The Response of U.S. Natural Gas Futures and Spot Prices to Storage Change Surprises and the Effect of Escalating Physical Gas Production

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March 16, 2013

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We thank Louis Ederington, Peter Locke and an anonymous referee for their comments on an earlier draft of the paper. The authors gratefully acknowledge financial support for this research from the National Science Council of Taiwan, the University of Oklahoma and the Jackson College of Graduate Studies and Research at the University of Central Oklahoma. We also thank Andrew Stewart of Bloomberg for providing us with the analyst forecast data on natural gas in storage assembled by Bloomberg. An earlier version of this paper circulated under the title ""Fundamental News and the Behavior of Commodity Prices: Price Discovery and Jumps in U.S. Natural Gas Futures and Spot Prices".

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ABSTRACT

We study the behavior of U.S. natural gas futures and spot prices on and around the weekly announcements by the U.S. Energy Information Administration of the amount of natural gas in storage. Our study spans August 2002 through August 2011. We identify an inverse empirical relation between changes in futures prices and surprises in the change in natural gas in storage and that this relation is not driven by the absolute size of the surprise. We also present direct evidence of price discovery occurring in the futures market for natural gas with that information then flowing to the spot market. We find that post 2005, corresponding to a period of significant increases in the production of natural gas in the United States, the response of prices to storage surprises became more negative. At a more general level our study provides insights into the association between price changes and information about changes in the amount of a commodity or asset held in storage and the implications of these associations for modeling the behavior of commodity prices changes.

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I. Introduction

Trading in the spot and derivatives energy markets continues to grow at an unprecedented rate. At the same time these markets have become increasingly more tightly integrated through the dependence of some cash market contract prices on futures prices (Federal Energy Regulatory Commission (FERC), 2006). Not the least interesting amongst the energy commodity markets is the market for natural gas. Open interest in the NYMEX natural gas futures contracts grew at a compound annual rate of 13.5% between January 1998 and January 2012 (http://www.cftc.gov/OCE/WEB/data.htm). At the same time extreme fluctuations in natural gas spot and futures prices have become distinctive characteristics of these markets. Finally, the physical natural gas market has undergone a significant transformation since 2005 with the ramping up of production from shale fields such as those located in Texas (Barnett), Oklahoma (Woodford), and Pennsylvania and surrounding states (Marcellus). Shale gas production now represents roughly 14-15% of total natural gas production in the United States. To put this in perspective between 1995 and 2005 annual gas production in the U.S. was fairly flat. The years 2006-2011 on the other hand saw gross gas withdrawals rise at a compound annual rate of roughly 4%.

Not surprisingly, natural gas price behavior has become a focal point amongst gas users as well as investors especially in light of recent credit problems within the industry and the exposure of many hedge funds and other investors to energy-related investments (e.g. Amaranth Advisors, MotherRock, L.P.). Significant demand for derivative products useful in the management of energy price risk as well as for pure investment purposes has arisen as a consequence (Geman, 2005; Leppard, 2005; Eydeland and Wolyniec, 2003). All told, understanding the nuances in the price behavior of this commodity is a crucial factor for successfully managing the risks associated with its use either as a factor of production or an investment. In particular, an understanding of these issues during the current physical gas regime that has been witnessed since 2005 is an important piece of the puzzle.

This study examines the relation between surprises in fundamental information, specifically, changes in the amount of natural gas in storage, and changes in natural gas futures and spot prices. We find an inverse relation exists between the change in storage surprise (actual change minus expected change) and natural gas futures price changes on the day of the EIA storage announcement. The price response is not differentially greater for larger absolute storage surprises. We find no evidence that futures prices respond differently to positive surprises as compared with negative surprises or that the market environment, measured using the level of storage, influences the response. We also find that storage surprises are not influenced by the dispersion of the predictions of individual analysts. Finally, we find that the market response was larger in absolute value during the post 2005 period, a period during which there was a significant ramp up of activity in the natural gas market.

One ubiquitous feature of natural gas spot and futures prices that complicates risk management is the proclivity of these prices to exhibit jumps. Figure 1 presents the time series of daily changes in the logs of the closing settlement prices for the front month

NYMEX natural gas futures contract over the period August 30, 2002 through August 30, 2011. The series exhibits what appear to be jumps.[1] Excess kurtosis for the *daily* log price change series is roughly equal to 8.1, while excess kurtosis values for the time series of *one-week* and *two-week* log price change series based upon the same raw data are equal to 2.5 and 2.0 respectively.[2] Das and Sundaram (1999) show that when excess kurtosis falls as the time horizon for computing returns increases a jump process may partially explain the price dynamics. Models of the dynamics of natural gas prices generally have treated sharp changes in prices as a generalized jump process with a constant jump parameter (see Clelow and Strickland, 2000; Deng, 2000; Seppi, 2002; Eydeland and Wolyniec, 2003; Geman, 2005, for examples and the references therein). Formal studies of the fundamental determinants of these jumps however are largely absent from the literature. Like Linn and Zhu (2004) we focus on news about natural gas supply and demand conditions as reflected in the change in the amount of natural gas in storage. Linn and Zhu focus on the residual volatility in natural gas futures prices associated with news about the change in gas in storage but do not directly investigate the impact of storage change news on the change in the level of prices. In contrast we focus on the relation between price level changes and the storage change surprise, but account for heteroscedasticity. Our study provides an important compliment to the Linn and Zhu study. In addition, unlike the studies of Linn and Zhu and Gay, Simkins and Turac (2009), we also investigate both the relation between storage change surprises and spot

[1] Natural gas prices tend to also exhibit a seasonal pattern rising during the winter months and falling during the summer months.

[2] The kurtosis of the daily log price change equal to 7.7 is computed excluding the close Friday to close Monday change. If the weekend change is included the kurtosis increases to 11. Technically the term ‘return’ is not appropriate when speaking of a futures contract since there is no initial investment and so we opt for log price change.

natural gas price changes as well as the relation between spot price changes and futures price changes coincident with the release of storage change information.

