Revisiting the Economic Impacts of Fracking in Pennsylvania

Timothy J. Considine
Department of Economics
University of Wyoming
Laramie, WY 82071 USA
tconsidi@uwyo.edu

JEL: Q2, Q3, Q4
Released: October, 2017
Last Major Revisions: October 20, 2017

JEL: Q2, Q3, Q4

Keywords: Economic impacts, shale energy, econometric analysis

Abstract

\[^{1}\] This paper is sponsored under a research contract with Strata Policy. The analysis, findings, and conclusions in this paper are solely those of the author and are not necessarily those of the University of Wyoming or Strata Policy. Research assistance from Brian Isom, Adam Bahr, and Jake Cottle is gratefully acknowledged. Comments from Ben Gilbert, Brian Gilbert, and Michael Reed are also appreciated. The author accepts all responsibility for any remaining errors or omissions.
This study examines why ex post econometric studies often find that the economic impacts of shale gas development are considerably smaller than those found by ex ante input-output (IO) studies. Besides the obvious methodological differences, the econometric studies use proxies for shale development while IO approaches use monetary measures of investment and production. This paper unifies these two approaches with a measure of shale industry spending that includes the value of investments in new wells and the value of new natural gas output and natural gas liquids production. An econometric analysis is conducted using three data sets: monthly time series, annual county data, and quarterly time series. The monthly models find employment multipliers between 12 and 14 jobs per million dollars of shale spending, which is close to estimates using input-output models. A structural break in the employment multiplier is found corresponding with the adoption of horizontal drilling in 2007. The county panel data analysis finds employment multipliers between 4.8 and 6.6 and income multipliers between $1 and $1.2 thousand of personal income generated per million dollars of shale industry spending. Finally, the quarterly data are modeled using a vector autoregressive (VAR) model of value added, income, and employment. A dynamic VAR simulation finds that a $1 million shock in shale investment and production generates 16 jobs, $1.75 million in value added, and $3.0 million in total personal income after 18 months. These findings suggest that the economic impacts from shale energy investment and production may be greater than many previous ex post econometric studies have found.
1. Introduction

Advances in oil and gas extraction technology, specifically hydraulic fracturing (aka fracking), horizontal drilling, and seismic sensing, have allowed the development of enormous reserves of shale gas that previously were uneconomic to exploit, see Joskow (2013). Particularly noteworthy are the Marcellus, Utica, and Upper Devonian shale energy resources in Pennsylvania that have emerged as a major source of natural gas and natural gas liquids (NGLs), such as propane, ethane, and butane. The objective of this research is to estimate the economic impacts of developing these unconventional oil and gas resources in Pennsylvania.

This paper presents an econometric analysis of how shale gas drilling and production affect employment, income, and output. Several recent studies examine other phenomena with shale development, including impacts on housing values by Muehlenbachs, et al. (2015), the economy and crime by Feyrer et al. (2017), and the environment by Olmstead, et al (2013) and Considine et al. (2016). This paper does not attempt a comprehensive cost benefit analysis of shale gas development but instead focuses upon estimation of shale industry activity and how it affects employment, income, and output at the state and local levels. This effort is motivated by a series of recent papers on the economic impacts of shale energy development.

These papers share a common thread in which economic outcomes are compared either before or after shale development or between regions with and without unconventional oil and gas production. These differences-in-differences studies employ either cross sectional data or panel data across counties and years. Each study varies in its selection of control groups and various proxies for shale industry activity, such as the number of wells drilled, producing wells, and production from existing or new wells. While the results vary significantly among studies, the general consensus is that the economic impacts of shale energy development are modest and in some cases negligible. In particular, many of these studies argue that ex ante input-output (IO) studies over-estimate the economic impacts of shale energy development.

The main contribution of this paper is the development of a comprehensive measure of shale industry spending that includes the value of investments in new wells and the value of new natural gas output and natural gas liquids production. Shale investment spending to drill and complete wells often precedes production by several months due to delays in the construction of pipeline networks and processing plants. Several previous studies use production as a measure of shale activity but this misses the economic impacts associated with drilling. Likewise, other studies use the number of wells drilled but this approach omits the economic impacts arising from royalties and other outlays associated with the production of gas and associated liquids. Our approach attempts to unify these various approaches in one measure of shale spending: the combined value of shale investment and new production. While our study also uses pooled time series and cross sectional as many other studies do, this effort also employs monthly and quarterly time series data. This approach permits tests for structural change and the estimation of multipliers that could include spillover effects at the state level.

---

2 There are many reasons for these delays, including cost conditions, price expectations, permitting, and other regulatory factors.
Our empirical focus is on Pennsylvania, which provides an ideal case study given the emergence and rapid growth of fracking for unconventional oil and gas since 2007. Pennsylvania went from producing 0.9% of the marketed natural gas in the United States during 2005 to 18.7% in 2016 based upon data reported by the U.S. Energy Information Administration (2017). This surge was accomplished with the investment of more than $75 billion to construct more than 9,400 wells from 2007 through the end of 2016. In addition, this boom involved the construction of an extensive network of pipelines, numerous gas processing and fractionation plants, and NGL export facilities.

The analysis begins in the following section with a presentation of ex ante estimates of employment and value added multipliers using IMPLAN's input-output (IO) models of Pennsylvania. Two different approaches are compared. The first approach assumes inter-industry coefficients for the conventional oil and gas industry prior to shale development. The second approach uses accounting data to estimate interindustry coefficients for the unconventional shale gas industry using the new industry approach developed by Miller and Blair (1989). The analysis reveals that the former approach estimates that roughly 6.5 jobs are created for every million dollars of shale spending while the latter suggests a multiplier of between 12 to 17 jobs per million dollars. These estimates provide a benchmark for comparison with the econometric estimates developed below, which are specified in light of recent ex post econometric studies using historical data reviewed in section three.

The econometric models developed in sections four and five involve regressing first differences in employment, value added, and income on shale industry spending and seasonal factors at different spatial, temporal, and sector levels of aggregation. Our estimates of shale spending, which includes the value of investment in new wells and production from recently completed wells, reveals substantially different patterns over time compared to trends in either new wells drilled or new production used in many previous studies.

The econometric analysis is divided into three sections and yields several interesting findings. The first section estimates the impacts of shale industry spending on employment changes at the state level using monthly data from January 2005 through December 2016 finding an employment multiplier of 12 jobs per million dollars of shale spending. Using tests developed by Andrews (1993) we find a statistically significant structural break in the employment multiplier in 2007, which is about the time when widespread adoption of horizontal drilling began, with employment multiplier increasing to 14 after the break. Our specification is tested alongside other specifications in the literature and is found to be preferred on the basis of Bayes Information Criteria. Nearly three quarters of the state level multiplier of

---

3 The number of wells includes vertical and horizontal wells drilled into unconventional formations based upon data provided by DrillingInfo (2017). Investment is estimated by multiplying the well count by finding costs per well, which are based upon company financial fillings described in section four below and in Appendix A.

4 Data on capital spending for downstream activities, such as the construction and operation of gas processing, transportation, and export facilities are not available for the econometric portion of this study. The economic impacts associated with these activities may be captured by our measures of shale gas spending to the extent that they are correlated with new well investment and new production.
originates from the impacts that shale industry spending has on manufacturing, professional and business services, and the construction sectors.

The second section estimates a panel data model in which per capita changes in employment and personal income are regressed on per capita shale industry spending using observations on all 67 counties in Pennsylvania from 2005 through 2014. The estimates using instrumental variables to account for the possible endogenous decisions of producers on where to drill result in employment multipliers between 4.8 and 6.6 and income multipliers between $1 and $1.2 thousand dollars of personal income generated per million dollars of shale industry spending.

The last econometric section estimates dynamic effects with a vector autoregressive (VAR) model of the statewide impacts of shale industry spending on output, income, and employment in Pennsylvania. The dynamic VAR simulation finds that a $1 million shock in shale industry spending generates 16 jobs, $1.75 million value added and $3.0 million in personal income after 18 months. The paper concludes with a discussion of the overall results and how they may relate to previous findings published in the economic literature.

2. Ex Ante Studies using Input-Output Models

The economic impacts of shale energy development occur during three phases. First, there are the impacts on value added, jobs, and tax revenues during the construction of wells, gathering systems, processing plants, and pipelines. During the second phase, economic impacts arise during the operation of these facilities as the income generated from these facilities is spent. The final phase includes the economic impacts arising from the construction and operation of downstream investments using shale hydrocarbons, such as electric power generating plants, petrochemical plants, and export terminals.

The spending during each phase influences the economy in several ways. The direct capital expenditures indirectly stimulate support industries. For example, capital expenditures for construction of shale gas wells involve purchases from companies that provide capital equipment, engineering and construction services, and other goods and services. These companies in turn acquire equipment and supplies from other companies, stimulating several rounds of indirect spending throughout the supply chain. The direct and indirect outlays generate additional employment and income, which induce households to spend on additional goods and services. Together these direct, indirect, and induced impacts during construction and operation constitute the total economic impacts of the shale energy development.

