WHAT DRIVES NATURAL GAS PRICES?

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Key Words: Natural Gas, Pricing, Substitution

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What Drives Natural Gas Prices?

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Abstract: For many years, fuel switching between natural gas and residual fuel oil kept natural gas prices closely aligned with those for crude oil. More recently, however, the number of U.S. facilities able to switch between natural gas and residual fuel oil has declined, and over the past five years, U.S. natural gas prices have been on an upward trend with crude oil prices but with considerable independent movement. Natural gas market analysts generally emphasize weather and inventories as drivers of natural gas prices. Using an error-correction model, we show that when these and other additional factors are taken into account, movements in crude oil prices have a prominent role in shaping natural gas prices. Our findings imply a continuum of prices at which natural gas and petroleum products are substitutes.

1. Introduction

For many years, natural gas and refined petroleum products were seen as close substitutes in U.S. industry and electric power generation. Industry and electric power generators switched back and forth between natural gas and residual fuel oil, using whichever energy source was less expensive. Consequently, U.S. natural gas price movements generally tracked those of crude oil. As shown by Yücel and Guo (*Energy Journal*, 1994), crude oil prices were shaped by world oil market conditions, and U.S. natural gas prices adjusted to oil prices.

Over the past 10 years, however, the number of facilities able to switch quickly between natural gas and refined petroleum products has declined. And, although U.S. natural gas prices have taken a general upward trend with crude oil prices over the past five years, they also have shown considerable independent movement. Natural gas prices rose above what was seen as their historical relationship with crude oil prices in 2000, 2002, 2003 and late 2005. In the early 2005 and the first half of 2006, natural gas prices seemed to fall well below this historical relationship. In apparent confirmation of these observations, Bachmeir and Griffin (2006) find only a weak relationship between oil and U.S. natural gas prices. In contrast, a more recent study by Villar and Joutz (2006) finds oil and natural gas prices to be cointegrated with a trend. In related work, Asche, Osmundsen and Sandsmark (2006) find cointegration between natural gas and crude oil prices in the U.K. market after natural gas deregulation, with crude oil prices leading those for natural gas.

None of the previous analyses take into account factors other than oil prices that might influence natural gas prices, but those watch natural gas markets emphasize the effects of other factors—such as weather, inventories, and shut in production. Our analysis reveals that weekly oil and natural gas prices still have a powerful relationship, but the relationship is conditioned by weather, seasonality, natural gas storage, shut in production in the Gulf of Mexico. When these additional factors are taken into account, movements in natural gas prices are well explained by crude oil prices.

2. Rules of Thumb for Natural Gas Pricing

Rules of thumb have long been used in the energy industry to relate natural gas prices to those for crude oil. Two simple rules use constant ratios between natural gas and crude oil prices. One seems to fit historical data, and one roughly reflects the difference in energy content between the commonly sold units of oil and natural gas. A third rule tries to relate parity in pricing of natural gas and residual fuel oil at the burner tip to prices for natural gas and crude oil at major trading hubs.

2.1 Simple Rules of Thumb

One simple rule of thumb is the 10-to-1 rule under which the natural gas price is one-tenth the price of crude oil price. A price of $20 per barrel for West Texas Intermediate crude oil

(WTI) would mean a natural gas price of $2 per million Btu at Henry Hub, and a $50 price would mean $5 natural gas. The rule—which seems to have been developed through observation—describes fairly well the relationship between crude oil prices and natural gas prices that prevailed in the 1990s (Figure 1).

Another simple rule reflects the energy content of a barrel of oil. Because a barrel of WTI contains 5.825 million Btu, some analysts have used a 6-to-1 rule, in which the price of a million Btu of natural gas ought to be roughly one-sixth the crude oil price. Under this rule of thumb, a WTI price of $20 per barrel would mean a natural gas price of $3.33 per million Btu at Henry Hub, and $50 oil would mean $8.33 natural gas.

When used to assess the relationship between U.S. natural gas prices and WTI over the past 20+ years, neither the 10-to-1 nor the 6-to-1 rule of thumb seems to perform well (Figure 1). The 10-to-1 rule consistently under-forecasts natural gas prices, and the 6-to-1 rule consistently over-forecasts them. Moreover, as oil and natural gas prices rise, their prices appear to be making a transition from the 10-to-1 rule to the 6-to-1 rule. As they fall, the transition seems reversed.