Understanding the influence of storage information on price changes is important for several reasons. First, if information about changes in the amount of gas in storage is predicted with error, then surprises will occur. Documenting whether surprises arise and the impact they have on prices will provide insights into the distribution of potential shocks to natural gas prices arising from the release of information about the actual change in gas in storage. This may have important implications for modeling natural gas price dynamics as well as for public policy regarding the timing of reports on gas in storage. Second, information about the change in natural gas in storage is currently released by the U.S. Energy Information Administration (EIA) at the same time each week. If there is an association between surprises about the change in storage and price jumps then it provides a basis for a deterministic timing component in dynamic models of North American natural gas futures and spot prices. Finally, if market participants condition their interpretation of storage change surprises on the size or the sign of the storage surprise, or on the general state of the market environment, then the influence of surprises may vary across time and market conditions. Knowledge of such conditions could contribute to refinements of dynamic models of natural gas prices based upon fundamentals. Our empirical analysis addresses each of these questions.

Our study also contributes to the literature on the quality and impact of analyst forecasts of fundamental variables on security prices. Our proxy for expectations about the change in gas in storage is a consensus forecast of analysts' predictions developed and distributed each week by Bloomberg. While much research has been done on analysts' forecasts of earnings and the impacts of those forecasts on security prices (for instance, Kothari, 2001; Bartov, Givoly and Hayn, 2002), little formal research has been done on forecasts of market specific fundamentals impacting commodities markets.

Finally, our results contribute to the growing literature on asymmetrical responses of financial market prices to news, extending that investigation to the arena of a commodity market. Several authors have explored the relation between market price responses to news conditional on whether the news is released during 'good' versus 'bad' times. Veronesi (2001) and Conrad, Cornell and Landsman (2002) for instance, suggest that security prices respond more to bad news in good times. There is evidence from the foreign exchange market (Anderson, et al., 2003), the equity market (Conrad, et al., 2002) and the T-bond futures market (Hautsch and Hess, 2002) supporting this thesis.[3] We present new evidence on the responses of futures prices for an economically important commodity, natural gas, to both the sign and size of the storage change surprise as well as to the market environment at the time the storage news is released.

In contrast, the spot price of natural gas reacts not on the day the EIA report is released but on the day after. This lagged response is consistent with the institutional fact that trading in the spot market is largely concluded prior to the time the EIA report is released. When we control for the change in the futures price that occurs on the day of the EIA report we find that the lagged association between the spot price change and the storage surprise vanishes. Thus, any information revealed to the spot market appears to

[3] McQueen and Vorkink (2004) develop a model in which investors become more sensitive to news following unexpected perturbations in stock prices and present evidence consistent with this their thesis. A related literature examines the influence of news on stock prices across the business cycle. McQueen and Roley (1993) examine the relation between equity prices and macroeconomic news and find evidence that stock price reactions to news is related to stages of the business cycle. Boyd, Hu and Jagannathan (2005) present evidence that the impact of news about unemployment on stock prices is conditional on whether the economy is in a contraction or an expansion phase.

have been completely impounded in the change in the futures price on the day on which the EIA report is released.

Transparency is considered a valued trait in futures markets. Our study provides important facts about the implications of the current system for reporting natural gas in storage for natural gas price changes. The results should therefore be of interest not only to academics who follow the energy markets and to risk managers and investors but also to policy-makers who regulate this aspect of the information flow to natural gas market participants. Further, our results show that storage change information is first reflected in the futures market and then impacts the spot price. This result heightens the importance of careful and thoughtful oversight of the futures market for natural gas.

The remainder of the paper is organized as follows. Section II provides a brief introduction to the general behavior of natural gas futures prices and some details regarding the physical natural gas market. Section III provides a description of the sample data. Section IV presents results on the character and accuracy of the analyst forecast data obtained from Bloomberg. Sections V and VI present and discusses empirical results from our study of the relation between surprises in the change in storage and natural gas futures price changes. Section VII presents results for spot price changes. The final section presents our conclusions.

II. Natural Gas Price Responses to News about Changes in Natural Gas Storage

The level of natural gas in storage follows a seasonal pattern, rising during slack demand periods, generally the second and third quarters of the year, and falling during peak demand periods, generally the fourth and first quarters.[4] Natural gas production in

[4] Energy Information Administration (EIA): http://tonto.eia.doe.gov/dnav/ng/hist/nw_epg0_sao_r48_bcfw.htm

the United States was basically flat between 1995 and 2005. Since 2005 however there has been a significant acceleration in production all largely due to shale gas production. The escalation was driven in part bybetter economics arising from technology innovations in horizontal drilling and hydraulic fracturing. [5] Since the end of 2005 gross withdrawals of natural gas have risen at a compound annual rate of roughly 4% per year.Aside from advances in technology another possible motivating factor for the shift was the adoption of the Energy Policy Act of 2005 that exempted natural gas drillers from some restrictions applying the Safe Drinking Water Act. . Aside from the apparent structural change in 2005, natural gas in in storage serves to act as the marginal source of supply providing a cushion for meeting unexpected changes in production or demand.

The change in natural gas in storage is equal to production minus demand (less any product used or lost as a result of the storage technology), and thus provides a measure of whether demand is in excess of production.[6] Due to the seasonal nature of consumption demand, during any particular calendar week there is an expected change in storage that would bring the total amount in storage to what we might refer to as the expected 'normal' level. The normal level is that level consistent with the current season and expected future demand. A conclusion which follows is that actual changes in the amount of gas in storage relative to expected changes should reveal fundamental information about changes in supply and demand conditions and consequently result in

[5] One study has estimated the breakeven price for shale gas to be in the range $5-$7 MMBtu depending on the location of the reserves (Berman and Pittinger, 2011, U.S. Shale Gas: Less Abundance, Higher Cost, http://www.theoildrum.com/node/8212

[6] Small amounts of gas are lost or used up as a result of the technologies for storing natural gas. For a non-technical discussion off details on gas storage technologies see Eydeland and Wolyniec (2003, pp. 351-367). Depleted natural gas and oil reservoirs are the primary underground storage facilities in the United States.

upward or downward pressure on the price of natural gas. The generally accepted model for commodity futures prices (Black, 1976; McDonald, 2006) states that the futures price today for delivery at time T equals today's spot price times an adjustment factor based upon the cost of storage, the interest rate and the convenience yield. A shift in beliefs regarding supply and demand conditions should cause a shift in both the spot price and the whole menu of futures prices.

