Investigation of The Relationship between Price of Futures Contracts of Energy Commodities and their Energy Generation Contribution to U.S 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 listed on commodities exchanges in the United States. By employing time series analysis, shifts in energy generation impacting the pricing dynamics of these key commodities are explored. 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 where the energy come from — namely natural gas, crude oil, and coal. Futures contracts are selected due to two reasons related to the nature of the commodities market: (i) most of the trading volume takes place on the futures markets and (ii) prices of these instruments are common benchmarks of the actual energy commodity prices. Given the energy needs around the world and size of the energy commodities market, aforementioned commodities not only fulfill basic needs but also significantly influence the financial markets globally. To perform this study United States was selected as a country of interest and therefore, the following hypothesis was investigated: 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 have causal relationship with corresponding commodity future price.

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 was to prepare the data to ensure comparability. After cleansing and preprocessing the data, the "Augmented Dickey-Fuller Test" was applied to determine whether the time series are stationary. If any time series were found to be non-stationary, they were transformed using the diff(log()) method until the "Dickey-Fuller Test" confirms stationarity. Once the series were stationary, they were used to construct vector autoregressive models (VAR models) to analyze the dynamic relationships. Additionally, Granger causality tests were performed to evaluate the direction and strength of causality between the variables as well as the distribution of the residuals was analyzed.

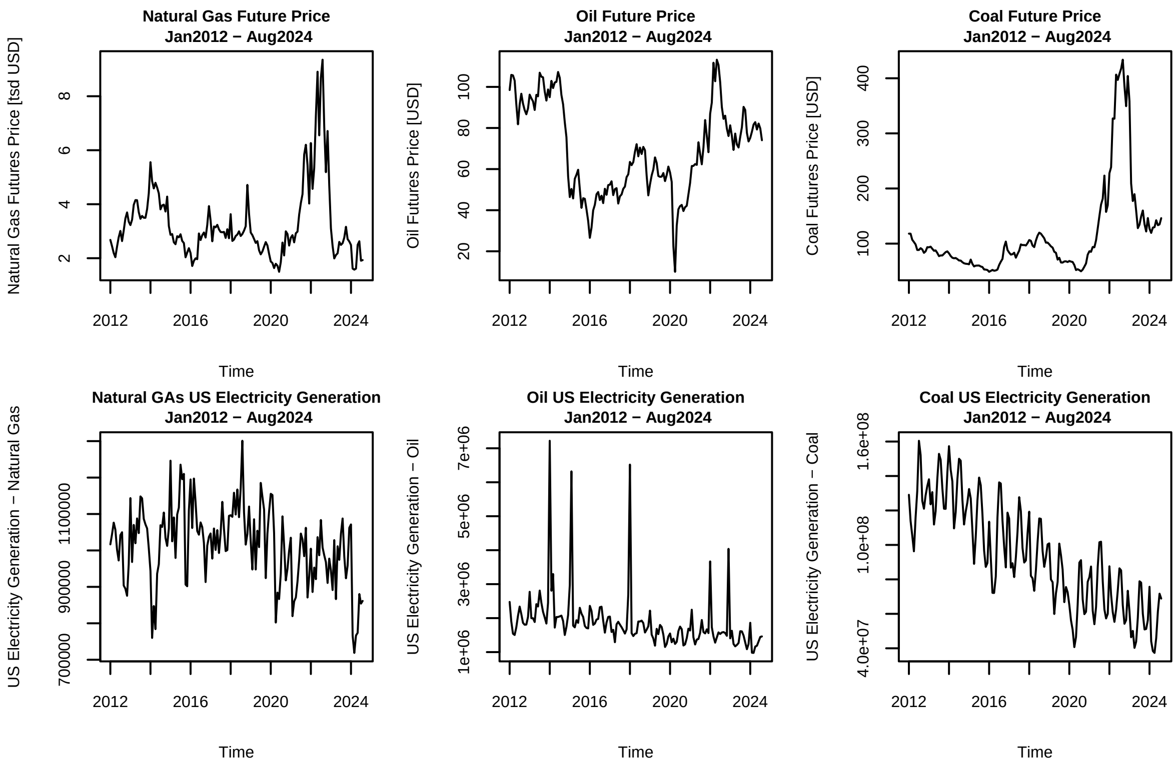
3.1 Data collection and preprocessing

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 were reported on a monthly basis and were 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

Data was prepared and used for analyzing time series data concerning futures prices of natural gas, oil, and coal, alongside U.S. electricity generation from these sources. The data, filtered from January

2012 to August 2024, was transformed into time series objects with a monthly frequency to facilitate further time series analysis and modeling. Plots generated from this data visually represent the trends in both futures prices and electricity generation over the specified period, allowing for preliminary observations on variability and potential correlation between market prices and electricity production.



