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ECO 441K

2 December 2024

The Effect of Natural Gas Storage Changes on Natural Gas Prices in the Shale Revolution

Abstract

This study investigates the relationship between monthly changes in underground natural gas storage and Henry Hub natural gas spot prices in the context of the U.S. shale revolution. Using a linear regression model, it incorporates key control variables such as WTI crude oil spot prices, natural gas exports, power demand, and heating degree days to isolate the impact of storage dynamics. The results show a marginally significant positive relationship between storage changes and prices, contrary to the expected inverse relationship. Diagnostic tests reveal issues of heteroskedasticity and multicollinearity, but alternative specifications, including a natural log transformation of the dependent variable, address omitted variable bias and non-normality. The study underscores the need for more granular and region-specific storage data to enhance market transparency and inform policy decisions in an increasingly complex energy landscape.

Introduction

Natural gas pricing is a cornerstone of the global energy market, influencing industrial competitiveness, energy security, and economic stability. Among the various factors that drive natural gas prices, storage plays a unique and critical role. By acting as a buffer between supply and demand, natural gas storage absorbs excess gas during low-demand periods and releases it during peak-demand seasons, helping stabilize prices (Hartley & Medlock, 2012). As storage levels fluctuate, they provide key signals about market conditions, making them an essential variable in understanding natural gas price dynamics. Additionally, the Shale Revolution has been especially impactful towards transforming the U.S. energy landscape. Technological advancements in hydraulic fracturing and horizontal drilling have unlocked vast reserves of shale gas, leading to a substantial increase in production. This surge has lowered domestic natural gas prices while enhancing energy security altering global energy markets (Wang & Krupnick, 2013). Additionally, the shale revolution has expanded the role of natural gas storage in balancing seasonal demand and mitigating price volatility, making the study of storage changes even more pertinent (Moniz, Jacoby & Meggs, 2011).

This study hypothesizes that changes in natural gas storage exert a significant inverse effect on Henry Hub spot prices. Specifically, higher storage injections are expected to reduce prices by signaling an oversupplied market, while greater withdrawals during periods of peak demand are likely to increase prices. The Henry Hub is chosen as the dependent variable because it is the primary pricing benchmark for natural gas in North America, serving as the most significant natural gas hub (in terms of volume traded) in the United States (EIA, 2023). Similarly, underground storage is selected as the primary independent variable of interest, considering it accounts for the vast majority of natural gas storage in the U.S. and plays a critical role in balancing supply and demand across seasonal cycles (Serletis & Shahmoradi, 2006). With a focus on these variables, this study isolates the impact of storage changes on natural gas prices, while controlling for other factors such as crude oil prices, natural gas exports, electricity demand, and seasonal variations (measured by heating degree days). Understanding the influence of storage changes on natural gas prices is essential for policymakers, investors, and stakeholders in the energy sector. Insights from this analysis, therefore, can inform strategies for market participation, policy formulation, and investment decisions, especially in the context of the evolving energy landscape shaped by the shale revolution.

Literature Review

The dynamics between underground natural gas storage levels and market prices, especially at the Henry Hub, have been extensively studied in academic literature. Fluctuations in underground storage levels are pivotal in determining natural gas prices as seen by Li and colleagues (2017) who utilized factor analysis to extrapolate the determinants of Henry Hub natural gas prices from 1997 to 2016. The research identified that storage levels, along with economic conditions and energy demand, are significant factors influencing price movements. The study concluded that higher storage levels generally lead to lower natural gas prices due to increased supply availability. Additionally, Chen and colleagues (2023) investigated the asymmetric effects of natural gas storage on rig counts in the U.S. market. Their findings revealed that changes in storage levels had significant long-term effects on natural gas drilling activities, which in turn affect edsupply and pricing. Specifically, increased storage levels were associated with reduced drilling activities, leading to potential future supply constraints and upward pressure on prices.

Moreover, Qiu and colleagues (2024) introduced a stochastic path-dependent volatility model to analyze price-storage dynamics in natural gas markets. Their model accounts for the complex interactions between storage levels and price volatility, providing a framework for understanding how storage decisions impact market prices. Their study emphasizes that storage buffers supply and demand imbalances and also plays a critical role in price formation and volatility. Finally, Kleppe and Oglend (2017) developed a particle filter maximum likelihood estimator for the competitive storage model, centered on commodity markets like natural gas. Their research demonstrated that storage activities significantly influence spot prices, with higher storage levels leading to lower prices, due to increased availability. Ultimately, the current literature indicates that underground natural gas storage levels have a significant inverse relationship with market prices, particularly at benchmarks like the Henry Hub. Higher storage levels typically lead to lower prices due to increased supply, while lower storage levels can result in higher prices amid demand surges.

