

What Drives Natural Gas Prices?

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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 seven 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 (1994), crude oil prices were shaped by world oil market conditions, and U.S. natural gas prices adjusted to oil prices.

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Previous versions of this paper were presented at the International Natural Gas Seminar in Rio de Janeiro, August 2006 and USAEE/IAEE North America meeting in Ann Arbor, September 2006. The authors wish to thank three anonymous referees, Thomas B. Fomby, Frederick Joutz, Mark Rodekohr and James L. Smith, as well as Mark French, Peter Hartley, Mark Hayes, Franziska Holz, David Victor and other participants in the International Natural Gas Seminar and the USAEE/IAEE North America meeting for helpful comments and Raghav Virmani for very capable research assistance. The views expressed are those of the authors and do not necessarily represent those of the Federal Reserve Bank of Dallas or the Federal Reserve System.

Over the past 15 years, however, the number of facilities able to switch quickly between natural gas and refined petroleum products has declined. Although U.S. natural gas prices have taken a general upward trend with crude oil prices over the past seven 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, 2004 and late 2005. In 2006 and the first half of 2007, 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, and crude oil prices leading those for natural gas.

In a slightly different vein, Hartley, Medlock and Rosthal (2007) find that substitution between residual fuel oil and natural gas is particularly strong in the U.S. North American Electric Reliability Council (NERC) regions where there is sufficient fuel-switching capability. They also find limited substitutability between natural gas and heating oil for space heating and between the use of gas-fired and distillate-fired peaking plants for the generation of electricity. Because natural gas and crude oil price do not move in perfect synchronization, these findings suggest a continuum of substitution opportunities, with the price of natural gas being set by a marginal user, and that user being determined by the relative prices of oil and natural gas.

None of the previous analyses of the relationship between natural gas and crude oil prices take into account factors other than oil prices that might influence natural gas prices, but those who watch natural gas markets emphasize the effects of other factors—such as weather, inventories, and shut in production. Our analysis reveals that crude oil and natural gas prices still have a powerful relationship, but the relationship is conditioned by weather, seasonality, natural gas storage, and 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. THE RELATIONSHIP BETWEEN OIL AND NATURAL GAS PRICES

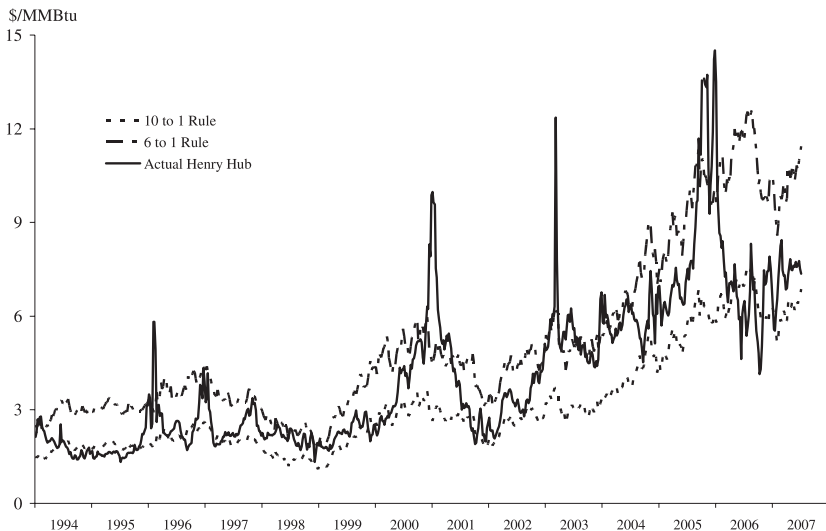
Given the historical importance of substitution between natural gas and petroleum products, the energy industry has long used rules of thumb to relate natural gas prices to those for crude oil. Two simple rules of thumb use constant ratios between natural gas and crude oil prices. One seems to fit historical data, and one roughly reflects the difference in energy content between the commonly sold units of oil and natural gas. Other rules of thumb try to relate parity in the pricing of natural gas to residual fuel or distillate fuel oil at the burner tip and trace back the implications for natural gas and crude oil prices at major trading hubs.