Regional economic impact analysis using input-output (IO) tables provide a means for measuring these economic impacts. The hallmark of input-output models is detailed accounting of inter-industry transactions between various sectors of the economy. These models provide a means for estimating how spending in one sector affects other sectors of the economy. IO tables are available from IMPLAN, Inc. (2017) based upon data from the U.S. Bureau of Economic Analysis in the U.S. Department of Commerce. These models are widely used to provide ex ante estimates of the economic impacts from public investment projects, renewable energy development, and many other economic development projects.
One of the difficulties in evaluating IO based economic impact studies of shale energy development is that the ways in which these models are applied vary considerably among studies. This study compares and contrasts two different approaches. The first approach models the economic impact of shale gas development as an output change to existing oil and gas drilling and extraction industries. An example of this approach is conducted here with a simulation using IMPLAN’s 2013 IO model for Pennsylvania. A $1 million spending shock from shale investment and production is modeled by increasing output by $500 thousand in oil and gas drilling and another $500 thousand in the oil and gas extraction sector.

The IO model indicates that the $500 thousand increase in drilling activity raises direct employment by 1.23 jobs, adds another 0.58 jobs indirectly, and induces another 1.19 jobs via spending of additional household income for a total increase in 3.0 jobs. A corresponding increase of $500 thousand in oil and gas extraction leads to 1.35 direct jobs, 0.58 indirect jobs, and 1.65 induced job gains for a total of 3.59 jobs created. Combining the $1 million gain in drilling and extraction results in 2.58 direct jobs, 1.17 indirect jobs, and 2.84 induced jobs for a total employment gain of 6.59 per million dollars of shale spending (see Table 1). This approach assumes that the IO model adequately represents the shale gas technology in terms of input requirements and other inter-industry transactions.

The second approach views the development of shale gas as a new industry that has input requirements that are different from conventional gas drilling and extraction industries. Unconventional oil and gas technology differs from conventional oil and gas drilling and extraction in several important ways. The drilling and completion of unconventional oil and gas wells are more complex, requiring horizontal drilling and hydraulic fracturing and employing considerably more factor inputs, such as concrete, steel, and engineering and professional services. In contrast, the oil and gas industry in Pennsylvania prior to 2007 was primarily engaged in developing shallow conventional wells.
Table 1: Pennsylvania multipliers for oil and gas drilling and extraction

<table>
<thead>
<tr>
<th>Impact Type</th>
<th>Impacts of $0.5 million shock in drilling</th>
<th>Impacts of $0.5 million shock in extraction</th>
<th>Impacts of $1 million shock in drilling &amp; extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Employment</td>
<td>Value Added</td>
<td>Employment</td>
</tr>
<tr>
<td>Direct</td>
<td>1.23</td>
<td>0.67</td>
<td>1.35</td>
</tr>
<tr>
<td>Indirect</td>
<td>0.58</td>
<td>0.18</td>
<td>0.58</td>
</tr>
<tr>
<td>Induced</td>
<td>1.19</td>
<td>0.20</td>
<td>1.65</td>
</tr>
<tr>
<td>Total Effect</td>
<td>3.00</td>
<td>1.04</td>
<td>3.59</td>
</tr>
</tbody>
</table>

Source: Minnesota IMPLAN, Inc.

Another difference between conventional and unconventional production is that shale gas wells have entirely different production decline curves than conventional wells with very high initial rates of production and steep declines thereafter, in sharp contrast to conventional wells. For these reasons, Considine et al. (2009) considered the development of shale gas in Pennsylvania as a new industry and, therefore, adopted a technique developed by Miller and Blair (1985) for introducing new industries into an input-output model of a regional economy. This approach requires estimating the input requirements of the new industry, which are the purchases made by Marcellus gas producers from other sectors of the economy. 5

To estimate these input requirements, Considine et al. (2009) collected a sample of detailed accounting data from some Marcellus producers to determine these inter-industry transactions. These surveys also provided information on the fraction of this spending that occurred in Pennsylvania, and the proportion of lease, bonus, and royalty payments paid to Pennsylvania residents. A comparison of the implicit employment multipliers from Considine et al. (2011) with other IO economic impact studies of the Utica and Marcellus shale plays appears in Table 2. The employment multipliers are considerably higher than

5 Miller and Blair (1985) also describe how to model the use of the outputs from a new industry. In this case, other sectors of the economy substitute natural gas for other fuels. This framework also could be extended to model the impacts from the creation of new industries induced by shale gas development, such as petrochemical production and the export of natural gas liquids.
those reported in Table 1 and range from 12.5 to 17.8. These higher multipliers reflect the greater input requirements associated with unconventional hydrocarbon production.

Table 2: Employment multipliers from various input-output based studies

<table>
<thead>
<tr>
<th>IO Based Studies</th>
<th>Shale Play</th>
<th>Jobs</th>
<th>Value Added*</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kleinhenz, et al. (2011)</td>
<td>Utica</td>
<td>178,088</td>
<td>10.0</td>
<td>17.8</td>
</tr>
<tr>
<td>Thomas, et al. (2012)</td>
<td>Utica</td>
<td>12,150</td>
<td>0.9</td>
<td>13.5</td>
</tr>
<tr>
<td>Kelsey, et al. (2011)</td>
<td>Marcellus</td>
<td>23,884</td>
<td>1.9</td>
<td>12.6</td>
</tr>
</tbody>
</table>

* Billion dollars

The multipliers presented in Tables 1 and 2 provide benchmarks of comparison for the econometric analysis presented below. While these models may be useful in ex ante studies of shale energy development, the new industry approach requires accurate estimates of spending by shale energy companies both within and outside the geographical boundaries of the study. Another limitation of both approaches is that input-output models assume fixed factor prices and, therefore, may under-estimate any crowding out of resources created by a shale energy boom.

### 3. Ex Post Econometric Analysis

With the benefit of hindsight, econometric approaches use historical data on economic outcomes to estimate the impacts of shale energy development. For example, the pioneering study by Weber (2012) estimates differences-in-differences (DiD) models in which economic impacts are estimated by comparing outcomes for counties with oil and gas development that form the treatment group to counties without shale wells, which constitute the control group. He uses a sample of 61 counties with oil and gas booms and 127 non-boom counties in Wyoming, Colorado, and Texas to estimate models with a dependent variable equal to the change in economic outcomes under treatment (1999-2007) less the change in outcomes prior to treatment (1993-1999). The explanatory variables include oil and gas production and several other variables as controls. High population and non-boom counties next to boom counties were dropped from his panel data model. Weber (2012) finds that the economic impacts are far smaller than IO studies of shale gas development but acknowledges that oil and gas production does not capture possible investment multipliers associated with construction and completion of oil and gas wells.

Following Weber (2012) are the studies by Paredes, et al. (2015) and Munasib and Rickman (2015) that employ propensity score matching and synthetic control methods respectively to estimate the economic impacts of shale development in various shale gas regions, including the Marcellus. While some of their estimates are statistically significant, their results support Weber’s (2012) finding that the effects from shale development are small.
Another recent study by Komarek (2016) estimates a regression model using pooled county and time series observations relating the logarithm of economic outcomes, such as employment and wages, to dummy variables for high fracking activity, another dummy for lower fracking activity, trend, and fixed county effects. Komarek (2016) finds that employment increases from 2.8 to 5.7 percent, which amounts to approximately 2,000 jobs on average in boom counties. In comparison, Paredes et al. (2015) only find modest total employment effects from 70 to 180 jobs comparing Pennsylvania and New York using panel data regressions. The analysis by Komarek (2016) also finds that employment and wages per job increase 7% and 11% respectively from the increase in shale gas drilling in the Marcellus region three years after the boom but decline after 4 years or more. Komarek (2016) finds no evidence of a resource curse increasing wages in manufacturing.

The study by Lee (2015) focuses on shale gas and tight oil development in Texas. Like prior studies, Lee (2015) uses a differences-in-differences approach examining changes in economic outcomes before and after unconventional oil and gas development both from a cross sectional perspective comparing pre and post treatment periods and from a panel data viewpoint, comparing all counties in Texas over time. Using both static and dynamic models, Lee (2015) finds substantially larger multipliers that allow spillover effects from one county to another, although his definition of multipliers differs from the aforementioned studies. Lee (2015) finds that roughly 15 jobs are created for each new well drilled.

The paper by Feyrer, et al. (2017) examines how income and employment shocks from fracking propagate over time and across geographic units and industries. They measure the effect that the value of new oil and gas production has on income and employment. Specifically, they estimate how much of the value of new production stays within a county and region where production occurs. Using a panel data set across thousands of counties in the US from 2005 to 2014, they find that 2.2 jobs at the state level are created per million dollars of new oil and gas production.

The model by Feyrer, et al. (2017) relates changes in economic outcomes to the value of new production, which reflects preexisting geology and newly introduced technology. They measure new production by gathering data on production from new wells from Drillinginfo (2017). For example, they measure annual new production by the cumulative production from new producing wells brought into operation during the year. Note that this measure is truly incremental and does not include production from wells brought into production in prior years, even if they produced more than in the previous year. Using this measure of fracking activity along with the inclusion of fixed regional and time effects they estimate their model at various levels of aggregation from the county, commuting zone, and state levels. Their approach inspired our measure shale industry activity, which is now discussed.

