THE RISE OF SHALE GAS:
IMPLICATIONS OF THE SHALE GAS BOOM FOR NATURAL GAS MARKETS,
ENVIRONMENTAL PROTECTION AND U.S. ENERGY POLICY

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By

Cassandra L. Lovejoy, B.A.

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Abstract

Through the processes of hydraulic fracturing and horizontal drilling, once overlooked deposits of natural gas in shale formations have become economically viable to extract. In the past decade, energy companies have rushed to produce this newly available resource. Energy economists believe that this influx of shale gas will lead to lower, more stable natural gas prices, reduce our country’s dependence on foreign oil, and reduce the use of coal for electricity generation. However, environmental advocates are concerned that shale gas production comes at too high an environmental price through groundwater contamination and methane emissions. This paper analyzed the relationship between shale gas production and natural gas prices through a fixed effects regression model. Results of the model indicated that state-level variations in natural gas supply were not sufficient to affect prices set at the national level. In terms of policy implications, the United States must be deliberate in deciding the role of shale gas in U.S. energy policy. Full-blown investment in shale resources should be delayed until the environmental impacts of hydraulic fracturing are more fully understood and appropriate precautions are put in place. In addition, if natural gas is to be used as a “bridge fuel,” care must be taken to ensure the expansion of natural gas does not undermine investments in alternative energy sources.
# Table of Contents

Introduction and Background ........................................................................................................1

What Is Hydraulic Fracturing? .....................................................................................................2

Literature Review ..........................................................................................................................3

Theoretical Model & Market for Natural Gas ................................................................................3

Environmental Concerns about Fracking ....................................................................................5

Research Design ..........................................................................................................................8

Shale Gas Production Data .........................................................................................................8

Variable Description ....................................................................................................................12

Hypothesis & Statistical Model .....................................................................................................14

Results ..........................................................................................................................................15

Model Considerations ................................................................................................................18

Policy Implications ......................................................................................................................21

Environmental Concerns ...........................................................................................................21

Price Estimates ............................................................................................................................22

International Considerations ......................................................................................................23

Natural Gas vs. Alternative Fuels ...............................................................................................25

Policy Outcomes ........................................................................................................................26

Conclusion and Next Steps ..........................................................................................................27

References ....................................................................................................................................29
Introduction and Background

The energy debate in the United States (U.S.) has raged for decades as the country’s reliance on fossil fuels has deepened and environmental concerns have highlighted the need for viable alternative fuel sources. Unfortunately, traditional fossil fuels such as oil, coal, and conventional natural gas all have drawbacks that make them less than ideal to meet the energy needs of the country. First, U.S. reliance on oil comes at the expense of a volatile international market and dependence on unstable foreign economies, second, coal is fraught with dangerous working conditions and high greenhouse gas emissions, and third, until recently, natural gas resources have been largely too expensive to extract. Sourcing energy by other means is also fraught with problems—nuclear energy carries the risk of nuclear meltdown and the difficulty of disposing of nuclear waste, and alternative energy sources are currently too insufficient, expensive and unreliable to carry the brunt of U.S. energy needs. As a result, energy producers have turned to unconventional fossil fuel extraction from shale formations, coal beds, and tight sands as a viable alternative to the current U.S. energy supply (EPA 2011).

As the unconventional practice of hydraulic fracturing has allowed shale gas to become an increasingly popular fuel source, policymakers have had to balance the economic opportunities and the environmental costs of shale gas extraction to determine this fuel’s role in the U.S. energy future. This paper investigates the role of shale gas in setting natural gas prices through a fixed effects statistical model that analyzes shale gas production in Arkansas, Kentucky, Louisiana, Oklahoma, West Virginia and Texas from 2004 to 2010. Then it discusses the economic and security benefits and the environmental concerns surrounding the process. Finally, it lays out a variety of policy options for shale gas development, depending on how much of a role policymakers want it to have in the U.S. energy future. The paper finishes with a
section describing questions that remain unanswered after this research and opportunities for further study of the topic.

*What Is Hydraulic Fracturing?*

Natural gas drilling has been a part of the US energy supply chain for almost 200 years, since the first natural gas well was drilled in 1821 in Chautauqua County, NY (dSGEIS 2009). However, as easily-extractable natural gas deposits ran dry, companies began to search for ways to access much larger gas reserves that lay deep below the surface. These additional deposits sit under thousands of feet of rock, trapped in porous shale formations that prevent the gas from being collected through traditional gas wells (H. Wiseman 2010). In the early 1900s, extractors discovered that if they could create fractures in the shale bed surrounding the gas deposit, the gas would be released from the rock and could be collected through gas wells. The first attempts at fracturing involved injecting foam into wells to cause cracks in the shale (dSGEIS 2009). Today, the process is called hydraulic fracturing or “fracking,” and involves much more sophisticated techniques.

In order to reach gas deposits deep in the earth, a gas extractor drills a vertical well down to where the deposits sit. Then, depending on the rock formation, concentration of gas in the deposit and location of the well, the extractor drills a vertical well or a horizontal well. A vertical well is drilled straight down into the formation. From there, horizontal wells may be drilled out from that central location extending in multiple directions and depths, allowing for greater penetration into the rock formation. Horizontal drilling allows for access to multiple shale gas deposits from one surface well. Once the well is drilled, a well casing and cement wall is installed down the full length of the well to prevent fluids and natural gas from escaping and
contaminating the ground around the well. The walls of the well are then perforated at targeted locations. (EPA 2011)

To “frack” the well, a proprietary mixture of water, chemicals and a propping agent, known as the “fracking fluid” is pumped into the well at a high pressure. The high pressure forces the fluid out through the perforations in the well walls and into the surrounding shale rock, creating fractures in the shale. The proppant, material such as grains of sand, ceramic, or other particulates that prevent the fractures from closing when the injection is stopped, lodges in the fractures to allow gas trapped in the shale formation to escape into the well. The fracking fluid is then pumped out of the well, allowing the newly- liberated natural gas to flow to the surface through the well. The well is then ready to be used for natural gas production (EPA 2011).