2.2 Burner-Tip Parity

A few analysts have interpreted the apparent transition from the 10-to-1 rule to the 6-to-1 rule as indicative of improving market conditions for natural gas. In fact, the apparent transition in pricing may reflect a more complex relationship between natural gas and oil prices. Burner-tip parity is a more complex rule that takes in account competition between petroleum products and natural gas occurs where they are used—at the burner tip. As generally implemented, the rule shows natural gas pricing yielding parity with residual fuel oil at the burner tip, and the price at

Henry Hub adjusting to whatever is necessary to achieve burner-tip parity.

Barron and Brown (1986) provide guidance for operationalizing burner-tip parity rules. For competition with residual fuel oil, the burner-tip parity rule takes into account the energy content of a barrel of residual fuel oil, the long-run relationship between prices for residual fuel oil and West Texas Intermediate crude oil (WTI), and the higher costs of transporting natural gas from Henry Hub to market. A barrel of residual fuel oil has an energy content of 6.287 million Btu, and historically residual fuel oil is priced at 95 percent of WTI, which suggests a price of $.1511 \cdot P_{WTI}$ for a million Btu of residual fuel oil. Barron and Brown report natural gas transportation differentials in a range of $0.10-1.10 per million Btu from the wellhead to powerplants and industrial users, but our examination of recent residual fuel oil prices and the Henry Hub price of natural gas prices shows an average transportation differential of about $0.50. Combining these elements, we obtain a pricing rule of thumb based on burner-tip parity as follows:

$$P_{HH,t} = -.5 + .1511 \times P_{WTI,t} \qquad \textbf{(1)}$$

where P_{HH} is the Henry Hub price of natural gas in dollars per million Btu and P_{WTI} is the price of West Texas Intermediate crude oil (WTI) in dollars per barrel. With this relationship, a $50 per barrel price for WTI would mean a natural gas price of $7.06 per million Btu at Henry Hub. For these prices, a 150 percent increase in the oil price would mean a 180 percent increase in the natural gas price.

Use of the burner-tip parity rule shows that U.S. natural gas prices generally track those of WTI (Figure 2). Nonetheless, there appear to be numerous occasions when natural gas prices have decoupled from those of crude oil. In particular, natural gas prices seem to have pulled away from oil prices in 2000, 2002, 2003 and late 2005 and fallen behind in early 2005 and 2006.

2.3 Simple Regression Analysis

A simple regression analysis using weekly data in levels for the interval from the week of January 7, 1994 to July 14, 2006 yields:

$$\begin{array}{l} P_{HH,t} = \underset{(-.9510)}{-.1104} + \underset{(38.3697)}{.1393} \times P_{WTI,t}, \end{array} \tag{2}$$

which is similar to the parameter values obtained through the burner-tip parity rule. With the values estimated through simple regression analysis, $50 WTI would mean $6.97 natural gas per million Btu at Henry Hub. For these prices, a 150 percent increase in the oil price would mean a 162 percent increase in the natural gas price. As might be expected, given the similar parameter estimates, the fitted values obtained through the simple regression model fare about as well as those found with the burner-tip parity rule (Figure 2).

3. Seasonality, Weather, Storage and Other Factors Driving Natural Gas Prices

The reduced opportunities for fuel-switching between oil and natural gas could result in substantially different dynamics in oil and natural gas pricing. Factors that affect natural gas demand and/or reflect the relative abundance of supply—seasonality, extreme weather events, natural gas in storage and disruptions to production—are what drives the prices of natural gas. Oil prices could be relatively unimportant, particularly in the short run.

Because natural gas consumption is seasonal but production is not, natural gas inventories are built during the summer for use in the winter. This seasonality leads to higher winter prices and lower summer prices. Variation in weather from the seasonal norm also affects prices, with above normal heating and cooling degree days adding upward pressure to natural gas prices. Inventories above the seasonal norm depress prices while inventories below the seasonal norm boost prices. Disruptions of natural gas production, such as happened during hurricanes Katrina and Rita, also may boost prices.