A natural set of predictions emerge from the preceding discussion. If the current reported change in natural gas in storage is less than the expected change, market participants are predicted to infer that the level of gas in storage is too low to meet future expected demand while at the same time acting as a buffer against demand shocks. These perceptions of tighter supply are predicted to manifest themselves in an increase in the price. If on the other hand the actual change in storage is above the expected change, then market participants are predicted to infer that too much gas has been stored. In the latter case the market is predicted to react by reducing the price. In sum we predict an inverse relation between natural gas price changes and surprises in the change in gas in storage measured as the difference between the actual change in storage and the expected change in storage.

III. The Data

The sample period for our study covers August 30, 2002 – August18, 2011. We examine the daily settlement prices of NYMEX natural gas front month contracts and daily volume-weighted spot prices for natural gas for delivery at the Henry Hub.[7] All

[7] The Henry Hub is the pricing point for natural gas delivery specified in the NYMEX Natural Gas Futures Contract (http://www.nymex.com/ng_pre_agree.aspx). The Henry Hub interconnects with thirteen natural gas pipelines, is located in Louisiana, and is operated by Sabine Pipeline LLC: (http://www.sabinepipeline.com/public/public_frame.asp) .

price data are obtained from Platts.[8] The bulk of spot trading for next-day delivery is concentrated in the morning prior to the deadline for scheduling of transmission (the nomination deadline) for next-day delivery set by the North American Energy Standards Board.[9] The spot price data are volume-weighted, so, the weighted-average transaction price for the day will reflect more of the trades done early in the day, in other words, prior to the EIA report release.[10]

We obtain actual storage survey data from the U.S. Energy Information Administration (EIA) website.[11] The weekly EIA report contains the actual level of natural gas in storage for the United States and the change in the level in storage. The EIA report is released on Thursday morning at 10:30 AM Eastern Time. The report provides storage data as of the prior Friday. When Thursday is a holiday the survey is usually released on Friday and when Thursday and Friday are holidays the survey is usually released on Wednesday. In order to avoid any potential biases we restrict the

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[8] See http://www.platts.com/Natural%20Gas/Resources/Methodology%20&%20Specifications/ for a complete description of the methods used by Platts in assembling spot price data.

[9] Nominations are formal requests to transport gas via pipeline. Among other things, nominations include the requested receipt and delivery points, the quantity to be transported, the upstream party providing the gas and the downstream party receiving the gas. The nomination process involves the parties interested in shipping gas competing for pipeline capacity. The NAESB standard is that timely nominations for next-day shipping must be concluded by 11:30 AM Central Time. In a conversation with an analyst in the natural gas section at Platts it was confirmed that in fact most nominations for next-day shipping are concluded by 9:30 AM Central Time. The EIA report is released at 10:30 AM Eastern Time so the heaviest spot trading of the day is largely over before the EIA report is released. The spot price data at our disposal are daily volume-weighted prices and so for any date the spot price observation will be weighted more toward trades done early in the day. Data from Platts confirm this statement which is also supported by comments in the industry press. For instance in a column highlighting the gas market's reaction to a news report on storage which appeared in the Gas Daily ("Whiplash: Volatile prices reverse course again", Gas Daily, January 5, 2004), the column states in reference to the spot market: "In the spot market, most trading was done by the time EIA released its storage report so cash prices were largely unaffected by the NYMEX contract's late plunge."

[10] Only the volume-weighted average transaction price series are available from commercial data providers such as our source Platts.

[11] EIA: http://tonto.eia.doe.gov/dnav/ng/hist/nw_epg0_sao_r48_bcfw.htm

sample in the following way. When a data revision due to an error or a change in computation methodology is reported in a weekly EIA storage report we delete that observation as well as the observation for the prior week, i.e. the observation that is being revised.[12]

Our benchmark for the expected week-to-week change in natural gas in storage is a weekly consensus analyst forecast published electronically by Bloomberg and which is available on the morning of but prior to the release of the weekly EIA report.[13] Bloomberg surveys analysts from the consulting industry, production companies and investment banks to obtain their forecasts of the change in storage for the time period covered by the EIA report. The Bloomberg report includes individual analyst projections of storage changes and the implied storage levels as well as the average projection. The Bloomberg survey of predicted changes in storage is generally regarded as the best available amongst practitioners and represents the forecasts that are most readily available to market participants. We examine the accuracy of these forecasts in the next section.

IV. Characteristics of the Bloomberg Survey of Storage Change Expectations

Panel A of Table 1 reports statistics on the general accuracy of the analysts' predictions about the change in the storage level as compared with the actual storage level change reported by the EIA. The absolute prediction error is computed as the

[12] During the period between May and August 2002, there were 6 revisions due to reporting errors or methodology changes. In the subsequent 3 and a half year period, the number of revisions is also 6.

[13] The use of analysts' predictions as a basis for measuring market predictions has been employed in numerous settings the most common being studies of earnings expectations. See Kothari (2001) and Bartov, Givoly and Hayn (2002) and the references therein for examples of this literature. We thank Andrew Stewart of Bloomberg for providing the analyst forecast data on natural gas in storage assembled by Bloomberg.

absolute value of the difference between the average predicted change from Bloomberg and the actual change as reported in the EIA report. The average absolute prediction error across all weeks in the sample period is about 7.98 Bcf (Billion cubic feet). We divide the calendar months into winter and summer seasons and classify the remaining months following industry practice as 'shoulder months'. The calendar month divisions used are: Winter: November to March; Summer: June to August; Shoulder1: April to May; Shoulder2: September to October. The average absolute prediction error is larger during the winter season (November to March) and is statistically different from the average absolute prediction errors during the other subperiods.[14] The absolute value of the prediction error as a fraction of the actual change in gas in storage is on average largest during the winter months and the first shoulder months. These results are generally consistent with results documented by Gay, Simkins and Turac (2009) who present a detailed analysis of the analyst forecast data.

