Investigation of the relationship between price of futures contracts of energy commodities and their energy generation contribution to US energy grid

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Contents

1. Introduction

Energy generation and its relationship to commodity markets have significant implications for financial stability and market behavior. This paper examines the influence of U.S. energy generation—categorized by sources such as natural gas, crude oil, and coal—on the corresponding commodities futures prices. By employing time series analysis, we explore how shifts in energy generation impact the pricing dynamics of these key commodities. While the focus of this documentation is on the primary findings and visualizations, supplementary charts and detailed analyses are included in the appendix.

2. Motivation

The interplay between commodity markets and energy generation is pivotal to understanding economic resilience and environmental sustainability in the contemporary energy landscape. This study is motivated by the need to dissect the dynamics between U.S. energy production and the futures prices of critical commodities—namely natural gas, crude oil, and coal. These commodities not only fuel the nation but also significantly influence the financial markets due to their integral role in energy generation. Therefore, the hypothesis under test in this study is that changes in U.S. energy generation impact the futures prices of natural gas, crude oil, and coal. It is aimed to verify this by analyzing time series data to understand if energy production fluctuations can predictably influence market trends.

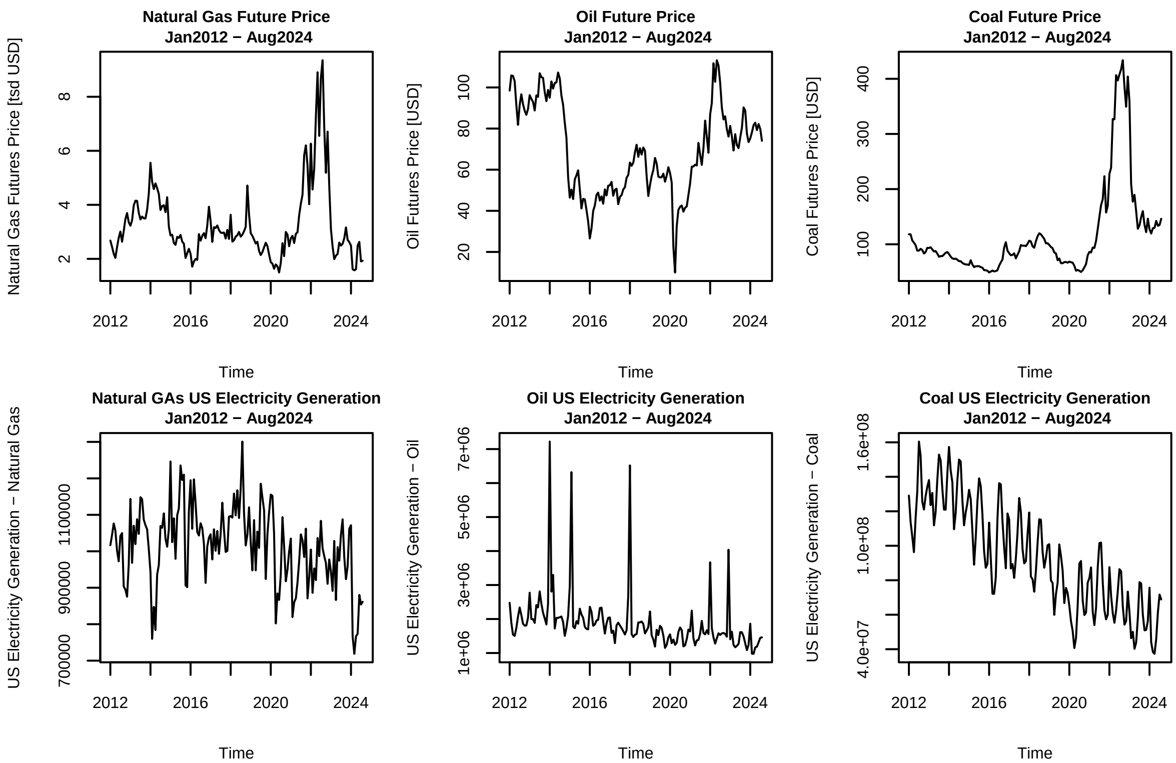
3. Methods

To investigate the causal relationship between U.S. energy generation by source and commodities futures prices for Natural Gas, Crude Oil, and Coal, the first step is to prepare the data to ensure comparability. After cleansing and preprocessing the data, the "Augmented Dickey-Fuller Test" is applied to determine whether the time series are stationary. If any time series are found to be non-stationary, they are transformed using the diff(log()) method until the "Dickey-Fuller Test" confirms stationarity. Once the series are stationary, they are used to construct vector autoregressive models (VAR models) to analyze the dynamic relationships. Additionally, Granger causality tests are performed to evaluate the direction and strength of causality between the variables.

