State Dependence in the Natural Gas and Rig Count Relationship

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Abstract

The goal of this analysis is to understand the relationship between natural gas prices and the north American natural gas rig count. Prior research has generally not included changes in the rig count as a determinant of contemporaneous or future changes in natural gas prices. We first show that when not allowing state dependence, then the rig count does not affect natural gas prices. We then show, when allowing state dependence in the natural gas and rig count relationship, changes in the rig count are an important determinant of future changes in gas prices when natural gas prices are high. That is, over our monthly sample from 1997 through 2013, we find that the rig count has a negative and significant relationship with future natural gas price changes (Granger-causes) when natural gas prices are above a $6.74/MMBtu threshold. However, when gas prices are below this threshold, then the rig count does not affect natural gas prices (though gas prices do affect the rig count). Moreover, we find evidence consistent with media reports that natural gas producers tend to 'kill any rally' in gas prices by markedly increasing gas production.

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1 Introduction

This paper investigates the existence and extent of state dependence in the relationship between natural gas and the rig count,[1] and the implications of such state dependence for explaining changes in these series. In particular, this analysis finds evidence that the rig count can be an important determinant of the changes in natural gas prices.

Prior literature on explaining the changes in natural gas prices has included the gas rig count only incidentally through an exogenous 'shutin' variable, which measures the proportion of natural gas production idled (mainly due to hurricanes in the Gulf of Mexico). Specifically, Ramberg and Parsons (2012), Brown and Yücel (2008), and Hartley, Medlock, and Rosthal (2008) include the 'shutin' variable as an exogenous determinant of the change in natural gas prices within the framework of an error-correction model. Notably, Ramberg and Parsons (2012) and Brown and Yučel (2008) sampled natural gas prices at the weekly frequency, which is too fine a partition for the change in the rig count to react to natural gas prices.

However, even considering analyses on monthly prices, the prior literature has not included the rig count itself as a determinant of natural gas prices. In this analysis, we first show that if you do not consider state dependence in the relationship between natural gas and the rig count, then you would

[1]This analysis relates logged differences in spot natural gas prices (Henry Hub) and logged differences in the north American natural gas rig count. For brevity, these will simply be referred to as 'natural gas' and the 'rig count' respectively.

come to the conclusion that natural gas affects the rig count, however the rig count does not affect natural gas prices. Thus the rig count would not need to be included as an explanatory variable for changes in natural gas prices. However, once you consider state dependence (where the state is dependent on the lagged natural gas price) then the rig count significantly affects natural gas.

In related research, Boudoukh et al (2007) illustrated the importance of including state dependence in the structural relationship between an asset's returns and its fundamentals. They do so by showing temperature affects frozen concentrate orange juice futures returns only when the temperature is near freezing. If the state dependence is not accounted for, then it appears temperature has no effect on orange juice futures returns.

Their paper was in response to earlier work (particularly Roll (1984) and Roll (1988)) which found fundamentals explained generally little of an asset's returns. Roll (1984) and Roll (1988) did not include state dependence in the functional relationship between the asset and its fundamentals.

This analysis differs from Boudoukh et al (2007) in several ways. First, the threshold at which temperature affects orange juice is well known, whereas we must estimate the threshold in the natural gas and rig count relationship. Second, temperature is exogenous, whereas natural gas and the rig count are both potentially endogenous variables necessitating the vector autoregression (VAR) form.

Lastly, understanding the determinants of changes in natural gas prices is of increasing importance because natural gas fired electricity generation is quickly increasing its share of the national power generation portfolio. Further, many vehicle fleets (particularly city buses, etc.) have converted from diesel to natural gas. Therefore any change in natural gas prices will have an increasingly large effect on the macroeconomy.

The paper is organized as follows. Section 1.1 affords an *a priori* reasoning for the existence of state dependence in the natural gas and rig count relationship. Sections 2 and 3 describe the data set and methodology respectively. Section 4 summarizes the results over various samples, and section 5 concludes.