The influence of these additional factors need not rule out an underlying relationship between natural gas and crude oil prices. Natural gas prices could be affected by crude oil prices as well as weather, seasonality, natural gas storage conditions, and disruptions in natural gas production.

3.1 Data

Our data set allows us to examine the relationship between weekly crude oil and natural gas prices over the period of January 7, 1994 through July 14, 2006. Taking into account the influence of weather, seasonality, natural gas storage conditions and disruptions in natural gas production on natural gas prices limits the period of analysis to June 13, 1997 through July 14, 2006. Heating and cooling degree days are the series that limit the starting date for the analysis because they are only available as a weekly series since June 1997.

We use the Henry Hub price of natural gas and West Texas Intermediate crude oil price as reported by the *Wall Street Journal* and obtained as a weekly series in the Haver Analytics data base. Heating degree days, deviations from normal heating degree days, cooling degree days, and deviations from normal cooling degree days are collected by the National Oceanic and Atmospheric Administration and are obtained from the Haver Analytics data base.[1] Data on U.S. natural gas storage are collected by the U.S. Energy Information Administration (EIA). We calculate a storage differential as the difference between the storage in a given week and the average for that week over the past five years (the latter series also reported by the EIA). Shut-in production is a series collected by the Mineral Management Service of the Department of Interior.

The use of four weather series—heating degree days, deviations from normal heating degree days, cooling degree days and deviations from normal cooling degree days—allows for both the influence of weather and seasonality. The normal seasonal influence of weather is reflected in the difference between heating degree day deviations and heating degree days, and the difference between cooling degree deviations and cooling degree days.[2]

3.2 Model Specification

As an initial step in our work, we check whether our price series are integrated or stationary. A time series that is integrated is said to have a stochastic trend (or unit root). Identifying a series as an integrated, non-stationary series means that any shock to the series will have permanent effects on it. Unlike a stationary series, which reverts to its mean after a shock, an integrated time series does not revert to its pre-shock level. Applying conventional econometric techniques to an integrated time series can give rise to misleading results.

Augmented Dickey-Fuller tests revealed that natural gas and oil prices are difference stationary (Table 1). The other variables proved stationary in their levels representation.

After determining that natural gas and oil prices are integrated of order 1, we test for cointegration between the two series. Two integrated series are cointegrated if they move together in the long run. Cointegration implies a stationary, long-run relationship between the two difference-stationary series. As such, the cointegrating term provides information about the long-run relationship. If cointegration is not taken into account, the relationship between the cointegrated variables could be misspecified, and/or parameters could be inefficiently estimated.[3] As shown in Table 2, the Johansen procedure finds a cointegrating relationship between natural gas and oil prices over the interval from February 1994 through July 2006.

A causal relationship between the two variables implies that changes in one variable lead changes in the other. To test for a predictive relationship between oil and natural gas prices, we perform Granger causality tests between the two variables. Because the price series are cointegrated, we account for cointegration by specifying an error-correction model in which changes in the dependent variable are expressed as changes in both the independent and the dependent variable, plus an error-correction term. For cointegrated variables the error-correction term reflects the deviations from the long-run cointegrating relationship between the variables. The coefficient on the equilibrium error reflects the extent to which the dependent variable adjusts during a given period to deviations from the cointegrating relationship that occurred in the previous period.[4]

Therefore, we utilize an error-correction model to specify the relationship between natural gas and crude oil prices and represent the other variables as exogenous:

$$P_{HH,t} = \gamma + \beta P_{WTI,t} + u_t \qquad \textbf{(3)}$$

$$\Delta P_{HH,t} = a + \alpha(CI_{t-1}) + \sum_{i=1}^{n} b_i \Delta P_{WTI,t-i} + \sum_{i=1}^{n} c_i \Delta P_{HH,t-i} + \sum_{j=1}^{k} d_j X_{j,t} + \varepsilon_t \qquad \textbf{(4)}$$