3.1 Data collection and preprocessing

The historical futures prices for Natural Gas, Crude Oil (WTI), and Newcastle Coal were sourced from Barchart.com in the form of CSV files. Data on U.S. electricity generation, categorized by energy source, was obtained from the U.S. Energy Information Administration as XLSX file. This method required manual extraction and preparation. The availability of data varies: Crude Oil futures pricing data begins in 1983, Natural Gas futures data in 1990, Coal futures data in 2009, and U.S. energy generation data in 2001. All datasets are reported on a monthly basis and are available up to August 2024. Despite these differences in starting dates, the data was aligned to ensure consistency for the analysis period.

3.2 Data Preparation and Visualization



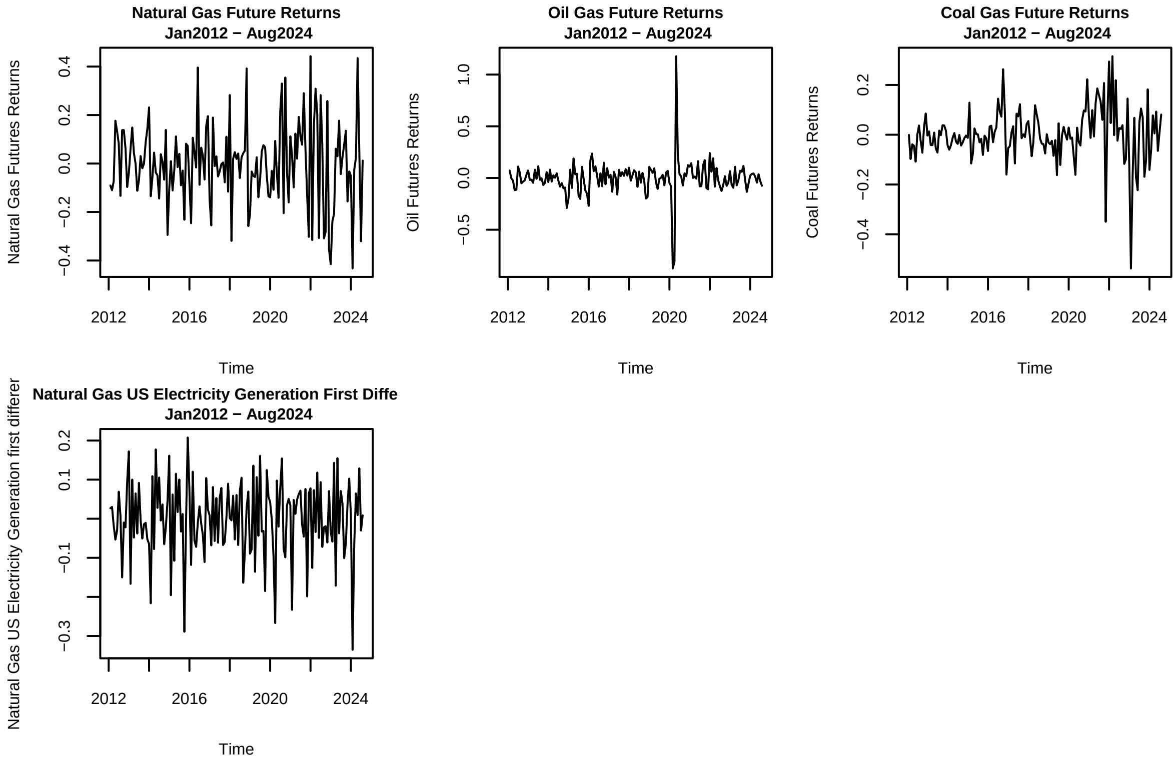
3.3 Time Series Sationarity

To develop the VAR models, it is essential to first ensure that all time series are stationary. A stationary time series is defined as one with consistent statistical properties over time, such as mean, variance, and autocorrelation. To verify stationarity, the Augmented Dickey-Fuller test is applied to each of the investigated time series. The test results, including p-values, are used to assess the stationarity of the time series data, such as futures prices of Natural Gas, Crude Oil, Coal, as well as U.S. energy generation by the energy source.