1.1 Motivation for State Dependence

We expect there to be state dependence between natural gas and the rig count driven by natural gas prices falling below marginal production costs. That is, when natural gas prices are near or below production costs, then the rig count will be highly dependent on natural gas prices as more costly rigs are idled. So the rig count is dependent on gas prices.

Alternatively, when natural gas prices are well above their production costs, increases in the rig count will cause a reduction in natural gas prices. That is, all rigs are brought online and thereby prices are tempered. In this case gas prices are dependent on the rig count.

A recent article[2] in the financial press highlights the relationship between

[2] http://www.bloomberg.com/news/2012-11-14/gas-prices-doomed-to-stay-low-as-

natural gas prices and the rig count. From the article:

> Gas producers in North America including Chesapeake Energy Corp. (CHK) are killing their commodity's biggest rally in 10 months by opening more wells, putting the U.S. on track to have record gas supplies this year.

This is anecdotal evidence that above some threshold, natural gas producers bring enough rigs online to negatively affect gas prices.

2 Data

Natural gas prices are logged monthly spot prices at the Henry Hub. Crude oil (west Texas intermediate) and heating oil prices are also logged monthly spot prices for delivery at Cushing, Oklahoma[3] and the New York harbor (number 2) respectively. All price data are from the Energy Information Agency at the U.S. Department of Energy. All prices in this analysis are inflation-adjusted using the consumer price index for all urban consumers and all items.

North American rotary rig count data are from Baker Hughes. We use the Baker Hughes provided rig count split by natural gas and crude oil.

Since the goal of this analysis is to investigate the relationship between natural gas prices and rig count, all data are sampled at the monthly fre-

producers-pump-faster.html

[3]For robustness we also use prices for Brent north sea.

quency. Given costs associated with starting or idling a rig, it is highly unlikely drillers will react to natural gas prices at frequencies of less than a month.

Natural gas storage data are monthly total working gas in storage (from the EIA). The variable $STOR$ denotes the monthly deviation of the total working gas in storage from its 5-year average for that month. The heating and cooling degree-day (HDD and CDD respectively) data are population-weighted national averages and are available from the U.S. National Weather Service's Climate Prediction Center. $HDDdev$ and $CDDdev$ denote the deviation of monthly total HDD and CDD from their historical monthly norm.

3 Methodology

We will use a multivariate threshold vector autoregression (VAR) to model the relationship between logged natural gas and rig count. For more on threshold cointegration models see Balke and Fomboy (1997), Tsay (1998).

Let $\mathbf{r}_t = (\Delta ng_t,\ \Delta rc_t)'$ where $\Delta ng_t = ng_t - ng_{t-1}$ and $\Delta rc_t = rc_t - rc_{t-1}$. Then we have the multivariate threshold $VAR(p)$:

$$\mathbf{r}_t = \begin{cases} \mathbf{c}_1 + \sum_{i=1}^{p} \mathbf{\Phi}^{(1)}{}_i \mathbf{r}_{t-1} + \sum_{i=1}^{p} \mathbf{\Lambda}_i^{(1)} \mathbf{Z}_{t-1} + \mathbf{a}_t^{(1)} & \text{if } ng_{t-1} \leq \gamma \\ \\ \mathbf{c}_2 + \sum_{i=1}^{p} \mathbf{\Phi}^{(2)}{}_i \mathbf{r}_{t-1} + \sum_{i=1}^{p} \mathbf{\Lambda}_i^{(2)} \mathbf{Z}_{t-1} + \mathbf{a}_t^{(2)} & \text{if } ng_{t-1} > \gamma \end{cases} \quad (1)$$

In this model the threshold variable is the prior period's logged natural gas price ng_{t-1}, and γ is the estimated threshold. $\mathbf{Z}_{t-1}$ is an optional vector of exogenous variables. The superscripts on the coefficient matrices refer to the estimated coefficients below (1) and above (2) the threshold. The threshold is estimated by finding the value, over the range of natural gas prices, which minimizes AIC. The value is found by a grid search.

