EMPIRICAL INVESTIGATION AND MODELING OF THE RELATIONSHIP BETWEEN GAS PRICE AND CRUDE OIL AND ELECTRICITY PRICES

Morsheda Hassan, Wiley College
Raja Nassar, Louisiana Tech University

ABSTRACT

Crude oil and natural gas are the main sources for energy in the US and around the word. Natural gas is a relatively clean source of energy compared to oil and could be cheaper to the consumer than oil especially if there is no coupling in price between oil and gas. Therefore, it is of interest to determine the long term relationship between oil and gas prices and to develop a model for predicting gas price. In this study, we used the Johansen integration test and showed that the logarithm of crude oil prices and the logarithm of natural gas prices are co-integrated in the sense that they are in a long term equilibrium relationship in which case the two series stay together and do not diverge over time. Any divergence is usually short term and eventually the two series come back together. Also, the logarithm of electricity price was found to be co-integrated with the logarithm of natural gas price. The logarithm of the GDP was also found to be co-integrated with that of natural gas price. Using data from 1973 to 2009, a time series model was developed that related the logarithm of natural gas price to that of crude oil and electricity prices. The model is useful for predicting, in the short run, gas price from knowledge of oil and electricity prices

INTRODUCTION

The United States as well as the rest of the world are heavily dependent on oil for their energy requirement. In the US, there has been an on- going call and a recent movement on the part of the government for developing alternative, renewable, and clean energy sources. A salient argument in favor of this move is to reduce our dependence on foreign oil for our own security and economic well being and to reduce environmental pollution. A sharp increase in crude oil prices over a short time period, caused by reduced oil production due to political instability in some of the oil rich countries, could cause inflation in the US and jeopardize its security.

Developing alternative clean energy sources such as wind, bio-fuel, solar and hydro power is a long term development that should be pursued. However, an immediate source of energy that is available in abundance domestically is gas. Natural gas is believed to be an important, if not the most important, energy source for the future. Natural gas is a relatively clean source of energy compared to oil and could be cheaper to the consumer than oil especially if there is no coupling in price between oil and gas. Hence, there has been some interest in the literature in looking at the relationship of crude oil and natural gas prices. An understanding of this relationship would help in market forecasts and utilization of both commodities.

In this paper, we use time series data of crude oil and natural gas prices on a yearly basis in the US to investigate the long term relationship between them as well as between natural gas price and electricity price. In addition, we develop an empirical model relating natural gas price to crude oil price and price of electricity

RELEVANT LITERATURE

There are a number of studies in the literature investigating the relationship between natural gas price and other energy prices such as oil and electricity. Asche et al (2006) studied the long term relationship between oil, gas and electricity prices. The authors' interest was in determining if prices of any two series are co-integrated in the sense that the two series stay together and do not diverge over time. Any divergence is usually short term and eventually the two series come back together. If two series are co-integrated, then they are deemed coupled.

There was evidence from the study pointing to a co-integrated relationship between energy prices in the United Kingdom (UK) for the period, 1995-1998. Also, Pangiotidis and Rutledge (2006) found evidence for co-integration between oil and gas prices in the United Kingdom in the period 1996 to 2003. Bachmeier and Driffin (2006) presented evidence for weak co-integration between natural gas, crude oil, and coal process in the US. They argued that weak integration between oil and gas prices may be caused by the fact that only in limited areas of energy utilization, such as residential and commercial heating, there is competition between oil and gas. Barcella (1999) found a co-integrated relationship between oil and gas prices in the US which was attributed to long-run economic factors. In addition, there was a high correlation of 0.916 between yearly prices of oil and natural gas.

Serletis and Herbert (1999) , using a short time period of only one year, found co-integration between fuel oil and natural gas prices, but not between natural gas and electricity prices. They developed univariate and bivariate models to determine the relations between energy prices.

De Vany and Walls (1999) reported on co-integration between electricity prices in eleven regional markets in the US. Likewise, Hendry and Juselius (2000, 2001) found co-integration between weekly gasoline prices in different regional markets.

Brown and Yuecel (2007) using the Johansen method for co-integration and an error-correction model showed that natural gas prices and crude oil weekly prices in the US were co-integrated over the period 1994-2006. This was attributed to the fact that natural gas and crude oil are used as substitutes in energy consumption. Also, it was reported that oil price, as the independent variable, had an influence on gas price, as the dependent variable. On the other hand, gas price as an independent variable has no significant effect on crude oil price. In other words, causality was only from oil to natural gas.