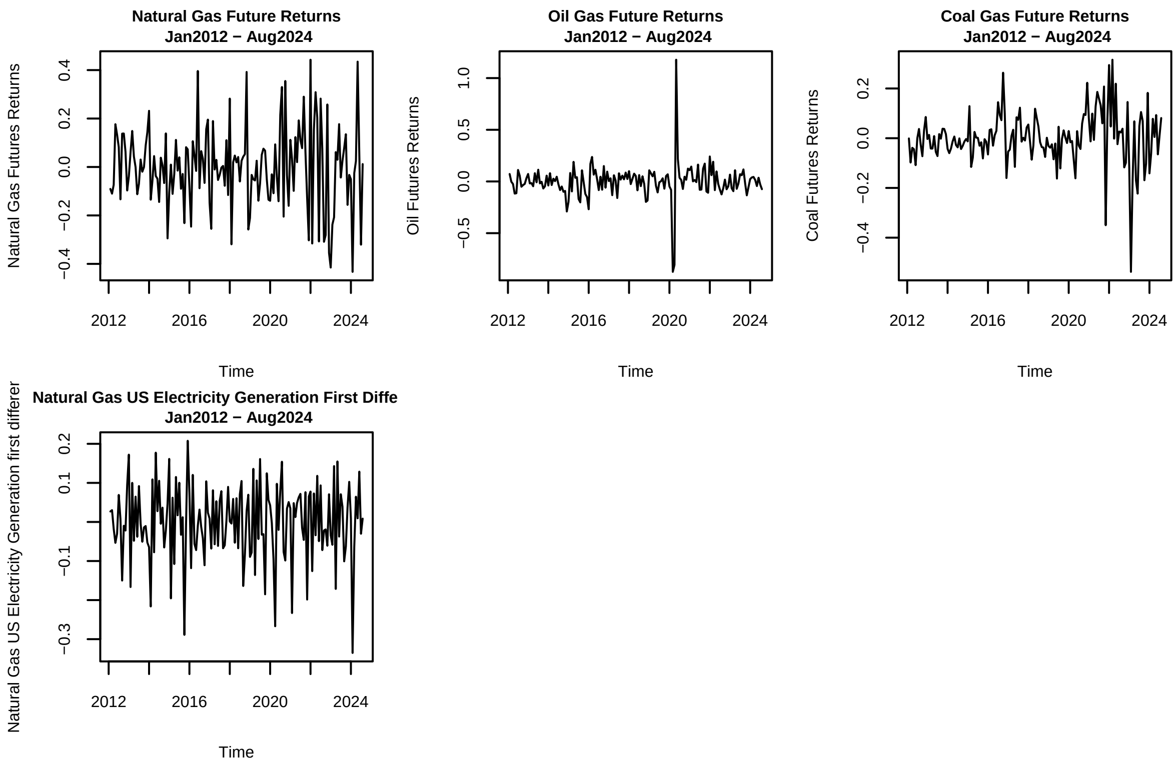
3.3 Time Series Stationarity

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 was applied to each of the investigated time series. The test results, including p-values, were 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, were classified as non-stationary. To address this, stationarity was 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) were transformed to significant results below the threshold of 0.05.

4. VAR Model and Granger Causality

Once the time series were made stationary by applying first differences, the next step was 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. Given three different commodities three separate analyses were performed which followed the same structure:

- Determine the lag for the model using Akaike information criterion (AIC)
- Determine the formula for VAR model for the investigated commodity
- Perform Granger causality test
- Analyse the diistribution of the residuals
- Interpret the output

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. Specifically a VAR model with two explanatory variables was calculated as Natural Gas futures returns as well as differenced Natural Gas U.S energy generation data were analyzed. A VAR model with 2 variables Xt, Yt and lag = 1 was built. The final model looks like this:

$$\Delta \text{Nat\_Gas\_Futures\_Returns}_t = \alpha_1 + \beta_{11}\Delta \text{Nat\_Gas\_Futures\_Returns}_{t-1} + \beta_{12}\Delta \text{Nat\_Gas\_US\_Elec\_Diff}_{t-1} + \epsilon_{1t}$$
$$\Delta \text{Nat\_Gas\_US\_Elec\_Diff}_t = \alpha_2 + \beta_{21}\Delta \text{Nat\_Gas\_Futures\_Returns}_{t-1} + \beta_{22}\Delta \text{Nat\_Gas\_US\_Elec\_Diff}_{t-1} + \epsilon_{2t}$$

In the next step, Granger causality tests indicated no significant causal relationship between Natural Gas Futures Data and Natural Gas U.S Electricity generation given the p-value above 0.05. Running JB-Test we cannot state that data is normally distributed. The p-value is less than 0.05 rejecting the hypothesis about normal distribution of residuals. 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 given p-value of 0.06, the results were checked out of curiosity. This section explored the relationship between natural gas futures returns and U.S. electricity generation from natural gas without differencing. Similarly to section 4.1a a VAR model with two explanatory variables was calculated. This time Natural Gas futures returns and Natural Ga U.S energy generation data were analyzed. A second VAR model with 2 variables Xt, Yt and lag = 1 was built. The final model looks like this:

$$\text{Nat\_Gas\_Futures\_Returns}_t = \alpha_1 + \beta_{11}\text{Nat\_Gas\_Futures\_Returns}_{t-1} + \beta_{12}\text{Nat\_Gas\_US\_Elec}_{t-1} + \epsilon_{1t}$$
$$\text{Nat\_Gas\_US\_Elec}_t = \alpha_2 + \beta_{21}\text{Nat\_Gas\_Futures\_Returns}_{t-1} + \beta_{22}\text{Nat\_Gas\_US\_Elec}_{t-1} + \epsilon_{2t}$$

Comparably to section 4.1a, the results were insignificant, underscoring the importance of using differenced data for stationarity. Running JB-Test we can state that data is normally distributed. The p-value is with 95% confidence interval and null hypothesis cannot be rejected. Exact results and plots can be found in the appendix.

4.2 Oil Futures Returns vs Oil US Electricity Generation

In the next model the relationship between oil futures returns and U.S. electricity generation from oil was analyzed. Another VAR model was built fitting Crude Oil futures returns and Crude Oil U.S energy generation data. A VAR model for Crude Oil has two variables Xt, Yt and lag = 1 and looks as follows:

$$\Delta \text{Oil\_Futures\_Returns}_t = \alpha_1 + \beta_{11}\Delta \text{Oil\_Futures\_Returns}_{t-1} + \beta_{12}\Delta \text{Oil\_US\_Elec}_{t-1} + \epsilon_{1t}$$
$$\Delta \text{Oil\_US\_Elec}_t = \alpha_2 + \beta_{21}\Delta \text{Oil\_Futures\_Returns}_{t-1} + \beta_{22}\Delta \text{Oil\_US\_Elec}_{t-1} + \epsilon_{2t}$$

Granger causality tests again showed no significant effects, confirming that changes in oil-based electricity generation do not cause oil futures prices. Running JB-Test we cannot state that data is normally distributed. The p-value is less than 0.05 rejecting the hypothesis about normal distribution of residuals. Detailed results and plots are available in the appendix.

4.3 Coal Futures Returns vs Coal US Electricity Generation

The last analysis investigated the impact of changes in coal-based U.S. electricity generation on coal futures returns. The VAR model for this section fits Coal futures returns and Coal U.S energy generation data, variables Xt and Yt, at lag = 1:

$$\begin{aligned} \Delta\text{Coal\_Futures\_Returns}_t &= \alpha_1 + \beta_{11}\Delta\text{Coal\_Futures\_Returns}_{t-1} + \beta_{12}\Delta\text{Coal\_US\_Elec}_{t-1} + \epsilon_{1t} \\ \Delta\text{Coal\_US\_Elec}_t &= \alpha_2 + \beta_{21}\Delta\text{Coal\_Futures\_Returns}_{t-1} + \beta_{22}\Delta\text{Coal\_US\_Elec}_{t-1} + \epsilon_{2t} \end{aligned}$$