Time series	p-value
Natural Gas Futures Price	0.353
Crude Oil Futures Price	0.610
Coal Futures Prices	0.056
US Electricity Generation Natural Gas	0.068
US Electricity Generation Crude Oil	0.010
US Electricity Generation Coal	0.010

Table 1: Augmented Diickey-Fuller test results for investigated time series

Time series with a P-value greater than 0.05, such as Natural Gas U.S. energy generation and futures prices of Natural Gas, Crude Oil, and Coal, are classified as non-stationary. To address this, stationarity is introduced by applying diff(log()) transformation.



Time series	p-value
Natural Gas Futures Price	0.01
Crude Oil Futures Price	0.01
Coal Futures Prices	0.01
US Electricity Generation Natural Gas	0.01

Table 2: Augmented Dickey-Fuller test results for investigated time series after first differences

After applying the diff(log()), the previously insignificant results (non-stationary) have been transformed to significant results below the threshold of 0.05.

4. VAR Model and Granger Causality

Once the time series are made stationary by applying first differences, the next step is to fit a Vector Autoregressive model to the stationary data. The VAR model captures the linear relationships between a variable and its own past values, as well as the past values of other endogenous variables. This approach allows for the exploration of the dynamics and feedback among multiple interrelated time series, offering insights into the causal relationships within the data.

4.1a Natural Gas Futures Returns vs Natural Gas US Electricity Generation Difference

In this analysis, the relationship between differenced natural gas futures returns and changes in U.S. electricity generation from natural gas was examined using VAR models. The Granger causality tests indicated no significant predictive relationship. Detailed results and plots are available in the appendix.

4.1b Natural Gas Futures Returns vs Natural Gas US Electricity Generation

Natural Gas Data is not stationary but give p-value 0.06 checking the results out of curiosity This section explored the relationship between natural gas futures returns and U.S. electricity generation from natural gas without differencing. The results were insignificant, underscoring the importance of using differenced data for stationarity. Exact results and plots can be found in the appendix.

4.2 Oil Futures Returns vs Oil US Electricity Generation

The relationship between oil futures returns and U.S. electricity generation from oil was analyzed. Granger causality tests showed no significant effects, confirming that changes in oil-based electricity generation do not predict oil futures prices. Detailed results and plots are available in the appendix.

4.3 Coal Futures Returns vs Coal US Electricity Generation

This analysis investigated the impact of changes in coal-based U.S. electricity generation on coal futures returns. The results were insignificant, indicating no predictive causality between the two. Exact results and plots can be found in the appendix.

5. Results & Conclusion

The study initiated with Augmented Dickey-Fuller tests which identified non-stationarity in the time series data concerning U.S. energy production and commodity futures prices. To achieve stationarity, necessary for accurate econometric analysis, a diff(log()) transformation was applied. This method effectively stabilized the variance and mean of the series, allowing for further analysis with Vector Autoregression (VAR) models.

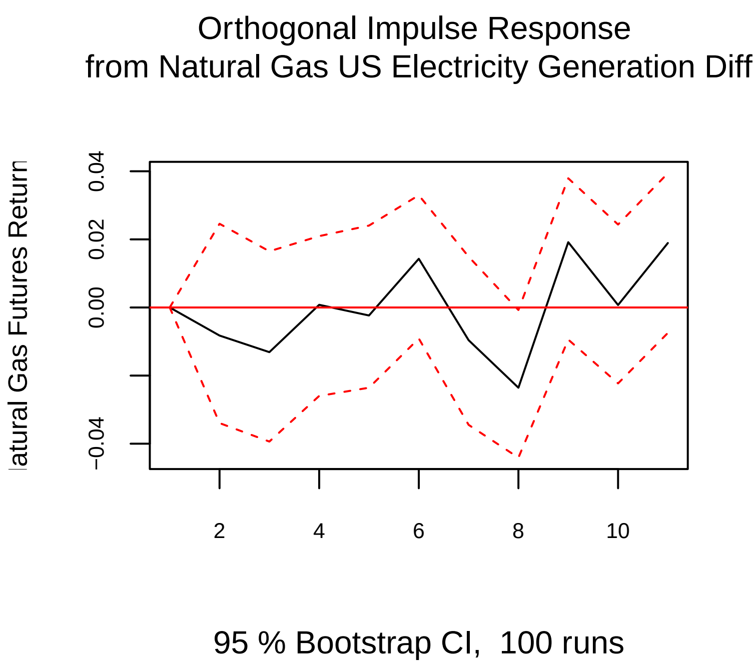
Employing VAR models and subsequent Granger causality tests, the study aimed to determine if historical data on energy production could predict futures prices for natural gas, crude oil, and coal. The causality tests, however, did not reveal significant predictive relationships between these variables.