Note that drillers certainly use expectations of future natural gas prices to decide whether to idle or bring a rig online, as opposed to using only present or past prices. The VAR models these expectations to long as the drillers' expectations are formed using present and lagged values of the variables within the VAR. Hence, for robustness we also estimate the VAR with other variables (crude and heating oil, crude oil rig count, etc) which may affect expectations of natural gas prices. We also estimate the model using deseasonalized prices and rig count for robustness.

4 Results

4.1 Full-Sample without State Dependence

First we estimate a $VAR(2)$,[4] without allowing for state dependence, on the full-sample of logged differences in natural gas and the rig count, and test for Granger-causation. We find that natural gas Granger-causes the rig count at the 0.1% level of significance, however the rig count does not

[4]The number of lags in the VAR was chosen using AIC

Granger-cause natural gas prices. This result explains why earlier analyses of the determinants of the changes in natural gas prices have not included the rig count as an explanatory variable. That is, without considering state dependence in the natural gas price and rig count relationship, you would conclude that the rig count does not affect gas prices.

4.2 Full-Sample Threshold $VAR(2)$

The results of the threshold $VAR(2)$ estimated over the full sample period (from February 1997 to June 2013) are shown in table 1. First, the threshold was estimated to be $6.74/MMBtu (in July 2013 dollars). Below this threshold, both lagged changes in natural gas and the rig count positively and significantly affect present changes in the rig count. However, natural gas is unaffected by lagged changes in natural gas and the rig count. Conversely, above the $6.74 threshold, lagged changes in the rig count have a negative and significant affect natural gas, though not vice versa.

So below the threshold, an increase in natural gas prices will tend to increase the rig count in subsequent months. Further the rig count has no effect on natural gas prices. However, above the threshold an increase in the rig count will tend to lower natural gas prices in the following months, and there is no effect of natural gas on the rig count. This is evidence that both the sign of the natural gas and rig count relationship, and the flow of causation, are state-dependent.

Table 1: Threshold VAR Results on the full sample from February 1997 to June 2013. The sample size is 197 and there are 21 estimated parameters. NG denotes natural gas in $/MMBtu in July 2013 dollars, and ng denotes its natural log. rc denotes the natual log of the north American natural gas rig count. The standard error is below each estimated coefficient in parentheses. . **, ***, *** denoted statistical significance at the 10%, 5%, 1%, and 0.1% level respectively.

Estimated Threshold: Natural Gas is $6.74/MMBtu				
	$NG_{t-1} < \$6.74$		$NG_{t-1} > \$6.74$	
	Δng_t	Δrc_t	Δng_t	Δrc_t
constant	0.0132	-0.0013	-0.0081	0.0035
	(0.0117)	(0.0029)	(0.0197)	(0.0049)
Δng_{t-1}	0.0620	0.0716	0.0799	-0.0002
	(0.0979)	(0.0241)**	(0.1033)	(0.0254)
Δrc_{t-1}	0.0850	0.6481	-2.8135	0.3478
	(0.3139)	(0.0773)***	(0.7730)***	(0.1904).
Δng_{t-2}	0.0975	0.0703	-0.1040	0.0314
	(0.0961)	(0.0237)**	(0.0989)	(0.0244)
Δrc_{t-2}	0.0108	0.0327	2.0608	0.2062
	(0.3105)	(0.0765)	(0.8028)*	(0.1977)
AIC		-2117.407		

Moreover, this evidence is consistent with the hypothesis that below the threshold there is a positive relationship whereby natural gas affects the rig count in subsequent periods. However, above the threshold the rig count is inversely related to subsequent changes in natural gas. This latter result is consistent with the anecdotal evidence that, in response to rallies in natural gas prices, producers increase the rig count to such as extent that natural gas prices are depressed.

