Bidirectional Causality in Oil and Gas Markets

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Abstract

Do events in the natural gas market cause repercussions in the crude oil market? This paper studies linkages between the two markets using high-frequency, intraday oil and gas futures prices. By analyzing the e ect of weekly oil and gas inventory announcements on price volatility, we show a bidirectional causal relationship. Both inventory gluts and shortages have cross-commodity e ect on price volatility not only for the next-month nearby futures contract but also for the following six months' contracts.

JEL Classi cation: Energy Demand and Supply Q41, Energy and the Macroeconomy Q43, Energy Forecasting Q47, Futures Pricing G13

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concluded that the energy market was integrated with the oil price being the exogenous leading price. Similarly, Pindyck (2004) conducted Granger causality tests between daily oil energy, leading to the energy mix in the U.S. changing in favor of gas. In 2003, crude oil and natural gas comprised 40% and 23% of the U.S. energy consumption, respectively. By 2010, the mix between oil and gas has changed to 37% and 25%, respectively.[2] This trend is likely to continue as North America has witnessed unprecedented discoveries of shale gas in the last several years. In addition, trading in the oil and gas futures markets has increased dramatically, ranking the oil and gas futures as the first and the second largest energy futures, and the first and the ninth largest commodity futures by volume in 2008, respectively.[3] Understanding of how commodity markets relate to one another can help policy-makers, consumers and investors more efficiently incorporate risk spillovers into their decisions.

2 Methodology

To study linkages between the oil and gas markets, we use high-frequency, intraday oil and gas futures prices. Our choice of the 10-minute time interval trades off noise due to the data microstructure and loss of information. One approach, the volatility signature plot technique, graphs the scaled realized volatility (daily average of squared returns), against time intervals in multiples of one minute (Andersen, Bollerslev, Diebold & Labys, 2000). We choose the 10-minute interval as the appropriate length since realized volatility stabilizes at that interval length.[4]

[2] EIA Annual Energy Review 2010.

[3] Futures Industry Magazine Annual Volume Survey: 2008 A Wild Ride.

[4] See Dacorogna, Gencay, Muller, Olsen and Pictet (2001) for a discussion of scaling factors. Also, note that the realized volatility is used only to choose the appropriate interval. It is not used in the regressions. The dependent variable in the volatility regressions is defined as the absolute return. As a robustness check, the regressions are repeated using 15-minute and 30-minute intervals. The results do not change materially.

Oil trading ceases on the third business day prior to the twenty-fifth calendar day of the month preceding delivery. At expiration, oil has to be physically delivered to Cushing, OK. Gas trading ceases three business days prior to the first day of the delivery month. At expiration, gas has to be physically delivered to Henry Hub, LA. Very few market participants make physical delivery at contract expiration opting instead to roll over positions into a new contract. We create a continuous record of the futures contract prices by using current contracts until expiration date. Because trading may be thin during the last few days before the contract expiration date, we tested switching to the next contract as soon as its daily contract volume exceeds the current contract volume as an alternative method for creating a continuous record of prices. The results do not materially differ between the two methods, so only the results using the expiration date method are reported.

As is customary in these studies, we measure volatility as the absolute value of returns, $|R_j|$, where R_j is the difference between the log price at the end of interval *j* and the log price at the end of interval *j-1*: $R_j = \ln(P_j) - \ln(P_{j-1})$ where P_j is the price at the end of period j. To validly undertake hypothesis testing about the regression parameters, we test for stationarity of the return series. The series is stationary as gauged by an augmented Dickey-Fuller test.

Following Ding, Granger and Engle (1993), Ederington and Lee (1993), Gwilym, McMillan and Speight (1999), McKenzie (1999), Bollerslev, Cai and Song (2000), and Ederington and Guan (2005), we measure the response of volatility to unexpected changes in inventories.