We treat the Henry Hub price of natural gas as generally representing overall market conditions for natural gas in the United States, and use it in evaluating the relationship between crude oil and natural gas prices. Henry Hub, near New Orleans, handles the highest volume of natural gas of any U.S. transportation node and is close to the largest concentration of natural gas producing regions in the country. Although the physical links between Henry Hub and Eastern markets are more prominent than those between Henry Hub and other regional markets, numerous studies show that the U.S. natural gas market has been generally integrated by open access and other regulatory changes. De Vany and Walls (1993, 1994), Doane and Spulber (1994), and MacAvoy (2000) all find U.S. natural gas markets to have been progressively integrated and that the “US market for gas has evolved into a competitive market for a homogeneous commodity.”¹ Serletis and Herbert (1999) add that the Henry Hub spot price is strongly correlated with the NYMEX futures price, which is the most widely traded natural gas contract in the world.

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

Figure 1. Actual and Implied Natural Gas Prices



1. Doane and Spulber (1994), p. 479.

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 \$50 per barrel would mean a natural gas price of \$8.33 per million Btu at Henry Hub.

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 consistently well after 2000 (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, the price of natural gas appears to be making a transition from the 10-to-1 rule to the 6-to-1 rule.

2.2 Burner-Tip Parity Rules

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 rules are based on the idea that substitution between natural gas and petroleum products yield competitive prices where they are used—at the burner tip. As generally implemented, these rules convert a crude oil price to a petroleum product price and relate it back to an implied price at major trading hub, such as Henry Hub. The validity of such trading rules may be underscored by research, such as Hartley, Medlock and Rosthal (2007) and Huntington (2007), that finds substitution between petroleum products and natural gas remains important.

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 residual fuel oil is priced at about 85 percent of WTI, which suggests a price of $0.1352 \cdot P_{WTI}$ 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 power plants and industrial users. Our examination of recent residual fuel oil prices and the Henry Hub price of natural gas prices suggests that the transportation differential for the marginal user has averaged about \$0.25 over the past 15 years. Combining these elements, we obtain a pricing rule of thumb based on burner-tip parity as follows:

$$P_{HH,t} = -.25 + .1325 \times P_{WTI,t} \quad (1)$$

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 \$6.37 per million Btu at Henry Hub.

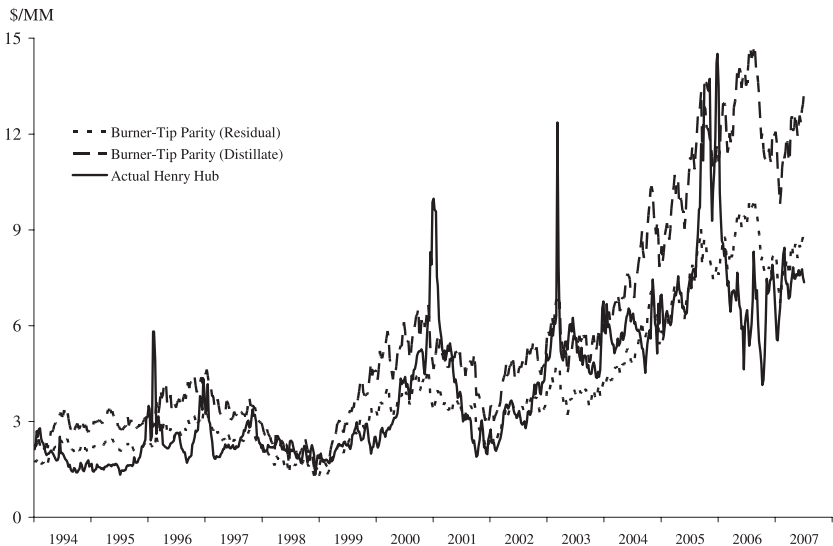
Distillate fuel oil is generally a higher-priced product than residual fuel oil. In those areas of the country with high natural gas distribution costs, natural gas may compete with distillate fuel oil rather than lower-priced residual fuel oil. On those occasions when natural gas prices are high relative to oil, we may see more widespread natural gas to distillate competition. The heat content of distillate fuel oil is 5.825 million Btu per barrel. Historically, distillate has sold, on average, 1.2 times the price of WTI, which suggests a price of $0.2060 \times P_{WTI}$. With a transportation differential of about \$0.80, this burner-tip parity rule becomes:

$$P_{HH,t} = -.80 + .2060 \times P_{WTI,t} \tag{2}$$

With this relationship, a \$50 per barrel price for WTI would mean a natural gas price of \$9.50 per million Btu at Henry Hub.

