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The Relationship between Crude Oil and Natural Gas Prices: The Role of the Exchange Rate

Peter R. Hartley

and

Kenneth B. Medlock III

Rice University

Overview

- Since fuels can substitute for each other, we expect their prices to be related
- Previous studies have found US oil and natural gas prices to be cointegrated
- There is also evidence, however, that the relationship is unstable
- One explanation is that technological changes alter the substitutability between natural gas and oil products
- We reaffirm this finding, but also find evidence that the exchange rate influences the relative price of oil to natural gas in the United States
- As in previous studies, we again find that short run departures from long run equilibrium are influenced by:
  - weather
  - product inventories
  - other seasonal factors and
  - supply shocks such as severe tropical storms in the Gulf of Mexico

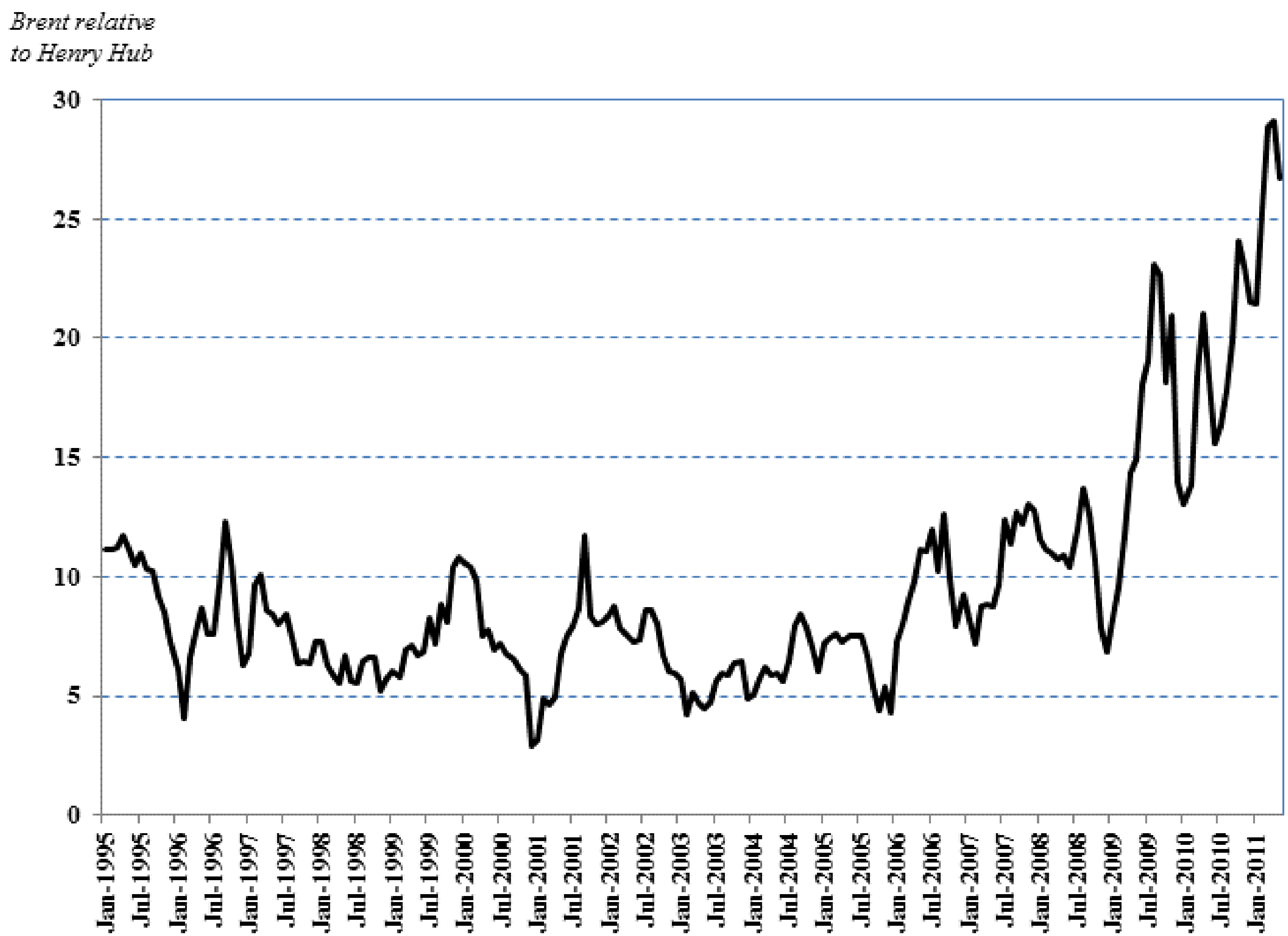
Why is the topic of interest?