Panel A also reports the standard deviation of the weekly survey errors for each subperiod where the error equals the actual change in storage minus the consensus average forecast of the change from the Bloomberg survey. We label the error ΔS_t^{sur}, where t indexes the date of the EIA report. For the winter months the standard deviation of the error equals 13.89 Bcf, the largest value across the calendar subperiods. These results suggest that analysts' predictions about the storage change are subject to more error during the winter months.

[14] The t-test statistics (two sample assuming unequal variance) are -3.70 (summer versus winter, $p < .01$), -4.77 (shoulder1 versus winter, $p < .01$), -3.84 (shoulder2 versus winter, $p < .01$). Tests for median equality (Conover, 1980) are consistent with the mean tests.

One part of our analysis involves controlling for uncertainty in beliefs about the expected change in storage. We use the cross-sectional standard deviation of the individual analysts' forecasts for each separate Bloomberg report as a measure of uncertainty.[15] For each Bloomberg survey report we compute the standard deviation of the forecasts included in the survey, giving us a sample of standard deviations, $StdDev_t$, for t = 1, ..T where T equals the number of reports available for the calendar period we study . The last two rows of Panel A report the average standard deviation of the analysts' forecasts for the whole sample period and for the individual subperiods along with the average number of analysts. The average standard deviation is largest during the winter months suggesting there is more disagreement amongst analysts during those months, potentially due to greater uncertainty about demand.[16]

We test the hypothesis that the Bloomberg consensus forecast of the change in storage is an unbiased prediction of the actual change in the storage level using the following model

$$\Delta S_t = \alpha_0 + \alpha_1 \Delta \bar{S}_{B,t} + \varepsilon_t \quad (1)$$

where ΔS_t is the actual storage change number as reported by the EIA on day t, $\Delta \bar{S}_{B,t}$ is our notation for the average predicted change reported by Bloomberg that applies to the EIA report issued on day t, and ε_t is a projection error. If the average predicted change $\Delta \bar{S}_{B,t}$ is an unbiased predictor of the actual change then we should observe that the

[15] There are numerous precedents for the use of the standard deviation of analysts' predictions as a measure of uncertainty, see Stanford, et al. (2009).

[16] The t-test statistics (two sample assuming unequal variance) are -6.18 (summer versus winter, p <. .01), -5.69 (shoulder1 versus winter, p <. .01), -3.56 (shoulder2 versus winter, p <.01) .

estimate of α_0 is not significantly different from zero and that the estimate of α_1 is not significantly different from one.[17] The results are reported in Panel B of Table 1. We reject the joint null hypothesis that $\alpha_0 = 0$ and $\alpha_1 = 1$ (p-value for the F test statistic < .001).[18] The estimated coefficient for the slope equals 1.02 suggesting the average forecast underestimates the actual by about 2%. The estimation results do however show that the Bloomberg predicted changes explain 98.7% of the variation in the actual changes. We also estimate a naïve model in which the average change in actual storage over the prior five years for the calendar week in question is substituted in place of the average analysts predicted change reported by Bloomberg. The results are also reported in Panel B of Table 1. The results show that the naïve model explains only 81.5% of the variation in the actual change.

We also compute Theil's U (inequality) statistic for assessing the predictive accuracy of the Bloomberg forecast and the naïve forecast (Theil, 1966). If the forecasts of a model are perfect the U statistic will equal 0. The U statistic for the Bloomberg forecast data equals .056 and for the naïve forecast data U equals 1.225, indicating that the predictive content of the Bloomberg forecast is superior. The root mean squared error equals 10.94 for the Bloomberg forecast data and 41.82 for the historic forecast data.

We conclude that the Bloomberg forecast contains more information about the actual change in storage than the naïve history variable. We speculate that the primary reason the Bloomberg predictions explain more of the variation in actual storage changes is that analysts contributing predictions incorporate both information about changes in

[17] The general specification in equation (1) has a long tradition across many disciplines and stems from the original work of Muth (1961).

[18] The Wald Chi-squared test also rejects the null with p>.001. Regressions using the median analyst forecast yield similar results both in terms of coefficient estimates and test statistics.

storage implied in the history for prior years as well as current information on other macro variables that may be of relevance. Curiously the results reported in Panel B do not reject the null hypothesis that the intercept and the slope coefficient in the model based on naïve forecasts are jointly equal to 0 and 1. We conclude that while the Bloomberg forecast is biased, it is less noisy than the naïve forecast. Based upon these results we feel justified in using the Bloomberg data as a basis for measuring predictions. In separate tests, not reported, we find that the forecast errors from equation (1) are larger during the Winter subperiod, consistent with the results reported in Panel A

V. A First Look at Futures Price Changes

Table 2 reports the mean log price change for the day on which the EIA survey report is released and for the days before and after the release. The sample mean for the EIA report day equals -.335%, with a median of -.542%, both of which are more negative than for the immediate surrounding days. We test the null hypothesis that the observed log price changes for the EIA report date are drawings from a normal distribution using the Jarque-Bera test and reject the null for each day shown. Because the data are not normally distributed we use nonparametric tests for comparisons between days -1 and +1 respectively and day 0. The Wilcoxon signed-ranks test (Conover, 1980) leads to rejection of median equality for each comparison at the .05 level as does the Kruskal-Wallis test.[19]

Table 2 also reports the means and medians of the absolute log price changes for each day, which by their nature are also not normally distributed. The mean (3.071%) and median (2.04%) absolute log price changes are more positive on the day of the EIA

[19] Test statistics: Day 0 versus Day-1, Wilcoson 2.46 (p=.013), Kruskal-Wallis 6.05 (p=.013), Day 0 versus Day+1, Wilcoxon 2.17 (p=.029), Kruskal-Wallis 4.75 (p=.029). See Conover (1980) for test descriptions.

report than for any of the surrounding days. If the log price changes on the day of the EIA report (Day 0 in the table) are proportional to ΔS_t^{sur}, we might expect to see more overall dispersion in the sample of Day 0 price changes relative to the surrounding days. We test the null hypothesis that the medians of the absolute log price change for days -1 and +1 are individually different from the median for the EIA report day, Day 0. We reject the null at the .01 level for days -1 and +1.[20] These test results suggest that the sample of log price changes on Day 0 exhibit more dispersion than is observed for the surrounding days. We speculate the large dispersion in the Day 0 data is induced by jumps resulting from the release of storage information revealing surprises about the change in gas in storage. We return to cross-sectional tests of this conjecture below.

