TIME-SERIES ANALYSIS OF PRICE INTERRELATIONS IN MAJOR U.S. FOSSIL FUELS MARKETS

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ABSTRACT

The objective of this study is to analyze price movements and interrelations of U.S natural gas, oil, and coal prices, as three main fossil fuels in the US. Structural break were identified in both natural gas and oil prices in February of 2009, at the peak of U.S. financial crisis. Both natural gas and oil are shown to be weak substitutes for coal, while the opposite relationships are not found. Stronger U.S. dollar led to lower fossil fuel prices, while only oil prices have been shown to depend on movement of income per capita and stock market.
Keywords: U.S. fossil fuel prices; time-series econometrics; structural breaks; weak substitutability

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1. Introduction

Natural gas, oil, and coal are essential to meeting the energy needs of the U.S. economy. These fossil fuels represent 80 percent of all energy consumption in the United States (http://www.EIA.gov). Recently, there has been a boom in natural gas and oil production in the U.S., which is due to advances in hydraulic fracturing and horizontal drilling. Hydraulic fracturing, also known as fracking, is done by pumping hydraulic fluid into semipermeable rock formations to create fractures in the rock, which allows oil and gas to escape. Horizontal drilling is a drilling process in which a drill can be directed horizontally from the original vertical well, giving drillers access to horizontal shale gas and oil layers. These two techniques have made production of previously inaccessible and costly resources economically viable, and have aided in the expansion of US gas and oil reserve estimates. For example, in 1995 the Bakken Shale formation in western North Dakota was estimated to have only 151 million barrels of technically recoverable oil, compared to 3.7 billion barrels of technically recoverable oil in 2008 (Klob, 2013).These technologies have greatly altered the energy landscape seen today in the U.S.

In the fall of 2008, the domestic and global markets saw the largest downturn since the great depression. Dubbed the great recession, commodities such as natural gas and oil plummeted to record lows. Preceding the crash, natural gas and oil prices were thought to share a long and short-run relationship, because that they can be produced simultaneously. However, after February of 2009, natural gas prices stayed low and continued to decrease, while oil prices rebounded.

Natural gas, oil, and coal are essential to the U.S. economy, yet no study has analyzed these commodities price movements and interrelations, and the impact of external shocks on their levels and behavior in a comprehensive way. The objective of this study is to fill this gap in the literature. Including the coal market in this study helps broaden the understanding of how these three fossil fuel prices are integrated, and at what level they interact with one another. With the recent shale gas and oil boom exclusively in the US, it seems relevant to focus solely on the U.S. market. There is some evidence from the previous literature, albeit not conclusive, that the fossil fuel markets may be integrated because of the partial substitutability in consumption among the three fossil fuels (Pindyck, 1979). Next, the great recession greatly influenced the commodity markets after 2008, and this paper will explore that impact on fossil fuel prices. Finally, the analysis will be accomplished via a comprehensive use of time series econometrics including univariate tests for structural breaks and breaks in trend, cointegration tests for price co-movements, causality tests, and multivariate price interrelations regression relations via error correction modeling.

2. Literature Review

This review contains only the papers deemed most relevant for the current research. More comprehensive review of pertinent literature can be found in, for example, Mjelde and Bessler (2009). The paper by Pindyck (1979) is considered to be fairly influential in the literature on energy demand and pricing. Among several contributions this paper made to the energy economics literature, it was the first paper that established and measured substitutability among three main fossil fuels in the United States: oil, natural gas, and coal. Uzawa’s partial elasticities of substitutions for the three fossil fuels reported in the paper have all been pretty small, and signs inconsistent. Hence, other than establishing the existence of a relationship among the three fossil fuels, the paper did not succeed in establishing well defined substitute or complement relationship between the commodities.

Bachmeir and Griffin (2006) tested for market integration of the crude oil, coal and natural gas markets in the United States using cointegration analysis. Their conclusion is rather different from Pindyck's in a sense that they found these three markets to be very weakly integrated, i.e., there is not a primary energy market. They suggest how it is not useful to think of a primary energy market other than in a very long run.

Mjelde and Bessler (2009) also conducted an energy market integration study using the vector error correction model. They showed that energy prices are cointegrated or linked. This linkage is explored in a multivariate model that offers insights not possible in the bivariate models used in previous studies. The degree of integration between markets varies. The markets are not linked to the extent that each market has the same importance in price discovery — some markets are more important than others at particular time intervals. Individual markets do retain some of their own characteristics.

The Paper by Brown and Yücel (2008), attempts to explain driving factors behind natural gas prices in the U.S. The authors compare the relationship between west Texas intermediate crude oil (WTI) and the Henry Hub spot price for natural gas. They examine the viability of rules of thumb for predicting the relationship of natural gas and oil such as the 10-1 rule and the burner tip parody. The study includes seasonality, weather, storage, and hurricane supply shocks as possible factors in determining the price of natural gas. An error correction model (ECM) was used to examine the long and short-run changes in natural gas price and oil. Weekly data was used for the time interval June 13, 1997 through June 8th, 2007. Their results found a significant long-run cointegrating relationship between natural gas and oil in the long-run, and that deviations in weather and storage amounts significantly affected natural gas price in the short-run.

The Paper by Hartley, Medlock III, and Rosthal (2008), also examines the relationship of natural gas to oil prices. The authors used an ECM with four endogenous variables: Henry Hub natural gas price, WTI crude oil price, residual fuel price, and the heating rate for generating plants in the U.S. The data used was monthly data from February 1990 to August 2006. Results from the paper revealed an indirect relationship between natural gas and crude oil via a competitive relationship between natural gas and residual fuel oil. The authors also found similar results to the Brown and Yücel (2008), in that weather, inventories, and hurricanes had a significant effect on the short-run adjustment of natural gas price.