- The permanence of any relationship is important for investment decisions such as:
  - Investment in GTL, CNG or other technologies to get natural gas into transportation
  - Examining LNG export opportunities where targeted consumers have oil-indexed prices
- Policy-makers need to understand the pricing relationship when considering policies to encourage the use of one fuel over another
- Traders in energy derivatives contracts might like to know determinants of short term dynamics in the relationship between prices to exploit potential arbitrage opportunities

Previous research

- Villar and Joutz (2006) showed the cointegrating relationship of WTI oil and Henry Hub gas prices exhibited a positive time trend
  - After allowing for the trend, they estimated an ECM with natural gas storage, seasonal dummies, and dummies for other transitory shocks as exogenous variables
- Brown and Yücel (2008) analysed weekly prices from January 1994–July 2006
  - They found a stable cointegrating relationship, but also reported that a cointegrating relationship does not exist for June 1997–July 2006
  - Using the cointegrating relationship from the longer period, they found storage levels, weather, and production shut-in by hurricanes could explain short run deviations
- Hartley, Medlock and Rosthal (2008) estimate a vector ECM using monthly data from 1990–2006 and found a stable cointegrating relationship after allowing for changes in the heat rate of electric generating plants
- Ramberg and Parsons (2011) examined weekly data from 1991–2010 and found that the cointegrating relationship can shift substantially through time
  - As in Brown and Yücel (2008) they estimated an ECM to explain short run adjustment

Plot of relative price



A simple trade model: home country gas

- Supply in the home market: $\hat{s}_{g,h} = \hat{z}_{s,h} + \beta_{1,h}\hat{p}_{g,h}$
- Demand in the home market: $\hat{d}_{g,h} = \hat{z}_{d,h} - b_{1,h}\hat{p}_{g,h} + I_{sw,h} b_{2,h}\hat{p}_{o,h}$
- If the home country does not engage in trade in natural gas $\hat{d}_{g,h} = \hat{s}_{g,h}$ and

$$\hat{p}_{g,h} = \hat{z}_h + \lambda_h \hat{p}_{o,h}$$

where $\hat{z}_h = \dfrac{\hat{z}_{d,h} - \hat{z}_{s,h}}{\beta_{1,h} + b_{1,h}}$ and $\lambda_h = \dfrac{b_{2,h}}{\beta_{1,h} + b_{1,h}} I_{sw,h}$

- Relationship between crude oil and natural gas prices is primarily determined by the ability to switch between fuels
- For this autarkic equilibrium to persist, the cost of developing export or import capability must be prohibitive relative to anticipated price differentials

Trade model: oil market

- Assuming oil supply and demand curves analogous to the natural gas ones, the percentage change in imports can be approximated by $\hat{m}_{o,h} = \theta_{o,h}\hat{d}_{o,h} + \left(1-\theta_{o,h}\right)\hat{s}_{o,h}$

  that is, $\hat{m}_{o,h} = \theta_{o,h}\left[\hat{w}_{d,h} - a_{1,h}\hat{p}_{o,h} + I_{sw,h}a_{2,h}\hat{p}_{g,h}\right] + \left(1-\theta_{o,h}\right)\left[\hat{w}_{s,h} + \alpha_{1,h}\hat{p}_{o,h}\right]$

  where $\theta_{o,h} \equiv d_{o,h} \big/ \left(d_{o,h} - s_{o,h}\right) > 1$. Oil exports from the "composite" foreign country

  $$\hat{x}_{o,f} = \theta_{o,f}\left[\hat{w}_{d,f} - a_{1,f}\hat{p}_{o,f} + I_{sw,f}a_{2,f}\hat{p}_{g,f}\right] + \left(1-\theta_{o,f}\right)\left[\hat{w}_{s,f} + \alpha_{1,f}\hat{p}_{o,f}\right]$$

  where

  $$\theta_{o,f} \equiv d_{o,f} \big/ \left(d_{o,f} - s_{o,f}\right) < 0$$

- Although both the foreign and the home country have access to the same technologies, there is no necessary reason for $I_{sw,h} = I_{sw,f}$
- In equilibrium, $\hat{m}_{o,h} = \hat{x}_{o,f}$ and $\hat{p}_{o,h} = \hat{p}_{o,f} + \hat{e}$