where $P_{HH,t}$ is the Henry Hub price of natural gas; $P_{WTI,t}$ is the price of West Texas Intermediate crude oil; $\Delta P_{HH,t}$ is first differences in the Henry Hub price of natural gas; $\Delta P_{WTI,t}$ is first differences in the price of West Texas Intermediate crude oil; the CI_t are equilibrium errors in the estimated cointegrating relationship between natural gas and crude oil prices ($CI_t \equiv u_t$); X_j is the vector of exogenous variables affecting the natural gas market such as heating degree days, deviations in heating degree days from its seasonal norm, cooling degree days, deviations in cooling degree days from its seasonal norm, the difference in natural gas storage from its seasonal norm and shut in natural gas production in the Gulf of Mexico; a, b, c, d_j, α, and γ , β, are parameters to be estimated; and ε_t is a standard normal error term.

For an error-correction model, causality runs from crude oil prices to natural gas prices if the coefficients on the cointegrating term and oil prices are jointly significant. In such an error-correction process, a shock drives the natural gas price out of alignment with its long-term relationship with crude oil price, and the price of natural gas adjusts at the weekly rate α to realign with its long-term relationship with crude oil. At the same time, the recent history of oil and natural gas price movements and the exogenous variables also shape short-term pricing dynamics.

A substantially similar error-correction model can be specified with crude oil prices as the dependent variable and natural gas prices as an explanatory variable. Causality would run from natural gas prices to crude oil prices if the coefficients on the cointegrating term and natural gas prices are jointly significant. Testing does not reveal causality from natural gas to crude oil prices.

3.3 Model Results and Interpretation

We find cointegration between oil and natural gas prices in the 1994-2006 sample, but not the shorter 1997-2006 sample. The cointegrating relationship between oil and natural gas prices shown in Table 2 is linear and β, the normalized coefficient on WTI is 0.14. This implies that a \$1 change in the price of crude oil is met with a \$0.14 change in the price of natural gas in the long run. Errors in this long-run relationship are expressed as the coefficient on the "cointegrating term" in Table 3.

After finding cointegration between oil and gas prices over the 1994-2006 sample, we examine three different specifications of the error-correction model—without the exogenous variables for the 1994-2006 sample (Model 1), without the exogenous variables for the 1997-2006 sample (Model 2), and with exogenous variables for the 1997-2006 sample (Model 3). For estimates over the shorter time period, we use errors in the cointegrating relationship estimated over the longer time period.

As is common, the Schwarz and Akaike information criteria offer conflicting views on the appropriate lags for differenced oil and natural gas prices—with the Schwarz criterion suggesting zero lags and the Akaike criterion suggesting five lags. Testing revealed neither five lags of differenced oil prices nor five lags of differenced natural gas prices to be jointly significant in any of the specifications, so we use Schwarz recommended lags for all three models.[5]

For all three specifications, the models show causality from oil to natural gas prices. The cointegrating term is significant in all three specifications. Moreover, estimates from Models 1 and 2 are substantially similar, suggesting the model is stable with respect to time specification—even though we only find cointegration over the longer time period.

For both Models 1 and 2, the coefficient on the equilibrium errors is estimated to be -0.08 and is significant at the one percent level. This estimate implies that if oil and natural gas prices shift away from their long-term relationship, natural gas prices will adjust to close the gap between the two at the rate of 8 percent a week, which implies 90 percent adjustment in just over 27 weeks.

The third model includes the exogenous variables. Adding the exogenous variables to the model more than doubles the coefficient on equilibrium errors to -0.18 while maintaining significance at the 1 percent level. This estimate implies that if oil and natural gas prices shift away from their long-term relationship, natural gas will adjust to close the gap between the two at a much faster rate of 18 percent a week, which implies 90 percent adjustment in less than 12 weeks.

In addition, all the exogenous variables except for cooling degree days are significant at the one percent level. The higher the heating degree days and the greater the deviation in heating degree days from the norm, the higher will be price of natural gas. Extremes in cold weather, as well as normal seasonal heating demand contribute to higher natural gas prices. Similarly, the greater the deviation in cooling degree days from the norm, the higher will be the price of natural gas. As expected, storage above the seasonal norm depresses natural gas prices, and shut-in natural gas production that results from hurricanes boosts natural gas prices.