3. Data

The variables used in the model are oil price, natural gas price, coal price, an overall time trend, net energy exports (EEXP), GDP per capita (GDPPC), U.S. dollar index (USD), Dow Jones Industrial Average (DOW), natural gas from fracking (FRACK), and an intercept (C2) and trend change (T2) dummies. Monthly data for all of the variables was collected for the period between January 2002 and December 2013 with a total of 144 observations. Hence the period of great recession is captured along with the period of significant increase in domestic oil and gas production. Energy prices and net energy exports were obtained from the Energy Information Administration website (http://www.EIA.gov). GDP per capita was obtained from ycharts.com and the Bureau of Economic Analysis. The U.S. dollar index was also found at ycharts.com. The monthly average for the Dow Jones Industrial average was taken from yahoo finance. Natural gas from fracking was taken from the Energy Information Agency website. Natural gas price is based on the Industrial price which is, “The price of natural gas used for heat, power, or chemical feedstock by manufacturing establishments or those engaged in mining or other mineral extraction as well as consumers in agriculture, forestry, fisheries and construction.” (EIA.com). Oil price is determined by the first purchase of crude oil from the original property. Coal price is the price of Sandy Barge 12000btu bituminous coal, less freight or shipping and insurance costs. All prices used are in nominal U.S. dollars. Prices are dollars per thousand cubic feet, dollars per barrel, and dollars per short ton for natural gas, oil, and coal correspondingly. Finally, all of the variables were logged except the net energy exports; hence the results are interpreted as elasticites.

4. Time Series Econometric Analysis of the Fossil Fuel Prices

Modeling and measuring price interrelations among different commodity prices is a complex, multi-step process. Natural gas, oil, and coal are mined, delivered and used in different ways, which makes substitution difficult to show but logically plausible since there is some overlap in their consumption. There are several steps to test the dynamic relationship among natural gas, oil, and coal prices. These steps are: (1) testing for unit roots to determine if the data is stationary or follows a random walk; (2) use the Perron method to test for a structural break in the series; (3) use cointegration techniques to identify long-run relationships; (4) test for endogeneity using Granger causality test; (5) and, estimate error correction model.

4.1 Unit Root Testing

The Augmented Dickey-Fuller (ADF) test is used to determine if a variable has a unit root or, in other words, if it is stationary (Dickey and Fuller, 1979). Including the constant and trend is the most general specification, and was the choice for this study. Also, the test allows for the specification of the number of lagged differenced terms. A lag of one was chosen for this study based on the lowest values of the Schwarz Information Criterion (SIC). Based on the results of the ADF test on each of the variables, the null hypothesis of a unit root cannot be rejected for level data (Table 1). Once the series is differenced once and retested, the results indicate that the null hypothesis is rejected and that the data does not have a unit root. Thus, after first differencing, all of the variables are integrated of order I(1). Notice that all remaining time series are I(1) as well; the results for those are available upon request from the authors.

Table 1. Augmented Dickey-Fuller Test

	Exogenous Variables	Lag Lenth	ADF statistic (levels)	ADF statistic (first diff.)
NGP	Constant and Trend	1	0.1494	0***
OILP	Constant and Trend	1	0.0296**	0***
COALP	Constant and Trend	4	0.0072***	0.0048***

* 10% significant
** 5% significant
*** 1% significant

The Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test (1992) was developed as a more powered unit root test alternative to the ADF test. The null hypothesis of the KPSS test is that the series is stationary.

Table 2. Kwiatkowski-Phillips-Schmidt-Shin Test

Variables	Exogenous Variables	LM-Stat (Level)	LM-Stat (First diff.)
NGP	Contstant and Trend	0.290431***	0.044676
OILP	Contstant and Trend	0.209999***	0.027813
COALP	Contstant and Trend	0.136533*	0.030205

* 10% significant
** 5% significant
*** 1% significant

Also, the test gives you the choice of including a constant or a constant and a linear time trend. As stated previously, a constant and trend were chosen for the test. Based on the results of the KPSS test, the null hypothesis is not rejected for all the variables after first differencing (Table

2). Hence, by using both the KPSS test and ADF test, it can be concluded that the data does not have a unit root and is stationary after being differenced once for both all prices as well as the other variables.

4.2 Testing for Structural Breaks

The Perron method tests whether a time series has a single structural break characterized by a change in intercept, trend, or both trend and intercept (Perron, 1989). This test is an alternative to the unit root with drift hypothesis. The null hypothesis is that the series has a unit root and possibly nonzero drift. This is generalized into three different models: Model (A) that allows an exogenous change in the intercept$(\alpha_2 - \alpha_1)$; Model (B) that allows for an exogenous change in the rate of growth $(\beta_2 - \beta_1)$; and Model (C) that allows for both a change in the intercept and rate of growth. The exogenous break is represented as T_β=February 2009, the month representing the peak of the financial crisis.

$$Model\ (A)\ \ y_t = \alpha_1 + \beta_{1t} + (\alpha_1 - \alpha_2)D\alpha_t + \varepsilon_t$$

$$Model\ (B)\ y_t = \alpha_1 + \beta_{1t} + (\beta_2 - \beta_1)D\beta_t{}^* + \epsilon_t$$

