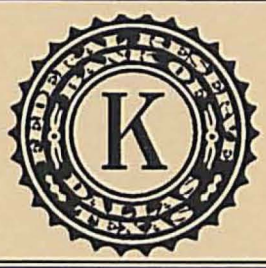

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Mine Yücel, Research Department
Federal Reserve Bank of Dallas

and

Shengyi Guo, Research Department
Federal Reserve Bank of Dallas

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Coal, Natural Gas and Oil Markets after World War II:

What's Old, What's New?

Mine K. Yücel, Research Department
Federal Reserve Bank of Dallas

and

Shengyi Guo, Research Department
Federal Reserve Bank of Dallas

COAL, NATURAL GAS AND OIL MARKETS AFTER WORLD WAR II: WHAT'S OLD, WHAT'S NEW?

Mine K. Yücel
Senior Economist and Policy Advisor

and

Shengyi Guo
Research Associate

Federal Reserve Bank of Dallas
P.O. Box 655906
Dallas, TX 75265-5906

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Energy is again becoming a hot policy topic. Concerns about the environment, energy security, global competitiveness and even the budget deficit are bringing energy policy into the limelight. To have successful energy policy however, one must have a good understanding of energy markets and energy price relationships. U.S. energy markets have undergone many changes since the end of World War II (WWII) and energy prices reflect these changes. The purpose of this paper is to provide a better understanding of the interactions and long-run relationships between coal, natural gas and oil prices. Such an understanding will also aid energy modeling efforts by showing whether we can study these markets independently or whether we must account for the interactions between them.

Our findings suggest that the relationship between coal, natural gas and oil has changed, and, consistent with conventional wisdom, oil has dominated these markets over the past twenty years. Consequently, no model of the energy market will be complete without oil.

A Brief History of Coal, Gas and Oil Markets

Coal, natural gas and oil constitute more than 88 percent of total U.S. energy consumption. The United States is relatively self sufficient in coal and natural gas, exporting 13 percent of coal production and importing only 9.2 percent of natural gas consumed. The United States is more reliant on world supplies of oil, importing 44.7 percent of the total oil and products

consumed domestically. To better understand the relationships between these three fuels, which are the backbone of our energy consumption, we briefly survey a history of coal, natural gas and oil markets after WWII.

The coal industry declined substantially after WWII, but a turnaround that began in the early 1960s has been sustained and production has been on an upward trend since. The declines after WWII were in the household and transportation sectors, but increasing demand from the electricity sector eventually offset these declines, leading to a resurgence in the coal industry in the 1960s (Zimmerman 1981). Gordon (1987) argues that coal was never a favored fuel in the United States, and environmental programs - beginning with the National Environmental Policy Act in 1969 - increased the cost of using and producing coal. Coal production declined slightly after reaching a decade high in 1970. However, the oil embargo of 1973-74 increased the demand for coal and catapulted real coal prices to an all-time high in 1975. Coal use in electricity production increased dramatically, and coal production in the United States has been on an upward trend since then. Real coal prices have been declining since 1975 however, due to increasing productivity in the coal sector.

The natural gas market has historically been a heavily regulated market, only recently have regulations been eased. The natural gas market has been regulated since the passage of the Natural Gas Act (NGA) of 1938. The NGA regulated the pipelines' entry into and exit from the market and also regulated the rates they would charge and the services they would provide. In 1954, wellhead prices of interstate gas were regulated. As Teece (1990) explains, the NGA's "just and reasonable price" was based on average, historical costs of production and was below the market value of natural gas

in the 1960s and 1970s, especially after the 1973 oil price hike. The regulations made natural gas prices unresponsive to market forces and led to shortages in some markets and gluts in others. The Natural Gas Policy Act (NGPA) of 1978 began the deregulation of wellhead natural gas prices, and by 1990, deregulation was virtually complete.

The pipeline segment of the natural gas industry also has been deregulated, causing natural gas prices in all end-use markets to be more responsive to market fundamentals. Until very recently, entry into the pipeline market was restricted, and long-term contracts were the rule in the industry. In 1985, a new policy of *open access* to pipelines emphasized their role as carriers of gas rather than as buyers and sellers of gas. The number of contracts declined substantially with open access. The new FERC order 636 is designed to complete the transition to open access and ensure that gas buyers have greater access to a competitive natural gas market. The market structure of the natural gas industry, along with the existence of long-term contracts, regulation, and access to the spot market have all affected the price of natural gas and its ability to be competitive with coal and oil prices.

The history of the oil sector is much better known than that of the natural gas or coal industries. Oil has constituted a much larger portion of the total energy consumed by the United States since the end of WWII and a disruption in supplies or a change in price has more repercussions than for any other fuel. The importance of the Middle East as a producing region has also grown since WWII, and the Middle East will remain dominant until Russia and China, among other regions, are more fully explored.