Similarly to previous analyses, the results were insignificant, indicating no predictive causality between the two investigated variables. Running JB-Test we cannot state that data is normally distributed. The p-value is less than 0.05 rejecting the hypothesis about normal distribution of residuals. 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

```
## AIC(n)  HQ(n)  SC(n) FPE(n)
##     16      1      1     16
```

```
##
## t test of coefficients:
##
##                                                        Estimate Std. Error
## Nat_Gas_Futures_returns:(Intercept)                  -0.0072354  0.0144347
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l1  -0.0924684  0.0970422
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l1     -0.1049815  0.2025568
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l2  -0.0872007  0.0986573
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l2     -0.2129212  0.2119597
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l3   0.1622384  0.0980269
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l3     -0.1141287  0.2138124
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l4   0.0839908  0.1018976
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l4     -0.1305009  0.2212887
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l5  -0.0930747  0.1021382
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l5      0.1065328  0.2276697
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l6   0.1385321  0.1016763
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l6     -0.1473560  0.2287658
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l7  -0.1558620  0.1046959
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l7     -0.3541059  0.2442075
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l8  -0.1362567  0.1037012
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l8      0.0306061  0.2410991
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l9  -0.2262281  0.1040897
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l9     -0.1069119  0.2355144
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l10  0.1599176  0.1054580
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l10     0.2260365  0.2367928
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l11  0.1962735  0.1063892
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l11    -0.0267601  0.2407226
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l12  0.0564848  0.1069871
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l12     0.2602755  0.2395848
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l13  0.1208096  0.1073650
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l13     0.0152084  0.2288114
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l14 -0.0783593  0.1029443
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l14    -0.1489690  0.2210376
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l15  0.0497371  0.1057323
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l15    -0.0369556  0.2133556
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l16 -0.2817772  0.1062549
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l16    -0.1494497  0.2008949
## Nat_Gas_US_Elec_diff:(Intercept)                    -0.0064975  0.0069851
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l1     -0.0105834  0.0469595
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l1        -0.3442764  0.0980188
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l2     -0.0366532  0.0477410
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l2        -0.3693681  0.1025689
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l3     -0.0306517  0.0474360
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l3        -0.3280626  0.1034654
```

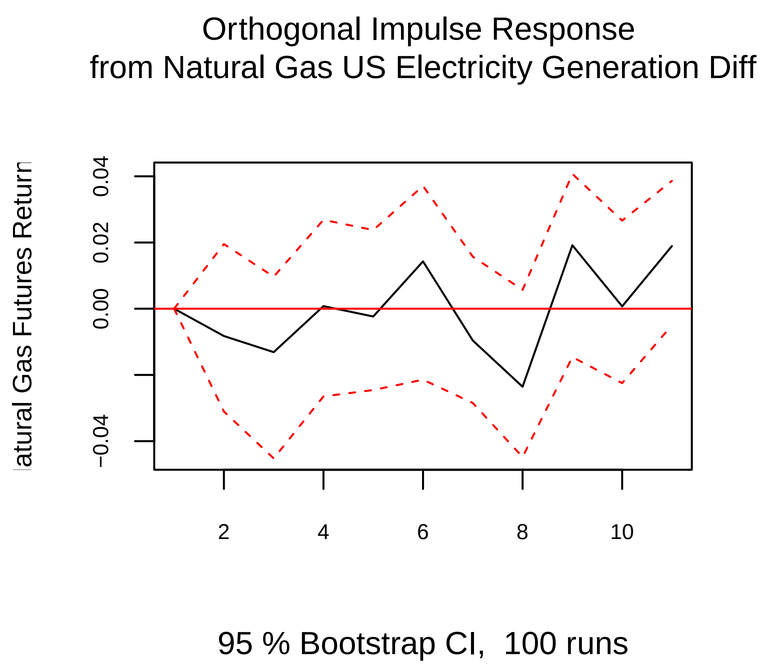
```
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l4      0.0415102  0.0493090
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l4        -0.3757592  0.1070833
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l5     -0.0754333  0.0494255
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l5        -0.3626802  0.1101711
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l6     -0.0465632  0.0492019
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l6        -0.2724007  0.1107015
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l7     -0.0405746  0.0506631
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l7        -0.2468158  0.1181739
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l8      0.0433570  0.0501818
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l8        -0.2149856  0.1166697
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l9      0.0397213  0.0503698
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l9        -0.3162471  0.1139672
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l10    -0.0512151  0.0510319
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l10       -0.2784393  0.1145858
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l11    -0.0145265  0.0514825
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l11       -0.2467939  0.1164875
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l12     0.0574483  0.0517719
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l12        0.0742749  0.1159369
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l13     0.0410567  0.0519547
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l13       -0.2081661  0.1107236
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l14     0.1379978  0.0498155
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l14       -0.1378986  0.1069618
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l15    -0.0256450  0.0511647
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l15       -0.1938686  0.1032444
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l16     0.0753608  0.0514175
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l16       -0.0613173  0.0972145
##                                                     t value  Pr(>|t|)
## Nat_Gas_Futures_returns:(Intercept)                 -0.5012 0.6172770
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l1  -0.9529 0.3429096
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l1     -0.5183 0.6053841
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l2  -0.8839 0.3788422
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l2     -1.0045 0.3174974
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l3   1.6550 0.1009903
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l3     -0.5338 0.5946554
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l4   0.8243 0.4117111
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l4     -0.5897 0.5566748
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l5  -0.9113 0.3643061
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l5      0.4679 0.6408351
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l6   1.3625 0.1760466
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l6     -0.6441 0.5209338
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l7  -1.4887 0.1396485
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l7     -1.4500 0.1501208
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l8  -1.3139 0.1918155
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l8      0.1269 0.8992345
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l9  -2.1734 0.0320646 *
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l9     -0.4540 0.6508287
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l10  1.5164 0.1325090
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l10     0.9546 0.3420494
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l11  1.8449 0.0679591 .
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l11    -0.1112 0.9117034
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l12  0.5280 0.5986744
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l12     1.0864 0.2798800
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l13  1.1252 0.2631353
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l13     0.0665 0.9471362
```