Table 2 also reports results for spot prices. Here we see that the response on the day the EIA report is released is negative but smaller. In contrast the negative response occurs on the day after. We conjecture that this is due to the fact that most spot trading is conducted on the day of the EIA release prior to the report release time.

VI. Price Response to the Storage Change Surprise

1. Control Variables

Changes in natural gas prices may respond to several factors on any day aside from information related to the change in gas in storage. Two important influences are the weather and oil prices.

We control for general weather effects in the following manner. We prepare two temperature measures, the Cooling Degree Day measure and the Heating Degree Day

[20] Wilcoxon test statistics: Day -1 (5.14, $p < 0.00$), Day +1 (4.87, $p < 0.00$). Similar p-values are found using the Kruskal-Wallis test.

measure. A Cooling Degree Day is one for which the actual temperature minus 65 degrees F is greater than zero. When this is the case the calendar day is assigned the value of the difference, when the condition is not met the day receives a value of 0. A Heating Degree Day occurs when 65 degrees F minus the actual temperature is greater than zero. When this condition is met the day is assigned the degree difference and is otherwise assigned a value of zero. Therefore, each day receives both a Cooling Degree Day measure (CDD) and a Heating Degree Day measure (HDD). Weather data are obtained from regional federal and state climate centers. Our dataset contains variables measuring actual weather conditions and the data on normal conditions measured over the prior 30 year period as of the date of relevance. Weather data are compiled for the following cities: Dallas, Baton Rouge, Atlanta, Chicago, Los Angeles, Phoenix, Saint Louis, New York, Philadelphia, Oklahoma City and Salt Lake City. We compute an aggregate weather index for the aforementioned cities. We then compute a Cooling Degree Day measure and a Heating Degree Day measure for each day on which an EIA storage report was released using the weather index. Therefore, each day during our sample period receives both a Cooling Degree Day measure and a Heating Degree Day measure.

Aside from changes in general weather conditions catastrophic surprise, weather changes, such as hurricane activity may also have an influence. We test the robustness of our results by controlling for hurricane activity.

Oil prices and natural gas prices are known to be related as they are often substitute energy sources (Villar and Joutz, 2006). Changes in oil prices are used as a control for changes in the prices of substitute goods for the generation of energy related outputs. The changes in the log daily settlement prices for the front month NYMEX crude oil contract are used as the oil price control. The oil price data are obtained from Platts.

2. The Statistical Model

We estimate the following general model for the day on which the EIA report is released.

$$R_0 = \alpha_0 + \alpha_1 OilPRET_0 + \alpha_2 CddDif_0 + \alpha_3 HddDif_0 + \alpha_4 \Delta S_0^{sur} + \varepsilon_0 \qquad (2)$$

where R_0 is the one day log price change for the nearby natural gas futures contract traded on NYMEX, or the one day log spot price change, *OilPRET* is the one day log price change of the nearby front month contract for Texas Intermediate Crude oil traded on NYMEX, *CddDif* is the difference between the actual Cooling Degree Day measure for the day and the 30-year average Cooling Degree Day measure for the day, and *HddDif* is the difference between the actual Heating Degree Day measure and the 30-year normal Heating Degree Day measure for the day. The variable ΔS_0^{sur} is defined as the actual storage change as reported in the EIA storage survey, minus the expected storage change as reported by Bloomberg.

We present results computed using least squares estimates. Newey-West HAC standard errors are employed to account for heteroscedasticity and autocorrelation.[21]

3. Price Response to the Storage Change Surprise

We have defined the storage shock as the difference between the actual storage change and the expected change. Hence a positive shock (surprise) indicates that gas in

[21] Newey and West (1987).

storage is higher than expected and conversely for a negative shock. The estimation results for equation (3) are reported in Table 3. On the day of the EIA news release, the estimated coefficient for the surprise variable ΔS^{sur} is negative and statistically significantly different from zero (p-value <.000). Results (not reported) indicate the effect of the surprise is concentrated on the day the EIA report is released.

As we pointed out earlier, there was a structural shift in the production of physical gas following 2005 as compared with the prior 10 years. We account for this structural change by introducing a dummy variable that takes the value 1 following 2005 and 0 otherwise. We also interact this variable with the storage change surprise variable. The results are presented in column 2. As can be seen from the results in column 2, the coefficient on the dummy variable is not significantly different from zero. However, the coefficient on the interaction variable is negative and statistically significant. This suggests that the market's response became more intense after the shift in natural gas production occurred.[22]

4. Control Variable Influences

The results presented in Table 3 clearly indicate that changes in gas futures prices are statistically significantly and positively related to changes in crude oil prices. Since oil prices are largely determined in a global market and have more depth geographically, and, the natural gas market is largely a domestic market, we hypothesize that oil prices

[22] In separate (not reported) results we investigate the relation between the change in the natural gas price on each of the four days prior to the EIA release and the factors described above with one exception. As the actual storage change is not known prior to the EIA release in place of the actual storage surprise we use the difference between the expected change from Bloomberg and the five-year average of the changes for the same week. The 'surprise' is therefore the difference between the Bloomberg forecast and a naïve forecast based upon historical data. We find that the oil price change is positively associated with the natural gas price change, that there is generally no association between the weather variables and the natural gas price change, and that the storage surprise variable is also unrelated to the price change.

impact gas prices, not the other way around. We also estimated the model (not reported) including the lag 1 oil price change and found no qualitative differences in the results.