Multinational oil companies were the key players in the Middle East

until the Teheran Agreement in 1971. Although the Organization of Petroleum Exporting Countries (OPEC) had been formed in 1960, the OPEC countries had not been very active in setting oil prices, nor did they have much equity in the producing properties. OPEC countries' equity in producing properties increased steadily after 1973, reaching 60 percent by January 1974 and 100 percent for almost all members after 1980. With increasing equity interest in producing properties came increased control of oil prices. In late 1973, OPEC announced production cutbacks and an embargo on oil supplies to the United States in retaliation for U.S. support of Israel in the Arab-Israeli war. By January 1974, oil prices had more than tripled in the world market. The Iranian revolution led to another spike in oil prices in 1979, and prices climbed to $36 per barrel by 1981. However, increased prices led to conservation efforts and increased production outside of OPEC. Coupled with low demand due to slow economic growth, oil prices plummeted to about $11 per barrel in 1986. Since then, oil prices have ratcheted up to around $20 per barrel, with another brief spike of near $40 per barrel in 1990 due to the Gulf War.

Empirical Analysis

The above summary of coal, natural gas and oil markets illustrates the changes these markets have undergone since WWII. It is reasonable to expect changes in the price relationships between these fuels in the same time frame. To analyze the coal, natural gas and oil markets, we utilize time series methods. The econometric work involves a number of steps. We first check whether the price series are stationary, and find that all of them have stochastic trends (or are integrated). For each of the series, we then test

for cointegration and use a series of reduced-form vector error-correction models to test for causality and adjustment to equilibrium error. We then calculate the sources of long-run price shocks and the persistence of these price shocks.

Estimation and testing uses annual data from the period 1947 - 1990. We use minemouth prices for bituminous coal and anthracite for the coal price variable, refiners' acquisition cost for oil, and wellhead prices for natural gas. All prices are on a Btu basis.

There have been structural changes in the oil market during these years, as explained earlier. Greater OPEC control over oil prices and the tripling of prices took place in 1974. Therefore, in addition to using the full sample, we divide the sample period into two subsamples, 1948 - 1974 and 1975 - 1990 to see whether the relationship between coal, gas and oil prices has changed over the two periods.

Integration and Cointegration

In an earlier paper using the same data series, we found all series to be integrated of order one for all sample periods (see Yücel and Guo 1993). We also found the series to be cointegrated in the two subsample periods, but not in the full sample.

An integrated time series implies that any shock to the time series will be permanent and that the series will not revert back to its mean after the shock. Two integrated time series are cointegrated if they move together; cointegration implies a stationary, long-term relationship between the

series.[1]

In Yücel and Guo (1993) we find that coal and oil are cointegrated in the earlier subsample, 1947-1974. The relationship between the fuels changes after 1974. We find that natural gas is also cointegrated with coal and oil during 1975-1990. The relationship is such that a 1 percent change in oil prices would lead to nearly a 1 percent change in natural gas prices, but only a half a percentage change in coal prices in the long run. These cointegration results are integrated into the VAR model we use for our causality tests.

Causality

A causal relationship between two variables implies that changes in one variable lead to changes in the other. To test for a predictive relationship between the variables, we performed Granger causality tests on pairs of the three fuel prices.

Because all our price series were cointegrated, we accounted for cointegration by specifying an error-correction model in which changes in the dependent variable are expressed as changes in both the independent variable and dependent variable, plus an error-correction term. The error-correction term specifies the adjustment to equilibrium error, i.e., the adjustment to deviations from the long-run cointegrating relationship. The coefficient on the equilibrium error, α, specifies what proportion of the disequilibrium from one period is corrected in the next period.[2]

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[1]If cointegration is not accounted for, any model involving the cointegrated variables would be misspecified and/or the parameter estimates could be underestimated.

[2] See Engle and Granger (1987).

The tests first involved estimating a reduced-form VAR model comprising the following set of equations for each pair of prices:

$$\Delta C_t = \Sigma^n_{i=1} a_i \Delta G_{t-i} + \Sigma^n_{j=1} b_j \Delta O_{t-j} + \Sigma^n_{k=1} c_k \Delta C_{t-k} + \alpha_1 CI_{t-n-1} + \mu_{1t} \quad (1)$$

$$\Delta G_t = \Sigma^n_{i=1} e_i \Delta O_{t-i} + \Sigma^n_{j=1} f_j \Delta C_{t-j} + \Sigma^n_{k=1} g_k \Delta G_{t-k} + \alpha_2 CI_{t-n-1} + \mu_{2t} \quad (2)$$

$$\Delta O_t = \Sigma^n_{i=1} m_i \Delta C_{t-i} + \Sigma^n_{j=1} p_j \Delta G_{t-j} + \Sigma^n_{k=1} q_k \Delta O_{t-k} + \alpha_3 CI_{t-n-1} + \mu_{3t} \quad (3)$$

where: C is the log of the price of coal,

G is the log of the price for natural gas,

O is the log of the price of oil,

CI is the errors in the cointegrating relationship, $(C_t - \beta_1 G_t + \beta_2)$[3]

a_i, b_j, c_k, e_i, f_j, g_k, m_i, p_j, q_k, α_1, α_2, α_3 are parameters to be estimated, and