Trade model: equilibrium price changes

- Aggregate supply equals aggregate demand for natural gas in the rest of the world, implying

$$\hat{p}_{g,f} = \hat{z}_f + \lambda_f \hat{p}_{o,f}$$

where $\hat{z}_f = \dfrac{\hat{z}_{d,f} - \hat{z}_{s,f}}{\beta_{1,f} + b_{1,f}}$ and $\lambda_f = \dfrac{b_{2,f}}{\beta_{1,f} + b_{1,f}} I_{sw,f}$

- Combining equations we get $\hat{p}_{o,h} = \hat{W} + \hat{Z} + \pi\hat{e}$ where

$$\hat{W} = \frac{\theta_{o,h}\hat{w}_{d,h} - \theta_{o,f}\hat{w}_{d,f} + \left(1-\theta_{o,h}\right)\hat{w}_{s,h} - \left(1-\theta_{o,f}\right)\hat{w}_{s,h}}{\left(1-\theta_{o,f}\right)\alpha_{1,f} - \left(1-\theta_{o,h}\right)\alpha_{1,h} + \theta_{o,h}\left(a_{1,h} - I_{sw,h}a_{2,h}\lambda_h\right) - \theta_{o,f}\left(a_{1,f} - I_{sw,f}a_{2,f}\lambda_f\right)}$$

$$\hat{Z} = \frac{\theta_{o,h}I_{sw,h}a_{2,h}\hat{z}_h - \theta_{o,f}I_{sw,f}a_{2,f}\hat{z}_f}{\left(1-\theta_{o,f}\right)\alpha_{1,f} - \left(1-\theta_{o,h}\right)\alpha_{1,h} + \theta_{o,h}\left(a_{1,h} - I_{sw,h}a_{2,h}\lambda_h\right) - \theta_{o,f}\left(a_{1,f} - I_{sw,f}a_{2,f}\lambda_f\right)}$$

$$\pi = \frac{\left(1-\theta_{o,f}\right)\alpha_{1,f} - \theta_{o,f}\left(a_{1,f} - I_{sw,f}a_{2,f}\lambda_f\right)}{\left(1-\theta_{o,f}\right)\alpha_{1,f} - \left(1-\theta_{o,h}\right)\alpha_{1,h} + \theta_{o,h}\left(a_{1,h} - I_{sw,h}a_{2,h}\lambda_h\right) - \theta_{o,f}\left(a_{1,f} - I_{sw,f}a_{2,f}\lambda_f\right)}$$

Home relative price changes

$$\hat{p}_{o,h} - \hat{p}_{g,h} = \left(1 - \lambda_h\right)\left(\hat{W} + \hat{Z} + \pi\hat{e}\right) - \hat{z}_h$$

- Assuming that
  - Own-price elasticities dominate cross-price elasticities in the home and foreign oil market, so $\pi > 0$, and
  - Own-price effects also dominate in the domestic gas market, so $\beta_{1,h} + b_{1,h} > I_{sw,h} b_{2,h}$ that is, $\lambda_h < 1$
- Then devaluations of the home currency will have a positive effect on the relative price of oil to natural gas in the home currency
- More generally, if there is trade in both oil and natural gas it can be shown that the effect of the exchange rate on the relative price is indeterminate