In general, we do not find that the weather in the summer (Cooling Degree Days, *CddDif*) has a significant impact on natural gas prices. Likewise, departure from the norm during the winter (Heating Degree Days, *HddDif*) does not tend to have a positive influence.

5. Size of the Storage Change Surprise and the Price Response

We extend our examination now to an investigation of whether the relation between gas price changes and the size of the storage change surprise is driven by large surprises only or whether the results reported in Table 3 present a uniform picture. We compute the absolute value of the difference between the EIA reported change in storage number and the Bloomberg survey change in storage number and replace the storage surprise variable with a new variable defined as $\Delta S_t^{sur}(M)$, where M represents an error threshold. The variable $\Delta S_t(M)$ equals the difference between the actual change and the Bloomberg consensus forecast where the absolute value of the difference exceeds M and equals 0 otherwise. For example, ΔS_t^{sur} (8) equals the value of the surprise when the surprise is larger in absolute value than 8 Bcf and equals zero otherwise. That is, surprises less than 8 Bcf in absolute value would be considered unimportant. The frequency distribution observations for x >M is [M (frequency): 1 (405), 4 (283), 8 (161), 10 (124), 15 (66)].

We estimated the following model:

$$R_0^f = \alpha_0 + \alpha_1 OilPRET_0 + \alpha_2 CddDif_0 + \alpha_3 HddDif_0 + \alpha_4 \Delta S_0^{sur}(M) + \varepsilon_0 \quad (3)$$

where f connotes the futures log price change. The estimated values of α_4 are respectively for M = 1: -0.00116, 4: -0.00115, 8: -.00108, 10: -.0011, 15: -.00113. Each of the estimates is significantly different from zero at a significance level <.0001 but not economically indistinguishable from one another. We conclude the absolute size of the error does not influence the market's reaction.

6. Other Potential Factors Influencing the Impact of the Storage Surprise on Price Changes

We investigate the influence of several possible variables upon which the market may condition its response to the EIA report. We modify the model estimated as follows:

$$(4) \quad R_0^f = \alpha_0 + \alpha_1 OilPRET_0 + \alpha_2 CddDif_0 + \alpha_3 HddDif_0 + \alpha_4 \Delta S_0^{sur} + \alpha_5 X_0 \Delta S_0^{sur} + \varepsilon_0$$

where $X_0 \Delta S_0^{sur}$ is an interaction variable that measures the conditioning effect on the storage news. [23]

Evidence from other markets suggests that prices respond to events differently when the news is good versus bad (foreign exchange market, Anderson, et al, 2003; equity market, Conrad, 2001; T-bond futures market, Hautsch and Hess, 2002). We test whether the storage surprise impact on prices depends on the shock being positive or negative, essentially a test for asymmetry of response. In this case, X is a dummy variable taking the value of 1 if the shock is positive and 0 if the shock is negative. The coefficient estimate of α_5 is not significantly different from zero however the remaining results are as indicated in Table 3, suggesting the market does not respond differently to positive versus negative surprises.

[23] The results are available from the authors upon request.

We also tested whether prices respond differently depending on the state of the market. We use the storage level as the state variable. The estimated coefficient on the interaction variable is not statistically different from zero. Again the remaining estimated coefficients are not qualitatively different from those reported in Table 3. We conclude that overall the state of the market as we have measured it does not influence the change in the storage surprise/price change relation.

Finally, we investigate the impact of market uncertainty on the price response. We use the cross-sectional standard deviation computed from the change in storage forecasts reported for the individual analysts in the Bloomberg survey for each week as a measure of market uncertainty, the variable we defined earlier as $StdDev_t$. As reported earlier analysts' predictions regarding the storage change vary across analysts and across calendar seasons (Table 1). The coefficient on the conditioning interaction variable is not significantly different from zero, while again the remaining estimated coefficients conform with those reported in Table 3.

VI. Storage Surprises And Spot Price Changes

Table 4 reports results on the relation between the log spot price change and the actual surprise in the change in storage, ΔS_t^{sur}. On the day of the EIA report the relation between the change in storage surprise and the change in the log of the spot price is not significantly different from zero (column 1). This is consistent with the observation that most spot contracting on Thursday for next day delivery is completed prior to the release of the EIA report. However, we do find that there is a negative and significant relation (p <.001) identified between the change in the log spot price and the change in storage surprise on the day following the EIA report, column 2 of Table 4.

Column 3 of Table 4 presents the estimation results for the model of Column 2 but augmented with the lagged change in the futures price. When we control for the futures price change, the impact of the storage surprise announcement in the spot market on the day following the EIA report vanishes. The coefficient point estimate for the variable ΔR_{-1}^{f} (lagged change in the log of the futures price) is equal to .466, which while significantly different from zero, is also significantly different from 1.

VII. Conclusions

This study focuses on how one important piece of fundamental news about the supply of natural gas consistently creates jumps in the behavior of natural gas futures and spot prices. Specifically, we document a systematic influence of news about surprises in changes in the supply of natural gas in storage on changes in natural gas futures prices and spot prices.

We examine the reaction of settlement prices for the NYMEX front month natural gas contract to unexpected news about changes in the amount of natural gas in storage. The Energy Information Administration releases a report on Thursday of each week detailing changes in the amount of natural gas in storage. Prior to that release market participants are privy to a report issued by Bloomberg revealing the consensus estimate of changes in the amount of gas in storage as predicted by natural gas analysts.

We find an inverse and statistically significant relation between the change in storage surprise and the log futures price change. Further, we find that the size of the reaction has become larger post 2005. The era following 2005 has been associated with a dramatic increase in the production of natural gas in North America as compared with the 10 year period through the end of 2005, during which production was basically flat. On the other hand we find no evidence that the market reacts differently to positive versus negative storage change surprises nor to the absolute size of the storage change prediction error. We also find no evidence that variables related to the total amount of gas in storage (market environment state variables) influence the price response. Likewise we find no evidence that storage surprises based upon the consensus forecasts are given less weight the more disperse are the predictions of individual analysts.