Literature Review

Theoretical Model & Market for Natural Gas

In discussions of the future of shale gas, most regulators and natural gas industry representatives have assumed that the shale gas boom has caused natural gas prices to drop. However, in the literature on natural gas markets, prices have been historically found to mirror oil prices. Until recently, the generally accepted rule of thumb was that The West Texas Intermediate (WTI, an oil price benchmark) price and the Henry Hub price (which is the benchmark for North American natural gas prices) were generally accepted to be related at a ratio of 10-to-1. Oil prices were set at an international level and natural gas prices settled relative to their petroleum counterparts.

Since the 1990s, however, natural gas prices have been diverging from the 10:1 ratio, fluctuating between 4:1 and 12:1, indicating a potential split between oil and natural gas pricing
As a result, recent research has begun to examine the factors that affect natural gas prices beyond the price of oil. This decoupling could be partially a result of reduced fuel switching capabilities, by which power plants can switch between producing electricity from oil or gas, depending on relative prices. Hartley, Medlock III and Rosenthal (2007) found that natural gas prices are closely tied to oil prices in regions where there is high fuel switching capability. Pyrdol and Baron (2003) demonstrated that fuel switching is becoming less common in electric power generation and the downward trend is likely to continue as fewer electricity plants invest in fuel switching technology.

On the other hand, Brown and Yuce (2008) argued that despite the reduction in fuel switching capability, natural gas and petroleum products are still substitutes. Noting that most research does not take other factors that affect natural gas prices into consideration, they controlled for extreme weather events, natural gas inventory, and shut-in production. Their results demonstrated that once these seasonal and short-term effects are taken out of the equation, natural gas prices are still closely linked to crude oil prices.

Hartley, Medlock and Rosenthal (2007, 2008) examined the relationship between natural gas prices and oil prices. They found that the relationship between crude oil and natural gas is indirect, acting through competition between natural gas and residential fuel oil. Along with Barden, Pepper and Aggarwal (2009), their results indicated that in some regions natural gas prices fell when oil prices rose, which they hypothesized was caused by the presence of highly valued liquids associated with the gas that offset any increase in demand resulting from the jump in oil prices.

Both Barden, Pepper and Aggarwal (2009), and Rosendahl and Sagen (2009) found liquid natural gas (LNG) has a large role to play in the future of natural gas prices. The former
found that natural gas prices will respond more to spikes in oil prices when gas-to-liquid capacity is present and can be expanded, while the latter suggested that investing in LNG infrastructure will lower the cost of natural gas due to the economies of scale provided by the transportation of gas in liquid form.

*Environmental Concerns about Fracking*

Of the many environmental concerns surrounding hydraulic fracturing, two stand out as the most potentially harmful: surface water contamination and greenhouse gas pollution. The literature on the environmental impacts of hydraulic fracturing is sparse, due in part to the short time period since the modernization of the process that researchers have had to analyze environmental impacts.

**Surface/Drinking Water Contamination:** Surface water contamination may occur when fracking fluid and natural gas from shale wells escape into the surrounding groundwater, leaching fracking chemicals and methane into the groundwater supply and nearby water wells. In addition, used fracking fluid is held in surface containment pools, where it can seep into the surrounding groundwater supply if the pool does not have sufficient lining. Until very recently, information on groundwater contamination caused by hydraulic fracturing has been anecdotal and reported by interest groups on both sides of the issue such as the Natural Resources Defense Council (NRDC) and the Marcellus Shale Coalition, whose membership includes natural gas extraction companies. The U.S. Environmental Protection Agency (EPA) began a study on groundwater contamination in 2004, but never progressed past the first phase.

In February 2011, EPA announced a study on the impacts of fracking on water quality. When complete, this report will include retrospective and prospective case studies of locations of
suspected water contamination due to hydraulic fracturing. The five retrospective case studies will examine whether water contamination occurred near wells that have previously been hydraulically fracked, and the two prospective case studies will monitor groundwater contamination throughout the fracking process from well drilling to extraction. The study will also include computer modeling, lab testing, a review of existing scientific literature and other techniques. The study will be released in two phases: preliminary results will be available in late 2012 and final results in 2014.

Finally, in December 2011, an EPA report indicated for the first time that groundwater near hydraulically fractured wells in Pavillion, Wyoming contained chemicals used in the fracking process. The investigation was conducted in response to resident complaints in 2008 about the odor, taste and color of the water in their wells. These water wells were located near the Pavillion Gas Field, which contained 169 vertical natural gas wells (DiGiulio, Wilkin and Miller 2011). Unfortunately, the unprecedented ruling following the investigation was not definitive. While EPA’s press release indicated that “ground water in the aquifer contains compounds likely associated with gas production practices, including hydraulic fracturing” (Jackson and Mylott 2011), it did not go far as to attribute the contamination directly to the nearby gas wells. Furthermore, the levels of chemicals found in the water were below established U.S. health and safety standards (DiGiulio, Wilkin and Miller 2011).