Use of the burner-tip parity rule for residual fuel oil suggests that U.S. natural gas prices generally track those of WTI (Figure 2). Nonetheless, there are numerous occasions when natural gas prices are not well explained by the rule. In particular, natural gas prices seem to have risen above that implied by the burner-tip parity rule for residual fuel oil in 2000, 2002, 2003, 2004 and late 2005 and fallen behind in 2006 and early 2007. The burner-tip parity rule for distillate oil offers no consistent forecasting ability.

Figure 2. Actual and Implied Natural Gas Prices



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 for 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—could drive natural gas prices out of alignment with crude oil, 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 those caused by 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 from January 7, 1994 through June 8, 2007. 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 June 8, 2007. 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 from 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.² Data on U.S. natural gas storage are collected by the U.S. Energy Information Administration (EIA). We calculate a stor-

2. 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. 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.

age 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 in the Gulf of Mexico is a series assembled from individual reports made by the Minerals Management Service of the U.S. Department of Interior.³

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 in the difference between cooling degree deviations and cooling degree days.⁴

3.2 Model Specification

As an initial step in our work, we check whether our data 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).⁵ 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.⁶ As shown in Table 2, the Johansen procedure finds a cointegrating relationship between natural gas and crude oil prices over the interval June 13, 1997 through June 8, 2007—with and without the stationary exogenous variables specified below.

3. For each hurricane or tropical storm that disrupts production in the Gulf of Mexico, the Minerals Management Service (MMS) reports the shut-in natural gas production that it considers noteworthy. During our estimation period, the MMS reported 16 such episodes for a total 85 weeks. We use actual shut in data for the reported weeks and zero values for the non-reported weeks. Because Hurricanes Ivan, Katrina and Rita account for 68 of the weeks and had outsized effects on natural gas production in the Gulf of Mexico, they dominate the data.

4. 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.

5. Because prices increase sharply over the analysis period, the two price variables are expressed in natural logs throughout the empirical analysis.

6. See Engle and Yoo (1987).

Table 1. Unit Root Tests

variables	Augmented Dickey-Fuller	
	Levels	First Differences
logged PHH	-1.4966	-13.2398**
logged PWTI	-0.4863	-7.7305**
HDD	-8.4684**	na
HDDDEV	-6.6887**	na
CDD	-6.8120**	na
CDDDEV	-7.9596**	na
STORAGE DIFF	-3.4063*	na
SHUT IN	-4.3109**	na

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

Because the crude oil and natural gas price series are cointegrated, we account for cointegration in their relationship by specifying an error-correction model in which changes in the dependent variable are expressed as changes in the independent and the dependent variable, plus an error-correction term, as recommended by Engle and Granger (1987). 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.

We utilize an error-correction model to specify the relationship between natural gas and crude oil prices and represent the stationary variables as exogenous:

$$P_{HH,t} = \gamma + \beta P_{WTI,t} + \mu_t \quad (3)$$

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

where $P_{HH,t}$ is the logged Henry Hub price of natural gas; $P_{WTI,t}$ is the logged 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 ($CI_t \equiv \mu_t$); X_j is the vector of stationary 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, movements in crude oil prices lead those of natural gas 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 stationary 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. Similar to Asche et al (2006), our testing shows only marginal causality from natural gas to crude oil prices.⁷

3.3 Model Results and Interpretation

As shown in Table 2, the cointegrating relationship between oil and natural gas prices is linear and β , the normalized coefficient on WTI, is quite similar whether we include or exclude the stationary exogenous variables. The estimated value of β is 0.932 in the specification without the exogenous variables and 0.865 with the exogenous variables. This implies that a one-percent change in the price of crude oil is met with around a 0.9 percent change in the price of natural gas in the long run. The adjustment coefficient, α , is 0.065 in the specification without the exogenous variables and 0.12 in the specification with exogenous variables.