Using unexpected changes in inventories assumes efficient markets, implying that only the unanticipated component of news announcements matters: the anticipated component has already been built into market participants' price forecasts. The unexpected component is the difference between the actual value, A_{kj}, and the expected value, E_{kj}, where $k \in \{O, G\}$ stands for oil and gas announcements. To come up with a common metric of "surprise" for oil and gas, which are measured, respectively, in thousands of barrels and billions of cubic feet, the unexpected component is divided by the actual value and then multiplied by 100. The resulting "surprise", $S_{kj} = \frac{A_{kj} - E_{kj}}{A_{kj}} \times 100$, is the percentage of actual inventory by which the expected inventory falls short of actual inventory.[5] Measuring surprise this way means

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A beginning-of-day dummy is included to account for unusual price movements at the beginning of the day. This dummy takes on the value of 1 during the first interval of the day and 0 in all other intervals. An end-of-day dummy is included in the same way to account for unusual price movements at the end of the day. These time-of-the-day effects have been identified in many financial markets, for example by Becker, Finnerty and Kopecky (1993), Bollerslev, Cai and Song (2000), and Linn and Zhu (2004). Alternative specifications are run where the beginning-of-day (end-of-day) dummy takes on the value of 1 for the first (last) two and three intervals. The results do not change.

A first-trading-day dummy is included that takes on the value of 1 in all intervals on the day after a non-trading day, i.e., after a weekend or a holiday, to allow for effects due to the market being closed for an extended period of time. A trader composition variable, defined as the ratio of non-commercial financial traders volume to the traditional commercial traders volume, is added to account for a change in the composition of firms trading oil futures. As documented by Buyuksahin et al (2008), the proportion of non-commercial financial traders has been on the rise and the proportion of traditional commercial traders has declined. The three-month Treasury bill rate is included to account for the cost of holding inventory (Pindyck, 2004). Trading volume (measured in 1000s of executed contracts) is added to account for various unobservable sources of volatility. We tried both contemporaneous and lagged volume as a control variable. The results were very similar and the lagged volume

Control variables for gasoline inventory, distillate fuel oil (referred to as \distillate") inventory and re nery utilization are also included because these data are released at the the same time as the oil inventory data, hence their announcements could possibly pro-

3 Data

Our price data consists of weekday transactions prices from 9 a.m. to 2:30 p.m. ET for oil futures with maturities of one month to nine years and gas futures with maturities of one month to 12 years traded on NYMEX during the period from June 13, 2003 to September 24, 2010.[9] There are 27 and 33 intervals within a trading day depending on whether the market opened at 10 a.m. or 9 a.m. ET.[10] This proprietary data is provided by Tick Data, Inc., a company that specializes in intraday time series data for equities, futures and options. The data are transaction data, i.e., not bid-ask quotes.[11]

In our sample period, there are 20 days when the NYMEX market closes earlier than normal, usually due to an upcoming holiday. These days are eliminated to prevent skewing intraday patterns. Only 0.20% and 0.45% of all observations for the oil and gas nearby contracts, respectively, are missing because no trade occurred in a 10-minute interval. These missing prices are set equal to the previous prices. The resulting sample contains 54,884 10-minute intervals on 1,826 days, a period of 380 weeks.

The data on the U.S. oil and gas inventory come from, respectively, the Weekly Petroleum Status Report and the Weekly Natural Gas Report, both published by the EIA based on companies submitting weekly forms stating their current inventory, as mandated by law.[12]

[9] The sample starts as of June 13, 2003 because Bloomberg surveys of market expectations are not available for oil prior to this date. This sample period is interesting because it captures a recent period of high volatility in energy prices.

[10] Until January 31, 2007, the trading day starts at 10:00 a.m. ET whereas after January 31, 2007, the trading day starts at 9:00 a.m. A variable added to control for this change was insigni cant at conventional p-values. Night trading is not analyzed in this paper since the day and night trading sessions may di er from the information arrival standpoint.

[11] Oil and gas futures contracts are also traded on the InterContinental Exchange (ICE) in London. This paper focuses on the NYMEX futures data because the NYMEX market is approximately twice as liquid as the ICE market during the sample period.