DATA

Data for the United States on gas price (residential, cents per 1000 cubic feet) , oil price (Crude oil domestic, cents per barrel), electricity price (Retail price, hundredth cent per kilowatt-hour), average yearly temperature, coal consumption (residential sector, 1000 short ton), and GDP for the year 1973 to 2009 were obtained from different sources, Energy Information Administration (www.eia.doe.gov), National Climate Data Center (www.ncdc.noaa.gov/), and Economic Time Series Page (www.economagic.com).

Plots of the natural gas price, crude oil price, and electricity price for the years 1973-2009 are presented in the Appendix. These were the three variables represented in the time series model.

METHODOLOGY

The SAS software was used in the data analysis. The johansen co-integration analysis was performed in order to determine if co-integration exists between gas price and oil price and between gas price and electricity price for the US data. Also, time series transfer function analysis was used to build an empirical model relating gas price to oil price and electricity price.

Co-integration

Two time series variables are co-integrated if they possess a long-run equilibrium relationship, in which case the two series stay together and do not diverge over time. Any divergence is usually short term and eventually the two series come back together. Furthermore, two series that are co-integrated may or may not be correlated in the short-run.

Table 1 presents the co-integration analysis results for oil, gas and electricity using the Johansen co-integration test, Johansen (1988).

It is seen that for oil and gas there is no indication that the two are co-integrated (both rank = 0 or 1 are not for null and alternative hypotheses cannot be rejected since the trace value is less than the critical value for rejection at the 5% level). However log(oil) and Log(gas) seem to be integrated since the trace value is larger than the critical value when the rank is 0, but less than when the rank is 1. This says that there is long-term linear relationship between the logarithms of oil and gas. There was evidence, using the Box-Cox transformation technique, that a log transformation may be required in order to stabilize the variance. This is so in spite of the fact that the series as seen in Fig. 1 do not show strong fluctuation over time. The fact that oil and gas are only co-integrated when using a variance stabilizing transformation may indicate that the co-integration is not strong enough to manifest itself without the transformation. Weak co-integration, as pointed out by Bachmeier and Griffin (2006), may be caused by the fact that only in limited areas of energy utilization, such as residential and commercial heating, there is competition between oil and gas.

Results from Table 1 show that log(gas) and log(electricity) are co-integrated. Also gas and electricity, without the log transform, are co-integrated. The co-integration between gas and electricity may be due to the fact that natural gas is used for residential heating and for generating electricity for residential use.

The GDP time series was found also to be integrated with gas. This was true under a log transform. Although the two series were integrated they were not correlated or functionally related as evident from the fact that the time series transfer function analysis did not show any significant relationship between log GDP and log gas. This can occur since co-integration does not imply correlation.

Table 1: Johansen co-integration Rank test for oil, gas and electricity prices.

Variables	H_0 : rank = r	H_a: rank > r	Trace	Critical Value
Oil, gas	0	0	9.27	12.21
	1	1	2.04	4.14
Log (oil), log(gas)	0	0	23.21	12.21
	1	1	2.23	4.14
electricity, gas	0	0	17.94	12.21
	1	1	1.37	4.14
Log(elec), Log(gas)	0	0	21.49	12.21
	1	1	2.57	4.14

Transfer function time series modeling

In addition to the long-run co-integration question, it is of interest to determine a short run functional relationship between gas price and other independent variables such as oil, electricity, temperature, GDP and coal. GDP, coal, and temperature have been cited among the variables that could have an effect on gas prices (US Energy information release, 2010). A strong economic growth can cause an increase in demand for natural gas and therefore a higher price. Coal and natural gas markets can interact since they can be used interchangeably for energy and electricity generation. Cold temperatures can influence residential and commercial demands for natural gas and influence prices.

For time series model, the best modeling approach is to use the transfer function analysis approach (Wei, 2006) where an output series (in this case natural gas price) is related to one or more input series. This approach is especially relevant when there is no feed back between the output and input series as determined by the cross-correlation function. If the cross-correlation between two stationary series is significant for only zero and positive lags, then there is no feed back between the output and input series (Wei, 2006). This was the case for the series considered in this study.

A transfer function model between two series, y and x, can be expressed as

$$Y_t = v(B)x_t + e_t \qquad (1)$$

where e_t is noise series that is independent of x_t.