The results above motivate tests for Granger-causation above and below the threshold. We can see in table 2 that when natural gas is below the \$6.74/MMBtu threshold, then changes in natural gas granger-cause changes in the rig count. However rig count does not granger-cause natural gas. Conversely, when natural gas is above its threshold, then rig count granger-causes natural gas, but natural gas does not cause the rig count.

Table 2: Tests for Granger-causality in the full-sample Threshold $VAR(2)$. $\Rightarrow$ denotes Granger-causation. ng denotes natural log of natural gas prices. rc denotes the natural log of the north American natural gas rig count. The p-value is below each estimated coefficient in parentheses. . **, ***, *** denoted statistical significance at the 10%, 5%, 1%, and 0.1% level respectively.

Estimated Threshold: Natural Gas is \$6.74/MMBtu		
	$NG <$ \$6.74	$NG >$ \$6.74
	F-Statistic	F-Statistic
$\Delta ng \Rightarrow \Delta rc$	13.4962	1.6963
	(0.0000)****	(0.1920)
$\Delta rc \Rightarrow \Delta ng$	0.2577	4.1683
	(0.7731)	(0.0201)**

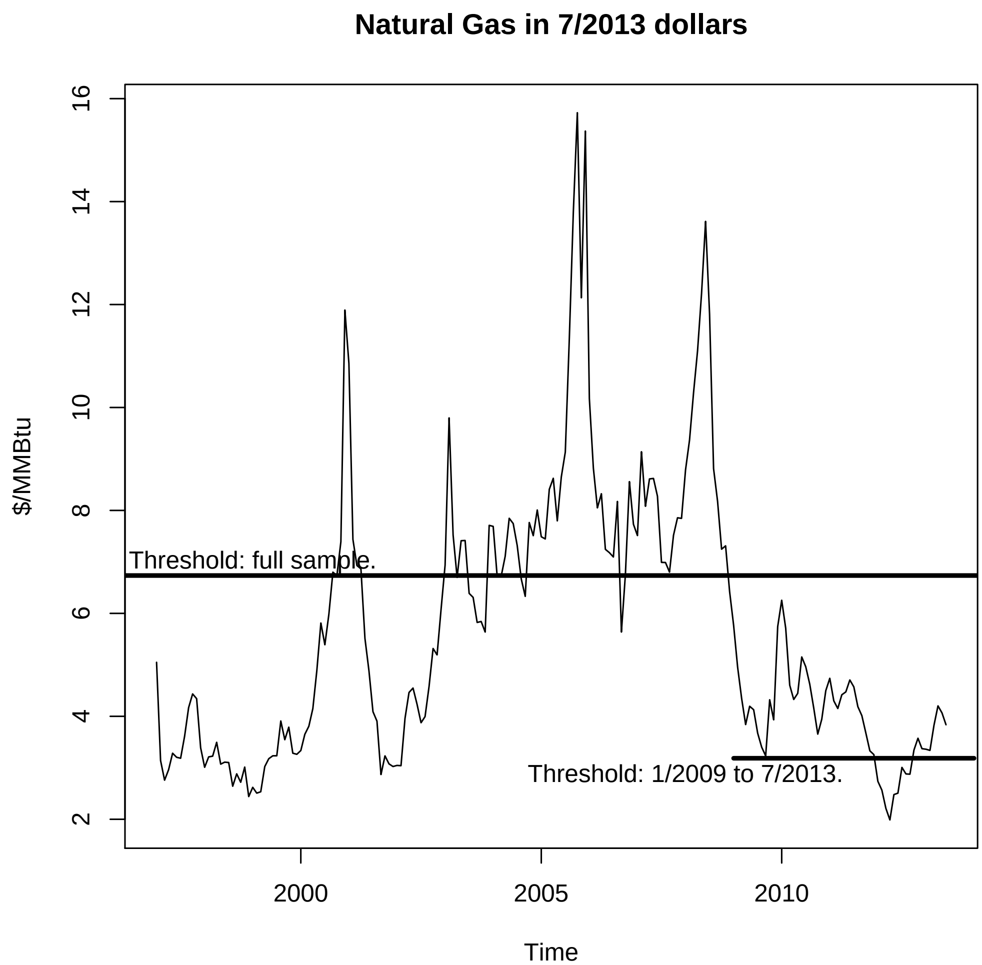
In sum, these results are evidence of both an endogenous relationship between natural gas and the rig count, and the existence of state-dependence in the nature of the relationship. They motivate the inclusion of the rig count, as a state-dependent variable, in analyses of natural gas price changes at the monthly sampling frequency and longer.