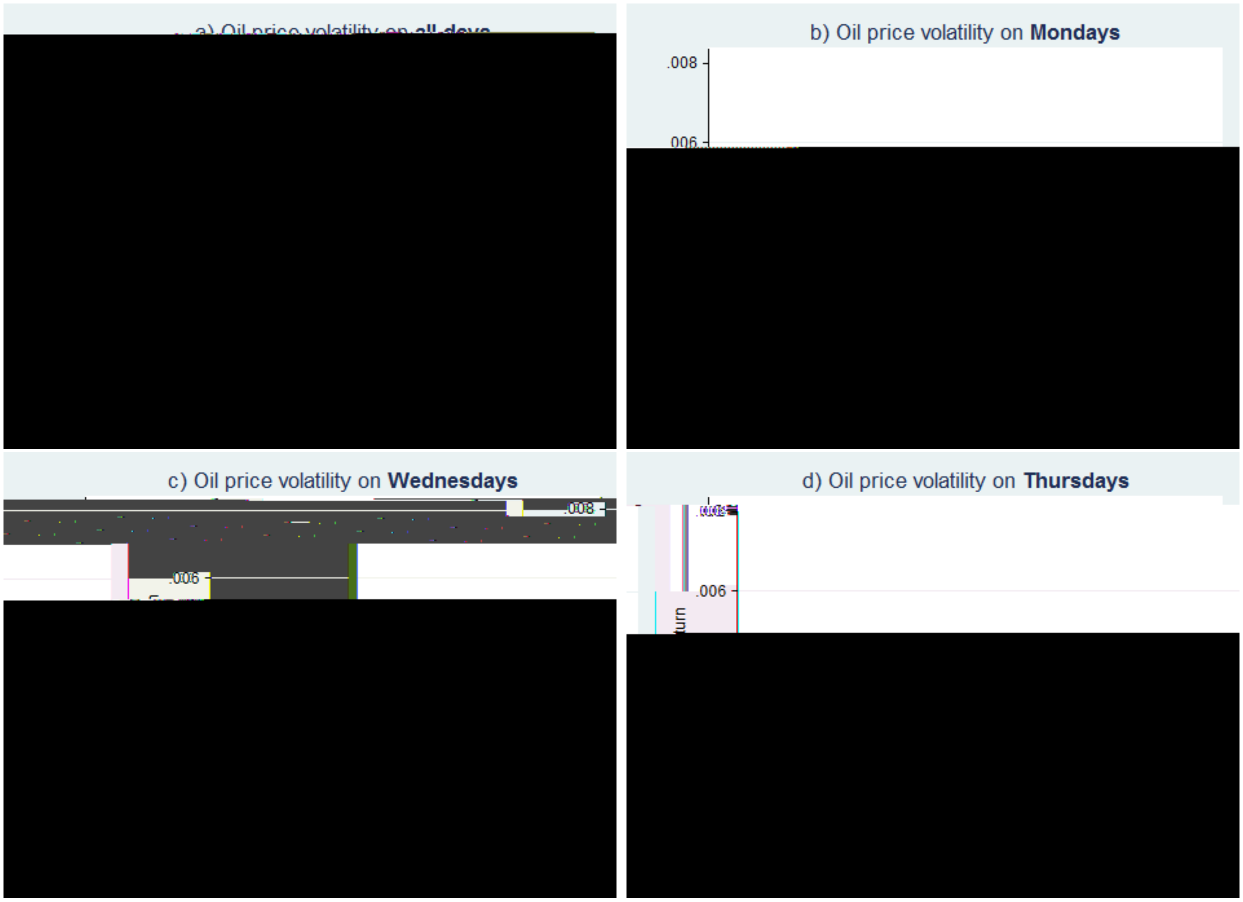
[12] Only commercial inventory is considered in this paper. The Strategic Petroleum Reserves (SPR) held by the U.S. government are excluded since weekly changes in the SPR inventory on average amount to only

The oil report is released weekly on Wednesday at 10:30 am ET for the week ending on the previous Friday. [13] The data are in thousands of barrels. The gas report is released weekly on Thursday at 10:30 am ET for the week ending on the previous Friday unless Thursday falls on a public holiday. The data are in billions of cubic feet.