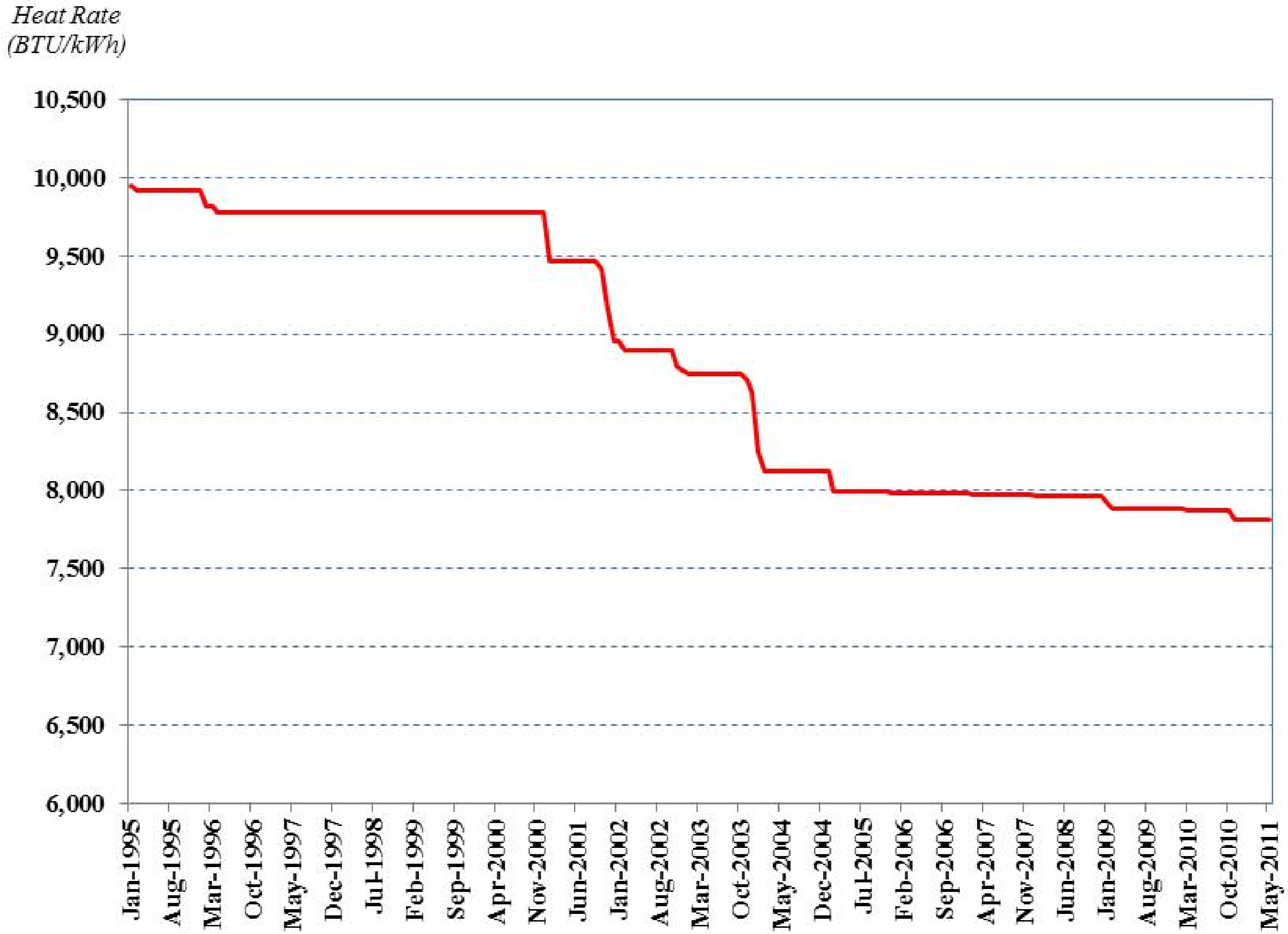
Data sources

- Monthly price data from January 1995 to March 2011 from the EIA
  - We use Brent rather than WTI to take account of the disconnect between WTI and Brent as a result of the recent take-away constraint at Cushing
- Use the broad trade weighted exchange rate index compiled by the Fed for *e*
- Got HDD and CDD deviations from 30-year average from the National Climate Data Center
- Used monthly indicator variables and an indicator for serious capacity constraint episode in Chicago in February 1996
- Constructed three other variables discussed in detail on following slides:
  - A relative heat rate index
  - Inventory (working gas in storage at the beginning of the month) was split into anticipated and unanticipated components
  - An estimate of production losses from hurricanes in the Gulf

Relative heat rate variable

- We needed a different method than used in Hartley, Medlock & Rosthal (2008) since the NEEDS database is not available for more recent years
- We divided the monthly fuel use by the amount of electricity generated from a specific type of plant
  - These will vary as different plants on the stack are used in addition to changes in technology
- We construct a “marginal” heat rate such that no heat rate in later months can be greater than a heat rate realized in a previous month
- The resulting series are graphed on the next two slides