μ_{1t} and μ_{2t}, μ_{3t} are white noise.[4]

The coefficients α_1, α_2 and α_3 represent the adjustment to equilibrium error.

All variables are expressed in logarithms.

Causality runs from natural gas prices to coal prices if α_1 and the a_i jointly are statistically different from zero. Similarly, causality runs from oil prices to coal prices if α_1 and the b_j are jointly statistically different from zero. If both sets of coefficients are significantly different from zero, causality is bi-directional. The same analysis holds for equations

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[3] The error-correction term is included because all prices are cointegrated with each other (see Engle and Granger (1987).

[4] The value of n was set in the Johansen procedure to assure white noise in the residuals.

2 and 3.

As shown in Table 1, causality results are dependent upon the time period under analysis. We find no causality (at the 5 percent level) between any pairs of prices for the full sample period 1947-1990. This again leads us to suspect that the turmoil in the oil market in the early 1970s changed the relationships between these fuel prices in such a way that no consistent relationship exists for the entire time horizon. Looking at the two subperiods, we do find a change in the causal relationship between the prices. In the period ending in 1974, we find that all prices cause shocks in the prices with which they are paired.

In the later period, 1975-1990, we find bi-directional causality between natural gas and coal prices but not with oil prices. In this period, shocks in oil prices cause shocks in natural gas and coal prices, but do not respond to changes in coal or natural gas prices. This result is consistent with the new order in the oil market with the emergence of OPEC. After the early 1970s, the price of oil was controlled by OPEC and was not responsive to shocks in domestic coal or natural gas prices. From the early 1970s on, changes in oil prices began to lead changes in all other fuel prices.

Adjustment to Equilibrium Error

If there is cointegration between a number of variables, any movement away from the long-run cointegrating relationship will eventually be corrected and the variables will move back into their long-run relationship. The adjustment could be through one, two or all of the variables. Which variable adjusts to equilibrium error depends on many factors, including elasticities and market structure.

In a cointegrated system (such as that represented by equations 1 through 3), the presence of an error-correction term implies that the dependent variable adjusts to equilibrium error. The coefficient on the equilibrium error, α^i, reflects the extent to which a given price variable reacts in the short run to deviations from its long-run relationship with another price variable. In the equations where the α is significant, the dependent variable adjusts to deviations from the cointegrating relationship. In equations where the α is not significant, the dependent variable does not adjust to deviations from the cointegrating relationship.

As shown in Table 2, in the time period between 1947 and 1974, all prices adjust if there is a movement away from equilibrium. The quickest adjustment is made by coal and oil, while natural gas prices adjust more slowly. This evidence is consistent with our institutional knowledge about the three markets. The natural gas market in this period was under price controls, and slow adjustment is consistent with price controls. The coal and oil markets were more competitive, and adjustment was faster.

In the 1975-1990 time period, we find that oil prices do not adjust to deviations from equilibrium. As Table 2 shows, the α in the oil equation is not significant. An insignificant α implies weak exogeneity of the oil price variable, which is consistent with OPEC's impact on and relative control of world oil prices after the early seventies. Both coal and natural gas prices adjust to deviations from the equilibrium relationship in this time period. With the gradual deregulation of the natural gas market that began in 1978 and with the establishment of the spot market for natural gas in 1985, gas prices have become much more responsive to changing market conditions. We find that the natural gas market adjusts fastest to deviations from long-run equilibrium

during the 1975-1990 period.

Long-Run Source of Variance

To find out which prices were the most likely sources of shocks, we use the Choleski decomposition to calculate the variance decomposition.[5] The variance decomposition apportions the variance of errors in a given price to errors in the three different energy prices.

In the earlier time period, 1947-1974, the long-run source of variance is invariant to the ordering of the variables in the equations. We find that coal prices are the long-run source of shocks for all three prices.

In the 1975-1990 period, the ordering of the variables changes the results. When ordering changes the source of long-run variance for the prices, we prefer the ordering in which innovations in oil prices are placed first. This ordering presumes that shocks are most likely to originate in oil prices, which fits our priors that OPEC became a force to reckon with in the world oil market during this time period. If the change in oil prices is placed first, then oil prices are a very strong source of variance, accounting for almost 100 percent of the variance in oil and gas prices. In the coal equation, both oil and coal prices are equal sources of shock.