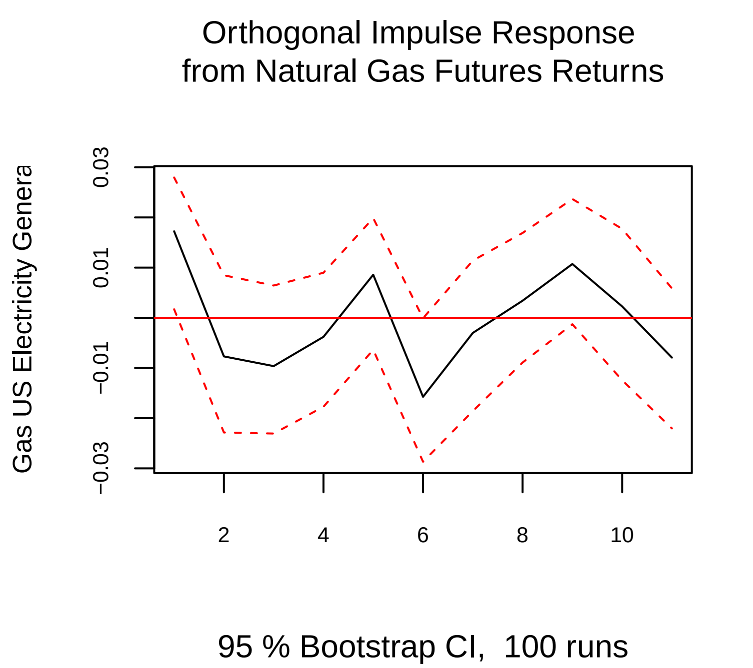
```
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l14 -0.7612 0.4483048
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l14    -0.6740 0.5018654
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l15  0.4704 0.6390691
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l15    -0.1732 0.8628287
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l16 -2.6519 0.0092824 **
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec_diff.l16    -0.7439 0.4586351
## Nat_Gas_US_Elec_diff:(Intercept)                    -0.9302 0.3544669
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l1     -0.2254 0.8221407
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l1        -3.5124 0.0006633 ***
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l2     -0.7678 0.4444083
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l2        -3.6012 0.0004912 ***
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l3     -0.6462 0.5196208
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l3        -3.1707 0.0020083 **
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l4      0.8418 0.4018479
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l4        -3.5090 0.0006707 ***
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l5     -1.5262 0.1300544
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l5        -3.2920 0.0013674 **
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l6     -0.9464 0.3461963
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l6        -2.4607 0.0155469 *
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l7     -0.8009 0.4250678
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l7        -2.0886 0.0392351 *
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l8      0.8640 0.3896158
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l8        -1.8427 0.0682793 .
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l9      0.7886 0.4321785
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l9        -2.7749 0.0065691 **
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l10    -1.0036 0.3179513
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l10       -2.4300 0.0168474 *
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l11    -0.2822 0.7783890
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l11       -2.1186 0.0365505 *
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l12     1.1096 0.2697617
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l12        0.6406 0.5231870
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l13     0.7902 0.4312216
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l13       -1.8801 0.0629545 .
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l14     2.7702 0.0066581 **
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l14       -1.2892 0.2002333
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l15    -0.5012 0.6172925
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l15       -1.8778 0.0632701 .
## Nat_Gas_US_Elec_diff:Nat_Gas_Futures_returns.l16     1.4657 0.1458157
## Nat_Gas_US_Elec_diff:Nat_Gas_US_Elec_diff.l16       -0.6307 0.5296197
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## $Granger
##
##  Granger causality H0: Nat_Gas_Futures_returns do not Granger-cause
##  Nat_Gas_US_Elec_diff
##
## data:  VAR object VAR_est_nat_gas1
## F-Test = 1.3301, df1 = 16, df2 = 204, p-value = 0.1813
```

```
## $Granger
##
##  Granger causality H0: Nat_Gas_US_Elec_diff do not Granger-cause
##  Nat_Gas_Futures_returns
```

```
##
## data:  VAR object VAR_est_nat_gas1
## F-Test = 0.94873, df1 = 16, df2 = 204, p-value = 0.5146
```






```
## $JB
```

```
##
##  JB-Test (multivariate)
##
## data:  Residuals of VAR object VAR_est_nat_gas1
## Chi-squared = 9.88, df = 4, p-value = 0.0425
##
##
## $Skewness
##
##  Skewness only (multivariate)
##
## data:  Residuals of VAR object VAR_est_nat_gas1
## Chi-squared = 7.5953, df = 2, p-value = 0.02242
##
##
## $Kurtosis
##
##  Kurtosis only (multivariate)
##
## data:  Residuals of VAR object VAR_est_nat_gas1
## Chi-squared = 2.2847, df = 2, p-value = 0.3191
```

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

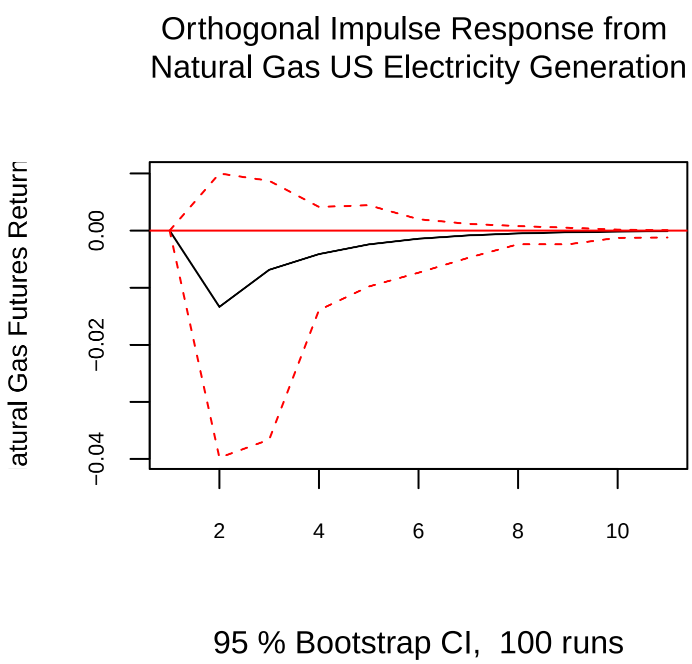
```
## AIC(n)  HQ(n)  SC(n) FPE(n)
##      1      1      1      1
```