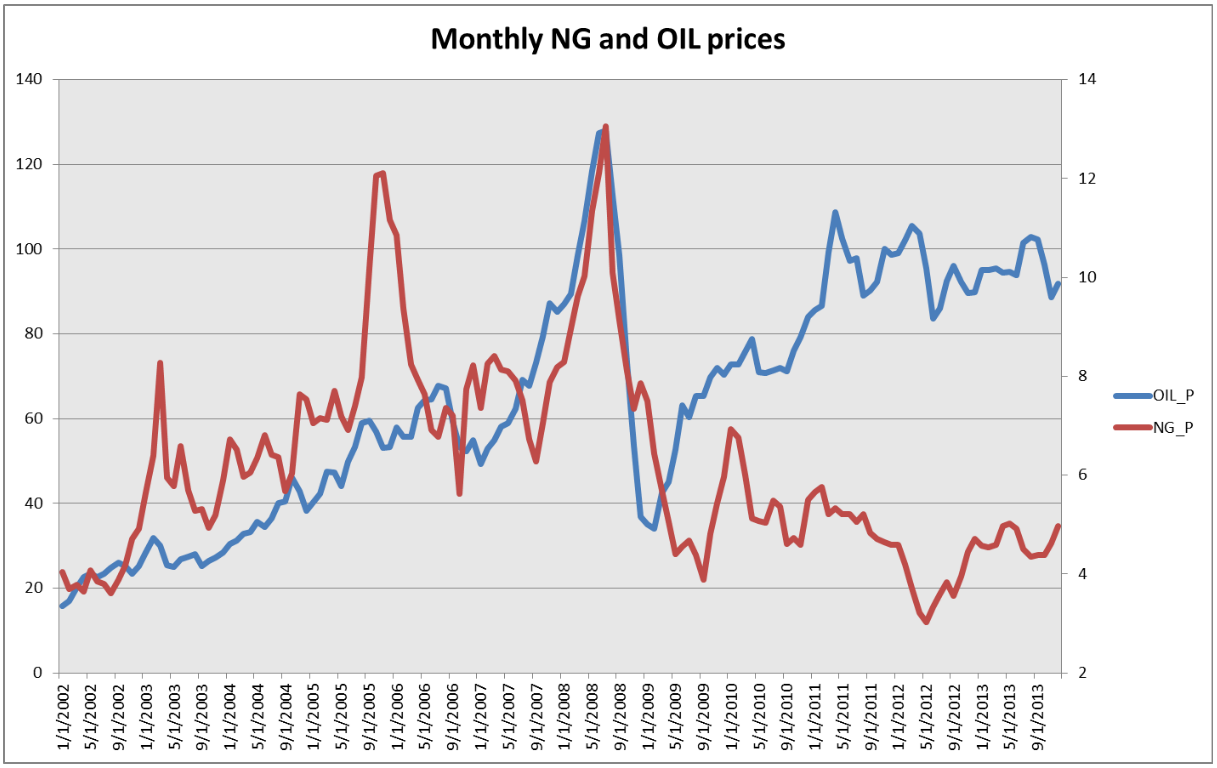
$$Model\ (C)\ y_t = \alpha_1 + \beta_{1t} + (\alpha_2 - \alpha_1)D\alpha_t + (\beta_2 - \beta_1)D\beta_t + \varepsilon_t$$

$$where\ D\alpha_t = 1\ if\ t - T_b + 1, \qquad 0\ otherwise$$

$$D\beta_t{}^* = t - T_\beta, \qquad and \quad D\beta_t = t \quad if \quad t > T_\beta\ and\ 0\ otherwise$$

The alternative hypothesis for all of the models is that the system is trend stationary. Under the alternative, model (A) allows for a single change in the intercept. Model (B) allows for an adjustment in the trend without a change in the intercept at the break. Model (C) allows for a simultaneous change both the trend and intercept. The third situation was chosen after running all three models, because the third case had the lowest Schwarz Information Criterion (SIC) value for natural gas and oil, while there was no structural break reported for coal.

Figure 1. Monthly Natural Gas and Oil Prices (January 2002-December 2013)