In a separate analysis of the impact of the change in storage surprise on log spot price change, we find strong evidence that price discovery occurs first in the futures market and then is reflected in the spot market. The results show a significant and positive relation between log spot price changes and lagged log futures prices changes. Further, while log spot price changes are associated with the storage surprise with a one-day lag, that association vanishes when we control for the lagged change in the log futures price.

Our results present new insights into the determinants of jumps in natural gas prices and clues as to how they might be incorporated into a dynamic model of such prices. Specifically, because the EIA natural gas storage report is released at the same time each week, and given that our results show that surprises about changes in the storage level have a significant impact on price changes, and that the impact depends upon the size of the surprise, dynamic models of natural gas prices can easily at a minimum control for this effect with a deterministic factor related to the day-of-the-week of the EIA announcement. In addition, our results have important policy implications for the timing of the EIA report. If jumps in prices are regarded as potentially troublesome, perhaps because a jump could under some circumstances be interpreted erroneously by some market participants, then a policy of releasing the weekly storage report after the close of day trading might allow market participants ample time to consider the implications of any storage change surprise. The trade-off is that because there is trading in the after-hours market and because trading during that period tends to be thin, reactions during the after-hours market might be accentuated and might have unusual consequences for opening price quotes.

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Figure 1
Change in ln futures price for the near month NYMEX natural gas contract
August 2002 - August 2011 (Source: U.S. Energy Information Administration)

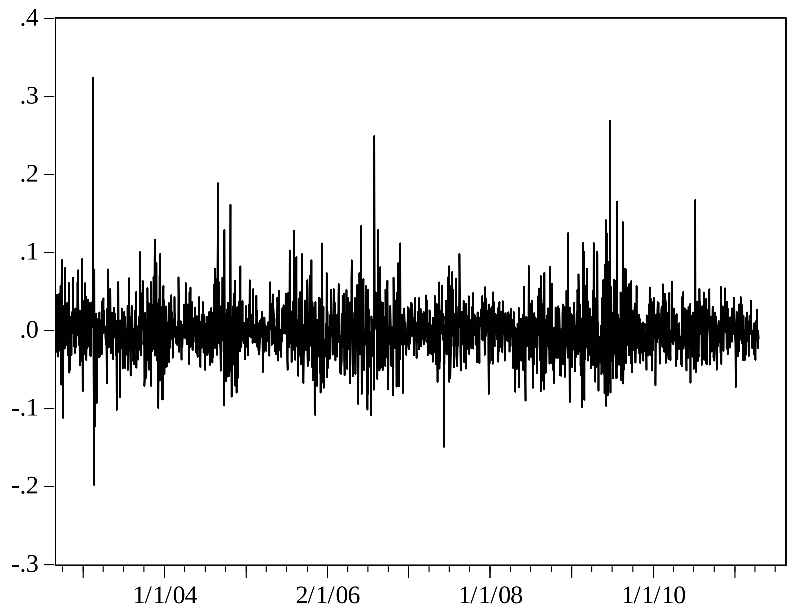

TABLE 1

Accuracy of the Natural Gas Storage Forecast Data

The U.S. Energy Information Administration compiles data on natural gas in storage in North America as of Friday of each week and releases the information in the form of a report the following Thursday at 10:30 AM Eastern Time. Panel A: Error = (Actual Change in Gas in Storage minus Consensus Average Forecast as reported by Bloomberg). Panels B, C: ΔS_t: actual change in the storage level reported on date t by the Energy Information Administration (EIA); $\Delta \overline{S}_{B,t}$: average of analysts' forecasts of the change in the storage level from Bloomberg (these data are a forecast of the change in the amount of gas in storage over the week covered by the EIA report); *StdDev*: the cross-sectional standard deviation of analysts' forecasts of the change in the storage level associated with the date t report; Dummy variables take the values 1 or 0 depending upon whether the report date falls within a specific calendar subperiod - *Winter*: November to March; *Summer*: June to August; *Shoulder1*: April to May; *Shoulder2*: September to October. Sample period August 30, 2002 – August 18, 2011. DW: Durbin Watson Statistic. P-values for tests are shown in parentheses. Newey-West standard errors.

Panel A Forecast versus Actual Change in Gas in Storage Descriptive Data

	Whole Period	Summer	Winter	Shoulder1	Shoulder2
Average Absolute Value Actual Storage Change (Bcf)	82.48	64.52	101.88	75.06	64.07
Average AbsoluteForecast Error (Bcf)	-7.98	6.15	10.56	6.03	6.34
% Absolute Error	12.5%	1.4%	20.9%	7.0%	10.8%
Error Standard Deviation (Bcf)	11.12	10.05	13.89	7.91	8.02
Average of the Standard Deviation of Analysts' Forecasts (Bcf)	10.09	6.31	13.59	7.71	8.78
Average Number of Analysts	21.89	21.40	22.0	22.11	21.281

TABLE 1 – continued

Panel B Test Of Whether the Analysts' Consensus Forecast Is An Unbiased Prediction of The Actual Change

$$\Delta S_t = \alpha_0 + \alpha_1 \Delta \bar{S}_{B,t} + \varepsilon_t$$

	α_0	α_1	DW	Adj R^2	F(α_0=0 and α_1 = 1.0)
Estimate	0.858	1.020	1.86	0.987	9.46
p-value	(0.115)	(<0.001)			(0.0001)
					F(α_1 = 1.0)
					12.17
					(.0005

Test Of Whether the Five-Year Average Change Is An Unbiased Prediction of The Actual Change

$$\Delta S_t = \alpha_0 + \alpha_1 \Delta \bar{S}_{5-yr} + \varepsilon_{t,5-yr}$$

	α_0	α_1	DW	Adj R^2	F(α_0=0 and α_1 = 1.0)
Estimate	-1.625	0.949	1.28	0.815	1.53
p-value	(0.53)	(p<0.001)			(0.217)
					F(α_1 = 1.0)
					1.64
					(0.200)

TABLE 2

Change In The Log Price For The Front Month Natural Gas Futures Contract and the Henry Hub Natural Gas Spot Price Surrounding The EIA Natural Gas Storage Survey Release

Log price changes are calculated based on the closing settlement prices of the NYMEX front month contracts traded during the period August 30, 2002 – August 18, 2011. The U.S. Energy Information Administration compiles data on natural gas in storage in North America as of Friday of each week and releases the information in the form of a report the following Thursday at 10:30 AM Eastern Time. In those cases when a national holiday falls on Thursday the report is released on Wednesday. Day 0 represents the day of the EIA report release while Days -1 and +1 are the prior and subsequent days respectively. The spot price is the volume-weighted daily spot price for natural gas from Platts. J-B is the Jarque-Bera test statistic for a test of the null hypothesis that the sample distribution of log price changes for a given day is a drawing from a Normal Distribution. All values except J-B are in percent form.