Here, $v(B) = \sum v_j B^j$,where B is the backshift operator, $Bx = x_{t-1}$.

The function v(B) is determined from the cross correlation between x and y.

The steps involved in the identification of the transfer function model are (Wei, 2006):

1. Prewhitening of the input series.

$$\phi\,(B)_x = \Theta_x(B)\,\alpha_t$$

or

$$\alpha_t = \phi\,(B)_x / \Theta_x(B) \qquad (2)$$

2. Compute the filtered output series

$$\beta_t = (\phi\,(B)_x / \Theta_x(B))\, y_t \qquad (3)$$

3. Calculate the sample cross correlation between α_t and β_t

   ($\rho_{\alpha\beta}$ (k)) so as to determine v_k, where

$$V_k = \rho_{\alpha\beta}\,(k)\,(\sigma_\beta/\sigma_\alpha) \qquad (4)$$

4. Identify v(B)

   Match the pattern of v(k) with the known theoretical patterns 0f v(B) in order to identify v(B).

   Once v(B) is identified, express e_t in Eq. (1) as

$$e_t = y_t - v(B)\,x_t \qquad (5)$$

   and identify the appropriate model fro Eq. (5) to determine the final model in Eq.(1).

In building the transfer function model, we used the logarithm of oil price differenced twice, the log of natural gas price differenced twice, the log of electricity price differenced twice, the log of GDP differenced twice, coal consumption differenced twice and temperature differenced once.

This was necessary in order to render each of these series stationary as determined from the dampening pattern of the autocorrelation (Wei, 2006) and the Dickey-Fuller test for unit root (Dickey and Fuller, 1979).

It was found that GDP, Coal consumption and temperature were not related to natural gas price. The cross-correlation between natural gas price and each of the three series above was not significant and the coefficient estimates in the transfer function model were also not significant. As a result, the final model we present expresses the log of natural gas price as a function of the log of oil price and the log of electricity price.

The model satisfied the diagnostic checking, namely

1. There was no cross correlation between the noise series and the independent or input series (log-oil and log-electricity), which indicates that the error was independent of the input series (Chi-squared tests gave p = 0.296 and 0.297 for crude oil price and electricity price, respectively.
2. Both the autocorrelation function, ACF, and the partial autocorrelation function, PACF, for noise in the model showed no pattern. Also a formal chi-squared test up to lag 6 confirmed that the noise was white noise (p=0.116).

As a result, the transfer function model below was an adequate model relating the log of natural gas price to that of oil and electricity.

$$\begin{aligned} lgp\,(1,1)_t = {} & -0.39829\, lgp(1,1)_{t-1} + 1.02977\, lep(1,1)_t - 0.48577\, lep(1,1)_{t-1} - 0.35683\, lep(1,1)_{t-2} \\ & + 0.14329\, lcop(1,1)_{t-1} + 0.05707\, lcop(1,1)_{t-2} + {}^{at} \qquad (6) \end{aligned}$$

where lgp (1,1) is the logarithm of natural gas price differenced twice, lep(1,1) the logarithm of electricity price differenced twice, and lcop(1,1) the logarithm of crude oil price differenced twice. Here, a_t is white noise.

FORECASTING

In using the model in (6) for forecasting lgp_t, one may replace $lgp(1,1)_t$ in Eq. (6) by

$(lgp_t - 2lgp_{t-1} + lgp_{t-2})$, (where lgp is the logarithm of the observed natural gas price) and

likewise for lep and lcop.

This gives

$$lgp_t - 2lgp_{t-1} + lgp_{t-2} = -0.39829 (lgp_{t-1} - 2lgp_{t-2} + lgp_{t-3}) + 1.02977 (lep_t - 2 lep_{t-1} + lep_{t-2})$$
$$-0.48577 (lep_{t-1} - 2lep_{t-2} + lep_{t-3}) - 0.35683(lep_{t-2} - 2lep_{t-3} + lep_{t-4})$$
$$+ 0.14329 (lcop_{t-1} - 2lcop_{t-2} + lcop_{t-3}) + 0.05707 (lcop_{t-2} - 2lcop_{t-3} + lcop_{t-4}) + a_t \qquad (7)$$

In order to obtain the forecast for lgp_t at time t, one needs to predict the value for lep_t.