The more comprehensive model shows that natural gas prices are anchored in a long-term relationship with crude oil prices, but the short-term dynamics of natural gas prices are driven by a variety of exogenous and transitory factors that include weather, seasonality, storage, and disruptions of production. Short-run dynamics and transitory factors can result in a wide range of differentials between natural gas and crude oil prices, but taking these factors into account along with oil prices well explains natural gas prices (Figure 3). Given the lag with which natural gas prices adjust to crude oil prices, it may not be surprising that some observers focus more on the transitory factors that shape natural gas prices rather than on oil prices.

4. Why Oil Prices Drive Natural Gas Prices

Substitution and competition between natural gas and petroleum products seems to be what links natural gas and oil prices. The estimated coefficient for the long-term relationship between natural gas and crude oil prices are generally consistent (but not perfectly so) with the idea that substitution between natural gas and residual fuel oil helps to anchor natural gas prices to movements in crude oil prices.

Pyrdol and Barron (2003) provide evidence that direct fuel switching capabilities between natural gas and residual fuel oil have become relatively limited in electric power generation, and many analysts expect such direct fuel-switching capabilities to diminish further over time. But focusing exclusively on direct fuel switching provides a limited view of the potential market links between natural gas and oil prices. In electric power generation, the choice between fuels can be made in deciding which plants to operate. The U.S. petrochemical industry rely heavily on natural gas as a feedstock, while much of its foreign competition relies on petroleum products. In addition, both Huntington (2006) and Rosthal, Hartley and Medlock (2006) provide empirical evidence that industrial natural gas consumption is sensitive to the relative prices of natural gas and petroleum products, and is likely to remain so. Huntington further demonstrates that if natural gas prices remain low relative to their long-term relationship with crude oil prices, U.S. industrial natural gas consumption can be expected to grow so rapidly that it will contribute upward pressure to the price of natural gas.

On the supply side, anecdotal evidence suggests that the market allocation of drilling equipment to natural gas or oil plays is sensitive to the differential between natural gas and crude oil prices. In addition, Liquefied Natural Gas (LNG), which is often priced outside the United States in contracts based on oil prices, is another potential link between natural gas and oil prices.

5. Conclusion: A Stable But More Complex Relationship

Simple rules of thumb, and even simple regression analysis, do not well explain differential movements in oil and natural gas prices. Perhaps the failure of these rules of thumb has contributed to the view that natural gas prices are determined relatively independently of those for crude oil. Such a view has been bolstered by the observation that industrial and electric power-generation facilities are less able to switch directly between natural gas and residual fuel oil than they were in the past.

In contrast with this view, we find that an error-correction model that takes into account crude oil prices weather, seasonality, storage and production disruptions well explains crude oil prices. Moreover the model shows U.S. natural gas prices are the related to those for crude oil with natural gas prices adjusting to changes in crude oil prices. The relationship has complex short-term dynamics, but is quite stable in the long run..

For simplicity, it may have once been desirable to think of the relationship between natural gas and oil prices as being set at a particular burner-tip in the electric-power industry, but our empirical work is more consistent with the idea that there is a continuum of market links between natural gas and crude oil prices. Natural gas prices are anchored in a long-term relationship with crude oil prices, but the short-run dynamics can result in considerable variation in relative natural gas and crude oil prices. Seen from the burner-tip perspective, such a continuum might be thought of as burner tips that are at a variety of distances from Henry Hub—with the burner tip furthest from Henry Hub that is currently using natural gas setting the current Henry Hub price for natural gas. In fact, the continuum is likely to be the result of more complex and subtle market forces.