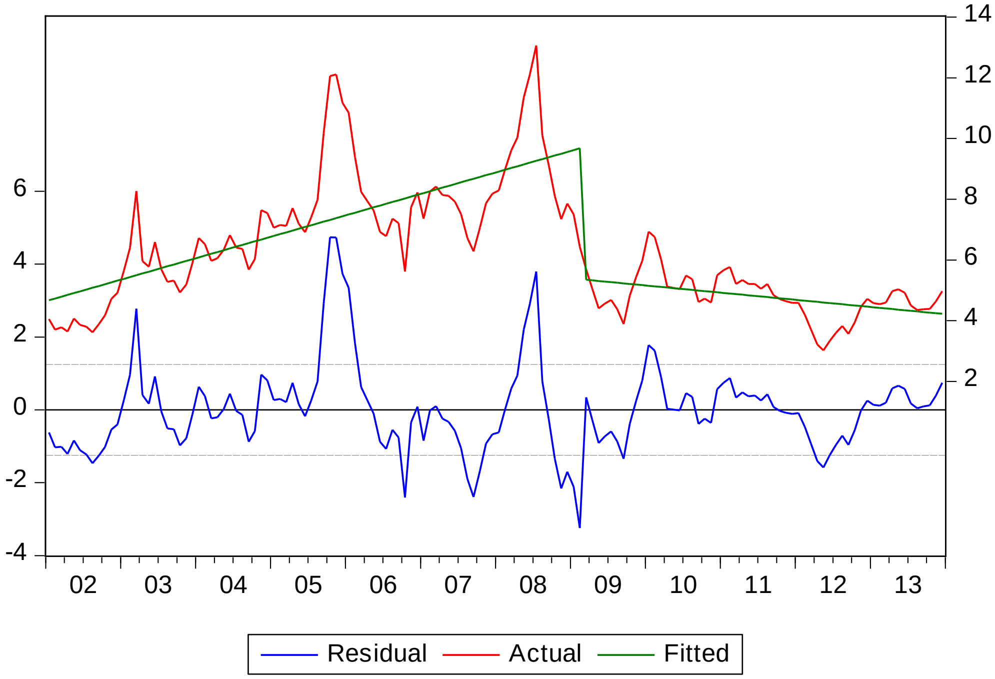


When analyzing figure 1 showing natural gas and oil prices over our sample period 2002:1-2013:12, it can be casually observed that starting in February 2009, there was a structural break in the intercept and trend. This break occurs during the peak of the financial crisis when the stock market was at its lowest and the beginning of significant amounts of shale gas and oil entering the market. This break is then tested formally (as illustrated on example of natural gas price series) by introducing a dummy variable that takes the value of 0 before and on 2009:2 and 1 thereafter, and a trend variable is added that takes the value of 0 before and on 2009:2 and the value (t-88) after 2009:2 (2009:2 is the 88th observation in the sample). Then the intercept (C), change in intercept (C2), trend (T), and change in trend (T2) are regressed against the price of natural gas (NGP) using the Ordinary Least Squares (OLS) method in equation (1).

$$NGP = \underset{[0.00]}{4.67C} + \underset{[0.03]}{2.44C2} + \underset{[0.00]}{.05T} - \underset{[0.00]}{.07T2} \qquad (1)$$

The results from the regression displayed in equation (1) show that the change in intercept dummy is significant at the 5% level and that the change in trend is significant at the 1% level. These results indicate that there was a structural break in early 2009 that altered both the intercept and trend of the series in the short run. The graph of the fitted trend is displayed in figure 2.

Figure 2. Change in Trend and Intercept Graph



4.3 Price Co-Movements or Cointegration Testing

The Johansen cointegration test is used to find the number of cointegrating vectors among the variables (Johansen, 1991; Johansen & Juselius, 1994). Cointegration is a linear long-run relationship between two or more variables. All of the variables must be integrated of the same order to be cointegrated (Table 3). With the results from the ADF and KPSS tests it can be concluded that all of the variables are integrated of the same order I(1). Albeit our primary interest in in fossil fuel price variables, one can make a strong case that there may be co-movement of the net energy exports, the U.S. dollar index, and the natural gas from fracking with the price variables; hence these variables are included in the test too.

Table 3. Johansen Cointegration Test Results

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.413081	120.9807	95.75366	0.0003
At most 1 *	0.324798	77.81832	69.81889	0.0100
At most 2	0.215033	46.00613	47.85613	0.1188
At most 3	0.185100	22.15845	29.79707	0.2898
At most 4	0.054377	5.578591	15.49471	0.7447
At most 5	0.012877	1.049812	3.841466	0.3055

Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.413081	43.16234	40.07757	0.0218
At most 1*	0.324798	31.81219	33.87687	0.0864
At most 2	0.255033	23.84768	27.58434	0.1401
At most 3	0.185100	16.57986	21.13162	0.1928
At most 4	0.054377	4.528778	14.26460	0.7997
At most 5	0.012877	1.049812	3.841466	0.3055

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

The Johansen technique uses two tests to detect the long-run relationships; the maximal eigenvalue test and the trace test. Results from the two tests indicate that there are two cointegrating vectors at the ten percent signicancelevel.

4.4 Determining Endogeneity-Granger Causality Test

The Granger causality tests (Granger, 1969), can help to identify if assumed endogenous variables can be treated as exogenous. The null hypothesis is that “X does not cause Y.” To test that hypothesis, one regresses Y against lagged values of Y and lagged values of X and then regress Y only against lagged values of Y. An F-test determines if lagged values of X significantly impact Y, and if they do then X is said to Granger cause Y. The variables in the study were lagged once and tested (Table 4). Endogeneity is considered to exist if there is two-way Granger causality, i.e., if each variable has a statistically significant impact on the other one. The results show that the price of coal Granger causes the price of oil price and oil price Granger causes coal price; hence there is two-way Granger causality thus endogeneity. Same finding of two-way Granger causality and in turn endogeneity holds for the relationship between coal price and natural gas price. Other pairs of variables exhibiting pairwise Granger causality and thus endogeneity are: coal price and U.S. dollar index; oil price and U.S. dollar index; and net energy exports and the natural gas from fracking. In all other pairs, the null hypothesis has not been rejected both ways or one-way Granger causality is discovered. Based on these results, no variable can be treated as exogenous in this multivariate system since each of them exhibited at least one and some even multiple two-way relations.

Table 4. Granger Causality Test

Null Hypothesis:	F-Statistic	Prob.
OILP does not Granger Cause NGP	0.42908	0.6527
NGP does not Granger Cause OILP	2.23235	0.1142
COALP does not Granger Cause NGP	5.07459	0.0085
NGP does not Granger Cause COALP	2.78125	0.0682
EEXP does not Granger Cause NGP	1.06588	0.3495
NGP does not Granger Cause EEXP	2.45160	0.0929
USD does not Granger Cause NGP	0.53060	0.5904
NGP does not Granger Cause USD	1.41937	0.2481
FRACK does not Granger Cause NGP	1.29121	0.2808
NGP does not Granger Cause FRACK	0.53013	0.5907
COALP does not Granger Cause OILP	2.55187	0.0821
OILP does not Granger Cause COALP	12.7742	2.E-05
EEXP does not Granger Cause OILP	1.39922	0.2530
OILP does not Granger Cause EEXP	0.07337	0.9293
USD does not Granger Cause OILP	2.54715	0.0876
OILP does not Granger Cause USD	2.76357	0.0693
FRACK does not Granger Cause OILP	2.46926	0.0913
OILP does not Granger Cause FRACK	0.30250	0.7398
EEXP does not Granger Cause COALP	1.53144	0.2227
COALP does not Granger Cause EEXP	1.45945	0.2387
USD does not Granger Cause COALP	9.68543	0.0002
COALP does not Granger Cause USD	5.47694	0.0060
FRACK does not Granger Cause COALP	0.06612	0.9361
COALP does not Granger Cause FRACK	0.05074	0.9506
USD does not Granger Cause EEXP	1.47256	0.2357
EEXP does not Granger Cause USD	0.04089	0.9600
FRACK does not Granger Cause EEXP	5.12668	0.0081
EEXP does not Granger Cause FRACK	4.80484	0.0108
FRACK does not Granger Cause USD	0.04628	0.9548
USD does not Granger Cause FRACK	0.18693	0.8299