This can be obtained from the following time series model fitted to the observed values of the time series lep(1,1):

$$Lep(1,1)_t = - 0.34123\ lep(1,1)_{t-4}$$

Or $$(lep_t - 2\ lep_{t-1} + lep_{t-2}) = - 0.34123 (lep_{t-4} - 2lep_{t-5} + lep_{t-6}) \qquad (8)$$

In Eqs. (7) and (8) t-k is observed data.

The models in Eqs. (7) and (8) were calculated based on the data with the last observation deleted (year 2009). Then, the model was used to predict the last observation for 2009. The predicted log of gas price was changed to gas price by taking its anti-log.

Table 1: Observed and predicted values for natural gas prices when the model was fitted to the data with the last 3 years, 2 years, or 1 year deleted.

	Data used:	Last 3 years deleted		Last 2 years deleted		Last year deleted	
Year	Observed	Predicted	Difference	Predicted	Difference	Predicted	Difference
2007	1308	1440	132				
2008	1389	1494	105	1294	95		
2009	1356	1535	179	1261	95	1438	82

As expected, it is seen that the model prediction (when the last 3 years were deleted from the data) was better for 2007 and 2008 then for 2009. However, all three predictions were not significantly different from their observed values at the 5% significance level.

When the model was fitted to the data, excluding years 2008 and 2009, the model predictions for 2008 and 2009 improved. The difference between observed and expected was reduced to 95. Also, the model fitted to the data with 2009 deleted, gave the best prediction for 2009 where the difference was reduced to 82. These results are consistent with what one expects in that prediction becomes less accurate for the distant future. In practice, one should use the model to predict the next year for a more reliable forecast.

CONCLUSION

Results of this study are useful in that they show a long-term relationship between the logarithm of oil and gas prices as well as the logarithm of gas and electricity prices. This is in agreement with what has been postulated in the literature. The fact the gas and oil prices when not transformed were not related or co-integrated may indicate a weak relationship. On the other hand, the co-integration between gas and electricity prices seem to be stronger in the sense that it held under untransformed as well as transformed data. A time series model was developed, based on data between 1973 and 2009, which related the output series (gas price) to the input series, crude oil price and electricity price. Eq. (7) shows that first, second, and third lags were involved in the functional relationship between gas and oil and electricity. The model was able to predict gas price adequately from knowledge of oil and electricity prices.

The most reliable approach for forecasting is to update the model when data become available and use it to predict the value for the next year in the future.