Our market expectations data of oil inventories are the median forecasts of Bloomberg's weekly survey of approximately twenty industry experts of expected EIA reported oil inventory (excluding the Strategic Petroleum Reserves). This paper uses the median forecast. The survey is published on Monday or Tuesday, prior to the actual values being released by the EIA. Similarly, Bloomberg conducts a weekly survey of approximately twenty- ve industry experts asking them what they expect the gas inventory to be once released by the EIA. We again use the median forecast.

Statistics for the oil inventory surprise, S_O, and the gas inventory surprise, S_G, are summarized in Table 1. In our sample period, there are no observations where the inventory surprise variables, S_O and S_G, are exactly zero. The mean values of these variables are close to zero, so it appears that the Bloomberg survey can be considered unbitoerg surveyorg surveyeybit

Figure 1: Intraday pattern of oil price volatility



Notes: This gure shows the intraday pattern of the NYMEX crude oil nearby contract futures price volatility. The volatility is de ned as the absolute return. The rst interval is not displayed to avoid skewing the graphs by the overnight gap as the rst interval is a ected by not only the rst ten minutes of the trading day but also the period since the market closed on the previous day. Source: Tick Data, Inc.

4.1.2 Cross-Commodity E ect

Table 2 shows results for the price volatility of the oil nearby futures contract. Speci cation (1) includes the oil inventory variables as well as control variables that have been used in exceeded actual inventory). The coe cient of -.00425 on the oil shortage means that when analysts overforecasted actual inventory by 1%, there was an .00425 increase in volatility.[15] The coe cient of +.00626 on the oil glut indicates that an under forecast of the actual inventory by 1% caused an .00626 increase in volatility.

Table 2: Price volatility regressions for oil nearby contract

	(1)	(2)	(3)
Oil shortage S < 0	***-.00425 (.00051)	***-.00426 (.00051)	***-.00231 (.00066)
Oil glut S > 0	***.00626 (.00074)	***.00627 (.00074)	***.00433 (.00077)
Gas shortage S < 0		**-.00205 (.00075)	***-.00209 (.00075)
Gas glut S > 0		***.00191 (.00052)	***.00194 (.00053)
Gasoline shortage S < 0			**-.00107 (.00048)
Gasoline glut S > 0			***.00212 (.00068)
Distillate shortage S < 0			**-.00139 (.00062)
Distillate glut S > 0			*.00093 (.00051)
Beg-of-day dummy	***.00795 (.00026)	***.00796 (.00026)	***.00797 (.00026)
End-of-day dummy	***.00098 (.00008)	***.00099 (.00008)	***.00100 (.00008)

affected. The coefficients of -.00205 and +.00191 on the gas shortage and the gas glut are about one-half and one-third the size of their oil counterparts, respectively, although gas inventory announcements still have a sizeable effect on the oil price volatility, especially when compared to the mean intraday absolute return of .00272 shown in Figure 1.[16]

Specification (3) adds control variables for the gasoline and distillate inventory. Even though adding these variables decreases the oil shortage and oil glut estimates, the gas shortage and gas glut estimates are unaffected, and, in fact, the gas inventory variables become more important relative to the oil inventory variables. The gas shortage impact becomes almost as large as that of an oil shortage while a gas glut has about one-half the impact of an oil glut.

We would expect that a gas shortage means anticipated increases in the price of gas, so firms that can use either fuel move, when possible, to oil, and similarly, a gas glut would regression (SUR) is estimated using the oil and gas equations specified by (1). Table 3 displays the results. Again, the coefficients are sizeable given the intraday absolute returns shown in Figure 1.