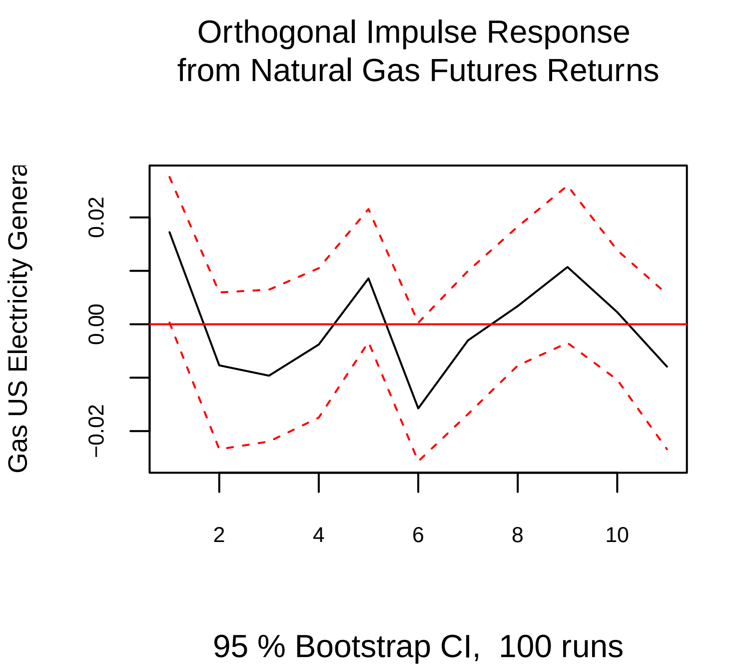
These findings from section 4 suggest that fluctuations in U.S. energy production do not significantly influence the futures prices of these commodities, indicating that other external factors such as global economic conditions, market sentiment, or geopolitical events likely have a greater impact. This highlights the complexity of the factors driving commodity markets and suggests that a broader perspective is necessary for understanding and forecasting movements in these prices.

6. Appendix

Section 4 - Additional information

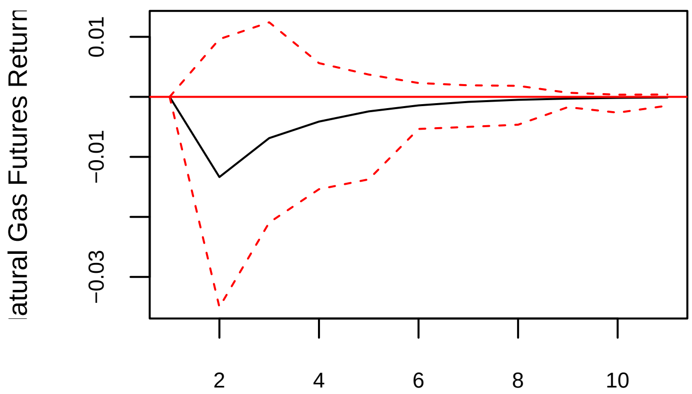
4.1a Natural Gas Futures Returns vs Natural Gas US Electricity Generation Difference





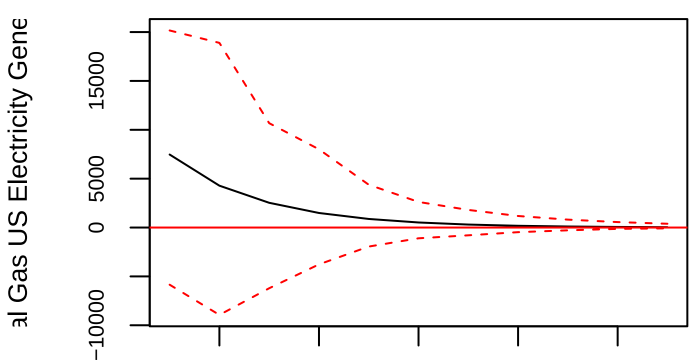
4.1b Natural Gas Futures Returns vs Natural Gas US Electricity Generation

Orthogonal Impulse Response from
Natural Gas US Electricity Generation



95 % Bootstrap CI, 100 runs

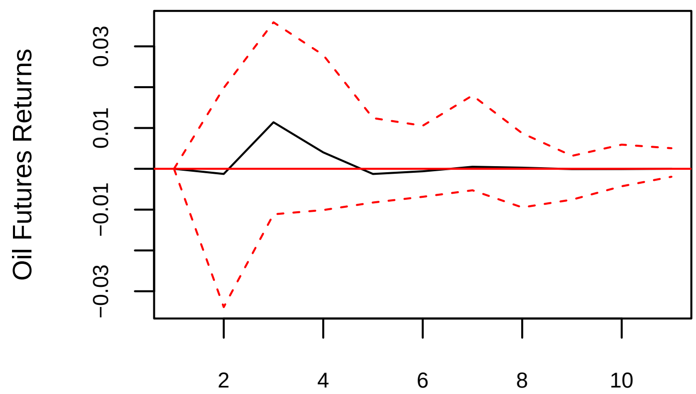
Orthogonal Impulse Response
from Natural Gas Futures Returns