4.5 Error Correction Model

A variable is considered to be integrated d of order d (or I(d)) if it must be differenced "d-times" in order for the variable to become stationary. If linear combination of two or more I(1) variables are found to be stationary, a long-run relationship between the variables exists amongst them and they are considered to be cointegrated (Engle and Granger; 1987). An important aspect of cointegrated variables is that over time they are influenced by any deviation from the long-run equilibrium. For the system to return to the long-run equilibrium, some variables must shift to respond to the movement of the disequilibrium. Engle and Granger (1987) have proved that a well-defined error correction mechanism (ECM) exists when two or more variables are cointegrated. The ECM term explains the short-run adjustment that the cointegrated variables must make in order to return to the long-run equilibrium. A Vector Error Correction (VEC) model is appropriate for this study because the specification has an ECM built into it so that the endogenous variables are restricted to their long-run relationship and allowed to make short-run adjustments.

Using a Vector Error Correction (VEC) model, information can be obtained on the short-run dynamics of the variables in a system. The VEC model used in this study consists of six endogenous variables (natural gas price (NGP), oil price (OILP), coal price (COALP), net energy exports (EEXP), natural gas from fracking (FRACK), and US dollar index (USD)), with two cointegrating vectors based on the results of table 3, and six exogenous variables (GDP per capita (GDPPC), Dow Jones Industrial Average (DOW), trend, change in trend (T2), intercept, and change in intercept (C2)). Please notice that statistical evidence of endogeneity was not overwhelming based on the Granger causality test results: six out of fifteen tested pairs exhibited two-way causality. While two-way Granger causality reveals clearly endogeneity among the three fossil fuel prices, and U.S. dollar index and two out of three prices, remaining pair-wise relationships are more complex and ambiguous. Given the number of possible combinations, it is virtually impossible to expect that all tested pairs will result in two-way causality. We assume, however, that our results warrant the VEC specification as presented. The six equations of the VEC are:

$$\begin{aligned}\Delta NGP_t = \alpha_{10} &+ \beta_{11}(NGP_{t-1} - \delta_1 OILP_{t-1} - \gamma_1 COALP_{t-1} - \mu_1 EEXP_{t-1} - \tau_1 USD_{t-1} \\ &- \upsilon_1 FRACK_{t-1}) \\ &- \beta_{12}(NGP_{t-1} - \delta_2 OILP_{t-1} - \gamma_2 COALP_{t-1} - \mu_2 EEXP_{t-1} - \tau_2 USD_{t-1} \\ &- \upsilon_2 FRACK_{t-1}) + \sum_i \alpha_{11i} \Delta NGP_{t-i} + \sum_i \alpha_{12i} \Delta OILP_{t-i} \\ &+ \sum_i \alpha_{13i} \Delta COALP_{t-i} + \sum_i \alpha_{14i} \Delta EEXP_{t-i} + \sum_i \alpha_{15i} \Delta USD_{t-i} \\ &+ \sum_i \alpha_{16i} \Delta FRACK_{t-i} + \alpha_{17} \Delta GDPPC_t + \alpha_{18} \Delta DOW_t + \alpha_{19} Trend_t + \alpha_{1,10} T2_t \\ &+ \alpha_{1,11} C2_t + \varepsilon_{1,t}\end{aligned} \tag{2}$$

$$\begin{aligned}\Delta OILP_t = \alpha_{20} &+ \beta_{21}(NGP_{t-1} - \delta_1 OILP_{t-1} - \gamma_1 COALP_{t-1} - \mu_1 EEXP_{t-1} - \tau_1 USD_{t-1} \\ &- \upsilon_1 FRACK_{t-1}) \\ &- \beta_{22}(NGP_{t-1} - \delta_2 OILP_{t-1} - \gamma_2 COALP_{t-1} - \mu_2 EEXP_{t-1} - \tau_2 USD_{t-1} \\ &- \upsilon_2 FRACK_{t-1}) + \sum_i \alpha_{21i} \Delta NGP_{t-i} + \sum_i \alpha_{22i} \Delta OILP_{t-i} \\ &+ \sum_i \alpha_{23i} \Delta COALP_{t-i} + \sum_i \alpha_{24i} \Delta EEXP_{t-i} + \sum_i \alpha_{25i} \Delta USD_{t-i} \\ &+ \sum_i \alpha_{26i} \Delta FRACK_{t-i} + \alpha_{27} \Delta GDPPC_t + \alpha_{28} \Delta DOW_t + \alpha_{29} Trend_t + \alpha_{2,10} T2_t \\ &+ \alpha_{2,11} C2_t + \varepsilon_{2,t}\end{aligned} \tag{3}$$