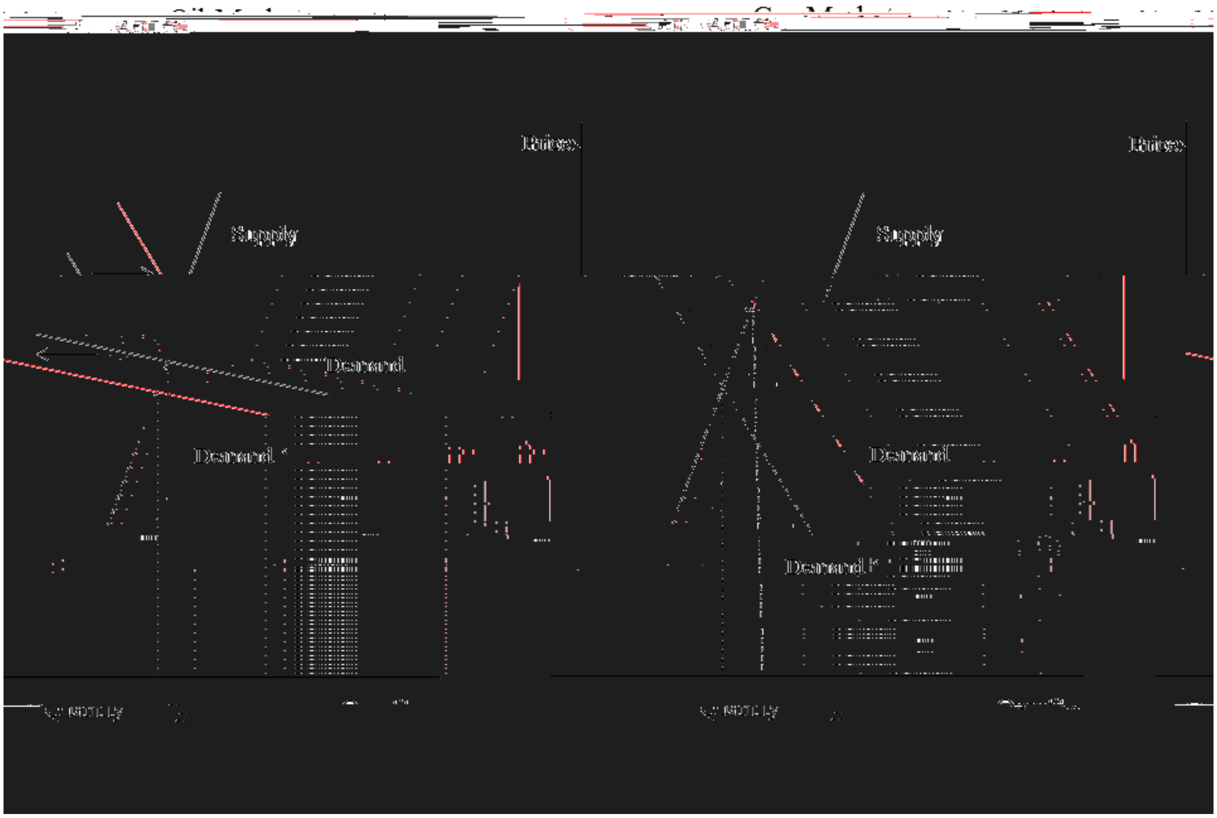
Table 3: SUR model for oil and gas price volatility

	Oil price volatility	Gas price volatility
Oil shortage S < 0	***-.00235 (.00030)	**-.00101 (.00041)
Oil glut S > 0	***.00436 (.00030)	**.00104 (.00040)
Gas shortage S < 0	***-.00212 (.00061)	***-.02432 (.00087)
Gas glut S > 0	***.00198 (.00044)	***.02110 (.00064)

Notes: ***, ** and * represent 99 %, 95 % and 90 % significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,850. Only the oil and gas inventory variables are reported to save space.