Empirical Model

This study employs a linear regression model to examine the effect of monthly changes in underground natural gas storage and the Henry Hub natural gas spot price. The model is specified as follows:

$$HHSpot = \beta_0 + \beta_1(StorageChange) + \beta_2(GasExports) + \beta_3(WTISpot) + \beta_4(PowerDemand) + \beta_5$$

Typically, the Henry Hub Spot Price is used as the benchmark market price for immediate delivery of natural gas represented in Dollars per Million British Thermal Units ($/MMBtu), but this model utilizes the Cents per MMBtu (¢/MMBtu) measurement solely for ease of interpreting empirical results. The independent variable of interest is the monthly change in underground natural gas storage, measured in billion cubic feet (Bcf), which reflects the balance between supply injections and withdrawals.

The model also includes key control variables to account for external factors influencing natural gas prices. Crude oil prices, represented by the West Texas Intermediate (WTI) spot price in dollars per barrel ($/bbl), capture cross-market dynamics between natural gas and oil. U.S. natural gas exports, measured in Bcf, account for the impact of external demand on domestic supply. Total U.S. electricity end-use, measured in Gigawatt Houts (GWh), reflects the influence of domestic energy consumption on natural gas prices. Lastly, Heating Degree Days (HDD), a measure of cold weather demand for heating, capture seasonal fluctuations in natural gas consumption.

Data

This study uses monthly, national-level data publicly from February 2010 to August 2024. The data source for the Henry Hub Natural Gas Spot Price and the WTI Crude Oil Spot Price, is the U.S. Energy Information Administration (EIA). These monthly benchmarks are an unweighted average of the daily closing spot prices for a given product over the specified time period. In this case, the specified period is one month

Monthly Underground Storage Changes were calculated by using natural gas storage levels published by the EIA every week and finding the net change per week using the formula: $Weekly\ Storage\ Change_t = Storage_t - Storage_{t-1}$, which was then summed for each month to derive the monthly net storage changes. Positive values indicate net injections (increased supply), while negative values represent net withdrawals (increased demand).

Data for Natural Gas Exports, which includes both pipeline and liquefied natural gas exports, is reported in Million Cubic Feet (MMcf) by the EIA and was divided by 1000 to convert the figure into Bcf. Total Electricity End-Use represents the nationwide consumption of electricity across residential, commercial, and industrial sectors, as reported monthly by the EIA in their Monthly Energy Review under Table7.1. Finally, Monthly Heating Degree Days are a measure of temperature-driven heating demand, calculated as the number of degrees the daily average temperature in the US falls below 65°F per day summed throughout a single month. This figure is regularly calculated by the National Oceanic and Atmospheric Administration (NOAA) and published in the EIA Monthly Energy Review under Table 1.11

Table 1 below shows the descriptive statistics. The Henry Hub Spot Price has a mean of 335.49 ¢/MMBtu with a minimum of 149 ¢/MMBtu in March 2024 (after a mild 2023 winter) and a maximum of 881 ¢/MMBtu in August 2022 (a few months after the Russian Invasion of Ukraine). Moreover, it is clear that Net Monthly Storage Changes have significant volatility ranging from a net outflow of 1,051 Bcf in January 2014 up to a net inflow of 524 Bcf in May 2019.

Table 1. Descriptive Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
HHSpot	175	335.4857	127.0956	149	881
StorageCha~e	175	5.377143	392.7455	-1051	524
GasExports	175	310.4441	196.1129	75.938	708.805
WTISpot	175	72.02183	21.62726	16.55	114.84
PowerDemand	175	327.4194	33.12418	273.132	405.962
HDD	175	338.8571	303.3949	4	971

Empirical Results

Table 2. Regression Results

Source	SS	df	MS
Model	922273.654	5	184454.731
Residual	1888400.06	169	11173.9649
Total	2810673.71	174	16153.2972