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Figure 1
Actual and Implied Natural Gas Prices

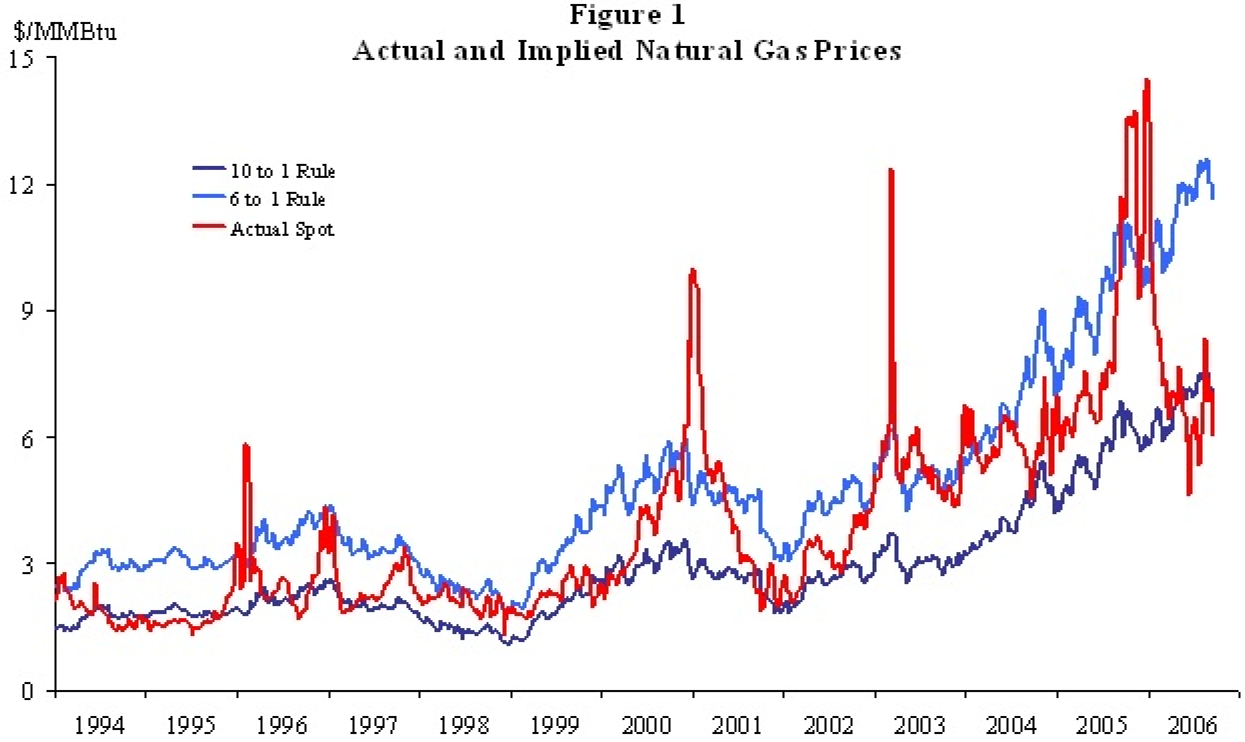
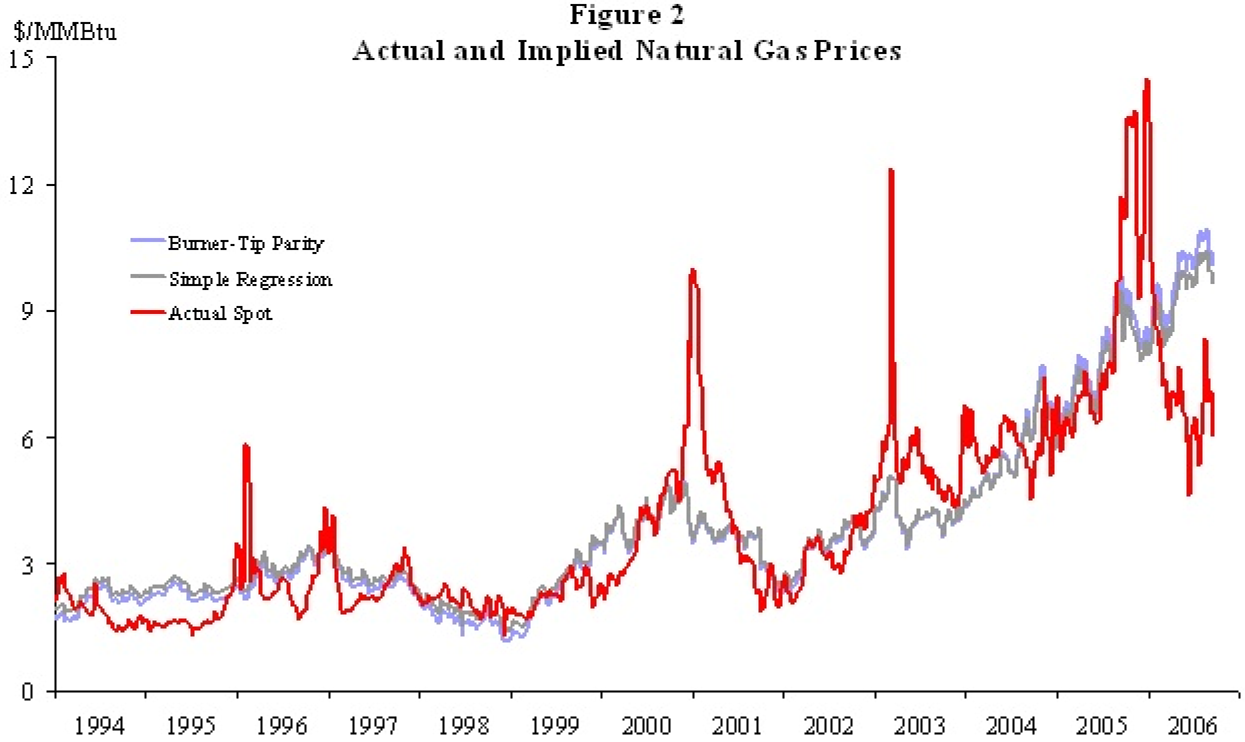