**Greenhouse Gas Emissions:** Natural gas has long been praised by its proponents because of its lower greenhouse emissions than oil or coal when used for electricity generation or as an automotive fuel. Natural gas is composed mostly of methane (CH₄), a greenhouse gas 21 times more harmful to the atmosphere than carbon dioxide (CO₂) over a 100-year period (EPA 2011). However, when natural gas is burned for energy production, it releases CO₂, not methane.
It also burns more efficiently than coal or oil, producing less than half of the CO\textsubscript{2} emissions of coal and 25\% less than oil for the same amount of energy\textsuperscript{1} (EPA 2007). As evidenced by Figure 1, natural gas represents 24 percent of energy consumption in the U.S. but is only responsible for 21 percent of U.S. carbon dioxide emissions. This estimate only considers direct carbon emissions from the burning of natural gas during use, but there is evidence that when greenhouse gas emissions during the production and transportation processes involved with shale gas are taken into consideration, natural gas is no less greenhouse gas-intensive than other fossil fuels.

Since shale gas is often found in remote areas with little existing infrastructure or access to pipelines, many of the resources needed for well completion and usage are brought in using trucks. Depending on the size of the well and technique used, fracking requires between 2 million and 9 million gallons of water. In most cases this water is brought to the site in tanker trucks (U.S. Department of Energy 2011). After fracking, the water must be trucked back out for permanent disposal, usually in empty wells. Shale wells require on average 1,000 truck trips during drilling and fracking (Christen 2010). The high-volume of trucks required for fracking adds both to the carbon emissions of the process and decreases air quality in rural areas with shale wells.

In the first peer-reviewed article on methane emissions associated with shale gas, Howarth, Santoro and Ingraffea (2011) found that the methane that escapes during shale gas

\textsuperscript{1} Coal emits 2,135.92lb of CO\textsubscript{2} per megawatt hour (MWh) of electricity, compared to oil at 1,243.95lb/MWh and natural gas, which emits 966.25lb/MWh (EPA 2007).
extraction and transportation negates the cleaner-burning advantages. The authors estimated that the leakage of natural gas out of wells and in poorly-sealed pipelines makes it as much as 20% more harmful to the environment than coal. A rebuttal of the article argued that the results of the study are unreliable because there is not enough data available to provide much more than anecdotal evidence (Cathles, et al. 2011). In a Congressional briefing on January 23, 2012, Mark Brownstein of the Environmental Defense Fund indicated that the Howarth et. al. study was a sign that industry needs to begin consistent monitoring the leakage of methane throughout the production process. If the Howarth et. al. analysis proves to be accurate, it could have far-reaching effects on the utility of shale gas as a “bridge fuel,” a cleaner alternative to coal and oil while the country transitions to clean and renewable energy sources.

**Research Design**

*Shale Gas Production Data*

Shale gas production in its modern form has only been technically and economically viable since the mid-2000s. As with any new technology, it takes time for data to be collected and made publicly available. While many state-level oil and gas agencies require disclosure of mineral resource extraction, only some states make it publicly available. In addition, many states do not separate out natural gas production by extraction method or geological formation, making it impossible to distinguish between shale gas and other natural gas production. As a result, the data for this study have been assembled from a variety of sources. The shale gas production data were retrieved from oil and gas regulatory agencies in six states: Arkansas, Kentucky, Louisiana, Oklahoma, Texas and West Virginia. The data from these states provide information on the shale formations that have seen the most development and extraction volume.
Arkansas data include production from the Fayetteville shale; Kentucky data provide production from the Marcellus shale; and Louisiana contains part of the Haynesville shale. In addition, Oklahoma is home to the Woodford shale; Texas contains parts of the Haynesville shale and all of the Barnett and Eagleford shale formations; and West Virginia data include another section of the Marcellus shale. Notable exclusions from this study are many of the states in which shale gas is a hotly contested issue, such as New York, Ohio, and Pennsylvania, all of which have significant production in the Marcellus shale. These exclusions are because the states listed do not have monthly shale gas production information available to the public in a way that comported with the rest of the study. While the states listed above require production reporting on a monthly basis, New York and Ohio report natural gas production on an annual basis and Pennsylvania on a bi-annual basis.

Table 1 provides information on the data included in the model. In general, shale gas production data was retrieved from the individual state regulatory agencies in Arkansas, Kentucky, Louisiana, Oklahoma, Texas and West Virginia. In all but Louisiana, well information does not include whether or not the gas was pulled from a shale formation, nor does it indicate whether or not an individual well was hydraulically fractured. As a result, most state production data includes all natural gas production from certain known shale gas formations. It is likely that there is gas retrieved from smaller shale formations that is not included in the production numbers, and that not all of the production included is in fact shale gas. For the purposes of this study, the assumption is being made that while these other gases were available for extraction throughout the time period being examined, any dramatic increases in production since states began fracking are caused by increased shale gas drilling.
Shale gas production data was limited to years 2004-2010. The lower limit was set at the time states began hydraulic fracturing and horizontal drilling beyond experimental wells. This enables a look at development trends from the very beginning of the shale gas boom. The latter date of December, 2010 was chosen due to data release limitations – not all states had data available for the same months in 2011 when this study began, necessitating the exclusion of the year 2011 from the analysis. The natural log (ln) was taken for each production variable. This helped to normalize the data and made sense for the analysis because production varied from 1.29 million cubic feet (mmcf) to more than 203 billion cubic feet (bcf) while overall natural gas prices varied by only $7.41 per million British thermal units (mmbtu). In addition, since shale gas production was reported in the included states on a monthly basis, natural gas prices likely responded to the previous month’s production numbers. The final model lead shale gas production by one month to account for this delay in market response.