Number of obs	=	175
F(5, 169)	=	16.51
Prob > F	=	0.0000
R-squared	=	0.3281
Adj R-squared	=	0.3083
Root MSE	=	105.71

HHSpot	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
StorageChange	.1344844	.0790551	1.70	0.091	-.0215784	.2905471
GasExports	.0077279	.0418831	0.18	0.854	-.0749536	.0904094
WTISpot	3.155801	.3746509	8.42	0.000	2.416202	3.895399
PowerDemand	1.113453	.4311643	2.58	0.011	.2622914	1.964615
HDD	.224878	.113127	1.99	0.048	.001554	.4482019
_cons	-335.6906	172.5913	-1.95	0.053	-676.4032	5.021952

The results of the regression analysis are summarized in the table above. The coefficient for Monthly Storage Change is positive at 0.134 with a $p - value = 0.091 < 0.10$, indicating statistical significance at the 10% level but not at more common 5% and 1% levels. This suggests that a one Bcf increase in net storage change is associated with an increase in the Henry Hub spot price of 0.134 ¢/MMBtu on average, holding all else constant. This result is contrary to the expected inverse relationship between storage changes and prices, where injections typically reduce prices.

Among the control variables, WTI Spot Price, with a coefficient of 3.1563, is highly significant with its p-value meting the 1% significance threshold, meaning that a one-dollar increase in The WTI Benchmark corresponds to a 3.156¢ increase on average in the Henry Hub Spot Price. Additionally, Power Demand, with a coefficient of 1.113, is also significant, but at the 5% level with a p-value of 0.01, indicating that a one GWh increase in electricity nationally leads to a 1.113¢ increase in the Henry Hub benchmark. Our last significant variable is HDD, with a p-value of 0.048 meeting the 5% significance threshold and suggesting that an increase of 1 Heating Degree Day per month results in a 0.225¢ increase in The Henry Hub Price.

Additional Diagnostic Tests

<u>Heteroskedasticity: Breuch Pagan Test - Failed</u>

```
. regress s1s HHSpot StorageChange GasExports WTISpot PowerDemand HDD
```

Source	SS	df	MS			
				Number of obs	=	175
				F(6, 168)	=	28.99
Model	5.2980e+10	6	8.8300e+09	Prob > F	=	0.0000
Residual	5.1163e+10	168	304544568	R-squared	=	0.5087
				Adj R-squared	=	0.4912
Total	1.0414e+11	174	598525862	Root MSE	=	17451

s1s	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
HHSpot	120.8426	12.69926	9.52	0.000	95.77186	145.9132
StorageChange	-25.2494	13.16251	-1.92	0.057	-51.23463	.7358325
GasExports	44.78521	6.915199	6.48	0.000	31.13333	58.43709
WTISpot	1.381042	73.7	0.02	0.985	-144.1164	146.8785
PowerDemand	-122.05	72.57194	-1.68	0.094	-265.3205	21.22044
HDD	-45.85586	18.89325	-2.43	0.016	-83.15463	-8.557083
_cons	11883.03	28810.31	0.41	0.681	-44993.86	68759.91

Based on the Breuch-Pagan Test results, the P-value is lower than 0.01 (0.000). Hence it can be concluded that the null hypothesis (homoskedasticity) is rejected and that there is heteroskedasticity in the residuals. This means the variance of the residuals is not constant, which could potentially bias the standard errors of the regression coefficients.

Multicollinearity: VIF Test - Failed

. vif

Variable	VIF	1/VIF
HDD	18.34	0.054514
StorageCha~e	15.01	0.066616
PowerDemand	3.18	0.314834
GasExports	1.05	0.951848
WTISpot	1.02	0.978141
Mean VIF	7.72	

The Variance Inflation Factor (VIF) results indicate potential multicollinearity issues in the model, particularly for Heating Degree Days (18.34) and Storage Changes (15.34), both exceeding the threshold of 10, which signals high multicollinearity. This suggests that these two variables are highly correlated with other predictors in the model, reducing their precision, making it difficult to isolate the individual effects of these variables on Henry Hub natural gas prices.