$$\Delta COALP_t = \alpha_{30} + \beta_{31}(NGP_{t-1} - \delta_1 OILP_{t-1} - \gamma_1 COALP_{t-1} - \mu_1 EEXP_{t-1} - \tau_1 USD_{t-1} - \upsilon_1 FRACK_{t-1}) - \beta_{32}(NGP_{t-1} - \delta_2 OILP_{t-1} - \gamma_2 COALP_{t-1} - \mu_2 EEXP_{t-1} - \tau_2 USD_{t-1} - \upsilon_2 FRACK_{t-1}) + \sum_i \alpha_{31i} \Delta NGP_{t-i} + \sum_i \alpha_{32i} \Delta OILP_{t-i} + \sum_i \alpha_{33i} \Delta COALP_{t-i} + \sum_i \alpha_{34i} \Delta EEXP_{t-i} + \sum_i \alpha_{35i} \Delta USD_{t-i} + \sum_i \alpha_{36i} \Delta FRACK_{t-i} + \alpha_{37} \Delta GDPPC_t + \alpha_{38} \Delta DOW_t + \alpha_{39} Trend_t + \alpha_{3,10} T2_t + \alpha_{3,11} C2_t + \varepsilon_{3,t} \quad (4)$$

$$\Delta EEXP_t = \alpha_{40} + \beta_{41}(NGP_{t-1} - \delta_1 OILP_{t-1} - \gamma_1 COALP_{t-1} - \mu_1 EEXP_{t-1} - \tau_1 USD_{t-1} - \upsilon_1 FRACK_{t-1}) - \beta_{42}(NGP_{t-1} - \delta_2 OILP_{t-1} - \gamma_2 COALP_{t-1} - \mu_2 EEXP_{t-1} - \tau_2 USD_{t-1} - \upsilon_2 FRACK_{t-1}) + \sum_i \alpha_{41i} \Delta NGP_{t-i} + \sum_i \alpha_{42i} \Delta OILP_{t-i} + \sum_i \alpha_{43i} \Delta COALP_{t-i} + \sum_i \alpha_{44i} \Delta EEXP_{t-i} + \sum_i \alpha_{45i} \Delta USD_{t-i} + \sum_i \alpha_{46i} \Delta FRACK_{t-i} + \alpha_{47} \Delta GDPPC_t + \alpha_{48} \Delta DOW_t + \alpha_{49} Trend_t + \alpha_{4,10} T2_t + \alpha_{4,11} C2_t + \varepsilon_{4,t} \quad (5)$$

(6)

$$\Delta USD_t = \alpha_{50} + \beta_{51}(NGP_{t-1} - \delta_1 OILP_{t-1} - \gamma_1 COALP_{t-1} - \mu_1 EEXP_{t-1} - \tau_1 USD_{t-1} - \upsilon_1 FRACK_{t-1}) - \beta_{52}(NGP_{t-1} - \delta_2 OILP_{t-1} - \gamma_2 COALP_{t-1} - \mu_2 EEXP_{t-1} - \tau_2 USD_{t-1} - \upsilon_2 FRACK_{t-1}) + \sum_i \alpha_{51i} \Delta\, NGP_{t-i} + \sum_i \alpha_{52i} \Delta\, OILP_{t-i} + \sum_i \alpha_{53i} \Delta\, COALP_{t-i} + \sum_i \alpha_{54i}\, \Delta EEXP_{t-i} + \sum_i \alpha_{55i}\, \Delta USD_{t-i} + \sum_i \alpha_{56i}\, \Delta FRACK_{t-i} + \alpha_{57} \Delta GDPPC_t + \alpha_{58} \Delta DOW_t + \alpha_{59} Trend_t + \alpha_{5,10} T2_t + \alpha_{5,11} C2_t + \varepsilon_{5,t}$$

(7)

$$\Delta FRACK_t = \alpha_{60} + \beta_{61}(NGP_{t-1} - \delta_1 OILP_{t-1} - \gamma_1 COALP_{t-1} - \mu_1 EEXP_{t-1} - \tau_1 USD_{t-1} - \upsilon_1 FRACK_{t-1}) - \beta_{62}(NGP_{t-1} - \delta_2 OILP_{t-1} - \gamma_2 COALP_{t-1} - \mu_2 EEXP_{t-1} - \tau_2 USD_{t-1} - \upsilon_2 FRACK_{t-1}) + \sum_i \alpha_{61i} \Delta\, NGP_{t-i} + \sum_i \alpha_{62i} \Delta\, OILP_{t-i} + \sum_i \alpha_{63i} \Delta\, COALP_{t-i} + \sum_i \alpha_{64i}\, \Delta EEXP_{t-i} + \sum_i \alpha_{65i}\, \Delta USD_{t-i} + \sum_i \alpha_{66i}\, \Delta FRACK_{t-i} + \alpha_{67} \Delta GDPPC_t + \alpha_{68} \Delta DOW_t + \alpha_{69} Trend_t + \alpha_{6,10} T2_t + \alpha_{6,11} C2_t + \varepsilon_{6,t}$$

where t is years, i is the number of lags, α_{jki} and $\beta_{kj,}$ are parameters to be estimated, $\delta_j, \gamma_j, \mu_j$, $\tau_j$and υ_j are estimated parameters from the cointegration vectors, and ε_i are errors. The errors and all of the terms involving $\Delta NGP_{t-i}, \Delta COALP_{t-i}, \Delta OILP_{t-i}, \Delta EEXP_{t-i}, \Delta USD_{t-i},$ and $\Delta FRACK_{t-i}$ are stationary. Thus, the linear combination of the lagged variables $(NGP_{t-1} - \delta_1 OILP_{t-1} - \gamma_1 COALP_{t-1} - \mu_1 EEXP_{t-1} - \tau_1 USD_{t-1} - \upsilon_1 FRACK_{t-1})$ must be stationary and represent the long-run equilibrium among the two variables. In this model there is only one error correction term that corresponds to the cointegration vector. In the long-run equilibrium the error correction term will equal zero, but if NGP, OILP, and COALP break from the long-run equilibrium, the error correction term will be nonzero and each variable will adjust to reestablish the equilibrium relation. Finally, the coefficient β_{kj} measures the speed at which the k-th endogenous variable adjusts toward equilibrium based on the cointegration vector j, j=1, 2.