After finding cointegration between oil and gas prices, we examine two different specifications of the error-correction model—without exogenous variables (Model 1), and with stationary exogenous variables (Model 2). 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 four lags. We report the results for four lags, but found substantially similar results for all lags from zero through four. We tested for autocorrelation and heteroskedasticity in both models. Using both the Breusch-Godfrey and Ljung-Box tests, we find no autocorrelation in the models.⁸ There is slight heteroskedasticity in the errors, which we find results from two severe weather events. When weeks corresponding to severe weather events—December 11, 1998, March 7, 2003 and March 14, 2003—are dummied out, we find no heteroskedasticity and the model results are substantially similar.⁹

7. The test on causality from Henry Hub natural gas prices to West Texas Intermediate crude oil prices is marginally significant at .0932.

8. Testing first- through sixth-order autocorrelation with the Breusch-Godfrey LM test reveals no significant autocorrelation. In addition, the correlogram of residuals shows insignificant Ljung-Box Q-statistics for all lags.

9. Including the three dummies, the F-value of the White heteroskedasticity test is 1.2130 (33, 470), which shows an insignificant probability of 0.1971. Excluding the dummies, the F-value of the White heteroskedasticity test is 5.4607 (30, 473), which shows a significant probability of 0.0000.

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

	Ho: rank=p	Eigenvalue	Trace Statistic	Max Eigenvalue Statistic
logged 6/13/1997 to 6/8/2007 (without exogenous variables)	p=0	0.0366	19.6577*	19.3116**
	p≤1	0.00067	0.3461	0.3461
	Standardized Eigenvalues or βs with Standard Errors			
		Henry Hub	WTI	
	1	-0.9322		
	0	(0.01083)		
Standardized α Coefficients with Standard Errors				
	Henry Hub	WTI		
	-0.0653	0.00838		
	(0.1083)	(0.0081)		
logged 6/13/1997 to 6/8/2007 (with stationary exogenous variables) [†]	Ho: rank=p	Eigenvalue	Trace Statistic	Max Eigenvalue Statistic
	p=0	0.0786	43.472**	41.242**
	p≤1	0.0044	2.229	2.229
	Standardized Eigenvalues or βs with Standard Errors			
	Henry Hub	WTI		
	1	-0.8649		
	0	(0.0631)		
Standardized α Coefficients with Standard Errors				
	Henry Hub	WTI		
	-0.1179	0.01626		
	(0.020)	(0.0107)		

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

[†]Significance may be better than shown here. The inclusion of stationary exogenous variables significantly increases the power of cointegration tests according to Seo (1998), and the appropriate critical values may be somewhat lower than are used here as shown by Boswijk and Doornik (2005).

For both specifications, the models show causality from oil to natural gas prices (Table 3). The cointegrating term and coefficients on lagged values of P_{WTI} are jointly significant in both specifications.¹⁰ The cointegrating term is significant by itself in both error-correction models, which confirms the cointegration found

10. The “cointegrating term” reported in Table 3 is the coefficient on the errors of the long-run cointegrating relationship between oil and natural gas reported in Table 2.