Natural gas plant marginal heat rates



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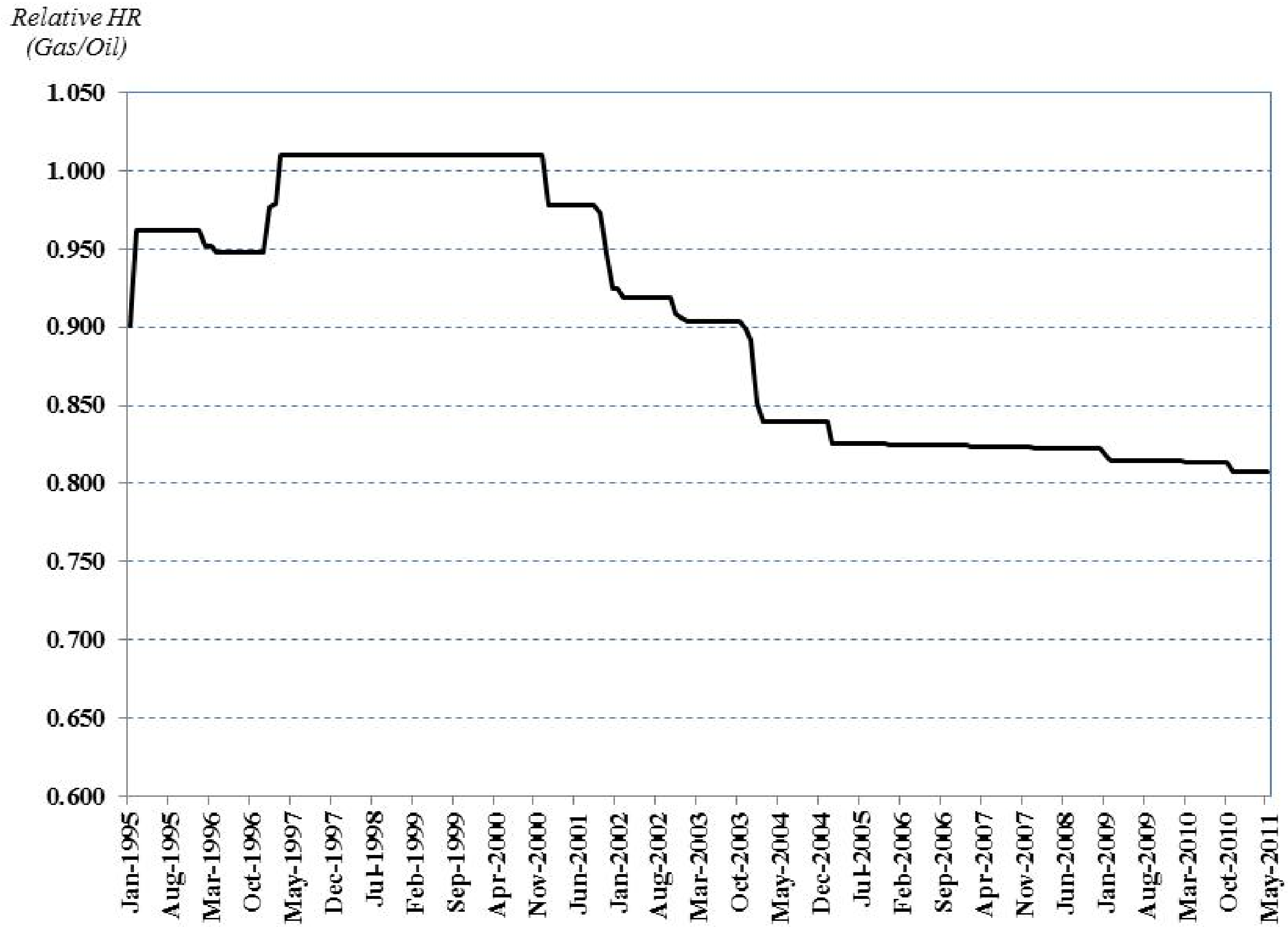
Natural gas to oil relative heat rates