4.3 Subsample

During the 2008 financial crisis the (inflation adjusted) price of natural gas fell below \$6/MMBtu, and has stayed below this value since. The 2008 crisis seems to have marked a structural shift in natural gas prices, and so we have estimated the threshold VAR over the period January 2009 to July 2013.

Doing so finds a lower threshold of \$3.19/MMBtu. However, tests for Granger causation above and below the threshold are all insignificant. This is likely caused by too few data. Confirming the full-sample results on the data after the 2008 financial crisis will likely require more years of data.

Figure 1: Natural Gas Prices with Thresholds



4.4 Threshold VAR with Exogenous Variables

In this section we test whether our earlier results are robust to the inclusion of exogenous variables, which are commonly known to affect natural gas prices, in the VAR. The exogenous variables are the deviation of US working gas in storage from its 5-year average ($STOR$), the deviation of CDD and HDD from their long term norm ($CDDDev$ and $HDDDev$ respectively), and lagged changes in logged crude oil prices (west Texas intermediate).

Note, here we are considering crude oil prices as an exogenous variable, which has been a point of some debate. However, there is enough support (Serletis and Rangel-Ruiz (2004); Villar and Joutz (2006)) to herein treat crude oil as at least weakly exogenous.

We find the earlier results of the threshold $VAR(2)$ are largely robust to their inclusion. Below the price threshold, lagged changes in natural gas and the rig count positively and significantly affect changes in the rig count. However these variables do not affect changes in natural gas prices.

Consistent with our main result, above the threshold lagged chages in the rig count negatively and significantly affect natural gas price changes. Also consistent is that natural gas does not significantly affect the rig count above the threshold.

The main difference from the earlier $VAR(2)$ without exogenous variables, is that the natural gas price threshold is \$8.05/MMBtu, as opposed to \$6.74. Note, the maximum natural gas price over the period was \$15.72/MMBtu.

Interestingly, below the threshold the natural gas storage variable inversely affects the change in natural gas prices (significant at the 1% level). However, above the threshold the storage variable is insignificant with respect to the change in natural gas prices, and the rig count variable is negative and significant.

This is evidence that, above and below the threshold, separate components of the natural gas supply chain affect prices. Below the threshold, the amount of gas in storage affects gas prices and not the rig count. Conversely, above the threshold rig count affects gas prices and not storage.

Table 3: Threshold VAR Results on the full sample from February 1997 to June 2013 with the inclusion of exogenous variables. The sample size is 192 and there are 53 estimated parameters. NG denotes natural gas in \$/MMBtu in July 2013 dollars, and ng denotes its natural log. rc denotes the natual log of the north American natural gas rig count. The exogenous variables are: wti the natural log of crude oil prices; $STOR$ the deviation of US working gas in storage from its 5 year average for each month; $CDDdev$ and $HDDdev$ denote the deviation of monthly CDD and HDD from their long-term norm. The standard error is below each estimated coefficient in parentheses. . **, ***, *** denoted statistical significance at the 10%, 5%, 1%, and 0.1% level respectively.