95 % Bootstrap CI, 100 runs

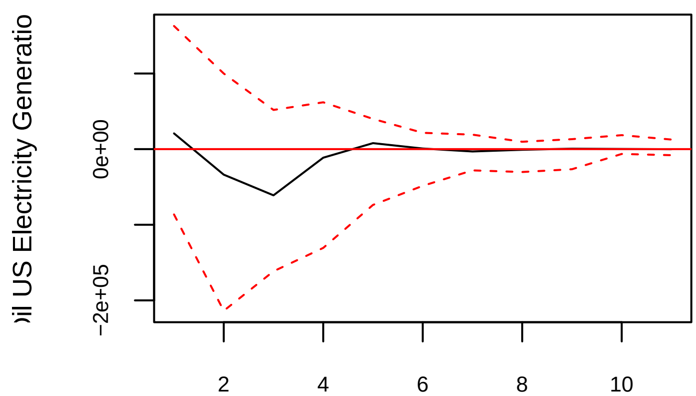
4.2 Oil Futures Returns vs Oil US Electricity Generation

Orthogonal Impulse Response
from Oil US Electricity Generation



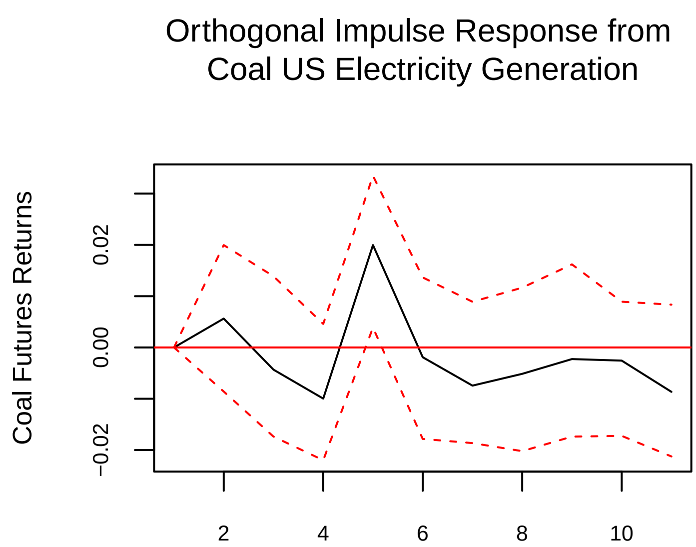
95 % Bootstrap CI, 100 runs

Orthogonal Impulse Response
from Oil Futures Returns

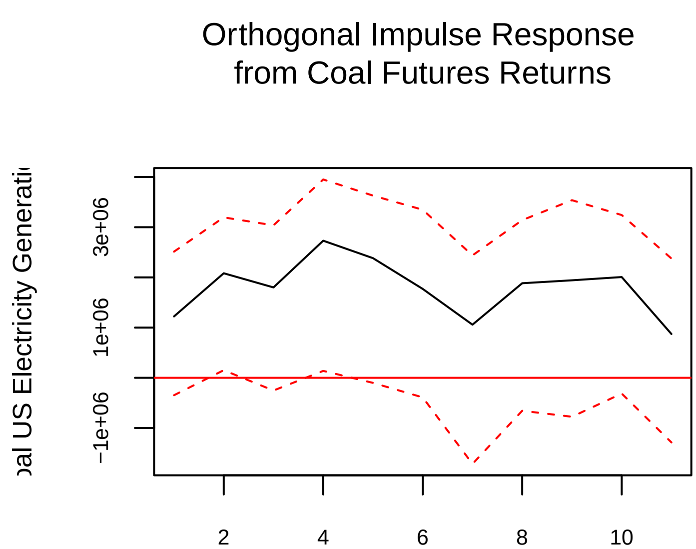


95 % Bootstrap CI, 100 runs

4.3 Coal Futures Returns vs Coal US Electricity Generation



95 % Bootstrap CI, 100 runs



95 % Bootstrap CI, 100 runs