4. Measuring Shale Activity

During the early stages of shale gas field development as companies drill to secure leases they develop an inventory of drilled but uncompleted wells. Eventually these wells are brought into production if market conditions warrant as connections to gathering systems, processing plants, and high compression interstate pipelines are made. Measuring shale activity by new production misses investment in well construction that in many cases may occur months or years before. Likewise, estimating activity by well
numbers misses the royalties and taxes generated once production commences. The lags between drilling and new production are illustrated in Figure 1. The date when a drill bit hits the ground is known in the industry as a well spud when its location and other characteristics are recorded and given a unique identification code by the American Petroleum Institute. State agencies also separately report when each well commences production. Drillinginfo (2017) collects and reports this information. Notice in Figure 1 that well spuds in Pennsylvania peak during early 2011, while the number of new producing wells, estimated by the first difference in the number of producing wells, continues to increase through 2013.

Another important factor is productivity. As Figure 1 illustrates, the number of new producing wells levels off between 2011 and 2013 and eventually declines after 2014. New production, however, displays a different pattern. Figure 2 plots horizontal and vertical wells drilled into the Marcellus, Utica, and Upper Devonian formations in Pennsylvania from 2005 through the end of 2016. During the early years of Pennsylvania shale development, hydraulically fractured vertical wells were common. Drillinginfo (2017) reports well spud data and production histories for each well including first-month production, which is plotted below in Figure 2. Notice that horizontal drilling (the red line in Figure 2) increased sharply during 2007 and 2008 and reached a peak in 2011. New production (the blue line in Figure 2), however, reached a peak three years later in 2014. This lag between drilling and production reflects market conditions, such as prices for natural gas and natural gas liquids, well costs, and the aforementioned logistical delays in gas network construction.

Figure 1: Well spuds and new producing wells in Pennsylvania
Measuring shale activity by new production would miss the investment boom from 2009 through 2011. Likewise using well spuds alone would miss the gas production boom from 2012 through 2014. This study solves these problems by combining these two measures into the value of investment and production. To measure the value of new production we follow Feyrer et al. (2017) and simply multiply first month natural gas production by prices for natural gas at the Henry Hub and first month new oil production by propane prices at Mont Belvieu because most reported unconventional oil production in Pennsylvania is natural gas liquids, including propane, ethane, butane, and other light hydrocarbons.

The value of new investment is estimated by multiplying new well spuds, including horizontal and vertical wells drilled into unconventional shale formations, by finding costs reported by 12 major shale energy firms on their annual 10k reports to the Securities and Exchange Commission. A monthly-weighted average is computed with weights given by the monthly share of wells drilled by each company. Finding costs include expenditures on property acquisition, wells, and infrastructure.\(^6\) A plot of prices for natural gas and propane, well finding costs, and value of new production and investment appears in Figure 3.

---

\(^6\) Appendix A provides a detailed explanation of well finding costs.
After two sharp peaks early in the sample between 2005 and 2008, real prices for natural gas, which are deflated by the consumer price index less food and energy, track downward through 2016. Propane prices exhibited wide swings, similar to prices for crude oil, and collapsed during 2015. Real finding costs steadily rise, reaching a peak in late 2014 and then decline, reflecting the deflation in well drilling and completion costs as oil and gas prices fell. The combined value of investment and new production is also reported in Figure 3. Notice there are two distinct peaks: one in 2011 during the drilling boom and another in 2014 during the production surge due to higher productivity and a larger number of wells entering production.

These higher levels of shale energy investment contributed to a very significant expansion in natural gas and liquids production in Pennsylvania illustrated in Figure 4. Prior to 2006, Pennsylvania produced on average 0.5 billion cubic feet (bcf) of natural gas per day. Three years into the fracking boom, production increased seven-fold to 3.6 bcf per day in 2011 and another four-fold by 2016 to 14.4 bcf per day (see Figure 4). Production of natural gas liquids also greatly expanded during this period.
These production gains directly translated into higher employment in the mining sector in Pennsylvania as illustrated in Figure 5. Employment gains in the mining sector, which includes oil and gas extraction, drilling, and support services amounted to 30,000 from 2006 to 2015. Similarly, real value added from mining in Pennsylvania increased $17.8 billion over the same period. The key question, addressed in the next section, is whether these direct impacts affected overall economic performance in Pennsylvania.
5. Econometric Analysis

As the previous section illustrates, the value of shale investment and new production, hereafter designated as *shale spending*, is our measure of the economic shock from the development of unconventional oil and gas resources in Pennsylvania. This section presents the results from a series of regressions to determine if this measure of shale industry activity influences economic outcomes in Pennsylvania using monthly statewide employment data, county level annual panel data for employment and income, and quarterly data for statewide employment, value added, and personal income.

5.1 Monthly Employment Models

This section presents the results of a series of regressions estimating the employment impact of shale spending, which is defined as the combined value of shale investment and the value of new unconventional oil and gas production in Pennsylvania. The analysis begins with an examination of how shale spending affects statewide monthly aggregate employment in Pennsylvania. Next, the impact of different specifications of shale industry activity on the estimated employment impacts from shale gas energy development is then explored. Estimates of employment impacts by sector and region within Pennsylvania are then presented.
5.1.1 Aggregate Statewide Employment

Labor is a factor of production so a theoretically rigorous approach would be to derive a labor demand function from a production or cost function. As Jerrell and Morgan (1988) observe, however, data on gross output or total costs are not available at the regional level. This necessitates the adoption of reduced form models of employment, similar to those reviewed above in the context of estimating the impact of shale industry development. Accordingly, this study estimates a simple reduced form model that relates first differences in employment to shale industry spending controlling for trend and seasonal monthly effects.

To understand the importance of trend in this analysis, monthly shale spending and seasonally adjusted changes in employment are plotted in Figure 6. The seasonally adjusted change in employment is defined as the residuals from the regression of monthly first differences in employment on monthly dummy variables. Notice the steep decline in the seasonally adjusted employment change during the recession of 2008 and 2009. Moreover, during and after the economic recovery, shale industry spending appears to closely track seasonal monthly employment changes. These observations suggest that controls for trend in this context, which are commonly used in the ex post econometric studies of fracking discussed above, may be nonlinear.

Figure 6: Shale spending and seasonally adjusted changes in Pennsylvania employment

Accordingly, the first model estimated regresses monthly first differences in employment on shale spending with controls for monthly fixed effects and nonlinear trend. The model is as follows:

\[ y_t - y_{t-1} = \alpha + \beta x_t + \sum_{j=1}^{n} \delta_j D_j + \tau T + vT^2 + \epsilon_t \]  

(1)
where $y_t$ is total non-farm employment, $x_t$ is shale spending, $D_{jt}$ are monthly dummy variables, $T$ is trend, and $\alpha, \beta, \delta_j, \tau, \upsilon$ are unknown parameters. Seasonal dummy variables are included because both employment and shale spending are not seasonally adjusted.

Five different versions of (1) are estimated\(^7\). The first version omits nonlinear trends while the second does not. The F-test for nonlinear trends is 8.21, decisively rejecting their absence. Given that both employment and shale activity are measured in millions, the estimated coefficient is an employment multiplier in terms of jobs per million dollars of shale activity. The coefficient on shale spending for the model with nonlinear trends is 12.03 suggesting that slightly over 12 jobs are created for every $1$ million in shale spending. Given the revolutionary nature of the development of the unconventional gas industry in Pennsylvania, a test for structural change is conducted. The Wald test finds a statistically significant structural shift occurring in January 2007 with the estimated employment multiplier increasing to 14.09 (see Table 3) after this time.

\(^7\) The STATA econometric estimation program for the models using monthly employment data are available in Appendix B, which is available along with the supporting data, from the author upon request.
Table 3: Estimates for monthly statewide employment models (robust standard errors)

<table>
<thead>
<tr>
<th></th>
<th>Monthly First Difference in Total Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Trend</td>
</tr>
<tr>
<td>Shale Spend</td>
<td>3.68</td>
</tr>
<tr>
<td></td>
<td>(1.94)</td>
</tr>
<tr>
<td>Jan.</td>
<td>-147.56***</td>
</tr>
<tr>
<td></td>
<td>(4.22)</td>
</tr>
<tr>
<td>Feb.</td>
<td>40.30***</td>
</tr>
<tr>
<td></td>
<td>(4.24)</td>
</tr>
<tr>
<td>Mar.</td>
<td>51.90***</td>
</tr>
<tr>
<td></td>
<td>(4.89)</td>
</tr>
<tr>
<td>Apr.</td>
<td>75.14***</td>
</tr>
<tr>
<td></td>
<td>(5.31)</td>
</tr>
<tr>
<td>May</td>
<td>49.55***</td>
</tr>
<tr>
<td></td>
<td>(3.44)</td>
</tr>
<tr>
<td>Jun.</td>
<td>8.30*</td>
</tr>
<tr>
<td></td>
<td>(3.94)</td>
</tr>
<tr>
<td>Jul.</td>
<td>-51.50***</td>
</tr>
<tr>
<td></td>
<td>(4.11)</td>
</tr>
<tr>
<td>Aug.</td>
<td>9.83***</td>
</tr>
<tr>
<td></td>
<td>(2.80)</td>
</tr>
<tr>
<td>Sep.</td>
<td>68.50***</td>
</tr>
<tr>
<td></td>
<td>(3.11)</td>
</tr>
<tr>
<td>Oct.</td>
<td>50.74***</td>
</tr>
<tr>
<td></td>
<td>(3.21)</td>
</tr>
<tr>
<td>Nov.</td>
<td>26.45***</td>
</tr>
<tr>
<td></td>
<td>(3.93)</td>
</tr>
<tr>
<td>Trend</td>
<td>-52.62***</td>
</tr>
<tr>
<td></td>
<td>(14.45)</td>
</tr>
<tr>
<td>Trend²</td>
<td>32.49***</td>
</tr>
<tr>
<td></td>
<td>(8.87)</td>
</tr>
<tr>
<td>Cons.</td>
<td>-15.64***</td>
</tr>
<tr>
<td></td>
<td>(2.49)</td>
</tr>
</tbody>
</table>