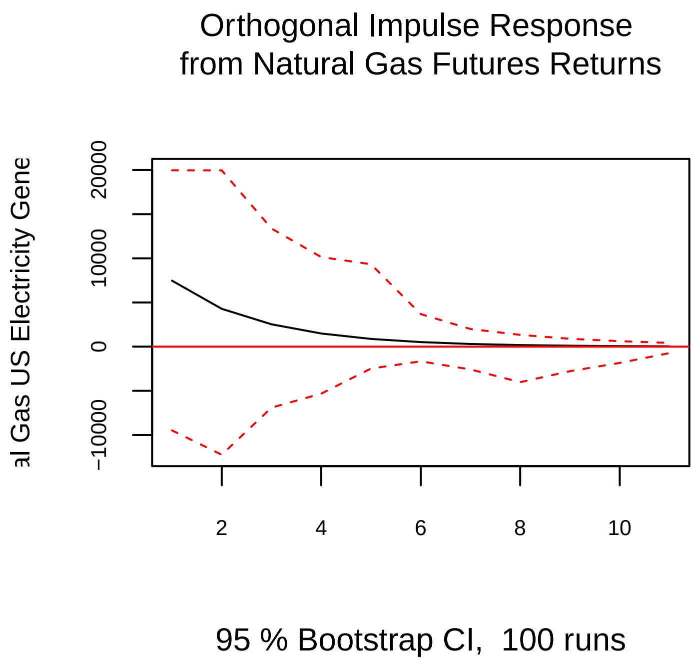
```
##
## t test of coefficients:
##
##                                                     Estimate  Std. Error
## Nat_Gas_Futures_returns:(Intercept)               1.5480e-01  1.3107e-01
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l1 -7.4128e-02  8.1773e-02
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec.l1        -1.5418e-07  1.2839e-07
## Nat_Gas_US_Elec:(Intercept)                       4.1655e+05  6.8779e+04
## Nat_Gas_US_Elec:Nat_Gas_Futures_returns.l1        -6.8935e+02  4.2910e+04
## Nat_Gas_US_Elec:Nat_Gas_US_Elec.l1                 5.8856e-01  6.7374e-02
##                                                   t value  Pr(>|t|)
## Nat_Gas_Futures_returns:(Intercept)                1.1811    0.2395
## Nat_Gas_Futures_returns:Nat_Gas_Futures_returns.l1 -0.9065    0.3661
## Nat_Gas_Futures_returns:Nat_Gas_US_Elec.l1        -1.2008    0.2318
## Nat_Gas_US_Elec:(Intercept)                        6.0563 1.111e-08 ***
## Nat_Gas_US_Elec:Nat_Gas_Futures_returns.l1        -0.0161    0.9872
## Nat_Gas_US_Elec:Nat_Gas_US_Elec.l1                 8.7356 4.991e-15 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## $Granger
##
##  Granger causality H0: Nat_Gas_Futures_returns do not Granger-cause
##  Nat_Gas_US_Elec
##
## data:  VAR object VAR_est_nat_gas2
```

```
## F-Test = 0.00025808, df1 = 1, df2 = 294, p-value = 0.9872

## $Granger
##
##  Granger causality H0: Nat_Gas_US_Elec do not Granger-cause
##  Nat_Gas_Futures_returns
##
## data:  VAR object VAR_est_nat_gas2
## F-Test = 1.442, df1 = 1, df2 = 294, p-value = 0.2308
```






```
## $JB
##
##  JB-Test (multivariate)
##
## data:  Residuals of VAR object VAR_est_nat_gas2
## Chi-squared = 4.7237, df = 4, p-value = 0.3168
##
##
## $Skewness
##
##  Skewness only (multivariate)
##
## data:  Residuals of VAR object VAR_est_nat_gas2
## Chi-squared = 2.9741, df = 2, p-value = 0.226
##
##
## $Kurtosis
##
##  Kurtosis only (multivariate)
##
## data:  Residuals of VAR object VAR_est_nat_gas2
## Chi-squared = 1.7496, df = 2, p-value = 0.4169
```

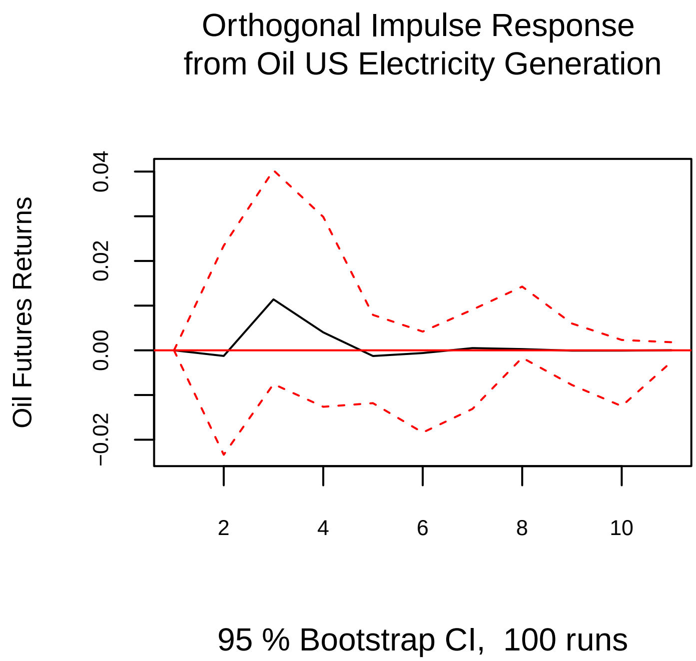
4.2 Crude Oil Futures Returns vs Oil US Electricity Generation