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APPENDIX

Figure 1: Plot of electricity price over years

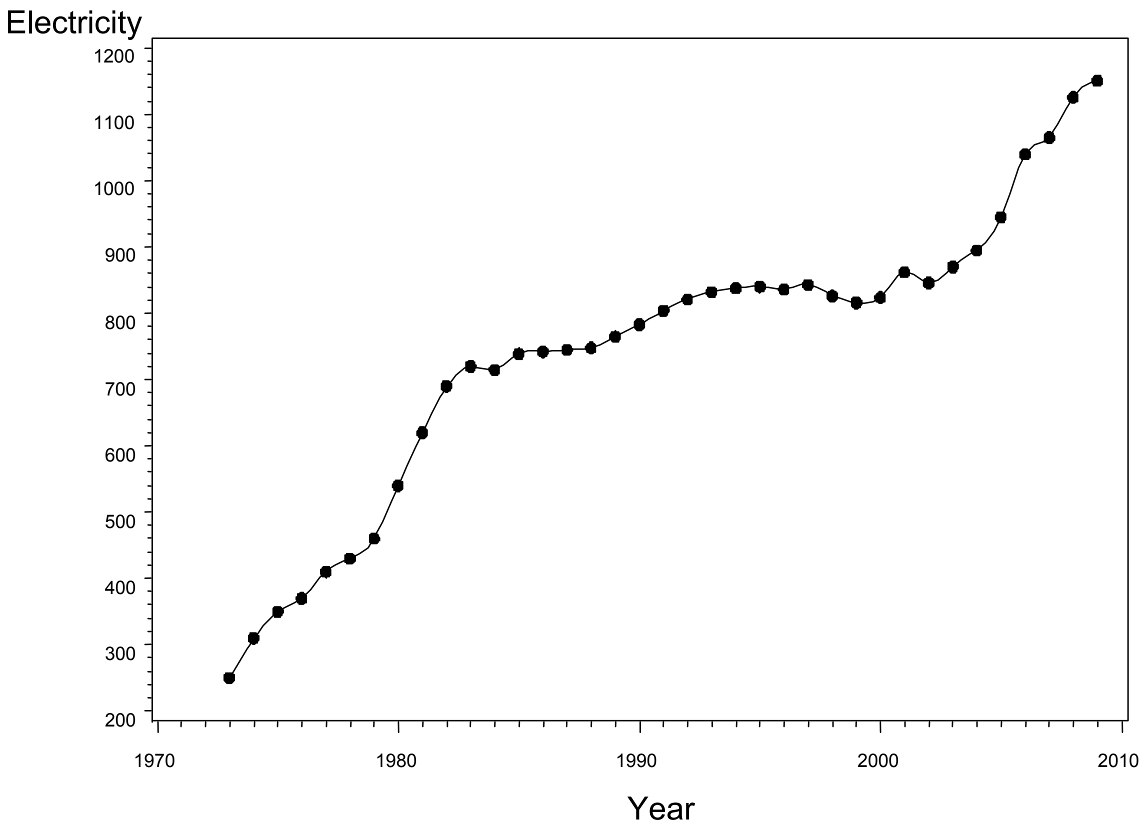

Figure 2: Plot of crude oil price over years.

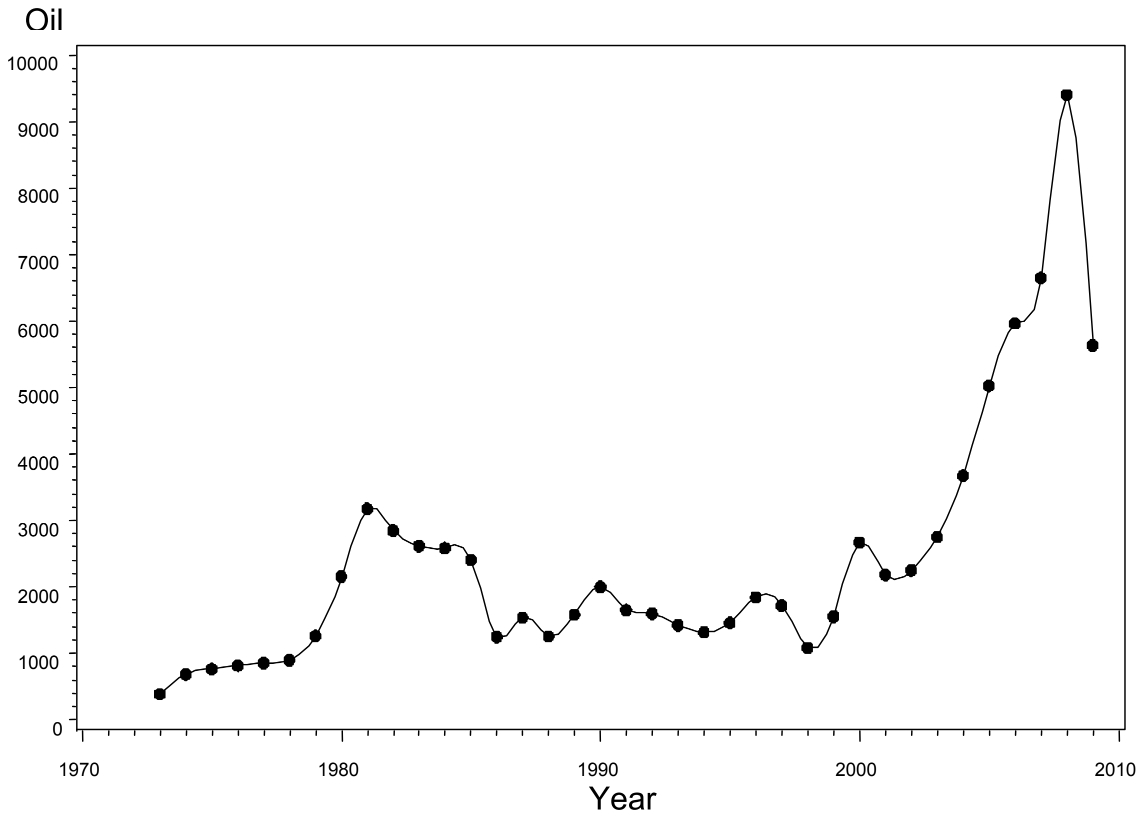

Figure 3: Plot of natural gas price over years.