R²            | 0.966     | 0.970           | 0.969       | 0.969     | 0.969     |
Obs.          | 143       | 143             | 120         | 143       | 143       |
BIC           | 1153.701  | 1146.474        | 979.147     | 1146.474  | 979.147   |
DW            | 1.515     | 1.767           | 1.755       |           |           |
F-test        | 8.21***   |                |             |           |           |
Wald          | 108.72*** |                |             |           |           |
Robust Score  | 0.235     | 0.828           |            |           |           |
p-value       | 0.628     | 0.363           |            |           |           |

*p<0.05, **p<0.01, ***p<0.001
The last two regressions use two different sets of instrumental variables with the first including the maximums for initial new oil and new gas production, real interest rates, monthly dummies, trend, and trend squared. Maximum initial production is included to capture the exogenous technological advances made in well design and productivity. The second set includes the first set of instruments plus lagged values for natural gas and propane prices and well costs. The $R^2$ coefficients for the first stage regressions, which are not reported in Table 3, are 0.72 and 0.83 for the two instrument sets respectively.

As Table 3 illustrates, the estimated employment multipliers using the instrumental variable estimator are close to the estimates found for the model using the sample after January 2007 and only 16 percent higher than the model with nonlinear trend (column three in Table 3) using the entire sample. Hence, subsequent regressions will use the entire sample. Finally, the hypothesis that shale spending is endogenous is tested using the robust score chi-squared test developed by Wooldridge (1995). These statistics are 0.235 and 0.828 with probability values of 0.628 and 0.363 respectively for the two sets of instruments (see Table 3). Hence, the hypothesis of endogenous shale spending cannot be accepted.

5.1.2 Impact of Different Measures of Shale Industry Activity

To gain some perspective on how the specification of shale industry activity affects the estimation of employment multipliers, several different measures of shale activity are compared in Table 4. First, new production and investment are separately used as explanatory variables in the second and third lines in Table 4.

The employment multiplier for new investment is 12.38 while the new production value multiplier is 107.1. Also reported in Table 4 is a model using new wells drilled which indicates each well drilled creates nearly 104 jobs, which higher than the 15 jobs per wells estimated by Lee (2015), and with an average cost per well of $5.8 million over the sample period implies 17.7 jobs per million dollars of well investment. The first model with the combined value of shale investment and the value of new production has the lowest Schwarz Bayesian Information Criterion (BIC) and, therefore, is the preferred model.
Table 4: Impacts of different shale spending measures (robust standard errors)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale Spending</td>
<td>12.03**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.58)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Production</td>
<td>107.10*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(50.34)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td></td>
<td>12.38**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.72)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wells</td>
<td></td>
<td></td>
<td>103.59**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(31.68)</td>
<td></td>
</tr>
<tr>
<td>R-Squared</td>
<td>0.970</td>
<td>0.967</td>
<td>0.970</td>
<td>0.970</td>
</tr>
<tr>
<td>BIC</td>
<td>1146.474</td>
<td>1157.510</td>
<td>1146.557</td>
<td>1146.762</td>
</tr>
<tr>
<td>DW</td>
<td>1.767</td>
<td>1.600</td>
<td>1.766</td>
<td>1.752</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001

5.1.3 Employment Multipliers by Sector and Region

The employment model with nonlinear trend is estimated for the full sample from January 2005 through December 2016 for 13 sectors and the results are reported in Table 5. Three sectors comprise 72% of the 12.03 total employment multiplier reported in Table 3. They are in order of importance: Manufacturing at 3.61, professional and business services at 2.77, and construction at 2.34. All three estimates are significant at the 1% level. Other significant employment multipliers include wholesale trade at 0.87, mining and logging at 0.73, and finance and real estate at 0.54. Like the three largest multipliers, these estimates are also highly statistically significant. These estimates suggest that the 12.03 aggregate employment multiplier originates largely from jobs gains in manufacturing, construction, and professional business services and the remaining gains come from wholesale and retail trade, mining and logging, and the financial and real estate sectors.
Table 5: Employment multipliers by sector (robust standard errors)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Estimate</th>
<th>Sector</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>2.34***</td>
<td>Professional &amp; Bus. Ser.</td>
<td>2.77***</td>
</tr>
<tr>
<td></td>
<td>(0.59)</td>
<td></td>
<td>(0.82)</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>3.61***</td>
<td>Leisure &amp; Hospitality</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>(0.78)</td>
<td></td>
<td>(0.68)</td>
</tr>
<tr>
<td>Mining &amp; Logging</td>
<td>0.73***</td>
<td>Other Services</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td></td>
<td>(0.18)</td>
</tr>
<tr>
<td>Transport. &amp; Utilities</td>
<td>0.96**</td>
<td>Government</td>
<td>-1.51</td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td></td>
<td>(1.11)</td>
</tr>
<tr>
<td>Wholesale Trade</td>
<td>0.87****</td>
<td>Finance &amp; Real Estate</td>
<td>0.54**</td>
</tr>
<tr>
<td></td>
<td>(0.17)</td>
<td></td>
<td>(0.16)</td>
</tr>
<tr>
<td>Retail trade</td>
<td>0.71</td>
<td>Education</td>
<td>-0.08</td>
</tr>
<tr>
<td></td>
<td>(0.63)</td>
<td></td>
<td>(0.94)</td>
</tr>
<tr>
<td>Information</td>
<td>0.04</td>
<td>Total Non-Farm</td>
<td>12.03**</td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td></td>
<td>(3.58)</td>
</tr>
</tbody>
</table>

Each estimate represents the \( \beta \) coefficient in the model given by (1) by sector.

*** \( p < 0.01 \), ** \( p < 0.05 \), * \( p < 0.10 \)

There are 38 counties in Pennsylvania with at least one horizontal well and 20 of those contain 96% of the total 9,426 horizontal wells in Pennsylvania, according to data reported by Drillinginfo (2017). Of these 20 counties there are two major producing regions, the northeast that largely produces dry natural gas and the southwest that produces natural gas and significant volumes of natural gas liquids. Together these two regions account for 90% of the horizontal wells. The remaining 10% is produced in the central counties of the state. Employment multipliers for these three regions are estimated by aggregating the counties listed in Table 6.
Table 6: OLS estimates of regional employment impacts (robust standard errors)

<table>
<thead>
<tr>
<th>Shale Spending in…</th>
<th>Northeast Change in Employment</th>
<th>Central Change in Employment</th>
<th>Southwest Change in Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast¹</td>
<td>0.77***</td>
<td>2.72**</td>
<td>3.51*</td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.84)</td>
<td>(1.56)</td>
</tr>
<tr>
<td>Central²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southwest³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-Squared</td>
<td>0.884</td>
<td>0.861</td>
<td>0.964</td>
</tr>
<tr>
<td>BIC</td>
<td>2154.322</td>
<td>2068.722</td>
<td>2653.497</td>
</tr>
<tr>
<td>DW</td>
<td>1.734</td>
<td>1.785</td>
<td>1.742</td>
</tr>
</tbody>
</table>

Coefficients for monthly dummies and trend terms are not reported. Sample is from Feb. 2005 through December 2016.
2. Clearfield, Elk, McKean, Clinton, & Potter
3. Washington, Greene, Butler, Westmoreland, Fayette, Allegheny, Armstrong, Lawrence, & Beaver

* p<0.05, ** p<0.01, *** p<0.001

The northeast employment multiplier is 0.77, which is rather low and could reflect the rural nature of this region (see Table 6). The employment multipliers for the central and southwest regions are considerably higher at 2.72 and 3.51 respectively, perhaps reflecting the location of industries supplying goods and services for shale drilling and production (see Table 6). All employment multipliers are highly significant and show the same geographic dispersion pattern found by Feyrer et al. (2017) with multipliers decreasing from the state to the local level.