Normality: Skewness-Kurtosis Test - Failed

. sktest HHSpot StorageChange GasExports WTISpot PowerDemand HDD

Skewness and kurtosis tests for normality

				Joint test	
Variable	Obs	Pr(skewness)	Pr(kurtosis)	Adj chi2(2)	Prob>chi2
HHSpot	175	0.0000	0.0000	47.30	0.0000
StorageChange	175	0.0001	0.0611	16.21	0.0003
GasExports	175	0.0040	0.0000	78.03	0.0000
WTISpot	175	0.5468	0.0000	20.98	0.0000
PowerDemand	175	0.0003	0.1686	12.60	0.0018
HDD	175	0.0262	0.0000	87.33	0.0000

The results of the Skewness-Kurtosis Test for the dependent variable reject the null hypothesis of normality, as both skewness and kurtosis have p-values approximately equal to 0. The joint test, with a p-value of 0, further confirms non-normality. This indicates that the Henry Hub Spot Price significantly deviates from a normal distribution, potentially impacting the reliability of hypothesis testing.

Ramsey Test - Failed

```
. ovtest

Ramsey RESET test for omitted variables
Omitted: Powers of fitted values of HHSpot

H0: Model has no omitted variables

F(3, 166) =   4.56
 Prob > F = 0.0043
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The Ramsey Test analyzes whether non-linear combinations of the fitted values help explain the dependent variable. From the result, it is clear that the p-value is significant (.0043) and hence we can reject the null hypothesis that there is no omitted variable bias and hence, the model fails the Ramsey Test.

Alternative Specifications

Since all Diagnostic Tests failed, running the regression with the natural log of the dependent variable will attempt to correct the Normality issue from the Skewness Kurtosis Test and the Omitted Variable bias seen in the Ramsey Test. From the Results below, we see that taking the natural log has helped the model pass both the Skewness Kurtosis test (0.066) and Ramsey Test (.6574) indicating that the model now achieves normality and has no Omitted Variable Bias.

```
. ovtest

Ramsey RESET test for omitted variables
Omitted: Powers of fitted values of lnHHspot