**Arkansas shale gas production:** Shale gas production information was collected from the website of the Arkansas Oil and Gas Commission. The data are limited to wells in the B-43 producing region, of which more than 97% extract gas from the Fayetteville shale. The original data file contained 2455 wells and 65,534 data points of monthly well production from 1968-2011. When limited to years 2001-2010, data for zero wells were removed for years prior to 2004 and data for 412 wells were removed for 2011. The production data were then aggregated by month, resulting in 84 months of statewide shale production data.

**Kentucky shale gas production:** Shale gas production information was collected from the website of the Kentucky Department of Natural Resources, Oil and Gas Division. In Kentucky, the shale gas determination was made based on “deepest pay formation,” which indicated the deepest point the well successfully produced gas in sufficient quantities. This was
likely the least accurate of the data collected, since there was no way to determine wells that were drilled into shale formations and lower non-shale formations. These data were then limited to the years 2004-2008 in potential shale formations; 2008 being the last year for which data was available. In sum, monthly production from 5,006 wells in eight formations was collected to create the data used in this study.

**Louisiana shale gas production:** Shale production was provided by the Louisiana Department of Natural Resources, Office of Conservation. Similar to the list of wells in Arkansas, Louisiana provided a list of shale wells in the Haynesville shale formation. These data go back to March 2008, when the state first began fracking and horizontal drilling of shale formations. The data from Louisiana were likely the most accurate, as they did not include any non-shale wells and should include all shale wells. This departure from the data collection of the other states improved the analysis because it did not include any extraneous production numbers.

**Oklahoma shale gas production:** Shale production was downloaded from the Oklahoma Corporation Commission, Oil and Gas Division. Natural gas production reporting included all of the formations from which gas was collected from a particular wellhead. All wells that reported production in either the Woodford or Caney shale formations in 2004-2010 were included in the data.

**Texas shale gas production:** Texas data came from the Railroad Commission (RRC) of Texas for years 2004-2010. Data were collected for 28 fields identified as shale fields. This included data from the Barnett, Bossier, Pregnant, Haynesville, Eagle Ford and Woodford shale formations. There were also five fields included that were labeled “shale” without a formation listed. Information on the RRC website was already aggregated so there is no information on the exact number of wells in the data. However, other resources available through the RRC indicated
that Texas has more than 15,000 shale wells as of March 2012 and in 2011, shale production accounted for 31% of all natural gas production in Texas.

**West Virginia shale gas production:** Shale production was downloaded from the West Virginia Department of Environmental Protection, Office of Oil and Gas. Well information was pulled by formation, while production information was available separately for all wells. Well information was downloaded for the Braller, Brown, Coffee, Devonian, Marcellus, Needmore and Upper Devonian shale formations, for a total of 2730 wells. Drilling in the Marcellus shale accounted for approximately 80% of the included wells. These data were then cross-listed with production information using the unique number assigned to the well by the American Petroleum Institute (API).

**Variable Description**

**Natural Gas Price:** This is the dependent variable in the model. The Energy Information Administration (EIA), the independent research arm of the U.S. Department of Energy, publishes monthly natural gas prices at a variety of points in the production and distribution process. The data collected for this study were the monthly citygate price for each of the five states examined. The citygate price is the rate at which commercial gas utility receives natural gas from a pipeline or transmission company. It is considered to be the second sale point in the transmission of natural gas from the ground to the consumer, the first being the wellhead price, which calculates the value of the gas based on production volume and costs. Citygate prices are generally considered to be wellhead prices plus transportation costs from wellhead to measuring or distribution station. While transportation methods vary from state to state, there should be few fluctuations in transportation costs from year to year in each state.
**Crude Oil Price:** Natural gas price is considered to be highly correlated with oil price. This is because the two fuels are substitutes, and historically many energy production plants could switch between oil and gas processing depending on their relative prices. It was important to control for oil price fluctuations in order to accurately observe the effects of shale gas production on natural gas prices. The data source used for this variable, the West Texas Intermediate (WTI) price, is widely considered to be a good indicator of oil prices. This data was adjusted for inflation using the producer price index (PP-I) for energy as reported by the U.S. Bureau of Labor Statistics. All amounts were in 2010 dollars.

**State Unemployment Rate:** As measured by the U.S. Bureau of Labor Statistics on a monthly basis, the state unemployment rate served as a general indicator of the economic wellbeing of each state, which could affect the price of natural gas. This variable was particularly valuable in controlling for the effects of the 2008 economic crisis, which was expected to have lowered prices due to decreased demand across the energy sector.