Table 3. Error-Correction Models of the Change in Natural Gas Price

explanatory variables	Model 1		Model 2	
	coefficients	joint significance	coefficients	joint significance
constant	0.0028 (0.7545)		-0.0050 (-0.3794)	
cointegrating term (t-1)	-0.0577 (-3.5274)**	0.0083	-0.1158 (-5.7203)**	0.0000
ΔP_{WTI} (t-1)	0.1071 (1.2002)		0.0840 (0.9941)	
ΔP_{WTI} (t-2)	-0.1252 (-1.3890)		-0.0651 (-0.7633)	
ΔP_{WTI} (t-3)	0.0255 (0.2808)		0.0540 (0.6300)	
ΔP_{WTI} (t-4)	-0.0919 (-1.0215)		-0.1296 (-1.5181) ⁺	
ΔP_{HH} (t-1)	0.0925 (2.0693)*	0.0464	-0.0301 (-0.6857)	0.3491
ΔP_{HH} (t-2)	0.0123 (0.2759)		-0.0336 (-0.7845)	
ΔP_{HH} (t-3)	-0.0351 (-0.7843)		-0.0433 (-1.0172)	
ΔP_{HH} (t-4)	-0.0844 (-1.8811) ⁺		-0.0602 (-1.4125)	
HDD (t)			$2.08 \cdot 10^{-4}$ (2.4748)*	0.0000
HDDDEV (t)			$1.06 \cdot 10^{-3}$ (5.6985)**	
CDD (t)			$-1.55 \cdot 10^{-4}$ (-0.6325)	
CDDDEV (t)			$2.97 \cdot 10^{-3}$ (4.5411)**	
STORAGE DIFF (t)			$-5.69 \cdot 10^{-5}$ (-3.5139)**	
SHUT IN (t)			$1.16 \cdot 10^{-5}$ (2.3054)	
	$R^2 = 0.05$ adj $R^2 = 0.04$		$R^2 = 0.18$ adj $R^2 = 0.15$	

Values shown in parentheses are t-statistics.

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

with the Johansen procedure, in accordance with Kremers et al (1992). Moreover, the estimated values of the coefficients on errors in the cointegrating relationship are similar to those found with the Johansen cointegration tests for both specifications. In contrast, the four lagged values ΔP_{wtt} of are neither independently nor jointly significant in either specification.

The coefficient on the equilibrium errors is -0.0577 in Model 1. This estimate implies that if oil and natural gas prices shift away from their long-term relationship, natural gas prices adjust to close the gap between the two at the rate of less than 6 percent a week. Because lagged dependent variables are significant, the history of natural gas prices contributes to its motion. Together these variables imply 90 percent adjustment in just over 39 weeks.

The second model includes the stationary exogenous variables—which contribute to the short-run dynamics of natural gas prices. Adding the exogenous variables to the model increases the overall fit as shown by the R^2 of 0.18. The coefficient on the equilibrium errors changes to -0.1158, 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 prices adjust to close the gap between the two at a rate of nearly 12 percent a week. Because the lags of the dependent variable are insignificant, the history of natural gas prices does not contribute to its own motion. The overall effect is 90 percent adjustment in less than 19 weeks. The addition of stationary exogenous variables to the model shortens the estimated amount of time required for natural gas prices to adjust to shocks in crude oil prices.

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 the 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 significant explanatory variables are also economically significant (Table 4). The standard deviation of first differences in the logged natural gas prices is 0.0858. A one-standard deviation shock in the first difference of the logged price of crude oil contributes a change to the first difference of the logged natural gas price of 0.0043 at one week; 0.0145 at four weeks; and 0.0373 in the long-run. A one-standard deviation shock in a statistically significant exogenous variable contributes a change to the first difference of the logged natural gas price of -0.0167 to +0.0236.

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 transitory and other exogenous factors that include weather, seasonality, storage, and disruptions of production. Short-run dynamics and transitory factors can result in a wide range of differen-

Table 4. Estimated Economic Contribution of Explanatory Variables (in Model 2)

variable	contribution*
$\Delta \ln P_{HH}^*$.0858
$\Delta \ln P_{WTI}$ (one week)	.0043
$\Delta \ln P_{WTI}$ (four weeks)	.0145
$\Delta \ln P_{WTI}$ (long run)	.0373
HDD	.0163
HDDDEV	.0236
CDD	—
CDDDEV	.0193
STORAGE DIFF	-.0167
SHUT IN	.0111

*For ΔP_{HH} the reported value is the standard deviation. For the variables other than ΔP_{HH} , the reported value is the standard deviation of the variable multiplied by the corresponding coefficient estimate. Because the lagged coefficients on WTI are insignificant, the one- and four-week values on ΔP_{WTI} is the contribution from partial adjustment to the cointegrating relationship.

tials between natural gas and crude oil prices, and taking these additional factors into account along with oil prices better explains natural gas prices than do rules of thumb—as shown in Figure 3—where the fitted values of the Henry Hub natural gas price are derived from Model 2 but are shown in levels along with the actual data.¹¹ 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 Baron (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 decision of which plant to operate can determine which fuel to use. The U.S. petrochemical industry re-

11. The tight fit implied in Figure 3 is the result of showing the actual and fitted data in levels. The R^2 reported in Table 3 is for a model estimated in differences of logged data. The series shown in the bottom panel is the difference between the fitted and actual prices—not the residuals from the estimation.