The results of the VEC model can be viewed in table 5. Based on both AIC and SIC, the optimal lag structure for the endogenous price variables has been set at one. Note that the difference between the R^2 and the adjusted R^2 is small suggesting good model specification. However, relatively low values of the coefficient of determination in the natural gas price and coal price equations suggest that there are factors outside the scope of this study affecting the monthly fluctuations in the price of natural gas and coal.

Table 5: Vector Error Correction Model Results

Explanatory Variables	NGP	OILP	COALP	EEXP	USD	FRACK
CointEq1	-0.228773***	0.240825***	0.324635***	0.241440*	-0.012356	-0.017783
	[-2.84521]	[4.52406]	[5.37913]	[1.82615]	[-0.73178]	[-0.26492]
CointEq2	0.014371	-0.421048***	0.353004***	0.237728	0.000327	-0.249014***
	[0.12666]	[-5.60558]	[4.14532]	[1.27429]	[0.01371]	[-2.62905]
NGP(-1)	0.516567***	0.043170	0.093862	-0.394167**	-0.002778	0.064078
	[4.29994]	[0.54279]	[1.04096]	[-1.99542]	[-0.11013]	[0.63892]
OILP(-1)	0.156773	0.224453**	-0.087877	-0.158747	-0.013714	-0.198032
	[0.97510]	[2.10874]	[-0.72822]	[-0.60049]	[-0.40620]	[-1.47544]
COALP(-1)	-0.354165***	-0.000648	-0.173643*	-0.221447	0.050865*	0.101989
	[-2.72063]	[-0.00752]	[-1.77718]	[-1.03455]	[1.86071]	[0.93848]
EEXP(-1)	0.014536	-0.041942	0.216379***	-0.453986***	0.015332	0.027130
	[0.21180]	[-0.92310]	[4.20052]	[-4.02290]	[1.06381]	[0.47351]
USD(-1)	-0.019591	-0.628900	0.013086	-2.049919**	0.263243**	0.000360
	[-0.03276]	[-1.58878]	[0.02916]	[-2.08505]	[2.09659]	[0.00072]
FRACK(-1)	0.141011	-0.256685**	-0.221373*	-0.138617	0.052233	-0.342407***
	[0.87559]	[-2.40752]	[-1.83140]	[-0.52346]	[1.54449]	[-2.54682]
C	-6.433364	30.48256***	2.495166	4.903023	-0.305024	2.883538
	[-0.68115]	[4.87501]	[0.35198]	[0.31571]	[-0.15379]	[0.36571]
TREND	-0.001312	0.000544	0.005265*	0.010907*	0.001170	0.002183
	[-0.33430]	[0.20952]	[1.78723]	[1.68996]	[1.41962]	[0.66605]
MC	-0.381709	2.564451***	0.988568*	1.252581	0.045020	0.947455*
	[-0.56179]	[5.70108]	[1.93847]	[1.12116]	[0.31553]	[1.67035]

MCT	0.005547	-0.026173***	-0.012127**	-0.015960	-0.000717	-0.009641
	[0.73920]	[-5.26835]	[-2.15308]	[-1.29345]	[-0.45490]	[-1.53890]
GDPPC	-0.456228	3.746710***	0.188895	0.455975	-0.023079	0.717226
	[-0.46281]	[5.74104]	[0.25530]	[0.28131]	[-0.11149]	[0.87153]
DOW	0.188672	0.752466***	-0.058597	-0.041835	0.005250	0.458298**
	[0.78083]	[4.70385]	[-0.32310]	[-0.10530]	[0.10347]	[2.27196]
R-squared	0.407	0.773	0.668	0.466	0.293	0.371
Adj. R-squared	0.375	0.761	0.634	0.393	0.158	0.351
AIC	-5.907	-4.042	-1.848	-2.798	-7.799	-5.599

Starting with the natural gas price equation, the results of the VEC model can be interpreted as following. The impact of changes in natural gas prices from the previous month, t-1, is significant and positive indicating that a 10 percent increase in the previous month's natural gas price leads to a 5.2 percent increase in the current month's natural gas price. This is rather typical characteristic of commodity prices to be positively correlated to their previous values. Coal price, however, is negative and significant indicating a complementary relationship between the two commodities: a 10 percent increase in the previous month's coal price leads to a 3.5 percent decrease in natural gas price. The coefficient of the first long-run adjustment equation identified by the cointegration tests indicate that there is long term adjustment in natural gas price when exogenous shocks affect the relationship among the three endogenous variables, i.e. the three fossil fuel prices, and the remaining endogenous variables..