<table>
<thead>
<tr>
<th>Variables in the Model</th>
<th>Type</th>
<th>Unit of Measure</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Ordinal</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>State</td>
<td>Ordinal</td>
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<td>N/A</td>
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<tr>
<td>Shale Gas Production</td>
<td>Continuous</td>
<td>Mmcf (million cubic feet)</td>
<td>29,313</td>
<td>1.29 – 203,479</td>
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<tr>
<td>Natural Gas Price</td>
<td>Continuous</td>
<td>Dollars per mmbtu ($)</td>
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<td>$2.56 – $9.97</td>
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<td>Oil Price</td>
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<td>Dollars per barrel ($)</td>
<td>$42.45</td>
<td>$25.60 – $63.67</td>
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<td>Unemployment Rate</td>
<td>Continuous</td>
<td>Percent (%)</td>
<td>5.71%</td>
<td>3.2% – 9.7%</td>
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<td>Season</td>
<td>Ordinal</td>
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<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Non-Shale Natural Gas Production</td>
<td>Continuous</td>
<td>Mmcf</td>
<td>138,040</td>
<td>301 – 532,161</td>
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<tr>
<td>Natural Gas Storage</td>
<td>Continuous</td>
<td>Mmcf</td>
<td>328,668</td>
<td>9627 – 734,850</td>
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<tr>
<td>Natural Gas Consumption</td>
<td>Continuous</td>
<td>Mmcf</td>
<td>76,106</td>
<td>3,155 – 339,873</td>
</tr>
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</table>
**Non-Shale Production:** An estimator of overall natural gas production without the shale component, this variable was constructed by taking state-reported monthly natural gas production and subtracting shale gas production as calculated above. Since the shale gas production data contained some error, this variable was subject to the same shortcomings. The natural log was calculated for this variable to normalize the distribution. Similarly to the shale gas production variable, non-shale production was reported monthly, leading to a delay in price response. The complete model included this variable with a one-month lead on the non-production variables. The non-shale production variable controlled for fluctuations in natural gas production that are not related to shale gas.

**Natural Gas Consumption:** This final state-level variable controlled for demand-side effects on natural gas prices. It came from EIA state-level consumption data from 2004-2011. This variable was reported in million cubic feet, and once again the natural log was calculated to normalize the data and provided a meaningful measure by which it can be compared to natural gas prices.

**Season:** Natural gas sales are seasonal, with demand peaking in the winter due to gas heaters in homes. In some regions, natural gas prices also peak in the summer due to its increasing use in electricity generation used for cooling. Similarly, both production and prices can be affected by weather fluctuations and extreme weather events. This variable was included to control for these seasonal effects.

**Hypothesis & Statistical Model**

This study examined increased natural gas production due to new developments in the shale gas extraction process in six states. Since natural gas prices are affected by factors other
than shale gas production, the model also controlled for the effects of other variables within the
each state, including non-shale natural gas production, natural gas storage, natural gas
consumption, and state economic health. Other variables accounted for seasonal fluctuations in
natural gas prices and crude oil price. The hypothesis tested was that increased shale gas
production was bringing natural gas prices down. Many projections about the future of shale gas
assume a strong relationship between these two factors, and this analysis attempted to inform
projections about the role of shale gas in the energy future of the U.S.

The analysis included a series of regressions in which variables were added sequentially
to demonstrate the effects of the variables on the overall model. The first two models were
Ordinary Least Squares (OLS) regressions that did not control for state-level or time effects.
Subsequent models were run using Fixed Effects that control for these time-constant variables.
All of the variables discussed above were included in the final model and took into account the
delay in market response between production reporting and price effects.

Results

Overall, the results indicated that there is not a statistically significant relationship
between state-level shale gas production and state-level natural gas prices. Once dummy
variables were included in the model to control for differences between years, the effects of all
non-macro variables became insignificant. This indicated that natural gas prices are set at a
national level and that the production, consumption, and storage within each state did not
independently affect the prices in each respective state.
Table 2 provides results of the statistical analysis. Model 1, which controlled for no price effects other than shale gas production, suggested that for every percent increase in shale gas production, prices decreased by $0.36. The $R^2$ value indicated that the model explains 26.63% of the variation in natural gas prices. Model 2 included state dummy variables, with Arkansas as the reference case. According to this model, a one percent increase in shale gas production was related to a $0.52 decrease in natural gas prices. This larger coefficient, relative to that in Model 1, indicated that once the model controlled for differences between states, there is a stronger

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
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<td>Shale Gas Production</td>
<td>-0.3637**</td>
<td>-0.5168**</td>
<td>-0.4858**</td>
<td>-0.0841</td>
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<tr>
<td></td>
<td>(0.0284)</td>
<td>(0.0474)</td>
<td>(0.1153)</td>
<td>(0.1124)</td>
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<td>-0.0301*</td>
<td>-0.0343*</td>
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<td>-0.5503*</td>
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<td></td>
<td>(0.0065)</td>
<td>(0.0094)</td>
<td>(0.0089)</td>
<td></td>
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<tr>
<td>Unemployment Rate (State)</td>
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<td></td>
<td></td>
<td></td>
<td>-0.5503*</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.2270)</td>
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<tr>
<td>Natural Gas Storage (State)</td>
<td>-0.8074</td>
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<td>-0.0140</td>
<td></td>
<td>-0.5503*</td>
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<td></td>
<td>(1.8473)</td>
<td>(0.9664)</td>
<td>(0.9925)</td>
<td></td>
<td>(0.2270)</td>
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<td>Non-Shale Production (State)</td>
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<td>0.0160</td>
<td>0.1129</td>
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<td></td>
<td>(0.2595)</td>
<td>(0.2329)</td>
<td>(0.2041)</td>
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<td>(0.3125)</td>
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<tr>
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<tr>
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<td>0.2663</td>
<td>0.4315</td>
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<td>$R^2$ (within)</td>
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<td>0.3164</td>
<td>0.5351</td>
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Values in parentheses are standard errors.
* indicates p<0.1, * indicates p<0.05 and ** indicates p<0.01
relationship between production and prices. The $R^2$ value was 0.4315, indicating that 43.15% of the change in natural gas prices was explained by the model, almost twice the explanatory power of the first model.