Anticipated versus unanticipated storage

- We first verified that $\ln inv_g$ was stationary
- We then regressed $\ln inv_g$ on monthly dummies and examined the acf and pacf
- After fitting an AR(2) model

$$\ln inv_{ng,t} = \sum_{i=1}^{12} \beta_{0i} I_{it} + \underset{(0.0466)}{1.3949} \ln inv_{ng,t-1} - \underset{(0.0537)}{0.4717} \ln inv_{ng,t-2} + u_t$$

we verified that the residuals were white noise

- We then used the exponential of the predicted values from this model for anticipated inventory levels and the difference between the actual and predicted values as the unanticipated inventory at the beginning of each month

Production losses from hurricanes

- Regressed natural gas production in the Gulf of Mexico region on
  - A cubic time trend and
  - A set of dummy variables representing periods when tropical weather, as reported by the National Hurricane Center (NHC), affected Gulf producing areas

$$ng_t^{Gulf} = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3 + \sum_j \sum_{t_j} \delta_{jt_j} D_{t_j} + \varepsilon_t$$

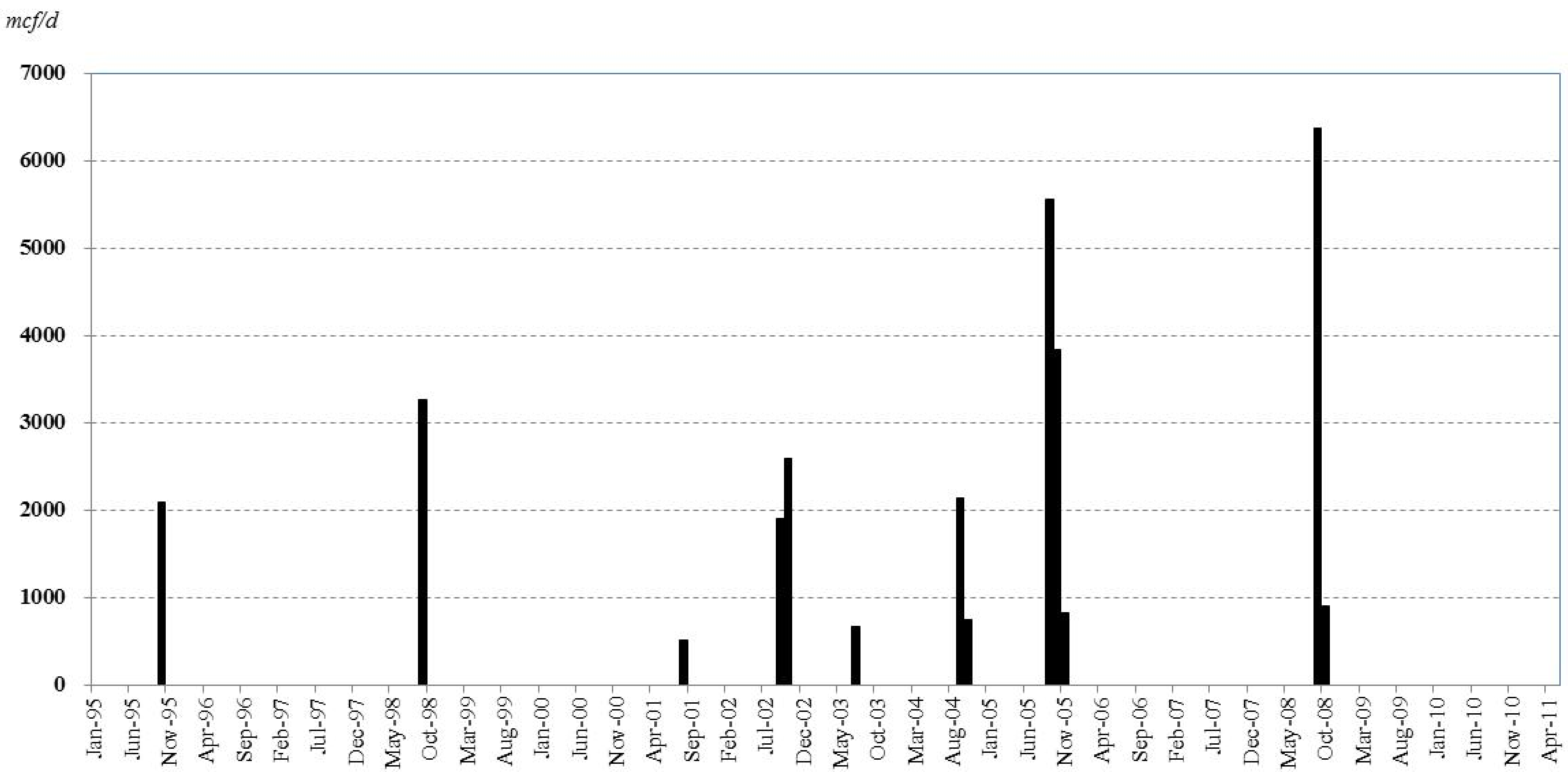
  where t_j indexes months for which storm j had a statistically significantly negative effect on production (relative to trend)