5.2 Annual Panel Data Analysis

To determine how employment multipliers vary by county, a panel data model is estimated using pooled annual time series for all 67 counties of Pennsylvania. Two different specifications are estimated, one with fixed time effects and another with nonlinear trends. The model with fixed time effects is as follows:

\[
\begin{align*}
\left( \frac{z_i - z_{i-1}}{\text{pop}_{it}} \right) &= \sum_{i=1}^{66} \alpha_i C_i + \beta \left( \frac{x_i}{\text{pop}_{it}} \right) + \sum_{t=2006}^{2015} \tau_t D_t + \epsilon_i,
\end{align*}
\]

where \( z_i \) is annual non-farm employment or personal income in county \( i \) in year \( t \), \( \text{pop}_{it} \) is population, \( x_i \) is shale spending, \( D_t \) are annual dummy variables, \( C_i \) are dummy variables for counties, \( \alpha_i \) are county fixed effects, \( \tau_t \) are annual fixed effects, and \( \beta \) is the county employment or income multiplier. The second model replaces the annual fixed time effects with nonlinear trend terms:
\[
\left( \frac{z_{it} - z_{it-1}}{\text{pop}_{it}} \right) = \sum_{i=1}^{66} \alpha_i C_{it} + \beta \left( \frac{x_{it}}{\text{pop}_{it}} \right) + \tau T + \nu T^2 + \varepsilon_i \tag{3}
\]

These models are estimated with fixed county effects using ordinary least squares and instrumental variables. New production from any one county depends on both the geological endowment of the area and firm decisions to drill and complete wells. As Feyrer, et al. (2017) observes, geological endowment is exogenous but firm decisions may not be because the cost of acquiring leases may be affected by land values and wages that may vary by county.

Accordingly, following the study by Feyrer et al. (2017), this study develops instrumental variables for new production and drilling activity in each county. This is accomplished by running a regression of new shale spending on time and county effects and taking the fitted values from this regression and expressing them in real per capita terms. This fitted per capita value is the instrumental variable for new shale spending in equations and (2) and (3) above. The adjusted R-squared for the first stage regression is 0.72 suggests that the instrumental variables are reasonably strong.

Standard errors are computed with clustering across counties and time periods. The estimation results appear in Table 7. The OLS estimates for the employment multiplier are between 0.2 and 0.3 (see Table 7). In contrast, the IV estimates of the employment multipliers are much larger at 4.8 and 6.6 respectively. The fixed time effects specification estimated using IV has the lowest BIC.

---

8 The data and STATA econometric estimation program for the models using county level panel data are available from the author upon request.
Table 7: Annual panel data estimates of county level employment and income 
(cluster standard errors)

<table>
<thead>
<tr>
<th></th>
<th>Employment Change per capita</th>
<th>Income Change per capita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed Time Effects</td>
<td>Nonlinear Trend</td>
</tr>
<tr>
<td></td>
<td>OLS</td>
<td>IV</td>
</tr>
<tr>
<td>Shale Spending per capita</td>
<td>0.216*</td>
<td>4.835***</td>
</tr>
<tr>
<td></td>
<td>(0.091)</td>
<td>(1.207)</td>
</tr>
<tr>
<td>R²</td>
<td>0.245</td>
<td>0.256</td>
</tr>
<tr>
<td>DF</td>
<td>378</td>
<td>378</td>
</tr>
<tr>
<td>BIC</td>
<td>-4713.5</td>
<td>-4724.1</td>
</tr>
<tr>
<td></td>
<td>92.068***</td>
<td>1223.603***</td>
</tr>
<tr>
<td></td>
<td>(15.153)</td>
<td>(270.451)</td>
</tr>
<tr>
<td>R²</td>
<td>0.231</td>
<td>0.227</td>
</tr>
<tr>
<td>DF</td>
<td>378</td>
<td>378</td>
</tr>
<tr>
<td>BIC</td>
<td>3902.9</td>
<td>3906.9</td>
</tr>
</tbody>
</table>

The fixed county and time effects are not reported. The sample includes annual observations from 2005 through 2015 for all 67 counties in Pennsylvania.

* p<0.05, ** p<0.01, *** p<0.001

The estimates of how shale spending affects personal income also appear in Table 7. Across both specifications, OLS and IV estimates indicate a significant relationship between shale spending and income at the county level. The OLS estimates indicate that between 92 and 80 dollars of income are generated for every million dollars of shale spending. Like the employment multipliers, the IV estimates of the income multipliers are considerably larger, falling between $1,032 and $1,224 for every million dollars of shale spending (see Table 7).

5.3 A Vector Autoregressive Model

Quarterly data on gross domestic product or valued added, employment, and total personal income are modeled following a vector autoregressive (VAR) four-equation system for shale spending, value added, income, and employment as follows:
where \( v \) denotes value added, \( n \) is income, \( e \) is employment, \( s \) is shale spending, \( d \) is the first difference operator, the \( D_j \) are quarterly dummies, and the \( \alpha, \lambda, \delta \) terms are unknown coefficients. This model is estimated using OLS and the impulse response functions are displayed in Figure 7. A shock to shale spending has rather sizeable impacts on employment that extends several quarters while impacts on value added and income are smaller. Shocks from value added, employment, and income, however, have no detectable influence on shale spending. This motivated the Granger causality tests presented in Table 8, which strongly indicate shale spending is exogenous. Accordingly, the VAR model is re-estimated without the shale spending equation and the lags of shale spending in the value added, income, and employment equations in (4) are replaced by shale spending in the current period.

---

9 The data and STATA econometric estimation program for the models using quarterly data are available from the author upon request.
Figure 7: Impulse response functions

Graphs by irfname, impulse variable, and response variable
Table 8: Granger causality tests

<table>
<thead>
<tr>
<th>Equation</th>
<th>Excluded</th>
<th>F</th>
<th>df</th>
<th>df_r</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale Spending</td>
<td>GDP Change</td>
<td>0.23768</td>
<td>1</td>
<td>36</td>
<td>0.6288</td>
</tr>
<tr>
<td>Shale Spending</td>
<td>Employment Change</td>
<td>0.17869</td>
<td>1</td>
<td>36</td>
<td>0.675</td>
</tr>
<tr>
<td>Shale Spending</td>
<td>Income Change</td>
<td>0.08294</td>
<td>1</td>
<td>36</td>
<td>0.775</td>
</tr>
<tr>
<td>Shale Spending</td>
<td>All</td>
<td>0.19025</td>
<td>3</td>
<td>36</td>
<td>0.9024</td>
</tr>
<tr>
<td>GDP Change</td>
<td>Shale Spending</td>
<td>0.53730</td>
<td>1</td>
<td>36</td>
<td>0.4683</td>
</tr>
<tr>
<td>GDP Change</td>
<td>Employment Change</td>
<td>0.34345</td>
<td>1</td>
<td>36</td>
<td>0.5615</td>
</tr>
<tr>
<td>GDP Change</td>
<td>Income Change</td>
<td>0.00558</td>
<td>1</td>
<td>36</td>
<td>0.9408</td>
</tr>
<tr>
<td>GDP Change</td>
<td>All</td>
<td>0.70173</td>
<td>3</td>
<td>36</td>
<td>0.5572</td>
</tr>
<tr>
<td>Employment Change</td>
<td>Shale Spending</td>
<td>2.3862</td>
<td>1</td>
<td>36</td>
<td>0.1312</td>
</tr>
<tr>
<td>Employment Change</td>
<td>GDP Change</td>
<td>1.6856</td>
<td>1</td>
<td>36</td>
<td>0.2024</td>
</tr>
<tr>
<td>Employment Change</td>
<td>Income Change</td>
<td>3.7264</td>
<td>1</td>
<td>36</td>
<td>0.0615</td>
</tr>
<tr>
<td>Employment Change</td>
<td>All</td>
<td>3.1467</td>
<td>3</td>
<td>36</td>
<td>0.0368</td>
</tr>
<tr>
<td>Income Change</td>
<td>Shale Spending</td>
<td>0.5557</td>
<td>1</td>
<td>36</td>
<td>0.4608</td>
</tr>
<tr>
<td>Income Change</td>
<td>GDP Change</td>
<td>5.2564</td>
<td>1</td>
<td>36</td>
<td>0.0278</td>
</tr>
<tr>
<td>Income Change</td>
<td>Employment Change</td>
<td>2.0025</td>
<td>1</td>
<td>36</td>
<td>0.1656</td>
</tr>
<tr>
<td>Income Change</td>
<td>All</td>
<td>4.5534</td>
<td>3</td>
<td>36</td>
<td>0.0083</td>
</tr>
</tbody>
</table>

The VAR estimates from this model are presented in Table 9. While shale spending has the correct sign in the value added and income equations, the standard errors are relatively high. The coefficient on shale spending in the employment equation is 9.41 and significant at the one percent level. The income coefficient and the trend terms are also significant in the employment equation.