As would be expected, there is little change in the estimated impacts of gas gluts and shortages on the volatility of oil. And consistent with spillover effects across the markets, surprise oil gluts and shortages have the expected directional impact on gas volatility. What perhaps needs explaining is that the effect of both *gas gluts and gas shortages* on the *oil* price volatility is more than twice as strong as the effect of *oil gluts and oil shortages* on the *gas* price volatility. At first thought, the stronger effect of gas gluts and shortages on oil prices when compared to the effect of oil gluts and shortages on gas prices may seem and for gas shortages are nearly equal in sign and magnitude.

Figure 2: Comparison of e ect of inventory change on oil and gas markets



4.1.4 E ect across Futures Contract Maturities

Table 4 displays the results for the oil and gas inventory variables. The two-way causality nouncements indicate that volatility is lower than usual for approximately 70 minutes before the oil announcements and 30 minutes before the gas announcements. After the announcement, oil volatility remains higher than usual for approximately 60 minutes following the oil announcements and 20 minutes following the gas announcements. This suggests that oil market participants decrease their trading activity while waiting for the inventory report announcements and increase their trading activity once the reports are released.

We find similar results for gas futures volatility, which remains higher than usual for approximately 40 minutes after the oil announcements and 30 minutes after the gas announcements. This fast adjustment is consistent with what has been found in other financial markets, for example, the effect of macroeconomic announcements on bond price volatility (Balduzzi, Elton and Green, 2001).

4.2 Robustness Checks

4.2.1 Structural Breaks and Business Cycle

The oil and gas markets were subject to numerous shocks and developments during the sample period, such as the increase in futures trading, the introduction of LNG technology, and the development of the shale gas fields. Hence we repeated our estimations adding dummy variables for individual years and, separately, for individual months. The sample period was also split into sub-periods before and after the recent recession. In addition, a structural break test was performed following Hansen (2001). The results indicating bidirectional causality were unaffected nor were the magnitudes of the parameter estimates appreciably different. Controlling for seasonal effects, likewise, had no material impact on our findings.

Finally, because oil and gas volatility varies during the sample period, we included ratios of the absolute value of the daily return to the absolute value of average daily return for each day of the week and added dummy variables for periods when oil and gas prices were below mean values. Again, there was no substantive change in our results.

Because oil and gas prices exhibit time-varying volatility, generalized autoregressive conditional heteroskedasticity (GARCH) models lend themselves as tools for analyzing the data in addition to the OLS. We, therefore, implemented the EGARCH(1,1) model with one ARCH term and one GARCH term with the Gaussian distribution that allows for an asymmetric reaction to positive and negative innovations.

$$R_j = \alpha + \sum_{i=1}^{I} \beta_i R_{j-i} + \sum_{k=1}^{K} \sum_{l=0}^{L} \gamma_{kl} S_{k;j-l} + \sum_{k=1}^{K} \sum_{l=0}^{L} \delta_{kl} S_{k;j-l} \cdot I(S_{k;j-l} > 0) + \sum_{m=1}^{M} \theta_m \{Z_m\} + \varepsilon_j; \quad (2)$$

$$\log(h_j^2) = \omega + \beta \log(h_{j-1}^2) + \alpha \left| \frac{\varepsilon_{j-1}}{\sqrt{h_{j-1}}} \right| + \gamma \frac{\varepsilon_{j-1}}{\sqrt{h_{j-1}}}; \quad (3)$$

where equation (2) is the mean equation, equation (3) is the conditional variance equation, and the distribution of the error conditional on an information set at time j, Ω_j, is assumed to be $\varepsilon_j | \Omega_j \sim N[0; h_j^2]$. The term $\frac{\varepsilon_{j-1}}{\sqrt{h_{j-1}}}$ captures the asymmetry because positive innovations $\varepsilon_j > 0$ are allowed to have different effects on the conditional variance than negative innovations $\varepsilon_j < 0$. The results were identical to what we found with OLS in terms of signs, significance, and relative magnitudes.