- Production lost due to severe tropical storms and hurricanes is then defined as

$$GoMShutIn_t = -\sum_j \sum_{t_j} \delta_{jt_j} D_{t_j}$$

- This method allows the effects on production to occur over an extended period and for the effects to vary by storm

Graph of shut-in production



Co-integrating relationship

$$\ln P_t^{ng} = \underset{(1.2030)}{-9.7148} + \underset{(0.0722)}{0.5806} \ln P_t^{oil} + \underset{(0.2465)}{1.9025} \ln e_t - \underset{(0.5362)}{1.0599} \ln\left(\frac{HR_t^{ng}}{HR_t^{oil}}\right) + \varepsilon_t$$

- Phillips-Perron test indicates the residuals are stationary
  - $Z(\rho) = -24.500$ (1% critical value -20.120) and $Z(\tau) = -3.521$, which has a MacKinnon approximate p-value of 0.0075
  - Original variables in this relationship were non-stationary
- The statistically significant (at the 5% level) negative coefficient on the relative heat rate indicates that improved relative thermal efficiency of natural gas generation raised the price of natural gas relative to crude oil, as found before
- The statistical significance of the exchange rate at even the 0.001 level supports the hypothesis that a weaker US dollar has a positive influence on the spread
- If we only regress on the oil price, the residual is stationary at the 5% level but not at the 1% level
  - This supports the results of Ramberg and Parsons (2011)

Short run dynamic relationship

Variable	Equation 14	Equation 14 alt
$\hat{\varepsilon}_{t-1}$	–0.1471*** (0.0343)	–0.1312*** (0.0348)
$\Delta \ln P^{ng}_{t-1}$	0.1800*** (0.0625)	0.1982*** (0.0625)
$\Delta \ln P^{ng}_{t-12}$	–0.2631*** (0.0616)	–0.2655*** (0.0610)
$inv_{ng,t}$	–8.63E-08*** (2.86E-08)	
$\widehat{inv}_{ng,t}$		–6.30E-08** (3.04E-08)
$invdev_{ng,t}$		–3.68E-07*** (1.38E-07)
$HDDdev_t$	0.00108*** (0.00019)	0.000692*** (0.000261)
$CDDdev_t$	0.00197*** (0.00052)	0.00158*** (0.00054)
$GoMShutIn_t$	2.68E-05** (1.30E-05)	2.28E-05* (1.30E-05)
$Chicago_t$	0.4267*** (0.1202)	0.4206*** (0.1190)
$Chicago_{t-1}$	–0.4681*** (0.1256)	–0.4773*** (0.1244)
N	184	184
R^2	0.4732	0.4871
Joint significance	$F_{20,163} = 7.32^{***}$	$F_{21,162} = 7.33^{***}$
Q-statistic (12 lags)	$\chi^2_{12} = 13.81$	$\chi^2_{12} = 9.51$
Breusch-Pagan heteroskedasticity test	$\chi^2_1 = 0.38$	$\chi^2_1 = 0.50$

Concluding remarks

- Our analysis verifies the findings in Hartley, Medlock and Rosthal (2008) that electricity generation technology has played an important role in establishing the relationship between crude oil and natural gas prices
- Similar to previous studies, we find that seasonal variables such as
  - weather and inventories (anticipated inventories are strongly seasonal);
  - tropical disturbances in the Gulf of Mexico; and
  - remaining monthly effects in dummy variables

  significantly affect short run movements in natural gas/crude oil relative prices
- We find that changes in the exchange rate can explain the recent rapid rise in the ratio between crude oil and natural gas prices