The economic impacts of a one period $1 million shock to shale investment and production is modeled with a dynamic simulation of this model over a 12-quarter period. The results are plotted in Figure 8. The simulation results indicate that in the first period, employment increases 9.4, value added is $1.12 higher, and personal income increases $2.06. After two quarters these gains are 16.0, $1.68, and $2.93 respectively for employment, value added, and personal income. The impacts of the shock level out after five quarters so that the long-run employment multiplier is 16.8 and the multipliers for value added and personal income are 1.75 and 3.0 respectively.
Table 9: VAR estimates with exogenous shale spending shocks (robust standard errors)

<table>
<thead>
<tr>
<th></th>
<th>GDP</th>
<th>Emp.</th>
<th>Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lagged Dif. Value Added</strong></td>
<td>0.04</td>
<td>0.66</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.59)</td>
<td>(0.26)</td>
</tr>
<tr>
<td><strong>Lagged Dif. Employment</strong></td>
<td>0.03</td>
<td>0.20</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.14)</td>
<td>(0.04)</td>
</tr>
<tr>
<td><strong>Lagged Dif. Income</strong></td>
<td>0.02</td>
<td>0.98**</td>
<td>-0.32</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.34)</td>
<td>(0.26)</td>
</tr>
<tr>
<td><strong>Shale Spending</strong></td>
<td>1.11</td>
<td>9.41**</td>
<td>2.06</td>
</tr>
<tr>
<td></td>
<td>(1.31)</td>
<td>(3.29)</td>
<td>(1.26)</td>
</tr>
<tr>
<td><strong>Quarter 1</strong></td>
<td>-8.35</td>
<td>-231.14***</td>
<td>-11.44*</td>
</tr>
<tr>
<td></td>
<td>(6.99)</td>
<td>(17.94)</td>
<td>(4.80)</td>
</tr>
<tr>
<td><strong>Quarter 2</strong></td>
<td>6.16</td>
<td>70.82***</td>
<td>8.51</td>
</tr>
<tr>
<td></td>
<td>(3.89)</td>
<td>(14.05)</td>
<td>(5.29)</td>
</tr>
<tr>
<td><strong>Quarter 3</strong></td>
<td>-2.62</td>
<td>-149.76***</td>
<td>-11.11</td>
</tr>
<tr>
<td></td>
<td>(8.28)</td>
<td>(21.10)</td>
<td>(6.37)</td>
</tr>
<tr>
<td><strong>Trend</strong></td>
<td>-0.36</td>
<td>-3.86*</td>
<td>-0.94</td>
</tr>
<tr>
<td></td>
<td>(0.57)</td>
<td>(1.47)</td>
<td>(0.51)</td>
</tr>
<tr>
<td><strong>Trend²</strong></td>
<td>0.01</td>
<td>0.07**</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.03)</td>
<td>(0.01)</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>4.95</td>
<td>100.86***</td>
<td>13.59**</td>
</tr>
<tr>
<td></td>
<td>(4.05)</td>
<td>(12.31)</td>
<td>(4.02)</td>
</tr>
</tbody>
</table>

- R²: 0.342, 0.980, 0.407
- BIC: 313.552, 413.963, 318.978
- Durbin-Watson: 1.933, 2.247, 2.072

* p<0.05, ** p<0.01, *** p<0.001
6. Summary and Conclusions

This study is motivated by several ex post econometric studies of the economic impacts of fracking that generally conclude that ex ante input-output (IO) studies over-estimate the economic impacts of shale energy development. To understand the grounds and robustness of this consensus, this study compares two approaches for impact analysis using IO models and employs monthly and quarterly time series and annual panel data econometric models to estimate how development of the Marcellus, Utica, and Upper Devonian shale formations affects employment, income, and output in Pennsylvania. The main innovation of this study is an ex post econometric analysis using the value of shale investment and new production as the exogenous economic shock from shale energy development, which is similar to the approach followed in IO studies.

During the early stages of shale gas field development as companies drill to secure leases they develop an inventory of drilled but uncompleted wells. Eventually these wells are brought into production as economic conditions warrant so that gathering systems and processing plants are built and connections with high compression interstate pipelines are completed. Measuring shale activity by new production misses investment in well construction that in many cases may occur months or years before. Likewise, estimating activity by well numbers misses the royalties and taxes generated once production commences. This study addresses this problem by combining these two measures into the value of investment and the value of new production.
The econometric analysis employs regressions using annual, quarterly, and monthly data for Pennsylvania performed at the county, regional, and state levels. Three classes of economic outcomes are modeled: total employment, value added, and personal income. First differences in these economic outcomes are regressed on the value of new investment and new production, seasonal dummy variables, and nonlinear trends.

Using methods developed by Andrews (1993) we test for structural change and find evidence for such a break in January 2007 coinciding with the widespread adoption of horizontal drilling. The estimated employment multiplier for the entire sample is 12, which is within the range of multipliers found using the input-output methodology developed by Miller and Blair (1985) for modeling the economic impacts arising associated with a new industry. After the structural break, the employment multiplier is 16 percent higher.

The measure of shale activity developed in this study is compared with three other approaches in the literature and is found to be preferred with the lowest Schwarz Bayesian information criterion. The employment multipliers are estimated at various levels of aggregation and imply that a $1 million shock to shale investment and production creates 0.2 jobs at the county level, up to 3.2 jobs at the regional level, and the aforementioned 12 jobs at the state level. County panel data regressions also indicate sizable employment multipliers between 4.8 and 6.6.

Finally, to capture how shale spending affects the dynamic interactions between value added, income, and employment, a vector autoregressive (VAR) model is developed. The dynamic VAR simulation finds that a $1 million shock in shale investment and production generates 16 jobs and $1.7 million and $3.0 million in additional value added and income respectively after 18 months.

These findings cast doubt on the view that the economic impacts of shale energy development are either small or negligible. One possible source for these discrepancies could come from the way we measure shale industry activity. Another possibility is that Pennsylvania may be a special case with a shale industry that rose to a very significant level over a relatively short period of time. This boom represents a significant economic shock to the Pennsylvania economy. Pennsylvania also may be unique given the presence of so many manufacturing industries that supply goods and services to the oil and gas industry, such as steel, cement, pumps, fabricated metals, and other industries. Construction of an expanding petrochemical industry and natural gas liquids export infrastructure in Pennsylvania also may explain our higher multipliers. Indeed, the estimation of statistically significant employment multipliers for manufacturing, construction, and professional and business services lends some support for this explanation.

Just as every shale play differs in terms of economics and geology, the economic impacts of shale development may be equally idiosyncratic. Perhaps the economic impacts from shale energy development are not the same for all states. Given the large and growing number of diverse shale gas and tight oil plays in the United States and across the globe, there will be no dearth of opportunities for economists to apply their analytical skills to compare and contrast the economic impacts of unconventional oil and gas development.
References


Appendix A

Data Sources and Methods for Measuring Capital Expenditures per Well

This appendix documents the methods and data sources used to estimate monthly capital expenditures per well. The methods involve the following steps:

- Collection of monthly well spud data by firm,
- Collection of annual capital expenditures per well drilled by firm,
- Estimation of monthly capital expenditures per well drilled by firm, and
- Computation of monthly weighted average capital expenditures for Pennsylvania.

These data and computations are performed in an Excel Workbook, which is available in the zip file that accompanies this study.

The monthly well spud data are collected by the Department of Environmental Protection of the Commonwealth of Pennsylvania and by the subscription service, Drillinginfo (2017). This study uses the Drillinginfo service to develop monthly time series for well spuds by firm. These data are used to identify firms that are publicly owned, therefore, disclose financial information in their reports to the US Securities and Exchange Commission. A summary of the top 25 firms drilling the Marcellus, Utica, and other unconventional oil and gas formations in Pennsylvania is presented in Table A1. Of these twenty-five firms, ten are publicly traded. Six firms are subsidiaries of integrated companies while the remaining nine are private companies. Accordingly, this study collects capital expenditures reported by the ten publicly traded firms in Table A1. These firms constitute 51.2 percent of all horizontal wells, 20.8 percent of vertical wells, and 48.6 percent of all unconventional wells.

The number of horizontal, vertical, and total wells drilled by the top twenty-five firms along with their ownership status appears in Table A1. The top three firms in terms of unconventional wells drilled – Range, Chesapeake, and EQT – are publically traded and, therefore, part of the sample of capital expenditures discussed below. These three firms constitute 27.9 percent of all wells drilled in Pennsylvania from January 2005 through the end of December 2016. Other publicly traded firms included in our sample include Cabot, Southwest (SWN), Rex Energy, PA General, EOG, EXCO, and Carrizo.
Table A1: Top 25 firms drilling unconventional oil and gas wells in Pennsylvania