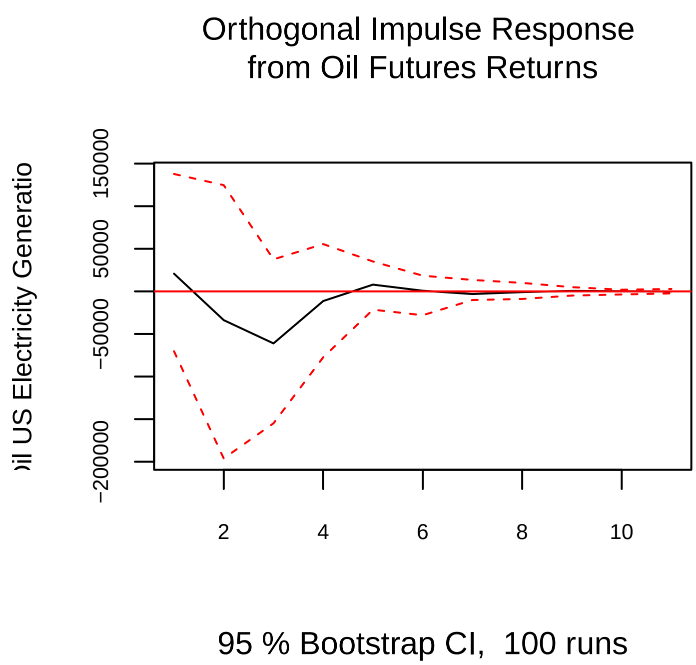
```
## AIC(n)  HQ(n)  SC(n) FPE(n)
##      2      1      1      2
```

```
##
## t test of coefficients:
##
##                                            Estimate  Std. Error t value
## Oil_Futures_returns:(Intercept)          -2.6944e-02  3.9699e-02 -0.6787
## Oil_Futures_returns:Oil_Futures_returns.l1  7.0850e-02  8.0160e-02  0.8839
## Oil_Futures_returns:Oil_US_Elec.l1       -1.5483e-09  1.6625e-08 -0.0931
## Oil_Futures_returns:Oil_Futures_returns.l2 -2.7402e-01  8.0225e-02 -3.4157
## Oil_Futures_returns:Oil_US_Elec.l2        1.4554e-08  1.6628e-08  0.8753
## Oil_US_Elec:(Intercept)                   1.2519e+06  1.9830e+05  6.3131
## Oil_US_Elec:Oil_Futures_returns.l1       -2.4058e+05  4.0041e+05 -0.6008
## Oil_US_Elec:Oil_US_Elec.l1                2.5773e-01  8.3042e-02  3.1036
## Oil_US_Elec:Oil_Futures_returns.l2       -3.1420e+05  4.0073e+05 -0.7841
## Oil_US_Elec:Oil_US_Elec.l2                7.1857e-02  8.3059e-02  0.8651
##                                           Pr(>|t|)
## Oil_Futures_returns:(Intercept)           0.498413
## Oil_Futures_returns:Oil_Futures_returns.l1  0.378246
## Oil_Futures_returns:Oil_US_Elec.l1        0.925929
## Oil_Futures_returns:Oil_Futures_returns.l2  0.000827 ***
## Oil_Futures_returns:Oil_US_Elec.l2        0.382878
## Oil_US_Elec:(Intercept)                  3.189e-09 ***
## Oil_US_Elec:Oil_Futures_returns.l1        0.548888
## Oil_US_Elec:Oil_US_Elec.l1                0.002302 **
## Oil_US_Elec:Oil_Futures_returns.l2        0.434287
## Oil_US_Elec:Oil_US_Elec.l2                0.388404
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## $Granger
##
##  Granger causality H0: Oil_Futures_returns do not Granger-cause
##  Oil_US_Elec
##
## data:  VAR object VAR_est_oil
## F-Test = 0.51677, df1 = 2, df2 = 288, p-value = 0.597
```

```
## $Granger
##
##  Granger causality H0: Oil_US_Elec do not Granger-cause
##  Oil_Futures_returns
##
## data:  VAR object VAR_est_oil
## F-Test = 0.39527, df1 = 2, df2 = 288, p-value = 0.6739
```






```
## $JB
##
##  JB-Test (multivariate)
##
## data:  Residuals of VAR object VAR_est_oil
```

```
## Chi-squared = 5013.2, df = 4, p-value < 2.2e-16
##
##
## $Skewness
##
##  Skewness only (multivariate)
##
## data:  Residuals of VAR object VAR_est_oil
## Chi-squared = 401.53, df = 2, p-value < 2.2e-16
##
##
## $Kurtosis
##
##  Kurtosis only (multivariate)
##
## data:  Residuals of VAR object VAR_est_oil
## Chi-squared = 4611.7, df = 2, p-value < 2.2e-16
```

4.3 Coal Futures Returns vs Coal US Electricity Generation

```
## AIC(n)  HQ(n)  SC(n) FPE(n)
##     15     11      5     15
```

```
##
## t test of coefficients:
##
##                                                  Estimate  Std. Error t value
## Coal_Futures_returns:(Intercept)               2.3613e-02  3.4539e-02  0.6837
## Coal_Futures_returns:Coal_Futures_returns.l1   1.4414e-01  9.5355e-02  1.5117
## Coal_Futures_returns:Coal_US_Elec.l1           6.7177e-10  1.1568e-09  0.5807
## Coal_Futures_returns:Coal_Futures_returns.l2  -8.1227e-03  9.7082e-02 -0.0837
## Coal_Futures_returns:Coal_US_Elec.l2          -9.9054e-10  1.2879e-09 -0.7691
## Coal_Futures_returns:Coal_Futures_returns.l3   2.8483e-01  9.4248e-02  3.0222
## Coal_Futures_returns:Coal_US_Elec.l3          -8.4942e-10  1.2733e-09 -0.6671
## Coal_Futures_returns:Coal_Futures_returns.l4   5.9502e-02  9.7652e-02  0.6093
## Coal_Futures_returns:Coal_US_Elec.l4           3.0436e-09  1.2298e-09  2.4749
## Coal_Futures_returns:Coal_Futures_returns.l5   1.1941e-01  9.7533e-02  1.2243
## Coal_Futures_returns:Coal_US_Elec.l5          -1.6586e-09  1.2063e-09 -1.3750
## Coal_Futures_returns:Coal_Futures_returns.l6  -2.2189e-01  9.8430e-02 -2.2543
## Coal_Futures_returns:Coal_US_Elec.l6          -5.6215e-10  1.2070e-09 -0.4657
## Coal_Futures_returns:Coal_Futures_returns.l7   9.4723e-02  9.8538e-02  0.9613
## Coal_Futures_returns:Coal_US_Elec.l7          -5.5690e-10  1.2110e-09 -0.4599
## Coal_Futures_returns:Coal_Futures_returns.l8   8.2521e-02  9.9484e-02  0.8295
## Coal_Futures_returns:Coal_US_Elec.l8           2.7599e-10  1.2342e-09  0.2236
## Coal_Futures_returns:Coal_Futures_returns.l9   2.1175e-01  9.9838e-02  2.1209
## Coal_Futures_returns:Coal_US_Elec.l9          -2.6426e-10  1.2387e-09 -0.2133
## Coal_Futures_returns:Coal_Futures_returns.l10 -1.1289e-01  1.0043e-01 -1.1241
## Coal_Futures_returns:Coal_US_Elec.l10          2.3755e-10  1.2380e-09  0.1919
## Coal_Futures_returns:Coal_Futures_returns.l11 -6.5088e-02  9.9823e-02 -0.6520
## Coal_Futures_returns:Coal_US_Elec.l11          1.2447e-10  1.2426e-09  0.1002
## Coal_Futures_returns:Coal_Futures_returns.l12 -1.5011e-01  1.0265e-01 -1.4624
## Coal_Futures_returns:Coal_US_Elec.l12          6.4439e-10  1.2887e-09  0.5000
## Coal_Futures_returns:Coal_Futures_returns.l13 -2.3592e-01  9.7439e-02 -2.4212
```

