies can offer detailed insights into their strategies for navigating oil price volatility and optimizing their position in the market.

References

Aruga, K. (2016). The US Shale Gas Revolution and Its Effect on International Gas Markets. *Journal of Unconventional Oil and Gas Resources*, *14*, 1-5. https://doi.org/10.1016/j.juogr.2015.11.002

Brown, R., Durbin, J., & Evans, J. M, (1975). Techniques for Testing the Constancy of Regression Relationships over Time. *Journal of the Royal Statistics Society*, *37*(2), 149- 192.

Cornot-Gandolphe, S. (2013). The Impact of the Development of Shal Gas in the United States on Europe's Petrochemical Industries. French Institute of International Relations.

Delavari, M., & Gandali Alikhani, N. (2012). *The Effect of Crude Oil Price on the Methanol price* (No. 49727). Munich Personal RePEc Archive. https://mpra.ub.uni-muenchen.de/id/eprint/49727

Ederington, L.H., Fernando, C.S., Hoelscher, S.A., Lee, T.K., & Linn, S.C. (2019). A Review of the Evidence on the Relation Between Crude Oil Prices and Petroleum Product Prices. *Journal of Commodity Markets*, *13*, 1-15. https://doi.org/10.1016/j.jcomm.2018.09.002

EIA. (2017). U.S. Ethane Production, Consumption, and Exports Expected to Increase Through 2018. https://www.eia.gov/todayinenergy/detail.php?id=29572.

EIA. (2018). U.S. Ethane Consumption, Exports to Increase as New Petrochemical Plants Come Online. https://www.eia.gov/todayinenergy/detail.php?id= 35012.

EIA. (2023). Natural Gas Explained Where Our Natural Gas Comes. https://www.eia.gov/energyexplained/index.php?page=natural_gas_where.

Engle, R.F., & Granger, C.W. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica*, *55*(2), 251-276. https://doi.org/10.2307/1913236

Erdős, P., & Ormos, M. (2012). Natural Gas Prices on Three Continents. *Energies*, *5*(10): 4040-4056. https://doi.org/10.3390/en5104040

Geng, J. B., Ji, Q., & Fan, Y. (2016). How Regional Natural Gas Markets Have Reacted to Oil Price Shocks Before and since the Shale Gas Revolution: A Multi-Scale Perspective. *Journal of Natural Gas Science and Engineering*, *36*, 734-746. https://doi.org/10.1016/j.jngse.2016.11.020

Gormus, N. A., & Atinc, G. (2016). Volatile Oil and the US Economy. *Economic Analysis and Policy*, *50*, 62-73. https://doi.org/10.1016/j.eap.2016.02.001

Jadidzadeh, A., & Serletis, A. (2017). How Does the US Natural Gas Market React to Demand and Supply Shocks in the Crude Oil Market?. *Energy Economics*, *63*, 66-74. https://doi.org/10.1016/j.eneco.2017.01.007

Johansen, S., & Juselius, K. (1990). Maximum Likelihood Estimation and Inference on Cointegration with Applications to the Demand for Money. *Oxford Bulletin of Economics and Statistics*, *52*(2), 169–210. https://doi.org/10.1111/j.1468-0084.1990.mp52002003.x

Le, M. T. (2018). An Assessment of the Potential for the Development of the Shale Gas Industry in Countries Outside of North America. *Heliyon*, *4*(2), pe00516. https://doi.org/10.1016/j.heliyon.2018.e00516

Melling, A. J. (2010). *Natural Gas Pricing and Its Future: Europe As the Battleground*. Carnegie Endowment for International Peace.

Mernier, A. (2007). *Putting a Price on Energy*. Energy Charter Secretariat.

Pesaran, M. H., Shin, Y., & Smith, R.J. (2001). Bounds Testing Approaches to the Analysis of Level Relationships. *Journal of Applied Econometrics*, *16*(3), 289-326. https://doi.org/10.1002/jae.616

Pesaran, M. H., & Shin, Y. (1998). An Autoregressive Distributed Lag Modeling Approach to Cointegration Analysis. In S. Strom (Ed.), *Econometrics and Economic Theory in the 20th Century: The Ragnar Frish Centennial Symposium* (pp. 371-413). Cambridge University Press.

Potts, T. B., & Yerger, D. B. (2016). Marcellus Shale and Structural Breaks in Oil and Gas Markets: The Case of Pennsylvania. *Energy Economics*, 57, 50-58. https://doi.org/10.1016/j.eneco.2016.04.017.