Model 3 included other energy sector indicators including national oil price, state-level natural gas storage, state-level non-shale gas production and natural gas consumption. According to economic theory, these variables should all have had strong relationships to natural gas prices. However, the only statistically significant variable in this new group was oil prices—for every dollar increase in oil prices, natural gas prices decreased by $0.02. A joint F-test indicated that while these variables were not independently significant, together they did have a significant effect on prices. Model 3 was a fixed effects regression using the command `xtreg` in the Stata statistical package. The $R^2$ value in this model did not include the state dummy variables in its calculation and only took into account the explanatory power within each state. Therefore, there was no way to compare the $R^2$ values between the OLS estimates of the first two models and the fixed effects estimate in the third.

The next iteration, Model 4, included year dummy variables that controlled for unobserved differences between seasons and years that affected prices. The shale gas production variable fluctuated from a highly significant p-value of 0.012 to a less significant p-value of 0.488. None of the other variables were particularly affected by the year dummies, except for the Spring variable, which lost partial significance. Another indication that the year variables had a large impact on the model was the explanatory power of the state fixed effects, indicated in fixed effects models by rho ($\rho$). In Model 4, $\rho = 0.914$, which indicated that most of the variation in the error term could be explained by the state fixed effects. This suggested that changes in the dependent variable that were not controlled for in the model were guided by state-level factors.
With the year dummies included, however, $\rho$ dropped to 0.248, indicating that much of the presumed relationship between state fixed effects and the price of natural gas could actually be explained by non-state specific changes over time. At the same time, $R^2$ jumped to 0.5351, indicating that the model explains 53.51% of the variation of natural gas prices.

Subsequent investigation turns up factors that explained differences in the impacts of individual years (Complete Model). For example, the economic downturn beginning in 2008 and continuing through 2010 and beyond had nation-wide implications that affected all states and the entire energy sector. Once the unemployment rate was included in the model, years 2009 and 2010 became insignificant; suggesting that the general economic health of the state was the primary reason 2009 and 2010 initially appeared significantly different from the reference year of 2004. Other year-specific factors that could have been included in the year dummies were the effects of Hurricane Katrina, which disrupted the entire energy sector in 2005.

The final statistical model only included two significant variables: oil price and unemployment rate. The $R^2$ value indicated that the model explained 55.51% of the variation in natural gas prices over the time period examined. Unemployment rate had a large effect on prices, with a 1% increase in unemployment rate leading to a $0.61 decrease in natural gas prices. Oil prices also had a statistically significant effect: a $1 increase in oil prices is related to a $0.03 decrease in natural gas prices.

**Model Considerations**

Investigation into potential correlations between variables indicated that the variables for shale gas production, non-shale production and natural gas consumption were highly correlated. This made sense since the two production variables together equal the total natural gas
production for the month. These variables were in the model one month ahead of the other variables. Consumption is driven partially by supply, so natural gas consumption from a given month should track closely with production from the previous month. An F-test to see if shale gas production, non-shale production and natural gas consumption had significantly different effects on natural gas prices was not significant. However, when the natural gas consumption variable was excluded there was very little change in the model, indicating that the multicollinearity was not causing significant distortions.

All other model considerations aside, the main shortcoming with the experiment was a presumption of state-specific effects of production on natural gas pricing that was not reflected in the results. CONSEQUENTIALIY, the model as presented does not provide insight into whether or not the shale gas boom is in fact responsible for depressed natural gas prices in the US. The design of the model was based partially on the assumption that shale gas extraction occurred ahead of natural gas transportation developments. As states that previously were not significant producers of natural gas began to extract from shale formations, distribution networks would be generally isolated from national pipeline systems. At the start of the shale boom, shale gas would drive down natural gas prices in states that had previously relied on imports from other parts of the country. Once they began producing locally-available shale resources that were cheaper than the national price for natural gas, prices in those states would be driven down. For example, Figure 2 shows average natural gas prices across the six states for the period of the study. In 2004 and 2005, Kentucky had one of the highest average prices relative to the other states. In 2010, Kentucky had one of the lowest average prices. The hypothesis suggested that this relative price change was due to a glut of in-state shale gas supply.
However, four of the states included in the study had a long history of natural gas production (Arkansas, Louisiana, Oklahoma and Texas), meaning that they have the most integrated intra- and interstate natural gas pipelines. The other two states, Kentucky and West Virginia, also had existing natural gas systems off of which to build. These states had robust natural gas markets prior to the development of hydraulic fracturing and horizontal drilling and were already producing and distributing most of the U.S. natural gas supply. In retrospect, this connection between available data and existing supply networks makes sense. The states that already had the regulatory and physical infrastructure to manage natural gas production had a much easier time incorporating shale gas into their existing systems than states that had to start from scratch because they had no infrastructure in place. Had the study been able to include states that did not traditionally produce natural gas, the results may have been different. For example, in 2007, EIA listed states that were at least 85% dependent on natural gas imports from other states. Delaware, New Jersey, New York, Ohio and Tennessee were all in this group. Since then, many of these states have begun shale gas production in the Marcellus shale, while transportation networks struggle to catch up to the new shale gas supply. In fall 2011, the Federal Energy Regulatory Commission (FERC) announced that two natural gas pipelines went into operation that link the northeast Marcellus shale supply

![Figure 2](image)

**Average Annual Natural Gas Prices**

![Bar chart showing average annual natural gas prices for different states from 2004 to 2010.](chart)

- AR
- KY
- LA
- OK
- TX
- WV

Average Natural Gas Price ($)

Year

2004 2005 2006 2007 2008 2009 2010

$0.00 $2.00 $4.00 $6.00 $8.00 $10.00 $12.00

~ 20 ~
to the national distribution system. These two pipelines have the capacity to carry 460 mmcf/d (million cubic feet per day) (Snow 2011). Furthermore, in 2011 alone, FERC approved new permits for an additional 3,095.9 mmcf/d of new pipelines to distribute Marcellus shale gas throughout the region and feed into the national distribution network (FERC 2012). To put this number in perspective, in 2008 natural gas pipelines from the southwest pumped approximately 10,200 mmcf/d to the northeast (EIA, Major Natural Gas Transportation Corridors n.d.).