Figure 2
Actual and Implied Natural Gas Prices



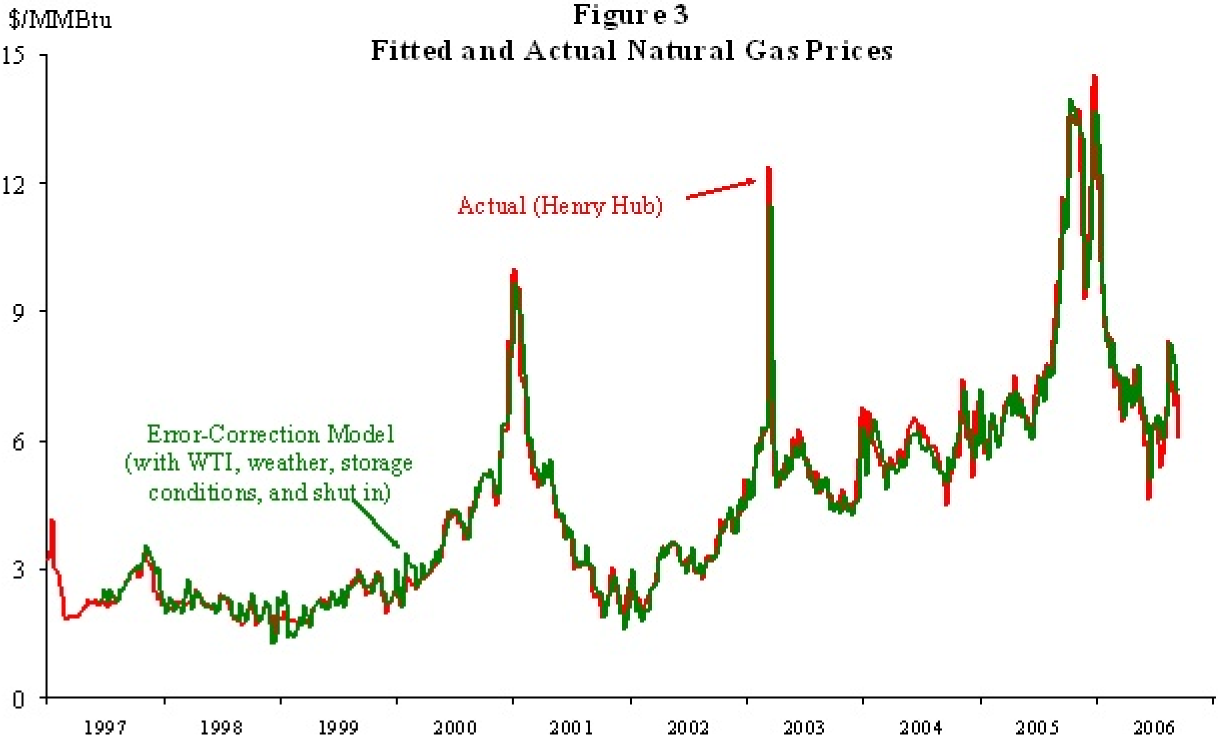


Figure 3
Fitted and Actual Natural Gas Prices

Table 1
Unit Root Tests

variables	Augmented Dickey-Fuller Levels	 First Differences
P_{HH}	-2.7221^{+}	-18.8819**
P_{WTI}	2.5387	-6.8757**
HDD	-8.6158**	na
HDDDEV	-12.8819**	na
CDD	-7.5377**	na
CDDDEV	-7.5940**	na
STORAGE DIFF	-2.9147*	na
SHUT IN	-3.8240**	na

$^{+}$, * and ** denote significance at better than 0.1, 0.05 and 0.01 percent, respectively.

Table 2
Bi-Variate Cointegration Tests
(Henry Hub and West Texas Intermediate)

variables	Ho: rank=p	Trace Statistic	Max Eigenvalue Statistic
levels 2/11/1994 to 7/14/2006	p=0 $p \leq 1$	17.6694* .9999	16.6695* .9999
logged 2/11/1994 to 7/14/2006	p=0 $p \leq 1$	15.8444* 0.0032	15.8413* 0.0032
levels 6/13/1997 to 7/14/2006	p=0 $p \leq 1$	14.2784^{+} 2.1270	12.1514 2.1270
logged 6/13/1997 to 7/14/2006	p=0 $p \leq 1$	11.4730 0.0098	11.4632 0.0098

$^{+}$, * and ** denote significance at better than 0.1, 0.05 and 0.01 percent, respectively.

Table 3

Error-Correction Models of the Change in Natural Gas Price

explanatory variables	Model 1 1/14/1994 to 7/14/2006 coefficients	Model 2 6/13/1997 to 7/14/2006 coefficients	Model 3 6/13/1997 to 7/14/2006 coefficients
constant	0.0054 (0.2633)	0.0213 (0.8116)	-0.1062 (-1.1388)
cointegrating term (t-1)	-0.0809 (-5.1243)**	-0.0802 (-4.3647)**	-0.1787 (-7.5000)**
HDD (t)			$1.98 \cdot 10^{-3}$ (3.2931)**
HDDDEV (t)			$6.85 \cdot 10^{-3}$ (5.3776)**
CDD (t)			$-9.44 \cdot 10^{-4}$ (-0.5501)