The underlying dynamic price relationships affecting the movements of oil price are analyzed next. The impact of changes in oil prices from the previous month, t-1, is significant and positive indicating that a 10 percent increase in the previous month's oil price causes a 2.2 percent increase in the current month's oil price. Other fossil fuel prices are not significant thus suggesting a lack of substitutability among the fossil fuels by energy producers. This result is similar to the findings of Miljkovic et al. (2016) who determined a lack of substitutability in consumption of petroleum, natural gas, and coal in the United States over the period of 1918-2013. The Dow Jones Industrial index was positive and significant indicating that a 10 percent increase in the index leads to a 7.5 percent increase in the price of oil. This result shows that there is a strong positive correlation between price of oil and the stock market. GDP per capita coefficient was positive and significant indicating that a 10 percent increase in income leads to a 37.5 percent increase in the price of oil. Hence oil is, as expected, a normal good. This result is potentially explaining the increase in fuel consumption from more families buying motor vehicles with their increase in income in spite of soaring gasoline prices. Negative impact of natural gas from fracking on oil prices could be potentially explained as a reaction of the oil sector on production level of natural gas in their attempt to maintain or increase market shares to the extent there is substitutability between the two; as we have seen before, the substitutability in consumption of fossil fuels among energy producers is rather low. The change in intercept and change in trend were both significant for the oil equation. These results merely confirm the findings from the Perron test for structural break. Remember that these changes take place starting in February of 2009, and are shown here to have a significant lasting effect on the price of oil. The change in trend is negative. This is potentially due to increases in the domestic supply of oil from fracking and the decrease in demand from the European Union due to their slow recovery. The intercept price of $30.48 per barrel is the autonomous price of a barrel of oil. The coefficients of the long-run adjustment equation identified by the cointegration tests indicate that there is long term adjustment in oil price when exogenous shocks affect the relationship among the six endogenous variables.

The results of the coal equation are interesting in their own right. The coefficients on both oil and natural gas price are not statistically significant indicating an absence of substitute relationship between coal and oil and coal and natural gas respectively. These results are not qualitatively consistent with the results from the original study by Pindyck (1979), but are consistent with the results in Miljkovic et al. (2016). Negative impact of previous period own price on its current value signals that large stocks in storage of coal prevent coal prices from moving far from steady state equilibrium. Natural gas from fracking has a negative impact on coal prices as a 10 percent in increase of fracking natural gas lowers the coal prices by 2.2 percent, likely in an attempt of coal producers to maintain or capture energy market share. The changes in intercept and trend are similar albeit less exaggerated as in the case of oil prices.

The results of remaining equations are of secondary interest for us in this research. There are a couple of interesting results, however, arising from the analysis. U.S. net energy exports are impacted in a significant way by the US dollar index which is negative and significant at the 5 percent significance level. This index is a weighted geometric mean of the U.S. dollar's value relative to a batch of foreign currencies: euro, yen, pound, Canadian dollar, Krona, and the Swiss franc. These results imply that a ten percent increase in the U.S. dollar index causes a 20.5 percent decrease in the net energy exports. Since 1957, the U.S. has been a net importer of fossil fuels which means that a stronger dollar decreases the relative cost of imports; indeed, an expected but interesting result, in particular the size of the coefficient being rather large. Finally, natural gas produced from fracking was also shown to be significantly impacted by the stock market: strong economy signals an incentive to invest in fracking of natural gas and the increased production. In the post 2009 period, the recovery of the stock market was very strong indeed, and natural gas producers responded to that incentive.

5. Conclusions

The United States obtains 27% of its energy from natural gas, 35% from petroleum, and 18% from coal which makes fossil fuels the primary energy sources consumed in the country (EIA Annual Energy Outlook, 2014). This price analysis of fossil fuel prices in the U.S. market between 2002 and 2013 captured the structural break in both natural gas and oil prices in February of 2009, at the peak of U.S. financial crisis. The model indicated that the prices of natural gas, oil, and coal share a long-run cointegrating price relationship with net energy exports, while coal and oil prices share a cointegrating relationship with natural gas from fracking.

The strongest results in the VEC model were from the oil price equation which had the highest R^2 value. The previous month price of oil, GDP per capita, and the Dow Jones Industrial index were all shown to have significant effects on the price of oil. The structural break in early 2009 was shown to have a significant effect on oil price. Remarkably, the trend after the break is slightly negative and suggests that the price of oil is trending downward slightly over time. This is potentially due to the domestic oil boom from fracking and should be further researched in the future.

Lack of substitutability among the three fossil fuels as indicating by the inter-price relations is consistent with recent findings in Miljkovic et al. (2016). Indeed, the energy infrastructure in the United States has been built and well developed for centuries. Sudden changes in use or substitution between different fossil fuels are unlikely because that would require not only large investment but also abandoning the existing energy sector infrastructure, and that is rather unlikely.

It is interesting to note the lack of a lag structure for the three prices. This possibly could be due to large amounts of speculation in the energy market. One issue with the model is relatively low explanatory power of the natural gas and coal price equation which indicates that volatility in natural gas price and coal price is being caused, in part, by variables outside the scope of this study. Given that energy prices can be heavily affected by the weather, future models may include adjustments for fluctuations in temperature, possible weather shocks, as well as other short term price shocks.

Based on results of the model, it seems that U.S. oil prices are much more susceptible to changes due to both domestic and international macroeconomic shocks via the movements of stock market and GDP per capita than either coal or natural gas prices. Given relative self-sufficiency of the U.S. in the natural gas and coal markets, stable domestic demand for these fossil fuels and relative lack of substitutability, this may not be a very surprising result. Hence further policy focus on promoting domestic natural gas and coal production and use may be considered if U.S. economy is to be better protected from the volatilities of the international oil market and that would require additional investments in these two subsectors. Moreover, if the U.S. is to pursue the policy of stronger dollar, that may also be creating an incentive towards more self-sufficient energy sector, i.e. lowering the energy net-exports via a decrease in oil imports.

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