H0: Model has no omitted variables

F(3, 166) =   0.54
 Prob > F = 0.6574

. sktest lnHHspot StorageChange GasExports WTISpot PowerDemand HDD

Skewness and kurtosis tests for normality
```

Variable	Obs	Pr(skewness)	Pr(kurtosis)	Joint test Adj chi2(2)	Joint test Prob>chi2
lnHHspot	175	0.0258	0.4767	5.42	0.0666
StorageChange	175	0.0001	0.0611	16.21	0.0003
GasExports	175	0.0040	0.0000	78.03	0.0000
WTISpot	175	0.5468	0.0000	20.98	0.0000
PowerDemand	175	0.0003	0.1686	12.60	0.0018
HDD	175	0.0262	0.0000	87.33	0.0000

Conclusions and Limitations

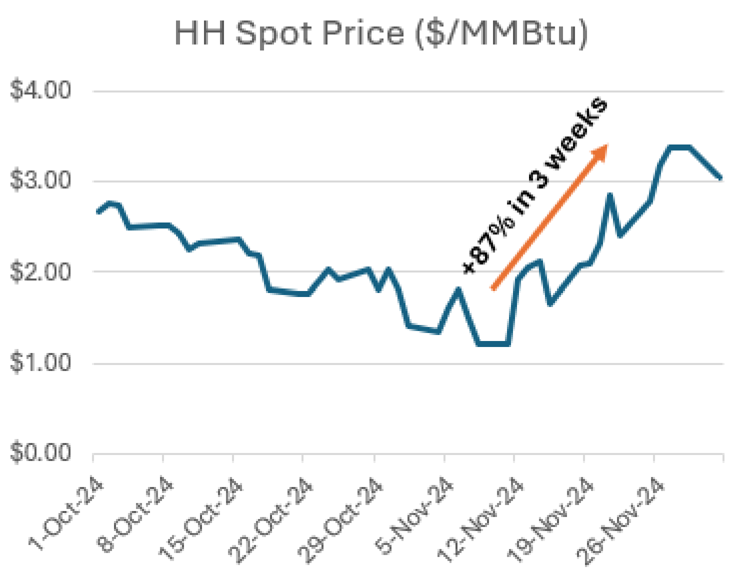
The empirical results partially support the hypothesis that changes in underground natural gas storage influence Henry Hub natural gas prices, as the relationship is marginally significant. However, the direction of the effect, with injections associated with higher prices, contradicts the expected inverse relationship. This suggests that traditional storage-price dynamics are complicated by modern market factors such as production surges and shifts in market behavior.

The findings contrast with the work of Serletis and Shahmoradi (2006), who found a robust inverse relationship in traditional supply-demand settings. However, the findings align with data from Qiu and colleagues (2024), who argued that the impact of storage on prices is often mediated by broader market volatility and influenced by price expectations. Similarly, the results reflect the observations of Wang and Krupnick (2013), who noted that the shale revolution has introduced complexities in natural gas production and storage, potentially altering their historical relationships with pricing.

These results underscore the importance of enhancing transparency in natural gas market data. Currently, monthly storage data provides a broad view of market trends but fails to capture the rapid fluctuations and intramonth volatility that significantly influence pricing (Figure 1). Publicizing more granular data in repositories, such as weekly or daily storage changes, would improve the ability of market participants and researchers to analyze price dynamics in real time. Additionally, disaggregating data by region could offer critical insights into localized supply-demand imbalances, further enhancing price forecasting and market efficiency. Ultimately, by identifying the evolving role of storage, this study highlights the need for modernized reporting and analysis tools to better capture the complexities of today's natural gas markets. Improved granularity in data, coupled with dynamic production and export models, would allow policymakers and market participants to manage volatility more effectively and stabilize prices in an increasingly interconnected energy landscape.

To enhance the robustness of the results, Alternative specifications, including a natural log transformation of the dependent variable, were employed to address diagnostic issues. These adjustments resolved non-normality (as confirmed by the Skewness-Kurtosis test) and omitted variable bias (as indicated by the Ramsey RESET test). However, challenges such as heteroskedasticity and multicollinearity persisted, underscoring the complexity of accurately modeling natural gas price determinants.

Figure 1. Daily HH Spot Price during October and November 2024, Source: Arya S. Kaushik



References

Chen, S.-H., Chen, W.-H., & Chang, C.-C. (2023). Asymmetric Effects of Prices and Storage on Rig Counts: Evidence from the U.S. Natural Gas and Crude Oil Markets. *Energies, 16*(15), 5752. https://www.mdpi.com/1996-1073/16/15/5752

Hartley, P. R., & Medlock III, K. B. (2013). Changes in the Operational Efficiency of National Oil Companies. *The Energy Journal, International Association for Energy Economics, 0*(2). https://ideas.repec.org/a/aen/journl/ej34-2-02.html

Kleppe, T. S., & Oglend, A. (2017). Estimating the Competitive Storage Model: A Simulated Likelihood Approach. *arXiv preprint arXiv:1701.02156*. https://arxiv.org/abs/1701.02156

Li, H., Zhang, H.-M., Xie, Y.-T., & Wang, D. (2017). Analysis of factors influencing the Henry Hub natural gas price based on factor analysis. *Petroleum Science, 14*(4), 822–830. https://link.springer.com/article/10.1007/s12182-017-0192-z

Moniz, E., H. Jacoby, A. Meggs, R. Armstrong, D. Cohn, J. Deutch, G. Kaufman, M. Kenderdine, F. O'Sullivan, S. Paltsev, J. Parsons, I. Perez-Arriaga, J. Reilly and M. Webster (2011): The Future of Natural Gas: An Interdisciplinary MIT Study. *Massachusetts Institute of Technology*, MIT Energy Initiative, June http://mit.edu/mitei/research/studies/natural-gas-2011.shtml

Qiu, J., Ware, A., & Yang, Y. (2024). Stochastic Path-Dependent Volatility Models for Price-Storage Dynamics in Natural Gas Markets and Discrete-Time Swing Option Pricing. *arXiv preprint arXiv:2406.16400*. https://arxiv.org/abs/2406.16400

Serletis, A., & Shahmoradi, A. (2006). Futures trading and the storage of North American natural gas. *OPEC Energy Review, 30*(1), 19–26. https://doi.org/10.1111/j.1468-0076.2006.00158.x

U.S. Energy Information Administration. (n.d). Factors affecting natural gas prices. https://www.eia.gov/energyexplained/natural-gas/factors-affecting-natural-gas-prices.php

Wang, Z., & Krupnick, A. (2013). A Retrospective Review of Shale Gas Development in the United States: What Led to the Boom? *Resources for the Future Discussion Paper*. Retrieved from https://media.rff.org/documents/RFF-DP-13-12.pdf