CDDDEV (t)			$1.27 \cdot 10^{-2}$ (2.8712)**
STORAGE DIFF (t)			$-5.14 \cdot 10^{-4}$ (-4.5680)**
SHUT IN (t)			$1.18 \cdot 10^{-4}$ (3.8777)**
	R^2=0.04 adj R^2= 0.04	R^2 = 0.04 adj R^2 = 0.04	R^2 = 0.18 adj R^2 = 0.17

Values shown in parentheses are t-statistics.

$^+$, * and ** denote significance at better than 0.1, 0.05 and 0.01 percent, respectively.

Notes:

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1. Heating degree days are available as a population or gas-weighted series. Cooling degree days are only available as a population-weighted series. For heating, natural gas is used directly. Consequently, gas-weighted heating degree days have more intuitive appeal and had a slightly better fit in the estimated equations. Consequently, we use gas-weighted heating degree days and population weighted cooling degree days. We find substantially similar results to those reported below when using the population-weighted data in place of the gas-weighted data.

2. Weekly dummies are an alternative way to reflect seasonality, but with a ten-year estimation period, such dummies might fit too well and give rise to idiosyncratic explanations for natural gas prices in any given week.

3. See Engle and Yoo (1987)

3. See Engle and Granger (1987)

5. To explore the sensitivity of the model to lag length, we estimated the model with zero through five lags of differenced oil and natural gas prices. For all lag lengths, we found substantially similar results to those reported here.