Estimated Threshold: Natural Gas is \$8.05/MMBtu				
	$NG_{t-1} < \$8.05$		$NG_{t-1} > \$8.05$	
	Δng_t	Δrc_t	Δng_t	Δrc_t
constant	0.0015	0.0025	-0.0152	0.0122
	(0.0128)	(0.0034)	(0.0407)	(0.0109)
Δng_{t-1}	-0.0122	0.0764	-0.3730	-0.0235
	(0.0886)	(0.0238)**	(0.2826)	(0.0760)
Δrc_{t-1}	-0.0423	0.5782	-5.7693	0.2356
	(0.2800)	(0.0753)***	(1.3409)***	(0.3609)
Δwti_{t-1}	-0.0611	0.0047	-0.1215	0.0845
	(0.1170)	(0.0315)	(0.3711)	(0.0999)
$STOR_{t-1}$	-0.0006	7.9e-05	2.0e-05	-3.0e-05
	(0.0001)***	(3.9e-05)*	(0.0005)	(0.0001)
$CDDdev_{t-1}$	-0.0007	0.0001	0.0043	-9.8e-05
	(0.0006)	(0.0001)	(0.0016)**	(0.0004)
$HDDdev_{t-1}$	-0.0006	8.8e-05	0.0016	-8.6e-05
	(0.0003)*	(7.4e-05)	(0.0007)*	(0.0002)
Δng_{t-2}	-0.0136	0.0553	0.4601	0.0221
	(0.0834)	(0.0224)*	(0.2474).	(0.0666)
Δrc_{t-2}	0.1535	0.0718	2.2238	-0.5860
	(0.2773)	(0.0746)	(1.9297)	(0.5193)
Δwti_{t-2}	0.2201	0.1224	0.9746	0.0402
	(0.1183).	(0.0318)***	(0.3190)**	(0.0858)
$STOR_{t-2}$	0.0006	-9.1e-05	0.0001	1.7e-05
	(0.0001)***	(3.6e-05)*	(0.0005)	(0.0001)
$CDDdev_{t-2}$	-2.2e-05	-0.0001	-0.0046	-1.2e-05
	(0.0005)	(0.0001)	(0.0015)**	(0.0004)
$HDDdev_{t-2}$	-0.0003	-1.4e-05	-0.0010	6.4e-05
	(0.0002)	(6.4e-05)	(0.0006).	(0.0002)
AIC		1136.5710		

5 Conclusion

This analysis contributes, in two main ways, to the literature on the determinants of changes in natural gas prices. First, we show that, if you don't consider state dependence, then the rig count has no affect on natural gas prices. However, taking into account state dependence, as natural gas increases above a price threshold changes in the rig count negatively and significantly affect (Granger-cause) subsequent changes in natural gas prices. This means natural gas prices decline in response to an increase in the rig count. Notably, above the threshold changes in natural gas prices have no effect on subsequent changes in the rig count.

Conversely, below the price threshold, changes in natural gas prices positively and significantly (Granger-cause) subsequent changes in the rig count. However, changes in the rig count do not affect subsequent changes in natural gas prices. This, along with the fact that this result obtains when not allowing state dependence, explains why the rig count has not been included as an explanatory variable in previous research into the determinants of the changes in natural gas prices.

This evidence is consistent with media reports stating natural gas producers often 'kill the commodity's rally'. That is, as natural gas prices rise while below the threshold, rigs with increasing marginal production costs are brought online in response. Gas prices affect the rig count. When prices rise above the threshold, and a large proportion of rigs are potentially profitable, enough supply is provided to negatively affect gas prices. The rig count affects gas prices.

These results have practical implications for understanding changes in gas prices, and for implementing future models thereof. Further, these results are likely of interest to natural gas producers, who have much to lose if they are the last to bring a rig online in the face of declining gas prices. This analysis may help producers identify the price threshold above which the rig count will negatively affect gas prices, and thereby choose to not increase the rig count above this price. Ultimately such behavior may afford producers greater profits, and moderate volatility in natural gas prices.

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