5 Implications and Conclusions

Despite strong theoretical foundations to expect two-way causality and empirical results the crude oil and natural gas markets concluded that the oil market affects the gas market but not vice versa. This paper dispels the notion of one-way causality, finding empirical support for bi-directional causality and lending support to a hypothesis of interrelated markets.

Our direct test measures how futures prices respond to surprises in inventory announcements. Our estimates indicate the immediate (meaning effect of the shock on the closest 10-minute interval) impact of a 1% surprise in gas inventory changes the oil price by $0.158. This compares to the average price change over 10-minute intervals on non-announcement days, i.e., Mondays, Tuesdays and Fridays, of $0.100 which is more than 50% increase. Applying this price impact on average daily open interest of futures contracts for the first six months to the worth of the market amounts to $84,000,000. This is a conservative estimate since it considers only the effect during the first 10-minute interval. And finally, as open interest contracts have been rising steadily, the magnitude of the impact on the worth of the market would be even higher now.

As documented by Buyuksahin, Haigh, Harris, Overdahl and Robe (2008) and Basu and Gavin (2011), the recent dramatic rise in oil and gas futures trading is mainly due to greater participation by financial institutions (investment banks, mutual funds, pension funds, university endowment funds and hedge funds) in trading commodity derivatives to increase gain and diversify risks. The results here allow commodity markets investors to better understand the sources of risks and price volatility spillovers between the markets. They also allow policymakers to better manage volatility spillovers between the energy markets and financial markets, mitigating risks and improving the efficiency of the economy.[18] Moreover, recent

[18] See, for example, Kilian and Park (2009), Cifarelli and Paladino (2010), and Hammoudeh, Yuan and McAleer (2010).

policy has promoted gas as a cleaner, cheaper and domestic alternative to oil. As shale gas discoveries lower the price of gas, supply shocks in the gas markets may increasingly reverberate through the oil market and economy in general.

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References

[1] Andersen, T.G., Bollerslev, T., Diebold, F.X., Labys, P., 2000. Great realizations. Risk (March), 105-109.

[2] Andersen, T.G., Bollerslev, T., Diebold, F.X., Vega, C., 2003. Micro e ects of macro announcements: Real-time price discovery in foreign exchange. The American Economic Review 93, 38-62.

[3] Asche, F., Osmundsen, P., Sandsmark, M., 2006. The UK market for natural gas, oil and electricity: Are the prices decoupled? The Energy Journal 27, 27-40.

[4] Ates, A., Wang, G.H.K., 2007. Price dynamics in energy spot and futures markets: The role of inventory

[23] Hansen, B.E., 2001. The new econometrics of structural change: Dating breaks in U.S. labor productivity. Journal of Economic Perspectives 15, 117-128.

[24] Kilian, L., Park, C., 2009. The impact of oil price shocks on the U.S. stock market. International Economic Review 50, 1267-1287.

[25] Kuper, G.H., van Soest, D.P., 2006. Does oil price uncertainty a ect energy use? The Energy Journal 27, 55-78.

[26] Linn, S.C., Zhu, Z., 2004. Natural gas prices and the gas storage report: Public news and volatility in energy futures markets. The Journal of Futures Markets 24, 283-313.

[27] McKenzie, M.D., 1999. Power transformation and forecasting the magnitude of exchange rate changes. International Journal of Forecasting 15, 49-55.

[28] Mu, X., 2007. Weather, storage, and natural gas price dynamics: Fundamentals and volatility. Energy Economics 29, 46-63.

[29] Pindyck, R.S., 2004. Volatility in natural gas and oil markets. The Journal of Energy and Development 30, 1-19.

[30] Samuelson, P.A., 1965. Proof that properly anticipated price changes uctuate randomly. Industrial Management Review 6, 41-49.

[31] Villar, J.A., Joutz, F.L., 2006. The relationship between crude oil and natural gas prices. Energy Information Administration, O ce of Oil and Gas, Washington DC.