<table>
<thead>
<tr>
<th>Firm (Stock Ticker Symbol)</th>
<th>Wells Drilled, 2005-2016</th>
<th>Cumulative</th>
<th>Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
<td>Total</td>
</tr>
<tr>
<td>Range Resources (RRC)</td>
<td>1,139</td>
<td>71</td>
<td>1,210</td>
</tr>
<tr>
<td>Chesapeake (CHK)</td>
<td>924</td>
<td>10</td>
<td>934</td>
</tr>
<tr>
<td>EQT Production LLC (EQT)</td>
<td>728</td>
<td>3</td>
<td>731</td>
</tr>
<tr>
<td>SWEPILP</td>
<td>574</td>
<td>151</td>
<td>725</td>
</tr>
<tr>
<td>Cabot Oil &amp; Gas Corporation (COG)</td>
<td>564</td>
<td>45</td>
<td>609</td>
</tr>
<tr>
<td>SWN Production Company, LLC (SWN)</td>
<td>603</td>
<td>5</td>
<td>608</td>
</tr>
<tr>
<td>Repsol Oil &amp; Gas USA LLC</td>
<td>516</td>
<td>1</td>
<td>517</td>
</tr>
<tr>
<td>Anadarko E&amp;P Onshore, LLC</td>
<td>440</td>
<td>8</td>
<td>448</td>
</tr>
<tr>
<td>Seneca Resources Corporation</td>
<td>395</td>
<td>25</td>
<td>420</td>
</tr>
<tr>
<td>CNX Gas Company, LLC</td>
<td>377</td>
<td>23</td>
<td>400</td>
</tr>
<tr>
<td>Chevron Appalachia, LLC</td>
<td>392</td>
<td>7</td>
<td>399</td>
</tr>
<tr>
<td>Chief Oil &amp; Gas, LLC</td>
<td>292</td>
<td>12</td>
<td>304</td>
</tr>
<tr>
<td>XTO Energy, Inc. (XTO)</td>
<td>254</td>
<td>22</td>
<td>276</td>
</tr>
<tr>
<td>Seneca</td>
<td>48</td>
<td>210</td>
<td>258</td>
</tr>
<tr>
<td>Rex Energy (REX)</td>
<td>213</td>
<td>8</td>
<td>221</td>
</tr>
<tr>
<td>Rice Drilling B LLC</td>
<td>201</td>
<td>4</td>
<td>205</td>
</tr>
<tr>
<td>PA Gen Energy Corp</td>
<td>187</td>
<td>11</td>
<td>198</td>
</tr>
<tr>
<td>EOG Resources, Inc. (EOG)</td>
<td>179</td>
<td>12</td>
<td>191</td>
</tr>
<tr>
<td>Talisman Energy USA Inc.</td>
<td>164</td>
<td>2</td>
<td>166</td>
</tr>
<tr>
<td>EXCO Resources Pa LLC (EXCO)</td>
<td>119</td>
<td>8</td>
<td>127</td>
</tr>
<tr>
<td>Energy Corp of Amer.</td>
<td>113</td>
<td>11</td>
<td>124</td>
</tr>
<tr>
<td>Carrizo (Marcellus), LLC (CRZO)</td>
<td>103</td>
<td>1</td>
<td>104</td>
</tr>
<tr>
<td>Hilcorp Energy Company, Inc.</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Snyder Bros Inc.</td>
<td>12</td>
<td>87</td>
<td>99</td>
</tr>
<tr>
<td>Vantage Energy App. LLC</td>
<td>97</td>
<td>0</td>
<td>97</td>
</tr>
<tr>
<td>Other firms</td>
<td>692</td>
<td>154</td>
<td>846</td>
</tr>
<tr>
<td>Total</td>
<td>9,426</td>
<td>891</td>
<td>10,317</td>
</tr>
</tbody>
</table>

Bloomberg (2017) and FactSet (2017) report annual capital expenditures for these public firms, which are collected from annual 10k reports to the Securities and Exchange Commission. These expenditures are for the entire firm across all geographical locations and include expenditures on exploration, development, and proved and unproved properties. Adjustments to three observations were made to omit property acquisitions outside Pennsylvania. These include $3.2 billion acquisition by Range in 2016, a $5.2 billion acquisition by Southwest or SWN in 2014, and a $942.9 million acquisition by EXCO in 2013.
Table A2: Capital Expenditures by top ten public firms operating in Pennsylvania

<table>
<thead>
<tr>
<th></th>
<th>RRC</th>
<th>CHK</th>
<th>EQT</th>
<th>COG</th>
<th>SWN</th>
<th>XTO</th>
<th>REX</th>
<th>EOG</th>
<th>EXCO</th>
<th>CRZO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.50</td>
<td>7.41</td>
<td>0.19</td>
<td>0.41</td>
<td>0.41</td>
<td>3.43</td>
<td>0.03</td>
<td>1.88</td>
<td>NA</td>
<td>0.12</td>
</tr>
<tr>
<td>2006</td>
<td>1.15</td>
<td>8.13</td>
<td>0.19</td>
<td>0.51</td>
<td>0.76</td>
<td>3.00</td>
<td>0.10</td>
<td>3.00</td>
<td>1.89</td>
<td>0.19</td>
</tr>
<tr>
<td>2007</td>
<td>1.17</td>
<td>8.69</td>
<td>0.32</td>
<td>0.59</td>
<td>1.37</td>
<td>6.94</td>
<td>0.04</td>
<td>3.60</td>
<td>2.93</td>
<td>0.23</td>
</tr>
<tr>
<td>2008</td>
<td>1.83</td>
<td>7.00</td>
<td>0.70</td>
<td>1.44</td>
<td>1.56</td>
<td>15.21</td>
<td>0.14</td>
<td>5.09</td>
<td>1.59</td>
<td>0.56</td>
</tr>
<tr>
<td>2009</td>
<td>0.81</td>
<td>4.67</td>
<td>0.72</td>
<td>0.59</td>
<td>1.53</td>
<td>3.28</td>
<td>0.05</td>
<td>3.91</td>
<td>0.64</td>
<td>0.17</td>
</tr>
<tr>
<td>2010</td>
<td>1.21</td>
<td>8.41</td>
<td>1.24</td>
<td>0.83</td>
<td>1.78</td>
<td>NA</td>
<td>0.10</td>
<td>5.46</td>
<td>0.91</td>
<td>0.33</td>
</tr>
<tr>
<td>2011</td>
<td>1.62</td>
<td>4.99</td>
<td>1.08</td>
<td>0.89</td>
<td>1.96</td>
<td>NA</td>
<td>0.25</td>
<td>6.60</td>
<td>1.29</td>
<td>0.55</td>
</tr>
<tr>
<td>2012</td>
<td>1.72</td>
<td>12.40</td>
<td>0.99</td>
<td>0.97</td>
<td>1.91</td>
<td>NA</td>
<td>0.24</td>
<td>7.07</td>
<td>0.45</td>
<td>0.77</td>
</tr>
<tr>
<td>2013</td>
<td>1.45</td>
<td>6.61</td>
<td>1.42</td>
<td>1.19</td>
<td>2.02</td>
<td>NA</td>
<td>0.34</td>
<td>7.00</td>
<td>0.33</td>
<td>0.78</td>
</tr>
<tr>
<td>2014</td>
<td>2.07</td>
<td>6.06</td>
<td>2.44</td>
<td>1.77</td>
<td>2.02</td>
<td>NA</td>
<td>0.39</td>
<td>7.90</td>
<td>0.38</td>
<td>1.12</td>
</tr>
<tr>
<td>2015</td>
<td>0.93</td>
<td>3.51</td>
<td>1.87</td>
<td>0.79</td>
<td>2.24</td>
<td>NA</td>
<td>0.22</td>
<td>4.93</td>
<td>0.25</td>
<td>0.57</td>
</tr>
<tr>
<td>2016</td>
<td>0.58</td>
<td>2.17</td>
<td>2.07</td>
<td>0.39</td>
<td>0.62</td>
<td>NA</td>
<td>0.04</td>
<td>6.31</td>
<td>0.06</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Capital expenditures per well are obtained by dividing total capital expenditures by the number of net wells drilled for each firm across all regions, which appears in Table A3. Capital expenditures per well for the ten publically traded firms appear in Table A4. For all other firms, capital expenditures per well are assumed to be equal to the average of the ten firms reported in Table A4.

Monthly capital expenditures per well for the 10 publically traded firms and the other firms are interpolated from the values in Table 4a. The July values in each year are set equal to the annual average and values in between are interpolated. Values prior to July 2005 and after July 2016 are assumed to equal their annual averages.
Table A3: Number of net wells drilled