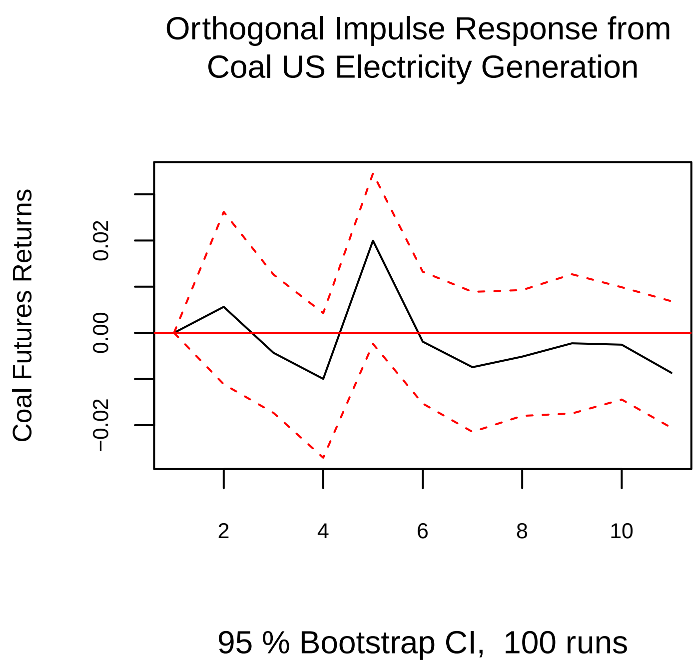
```
## Coal_Futures_returns:Coal_US_Elec.l13          6.5101e-10  1.3337e-09  0.4881
## Coal_Futures_returns:Coal_Futures_returns.l14  1.9619e-03  9.9764e-02  0.0197
## Coal_Futures_returns:Coal_US_Elec.l14          1.2653e-09  1.3375e-09  0.9460
## Coal_Futures_returns:Coal_Futures_returns.l15  2.5444e-01  1.0089e-01  2.5218
## Coal_Futures_returns:Coal_US_Elec.l15         -2.2551e-09  1.1562e-09 -1.9504
## Coal_US_Elec:(Intercept)                       1.0136e+06  2.9130e+06  0.3480
## Coal_US_Elec:Coal_Futures_returns.l1           1.3888e+07  8.0422e+06  1.7269
## Coal_US_Elec:Coal_US_Elec.l1                   5.6233e-01  9.7568e-02  5.7634
## Coal_US_Elec:Coal_Futures_returns.l2           2.7278e+06  8.1879e+06  0.3331
## Coal_US_Elec:Coal_US_Elec.l2                   1.1706e-01  1.0862e-01  1.0776
## Coal_US_Elec:Coal_Futures_returns.l3           1.3638e+07  7.9488e+06  1.7157
## Coal_US_Elec:Coal_US_Elec.l3                   3.3792e-02  1.0739e-01  0.3147
## Coal_US_Elec:Coal_Futures_returns.l4          -5.1749e+05  8.2359e+06 -0.0628
## Coal_US_Elec:Coal_US_Elec.l4                   2.7227e-02  1.0372e-01  0.2625
## Coal_US_Elec:Coal_Futures_returns.l5          -3.2292e+06  8.2259e+06 -0.3926
## Coal_US_Elec:Coal_US_Elec.l5                   4.8031e-03  1.0174e-01  0.0472
## Coal_US_Elec:Coal_Futures_returns.l6          -1.0425e+07  8.3015e+06 -1.2557
## Coal_US_Elec:Coal_US_Elec.l6                   6.6579e-02  1.0180e-01  0.6540
## Coal_US_Elec:Coal_Futures_returns.l7           8.6173e+06  8.3106e+06  1.0369
## Coal_US_Elec:Coal_US_Elec.l7                  -1.1536e-03  1.0214e-01 -0.0113
## Coal_US_Elec:Coal_Futures_returns.l8           1.4486e+06  8.3904e+06  0.1726
## Coal_US_Elec:Coal_US_Elec.l8                  -1.1642e-02  1.0409e-01 -0.1118
## Coal_US_Elec:Coal_Futures_returns.l9           8.0283e+06  8.4203e+06  0.9534
## Coal_US_Elec:Coal_US_Elec.l9                  -1.5614e-01  1.0447e-01 -1.4946
## Coal_US_Elec:Coal_Futures_returns.l10         -1.1169e+07  8.4699e+06 -1.3187
## Coal_US_Elec:Coal_US_Elec.l10                  1.2725e-01  1.0441e-01  1.2187
## Coal_US_Elec:Coal_Futures_returns.l11         -2.0997e+07  8.4190e+06 -2.4941
## Coal_US_Elec:Coal_US_Elec.l11                  2.9881e-01  1.0480e-01  2.8513
## Coal_US_Elec:Coal_Futures_returns.l12         -7.0363e+06  8.6576e+06 -0.8127
## Coal_US_Elec:Coal_US_Elec.l12                  3.2876e-01  1.0869e-01  3.0247
## Coal_US_Elec:Coal_Futures_returns.l13          2.2286e+06  8.2179e+06  0.2712
## Coal_US_Elec:Coal_US_Elec.l13                 -1.5585e-01  1.1249e-01 -1.3855
## Coal_US_Elec:Coal_Futures_returns.l14          1.2087e+07  8.4140e+06  1.4366
## Coal_US_Elec:Coal_US_Elec.l14                 -9.9969e-02  1.1280e-01 -0.8862
## Coal_US_Elec:Coal_Futures_returns.l15          3.2733e+06  8.5093e+06  0.3847
## Coal_US_Elec:Coal_US_Elec.l15                 -1.7021e-01  9.7514e-02 -1.7455
##                                                Pr(>|t|)
## Coal_Futures_returns:(Intercept)               0.495690
## Coal_Futures_returns:Coal_Futures_returns.l1   0.133623
## Coal_Futures_returns:Coal_US_Elec.l1           0.562692
## Coal_Futures_returns:Coal_Futures_returns.l2   0.933479
## Coal_Futures_returns:Coal_US_Elec.l2           0.443561
## Coal_Futures_returns:Coal_Futures_returns.l3   0.003153 **
## Coal_Futures_returns:Coal_US_Elec.l3           0.506181
## Coal_Futures_returns:Coal_Futures_returns.l4   0.543624
## Coal_Futures_returns:Coal_US_Elec.l4           0.014927 *
## Coal_Futures_returns:Coal_Futures_returns.l5   0.223563
## Coal_Futures_returns:Coal_US_Elec.l5           0.172069
## Coal_Futures_returns:Coal_Futures_returns.l6   0.026256 *
## Coal_Futures_returns:Coal_US_Elec.l6           0.642362
## Coal_Futures_returns:Coal_Futures_returns.l7   0.338618
## Coal_Futures_returns:Coal_US_Elec.l7           0.646573
## Coal_Futures_returns:Coal_Futures_returns.l8   0.408709
## Coal_Futures_returns:Coal_US_Elec.l8           0.823490
```