The results of the coal equation are consistent with institutional developments in the energy markets. Coal and oil were not competing fuels in

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[5]The Choleski decomposition decomposes the residuals, μ_{1t} and μ_{2t} into two sets of impulses which are orthogonal to each other. Orthogonalization allows one to take covariance between the residuals into account.

The Choleski decomposition imposes a recursive structure on the system in which the ordering of the dependent variables is specified. If the covariance between the residuals is sufficiently high, the ordering can affect the results. We experimented with permutations of the changes in all the prices.

many of the end-use sectors by this time. Coal had a very small share in the transportation sector, and a relatively small share in the industrial sector that continued to decline throughout the time horizon. On the other hand, the share of oil in the generation of electricity had declined considerably, while the share of coal had grown. Therefore, it makes sense that oil is not the dominant source of variance in this market. Demand or supply shocks to coal are also sources of shock in the coal market.

Conclusion

For successful energy policy, an understanding of the interrelationships between different energy markets is imperative. Especially when policy targets specific fuels, the long-run relationships between the fuels will determine the success of the policy.

Our analysis shows that the long-run relationships between coal, natural gas and oil prices have changed since WWII. This is evident from our finding no cointegration or causality between the three fuels in the full sample and finding different relationships between the fuels in the two subsamples.

Before the oil price shocks of the early 1970s, no fuel dominated the energy market. We found bi-directional causality among all three fuels, all fuel prices adjusted to deviations from long-run equilibrium, and the source of shocks was coal, invariant to ordering.

Our econometric tests are evidence that oil became the dominant fuel after 1974, consistent with conventional wisdom. After 1974, a change in oil prices causes changes in coal and natural gas prices, but not vice versa. Moreover, if there is a movement away from equilibrium, adjustment back to equilibrium is not through oil prices but through adjustments in coal and

natural gas prices. Oil is also the source of shocks to the oil and natural gas market. It is not the sole source of shocks in the coal market, underscoring how end-use markets for these two fuels has diverged in the past twenty years.

Our findings also suggest that modeling the coal and gas markets after 1974 without including oil would lead to a misspecification of the model. On the other hand, using oil prices as a proxy for energy prices would not be such a grave error.

REFERENCES

Balke, Nathan S., "Modeling Trends in Macroeconomic Time Series," Economic Review, Federal Reserve Bank of Dallas, May 1991.

Bohi, Douglas R., Analyzing Demand Behavior: A Study of Energy Elasticities, Johns Hopkins University Press for Resources for the Future, Baltimore, 1981.

Engle, Robert F. and C.W.J. Granger, "Co-integration and Error Correction: Representation, Estimation, and Testing," Econometrica, March 1987, 251-76.

Engle, Robert F. and Byung Sam Yoo, "Forecasting and Testing in Co-integrated Systems," Journal of Econometrics, 1987, 143-59.

Gordon, Richard L., World Coal, Cambridge University Press, Cambridge, 1987.

Stock, James H. and Mark W. Watson, "Variable Trends in Econometric Time Series," The Journal of Economic Perspectives, Summer 1988, 147-74.

Sims, Christopher A., James H. Stock, and Mark W. Watson, "Inference in Linear Time Series Models with Some Unit Roots," Econometrica, January 1990, 113-44.

Zimmerman, Martin B., The U.S. Coal Industry: The Economics of Policy and Change, The MIT Press, Cambridge, Massachusetts, 1981.

Table 1. Causality (Significance)

1947 - 1974

Price Pairs		Causality	
X	Y	X to Y	Y to X
Coal	Gas	0.00	0.00
Oil	Gas	0.00	0.00
Oil	Coal	0.01	0.00

1975 - 1990

X	Y	X to Y	Y to X
Coal	Gas	0.00	0.00
Oil	Gas	0.00	0.79
Oil	Coal	0.00	0.80

1947 - 1990

X	Y	X to Y	Y to X
Coal	Gas	0.08	0.99
Oil	Gas	0.35	0.19
Oil	Coal	0.99	0.89

Table 2. Adjustment to Equilibrium Error

1947 - 1974

	Coefficient	Significance
Coal	0.646	0.004
Gas	0.274	0.001
Oil	0.502	0.005

1975 - 1990

	Coefficient	Significance
Coal	0.062	0.006
Gas	0.269	0.000
Oil	0.035	0.80

Table 3. Long Run Source of Variance (Oil First)

1947 - 1974

	Sources of Variance		
Prices	ΔC	ΔG	ΔO
Coal	88 %	1%	11%
Gas	71	10	19
Oil	80	3	17

1975 - 1990

Coal	51%	4%	45%
Gas	1	2	97
Oil	0	0	100

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