**Policy Implications**

Despite the inconclusive results of the statistical analysis, there are many policy choices facing public officials and industry executives with regard to shale gas development and the effects these actions will have on the energy future of the U.S. The context of these choices includes environmental concerns about hydraulic fracturing, the future of natural gas, and desired energy portfolio outcomes.

*Environmental Concerns*

As discussed in the literature review, above, the environmental impacts of hydraulic fracturing are not fully understood. Industry proponents argue that with proper well casing and wastewater disposal, fracturing causes no threat to groundwater surrounding the wells. In terms of greenhouse gas emissions, even if the production process emits methane, there are simple fixes available such as flaring the methane—a process similar to a method used in landfills. On the other hand, environmentalists point to anecdotal evidence of groundwater contamination to argue that existing precautions are not sufficient. Since the effects of fracturing on the environment are still being understood, aggressive development of shale gas resources should be put on hold until
the true environmental impacts of fracking are determined and appropriate regulations are put in place to prevent groundwater contamination.

**Price Estimates**

One of the keys to ensuring a robust market for shale gas in the U.S. is keeping the price low enough to increase demand yet high enough to cover production and transportation costs. Shale gas producers will not drill wells if the gas costs more to produce than its sale price. With prices at historic lows, shale gas companies have already begun to cut back on their production. In January 2012, three large natural gas producers announced intentions to reduce gas drilling in response to unsustainably low prices. Chesapeake Energy, Conoco-Phillips, and a joint partnership between Noble Energy and Consol Energy all planned to reduce natural gas drilling by as much as half in the months that followed.

Unfortunately, it is difficult to determine what price is required to maintain high volumes of shale gas development today and in the future. Technological advances will lower production costs, but well production will become more expensive as easily-developed shale formations are exhausted, necessitating a move to more difficult extraction locations. Furthermore, the existing...
breakeven price is calculated many different ways using different units, making it difficult to compare calculations. FERC estimated the breakeven price at under $4/mmcf in 2010. Conversely, a 2008 NYMEX Bank of America report places it at approximately $8/mcf. The Massachusetts Institute of Technology (MIT) offers a sliding scale of breakeven prices as they relate to natural gas supply (Figure 3).

A Deloitte Consulting report indicates that low natural gas prices have a much larger effect on the market than high prices. As the price drops, it becomes less economically feasible to drill for natural gas. At the same time, EIA estimates that the price for natural gas will remain under $5/mcf through 2023, rising to $6.52/mcf by 2035. Deloitte estimates a price of $6.75/mmbtu in 2020, rising to $7.87 by 2030. Both of these estimates are above the breakeven prices suggested by FERC and MIT.

International Considerations

The 2012 EIA Annual Energy Outlook estimates that the United States will be a net exporter of natural gas by the year 2021, and even earlier, 2016, for liquid natural gas (LNG). This estimate assumes existing policies affecting the natural gas industry will remain unchanged and expects natural gas and LNG production to be strong throughout the period (EIA 2012). In order for this to occur, there will need to be significant investment in shale gas transportation infrastructure. The global natural gas market is currently underdeveloped primarily because of the high cost of liquefying natural gas and transporting it. Recent technological advances in LNG transportation have made it more efficient to export, and additional cost reductions are expected, leading to a worldwide market for natural gas in the near future. As the premier producer of natural gas, the U.S. is uniquely positioned to corner the market in the short term.
However, as the U.S. works to tap into international demand for natural gas, other countries are also developing their shale resources. In 2011, the EIA performed an initial assessment of shale gas resources throughout the world. The report analyzed the viability of 48 shale formations in 32 countries, including India, China, Australia, much of Europe, North America, northern Africa and much of South America. EIA’s prior estimate for worldwide technically recoverable natural gas was approximately 16,000tcf. The new report estimates an additional 5,760tcf of technically recoverable shale gas reserves outside of the U.S. (EIA 2011). U.S. reserves are estimated at 482tcf (EIA 2012).

It will be many years before these resources are exploited by the countries that own them. China, which drilled its first successful shale gas well late 2011, is determined to develop this resource quickly. In March 2012, China announced a target of producing 6.5 billion cubic meters (230bcf) per year of shale gas by 2015 (Hook 2012). Even if it meets this goal, the U.S. still has a competitive advantage. Domestic shale gas production was 5.0tcf in 2010 and EIA expects it to rise to 13.6tcf by 2035. China is the most promising shale gas producer outside of the U.S., particularly after Poland’s shale gas resource estimates were cut by a factor of 10 in March 2012\(^2\). Given China’s history of price controls and limited environmental controls, the entrance of the country into the international gas market will likely drive prices down, making it more difficult for U.S. producers to compete. However, even at full capacity, China alone cannot fulfill worldwide demand, leaving an opening for U.S. exports. In addition, transportation costs will make it cheaper for the U.S. to sell to certain markets.