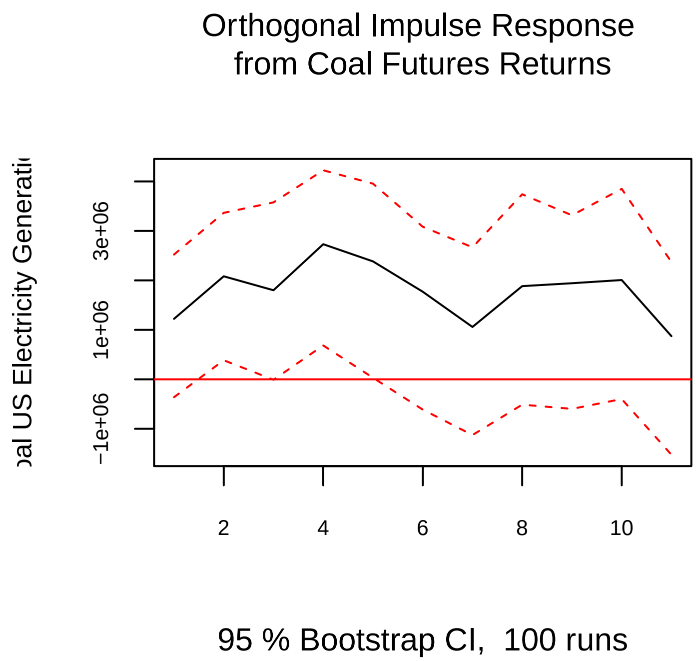
```
## Coal_Futures_returns:Coal_Futures_returns.l9   0.036284 *
## Coal_Futures_returns:Coal_US_Elec.l9          0.831471
## Coal_Futures_returns:Coal_Futures_returns.l10  0.263522
## Coal_Futures_returns:Coal_US_Elec.l10         0.848211
## Coal_Futures_returns:Coal_Futures_returns.l11  0.515802
## Coal_Futures_returns:Coal_US_Elec.l11         0.920402
## Coal_Futures_returns:Coal_Futures_returns.l12  0.146630
## Coal_Futures_returns:Coal_US_Elec.l12         0.618111
## Coal_Futures_returns:Coal_Futures_returns.l13  0.017184 *
## Coal_Futures_returns:Coal_US_Elec.l13         0.626489
## Coal_Futures_returns:Coal_Futures_returns.l14  0.984347
## Coal_Futures_returns:Coal_US_Elec.l14         0.346305
## Coal_Futures_returns:Coal_Futures_returns.l15  0.013176 *
## Coal_Futures_returns:Coal_US_Elec.l15         0.053790 .
## Coal_US_Elec:(Intercept)                       0.728561
## Coal_US_Elec:Coal_Futures_returns.l1           0.087123 .
## Coal_US_Elec:Coal_US_Elec.l1                  8.334e-08 ***
## Coal_US_Elec:Coal_Futures_returns.l2           0.739686
## Coal_US_Elec:Coal_US_Elec.l2                   0.283661
## Coal_US_Elec:Coal_Futures_returns.l3           0.089164 .
## Coal_US_Elec:Coal_US_Elec.l3                   0.753642
## Coal_US_Elec:Coal_Futures_returns.l4           0.950018
## Coal_US_Elec:Coal_US_Elec.l4                   0.793450
## Coal_US_Elec:Coal_Futures_returns.l5           0.695434
## Coal_US_Elec:Coal_US_Elec.l5                   0.962435
## Coal_US_Elec:Coal_Futures_returns.l6           0.211994
## Coal_US_Elec:Coal_US_Elec.l6                   0.514511
## Coal_US_Elec:Coal_Futures_returns.l7           0.302167
## Coal_US_Elec:Coal_US_Elec.l7                   0.991010
## Coal_US_Elec:Coal_Futures_returns.l8           0.863259
## Coal_US_Elec:Coal_US_Elec.l8                   0.911158
## Coal_US_Elec:Coal_Futures_returns.l9           0.342555
## Coal_US_Elec:Coal_US_Elec.l9                   0.138020
## Coal_US_Elec:Coal_Futures_returns.l10          0.190143
## Coal_US_Elec:Coal_US_Elec.l10                  0.225690
## Coal_US_Elec:Coal_Futures_returns.l11          0.014189 *
## Coal_US_Elec:Coal_US_Elec.l11                  0.005243 **
## Coal_US_Elec:Coal_Futures_returns.l12          0.418217
## Coal_US_Elec:Coal_US_Elec.l12                  0.003129 **
## Coal_US_Elec:Coal_Futures_returns.l13          0.786778
## Coal_US_Elec:Coal_US_Elec.l13                  0.168827
## Coal_US_Elec:Coal_Futures_returns.l14          0.153816
## Coal_US_Elec:Coal_US_Elec.l14                  0.377511
## Coal_US_Elec:Coal_Futures_returns.l15          0.701259
## Coal_US_Elec:Coal_US_Elec.l15                  0.083827 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## $Granger
##
##  Granger causality H0: Coal_Futures_returns do not Granger-cause
##  Coal_US_Elec
##
## data:  VAR object VAR_est_coal
```

```
## F-Test = 1.0918, df1 = 15, df2 = 210, p-value = 0.3655

## $Granger
##
##  Granger causality H0: Coal_US_Elec do not Granger-cause
##  Coal_Futures_returns
##
## data:  VAR object VAR_est_coal
## F-Test = 1.197, df1 = 15, df2 = 210, p-value = 0.2758
```






```
## $JB
##
##  JB-Test (multivariate)
##
## data:  Residuals of VAR object VAR_est_coal
## Chi-squared = 47.125, df = 4, p-value = 1.436e-09
##
##
## $Skewness
##
##  Skewness only (multivariate)
##
## data:  Residuals of VAR object VAR_est_coal
## Chi-squared = 6.4374, df = 2, p-value = 0.04001
##
##
## $Kurtosis
##
##  Kurtosis only (multivariate)
##
## data:  Residuals of VAR object VAR_est_coal
## Chi-squared = 40.688, df = 2, p-value = 1.461e-09
```