	Natural Gas Futures Prices				Natural Gas Spot Prices			
	Mean (Median) Log Price Change	Mean (Median) Absolute Log Price Change	StdDev	J-B (p-value)	Mean (Median) Log Price Change	Mean (Median) Absolute Log Price Change	StdDev	J-B (p-value)
Day -1	0.134 (0.139)	2.262 (1.687)	3.10	264.14 (0.000)	0.20 (0.254)	2.637 (1.801)	4.51	70143.93 (0.000)
Day 0 (EIA Report Released)	-0.3554 (-0.542)	3.071 (2.40)	4.19	502.95 (0.000)	-0.296 (-0.237)	2.666 (1.889)	3.97	1184.06 (0.000)
Day +1	0.042 (-0.197)	2.192 (1.795)	2.83	19.25 (0.000)	-1.49 (-1.125)	3.34 (2.639)	4.48	427.61 (0.000)

TABLE 3

Natural Gas Futures Price Responses To Storage Change Surprises On And After The Release Of The EIA Report

The estimated model has the following form

$R_0^f = \alpha_0 + \alpha_1 OilPRET_0 + \alpha_2 CddDif_0 + \alpha_3 HddDif_0 + \alpha_4 \Delta S_0^{sur} + \varepsilon_0$ where 0 indicates the day the EIA report is released, the variable R_0^f is the change in the log of the price for the front month natural gas NYMEX contract, *OilPRET* is the change in the log of the price of the front month crude oil NYMEX futures contract, *CddDif* is the difference between the actual Cooling Degree Day measure for the day (actual temperature minus 65 degrees if the temperature is greater than 65 degrees, 0 otherwise) and the 30-year average Cooling Degree Day measure for the day, and *HddDif* is the difference between the actual Heating Degree Day measure for the day (65 degrees minus the actual temperature if the actual temperature is less than 65 degrees and 0 otherwise) and the 30-year normal Heating Degree Day measure for the day. The variable ΔS_0^{sur} represents the difference between the actual change in storage and the expected change proxied by the Bloomberg consensus forecast. P-values for tests that an estimated coefficient is equal to zero (0) are reported in parenthesis. Sample period August 30, 2002 – August 18, 2011. Estimation is by least squares, standard errors for coefficient tests are Newey-West HAC. DW is the Durbin Watson statistic for the estimated regression.

Variable	R_0^f	R_0^f
$OilPRET$	0.4272 (0.000)	0.4316 (0.000)
$CddDif$	0.0013 (0.0666)	0.0011 (0.1155)
$HddDif$	-0.0007 (0.1375)	-0.0006 (0.1556)
ΔS_{t+i}^{sur}	-0.0012 (0.000)	-0.0009 (0.000)
Post-2005 Dummy		0.0033 (0.3048)
Post-2005 Dummy x ΔS_{t+i}^{sur}		-0.0006 (0.0407)
α_0	-0.0045 (0.0146)	-0.0065 (0.0111)
Adj R^2	0.164	0.168
DW	2.22	2.25

TABLE 4

Natural Gas Spot Price Responses To Storage Change Surprises On And After The Release Of The EIA Report

The estimated model has the following form $R_i^s = \alpha_i + \alpha_1 OilPRET_i + \alpha_2 CddDif_i + \alpha_3 HddDif_i + \alpha_4 \Delta S_0^{sur} + \alpha_5 R_0^f + \varepsilon_0$ where i=0 indicates the day the EIA report is released and i=1 indicates the following day, the variable R_0^s is the change in the log of the spot price for natural gas on the day of the storage change release and the subscript 1 indicates the day after, *OilPRET* is the change in the log of the price of the front month crude oil NYMEX futures contract, *CddDif* is the difference between the actual Cooling Degree Day measure for the day (actual temperature minus 65 degrees if the temperature is greater than 65 degrees, 0 otherwise) and the 30-year average Cooling Degree Day measure for the day, and *HddDif* is the difference between the actual Heating Degree Day measure for the day (65 degrees minus the actual temperature if the actual temperature is less than 65 degrees and 0 otherwise) and the 30-year normal Heating Degree Day measure for the day. The variable ΔS_0^{sur} represents the difference between the actual change in storage and the expected change proxied by the Bloomberg consensus forecast. The log futures price change on the day of the storage change announcement is given by the variable R_0^f P-values for tests that an estimated coefficient is equal to zero (0) are reported in parenthesis. Sample period August 30, 2002 – August 18, 2011. Estimation is by least squares, standard errors for coefficient tests are Newey-West HAC. DW is the Durbin Watson statistic for the estimated regression.

Variable	R_0^s	R_1^s	R_1^s
$OilPRET$	0.0969 (0.0671)	0.1629 (0.0891)	0.1522 (0.074)
$CddDif$	0.0017 (0.0265)	0.0018 (0.0548)	0.0019 (0.0764)
$HddDif$	0.0009 (0.2306)	-0.0002 (0.6917)	-0.0002 (0.7604)
ΔS_0^{sur}	-0.0002 (0.2119)	-0.0006 (0.0005)	-0.0001 (0.7888)
R_0^f			0.4667 (0.0004)
α_0	-0.0039 (0.0825)	-0.0157 (0.000)	-0.0147 (0.000)
Adj R^2	0.014	0.026	0.199
DW	1.97	1.86	1.57