\(^2\) The Poland Geological Institute revised EIA’s estimate of 5.3tcm (187tcf) of shale gas resources to between 3.46tcm and 7.68tcm (12.22tcf – 27.12tcf), with a high-end estimate of 1.9tcm (67.01tcf) of recoverable reserves.
Natural Gas vs. Alternative Fuels

Natural Gas is often cited as a “bridge fuel” that will allow the U.S. to reduce its dependence on coal in the short term while alternative fuel sources can be developed. Solar, wind and other clean energy technologies are still in their infancy. It will be years before they are sufficient to replace the country’s need for oil, gas and coal. On the other hand, coal emissions contribute significantly to greenhouse gases in the atmosphere. The carbon footprint of the U.S. could be greatly reduced if natural gas can be used to reduce dependence on coal in the short term. This makes natural gas an appealing option to fill the gap between the two energy scenarios. However, the use of natural gas as a bridge fuel will only work under certain conditions. First, natural gas currently makes up only 24% of electricity generation. Even with historically low prices, EIA estimates that natural gas will only account for 27% of electricity generation in 2035, while coal will still account for 39% (down from 45% in 2010) (EIA 2012). Natural gas does not overtake coal in electricity production because the transportation networks are not in place to efficiently and reliably transport natural gas to power plants across the country, and because coal subsidies keep prices artificially low. Both infrastructure inadequacies and price distortions need to be addressed before natural gas can be seen as a viable alternative to coal.

Second, investments will still need to continue in alternative fuel sources. If investments in natural gas development crowd out funding for wind and solar energy, natural gas may end up being a bridge fuel to nowhere. If natural gas is not incentivized over alternative energy in the short run, traditional energy producers will spend money figuring out how to make alternative energy sources cheaper and more reliable. On the other hand, if natural gas eclipses alternative energy in the short-term energy portfolio, energy companies will focus on improving their
natural gas outputs, letting alternative energy investments lag. This diversion of investments can already be seen across the country. For example, in 2009-2010, Ohio was in the midst of planning a wind farm to be installed in Lake Erie that could produce 1,000 megawatts (mw) of energy by 2020. Now, just two years later, the wind project does not have funding secured beyond the first phase. This is primarily due to excitement in the state over shale gas, which was a focus of Ohio Governor John Kasich’s energy policy proposals in March 2012 (Behr 2012).

Finally, there must incentives to switch from natural gas to alternative fuels at the other end of the bridge. If natural gas is abundant as current estimates suggest, there will be natural gas available far beyond the viability of alternative fuel sources. Consumers, power plants, the industrial sector and automobile makers will all need incentives to invest in a second round of infrastructure changes to accommodate alternative fuels. Therefore the discussion of natural gas as a bridge fuel requires certain policy choices to be in place, otherwise the natural gas boom will merely increase U.S. reliance on another fossil fuel and impede investments in alternative energy sources.

Policy Outcomes

Finally, the proper role for shale gas development in the U.S. energy portfolio may change depending on the overarching goal of policymakers. If policymakers become primarily concerned with energy independence or keeping domestic energy prices low, shale gas will need to formation an integral role in the U.S. energy mix. If reduction of greenhouse gases is the priority, shale gas may play an important role in the short term but should not crowd out investments in alternative, carbon-neutral energy sources. Finally, if the country is primarily concerned with protecting the environment, an aggressive move towards renewable and green
energy sources is needed, with little focus on shale gas development. In this case, discouraging
the shale gas market will preserve investments in alternative energy that does not have the
potential to destroy water supplies.

Conclusion and Next Steps

Moving forward, it will only become easier to gather and analyze data on the shale gas
production process. Even as this thesis was being written, states continued to update the
information they made available to the public, including more accurate and comprehensive data
on shale gas production, disclosure of fracking fluids, and environmental and economic impacts
of fracking in the region. The Energy Information Administration only began separating out
shale gas production from other extraction methods in 2008. It will only be a few years before
there is sufficient data to perform a more appropriate nationwide analysis of the impacts of the
shale gas boom on prices. More study—in the same vein as this thesis but with more accurate
data available—will be valuable to improve understanding of the best role for shale gas to play in
the U.S.’s energy future.

Finally, as a current hot-button issue, the political and media climate around shale gas
shifts regularly in response to new information on shale gas resources, health impacts and
regulatory framework. China has recently drilled its first producing shale well, France and
Bulgaria outlawed hydraulic fracturing completely and Poland’s shale gas resource estimates
were reduced dramatically. In addition, EPA for the first time ever found hydraulic fracturing is
the likely cause for contaminated drinking water in Pavillion, Wyoming. Even more surprising, a
report from Cuadrilla Resources in England admitted that hydraulic fracturing was the likely
cause of two earthquakes in the country and a report from the Oklahoma Geological Survey
found that more than 50 earthquakes of varying sizes occurred near a hydraulically fracked well within hours of fracking activity.

At the same time, President Obama announced his “all-of-the-above” energy strategy that includes aggressive development of shale gas resources, yet he vetoed the development of the Keystone XL oil sands pipeline for environmental reasons. This pipeline would have brought oil sands from Canada across the U.S. One highly-anticipated upcoming development will be the results of EPA’s study on the impacts of hydraulic fracturing on drinking water, which will likely have a significant effect on domestic policy on hydraulic fracturing. These and future developments offer a wide range of worthy research opportunities into the future of shale gas.
References