Figure 3a. Actual and Implied Natural Gas Prices

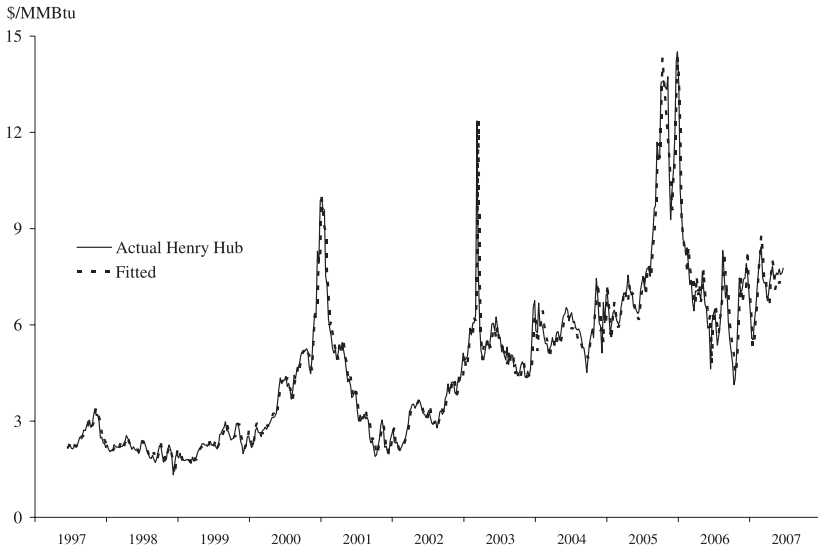
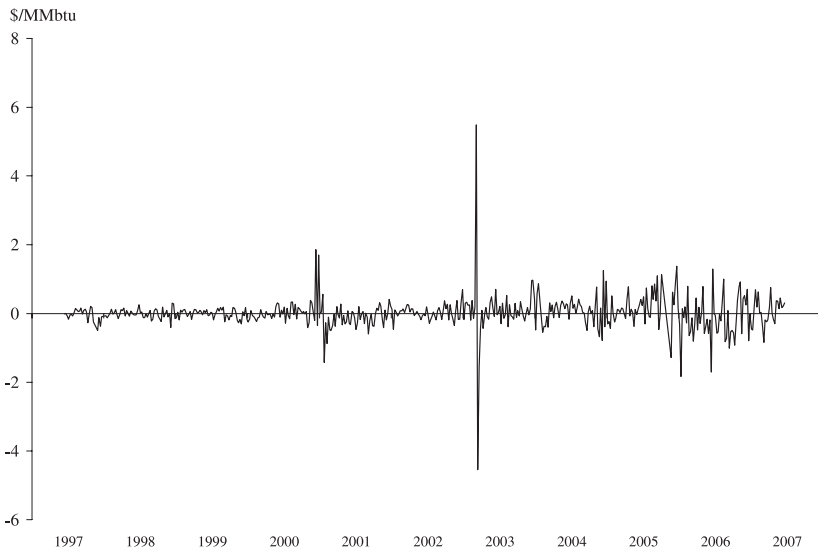


Figure 3b. Differences between the Actual and Fitted Natural Gas Prices



lies heavily on natural gas as a feedstock, while much of its foreign competition relies on petroleum products. In addition, Hartley, Medlock and Rosthal (2007) and Huntington (2007) 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, MORE COMPLEX RELATIONSHIP

Simple rules of thumb cannot explain differential movements in oil and natural gas prices. Perhaps the limited success 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 also takes into account crude oil prices, weather, seasonality, storage and production disruptions explains natural gas prices quite well. Moreover, the model shows U.S. natural gas prices are 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 that is farthest from Henry Hub and using natural gas as being the burner-tip that sets 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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