Ramberg, D. J., & Parsons, J.E. (2012). The Weak Tie Between Natural Gas and Oil Prices. *The Energy Journal*, *33*(2), 10-17. https://doi.org/ 10.5547/01956574.33.2.2.

Shokri, S., & Rasoulinezhad, E. (2022). Assessment and Evaluation of Energy Security in Russia Using the Factor Analysis Model. *World Sociopolitical Studies*, *6*(1), 61- 108. https://doi.org/10.22059/wsps.2022.343135.1303

Tiwari, A. K., Mukherjee, Z., Gupta, R., & Balcilar, M. (2019). A Wavelet Analysis of the Relationship Between Oil and Natural Gas Prices. *Resources Policy*, *60*, 118-124. https://doi.org/10.1016/j.resourpol.2018.11.020

Wakamatsu, H., & Aruga, K. (2013). The Impact of the Shale Gas Revolution on the US and Japanese Natural Gas Markets. *Energy Policy*, *62*, 1002-1009. https://doi.org/10.1016/j.enpol.2013.07.122

Wood, R., Gilbert, P., Sharmina, M., Anderson, K., Footitt, A., Glynn, S., & Nicholls, F. (2011). *Shale Gas: A Provisional Assessment of Climate Change and Environmental Impacts*. Tyndall Center, University of Manchester, Manchester, England.

Zou, C., Ma, F., Pan, S., Zhao, Q., Fu, G., Zhang, G., Yang, Y., Yu, H., Liang, Y., Lin, M., Wang, Y., Xiong, B., & Liu, H. (2023). Global Energy Transition Revolution and the Connotation and Pathway of the Green and Intelligent Energy System. *Petroluem Exploration and Development*, *50*(3), 722- 740. https://doi.org/10.1016/S1876-3804(23)60423-9.

Appendix

Table 1. Investigating the Co-Integration Relationship between Oil and Gas

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
r=0	r≥1	18.59543	15.49471	0.0165
r≤1	r≥2	1.537017	3.841466	0.2151
Trace test indicates one cointegrating eqn(s) at the 0.05 level				

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob
r=0	r≥1	17.05842	14.2646	0.0176
r≤1	r≥2	1.537017	3.841466	0.2151
Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level				

Source: Research Findings

Table 2. Investigating the Causality between Oil and Gas.

Null Hypothesis:	F-Statistic	Prob	Result
WTI does not Granger Cause HH	4.7084	0.0131	The price of oil is the cause of the gas price
HH does not Granger Cause WTI	0.69337	0.5044	

Source: Research Findings

Journal of WORLD SOCIOPOLITICAL STUDIES | Vol. 7 | No. 1 | Winter 2023

Table 3. Investigating the Reliability of Model Variables Using the ADF Test

Variable		t-Statistic	1% level	5% level	10% level	Prob*	Unit root in level
PE	Intercept	-1.09073	-3.5504	-3.5504	-2.59452	0.7137	Nonstationary
	Trend And Intercept	-2.09034	-4.12734	-3.49066	-3.17394	0.5399	Nonstationary
	None	-0.81688	-2.60616	-1.94665	-1.61312	0.3577	Nonstationary
wTI	Intercept	-1.41514	-3.54821	-2.91263	-2.59403	0.5688	Nonstationary
	Trend And Intercept	-1.4882	-4.12427	-3.48923	-3.17311	0.8225	Nonstationary
	None	-1.10167	-2.60544	-1.94655	-1.61318	0.2425	Nonstationary

Source: Research Findings

Table 4. Investigating the Reliability of Model Variables Using the ADF Test

Variable		t-Statistic	1% level	5% level	10% level	Prob.*	Unit root in 1 st difference
PE	Intercept	-5.8728	-3.5504	-2.91355	-2.59452	0.0000	stationary I(1)
	Trend And Intercept	-5.81882	-4.12734	-3.49066	-3.17394	0.0001	stationary I(1)
	None	-5.86978	-2.60616	-1.94665	-1.61312	0.0000	stationary I(1)
wTI	Intercept	-5.03788	-3.54821	-2.91263	-2.59403	0.0001	stationary I(1)
	Trend And Intercept	-5.05891	-4.12427	-3.48923	-3.17311	0.0006	stationary I(1)
	None	-5.02347	-2.60544	-1.94655	-1.61318	0.0000	stationary I(1)

Source: Research Findings