<table>
<thead>
<tr>
<th></th>
<th>RRC</th>
<th>CHK</th>
<th>EQT</th>
<th>COG</th>
<th>SWN</th>
<th>XTO</th>
<th>REX</th>
<th>EOG</th>
<th>EXCO</th>
<th>CRZO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>594</td>
<td>816</td>
<td>345</td>
<td>243</td>
<td>160</td>
<td>638</td>
<td>11</td>
<td>1448</td>
<td>NA</td>
<td>36</td>
</tr>
<tr>
<td>2006</td>
<td>704</td>
<td>1449</td>
<td>456</td>
<td>297</td>
<td>185</td>
<td>913</td>
<td>40</td>
<td>2094</td>
<td>301</td>
<td>45</td>
</tr>
<tr>
<td>2007</td>
<td>698</td>
<td>1919</td>
<td>456</td>
<td>386</td>
<td>307</td>
<td>1073</td>
<td>63</td>
<td>1667</td>
<td>405</td>
<td>68</td>
</tr>
<tr>
<td>2008</td>
<td>490</td>
<td>1733</td>
<td>533</td>
<td>349</td>
<td>301</td>
<td>1247</td>
<td>61</td>
<td>1545</td>
<td>400</td>
<td>88</td>
</tr>
<tr>
<td>2009</td>
<td>285</td>
<td>1003</td>
<td>538</td>
<td>112</td>
<td>258</td>
<td>1056</td>
<td>28</td>
<td>753</td>
<td>55</td>
<td>36</td>
</tr>
<tr>
<td>2010</td>
<td>266</td>
<td>1149</td>
<td>395</td>
<td>79</td>
<td>307</td>
<td>NA</td>
<td>30</td>
<td>1055</td>
<td>99</td>
<td>45</td>
</tr>
<tr>
<td>2011</td>
<td>266</td>
<td>1282</td>
<td>213</td>
<td>92</td>
<td>308</td>
<td>NA</td>
<td>35</td>
<td>968</td>
<td>148</td>
<td>54</td>
</tr>
<tr>
<td>2012</td>
<td>257</td>
<td>1272</td>
<td>130</td>
<td>118</td>
<td>271</td>
<td>NA</td>
<td>31</td>
<td>914</td>
<td>78</td>
<td>70</td>
</tr>
<tr>
<td>2013</td>
<td>209</td>
<td>985</td>
<td>224</td>
<td>154</td>
<td>258</td>
<td>NA</td>
<td>49</td>
<td>949</td>
<td>57</td>
<td>79</td>
</tr>
<tr>
<td>2014</td>
<td>239</td>
<td>682</td>
<td>265</td>
<td>176</td>
<td>221</td>
<td>NA</td>
<td>50</td>
<td>909</td>
<td>30</td>
<td>87</td>
</tr>
<tr>
<td>2015</td>
<td>141</td>
<td>428</td>
<td>238</td>
<td>133</td>
<td>347</td>
<td>NA</td>
<td>27</td>
<td>489</td>
<td>29</td>
<td>75</td>
</tr>
<tr>
<td>2016</td>
<td>102</td>
<td>239</td>
<td>156</td>
<td>76</td>
<td>73</td>
<td>NA</td>
<td>8</td>
<td>445</td>
<td>9</td>
<td>78</td>
</tr>
</tbody>
</table>

Source: Bloomberg & FactSet

Table A4: Capital expenditures per well in millions

<table>
<thead>
<tr>
<th></th>
<th>RRC</th>
<th>CHK</th>
<th>EQT</th>
<th>COG</th>
<th>SWN</th>
<th>XTO</th>
<th>REX</th>
<th>EOG</th>
<th>EXCO</th>
<th>CRZO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.8</td>
<td>9.1</td>
<td>0.6</td>
<td>1.7</td>
<td>2.6</td>
<td>5.4</td>
<td>2.5</td>
<td>1.3</td>
<td>NA</td>
<td>3.5</td>
</tr>
<tr>
<td>2006</td>
<td>1.6</td>
<td>5.6</td>
<td>0.4</td>
<td>1.7</td>
<td>4.1</td>
<td>3.3</td>
<td>2.4</td>
<td>1.4</td>
<td>6.3</td>
<td>4.3</td>
</tr>
<tr>
<td>2007</td>
<td>1.7</td>
<td>4.5</td>
<td>0.7</td>
<td>1.5</td>
<td>4.5</td>
<td>6.5</td>
<td>0.7</td>
<td>2.2</td>
<td>7.2</td>
<td>3.4</td>
</tr>
<tr>
<td>2008</td>
<td>3.7</td>
<td>4.0</td>
<td>1.3</td>
<td>4.1</td>
<td>5.2</td>
<td>12.2</td>
<td>2.4</td>
<td>3.3</td>
<td>4.0</td>
<td>6.4</td>
</tr>
<tr>
<td>2009</td>
<td>2.9</td>
<td>4.7</td>
<td>1.3</td>
<td>5.3</td>
<td>5.9</td>
<td>3.1</td>
<td>1.8</td>
<td>5.2</td>
<td>11.7</td>
<td>4.6</td>
</tr>
<tr>
<td>2010</td>
<td>4.6</td>
<td>7.3</td>
<td>3.1</td>
<td>10.5</td>
<td>5.8</td>
<td>NA</td>
<td>3.4</td>
<td>5.2</td>
<td>9.2</td>
<td>7.4</td>
</tr>
<tr>
<td>2011</td>
<td>6.1</td>
<td>3.9</td>
<td>5.1</td>
<td>9.7</td>
<td>6.4</td>
<td>NA</td>
<td>7.2</td>
<td>6.8</td>
<td>8.7</td>
<td>10.2</td>
</tr>
<tr>
<td>2012</td>
<td>6.7</td>
<td>9.7</td>
<td>7.6</td>
<td>8.2</td>
<td>7.1</td>
<td>NA</td>
<td>7.7</td>
<td>7.7</td>
<td>5.8</td>
<td>11.0</td>
</tr>
<tr>
<td>2013</td>
<td>7.0</td>
<td>6.7</td>
<td>6.3</td>
<td>7.7</td>
<td>7.8</td>
<td>NA</td>
<td>6.9</td>
<td>7.4</td>
<td>5.8</td>
<td>9.9</td>
</tr>
<tr>
<td>2014</td>
<td>8.6</td>
<td>8.9</td>
<td>9.2</td>
<td>10.1</td>
<td>9.1</td>
<td>NA</td>
<td>7.9</td>
<td>8.7</td>
<td>12.9</td>
<td>13.0</td>
</tr>
<tr>
<td>2015</td>
<td>6.6</td>
<td>8.2</td>
<td>7.9</td>
<td>6.0</td>
<td>6.4</td>
<td>NA</td>
<td>8.3</td>
<td>10.1</td>
<td>8.6</td>
<td>7.6</td>
</tr>
<tr>
<td>2016</td>
<td>5.7</td>
<td>9.1</td>
<td>13.3</td>
<td>5.1</td>
<td>8.5</td>
<td>NA</td>
<td>5.6</td>
<td>14.2</td>
<td>7.1</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Source: Bloomberg & FactSet
A monthly weighted average of capital expenditures is computed by multiplying monthly estimates of capital expenditures per well by firm by the shares of wells drilled in each month. A time series plot of the weighted average capital expenditures per well for Pennsylvania appears in Figure A1. The weights reflect the changing mix of wells drilled by each firm.

Figure 1: Weighted average capital expenditures per well

References


Appendix B

Stata Program for Estimation of Monthly Employment Models

clear all
set more off

**Set Working Directory

cd "/Users/timconsidine/Documents"

**Import Data

cd "/Users/timconsidine/Documents"

**Set Working Directory

cd "/Users/timconsidine/Documents"

**Import Data

use pa_monthly_employment.dta, clear

**Generate Month/year variable

gen int date = ym(year, month)
format date %tm

**Set Time Series

tset date

** OLS Regression
eg demp newrv m1-m11, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model1a, title(OLS)

** OLS Regression
eg demp newrv m1-m11 t tsq, robust
estat sbsingle
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model1, title(OLS)

** OLS Regression
eg demp newrv m1-m11 t tsq if year > 2006, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model1b, title(OLS)

***IV Set 1

quietly ivregress 2sls demp m1-m11 t tsq (newrv = maxfp maxfpo rrate m1-m11 t tsq), robust
estat endogenous
estadd scalar r_robust = r(r_score)
estadd scalar rp_robust = r(p_r_score)
estat firststage
estimates store model2, title(IV Set 1)

***IV Set 2

quietly ivregress 2sls demp m1-m11 t tsq (newrv = maxfp maxfpo rrate m1-m11 propl pngl wcostl t tsq), robust
estat endogenous
estadd scalar r_robust = r(r_score)
estadd scalar rp_robust = r(p_r_score)
estat firststage
estimates store model3, title(IV Set 2)

*** Table 3
estout model1a model1 model1b model2 model3 using Table3rv.rtf, ///
cells(b(star fmt(2)) se(par fmt(2))) ///
legend label varlabels(_cons Constant newrv Shale) ///
stats(r2 bic r_dw r_robust rp_robust, fmt(3) label(R-Sqr bic Durbin-Watson Robust-Score p-value))

** OLS Regression using Value of Production
gen prodval2 = (((poil * noil * 42 + pgas * ngas * 1.025) / 1000000) / cpilfe) / 1000
reg demp prodval m1-m11 t tsq, robust
reg demp prodval2 m1-m11 t tsq, robust
quietly reg demp prodval m1-m11 t tsq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model4, title(Production)

** OLS Regression using Value of Investment
quietly reg demp investval m1-m11 t tsq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model5, title(Investment)

** OLS Regression using Number of Wells
gen wellstr = wells / 1000
quietly reg demp wellstr m1-m11 t tsq, robust\nstat dwatson
estadd scalar r_dw = r(dw)
estimates store model6, title(Wells)

*** Table 4
estout model1 model4 model5 model6 using Table4.rtf, ///
cells(b(star fmt(2)) se(par fmt(2))) ///
legend label varlabels(_cons Constant newrv Shale) ///
stats(r2 bic r_dw, fmt(3) label(R-sqr BIC DW)) ///
drop(m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 t tsq _cons) ///
note (Monthly dummies and trend terms not reported)

*** OLS Regression - Construction Sector
gen dempcon = empcon - empcon[!n-1]
quietly reg dempcon newrv m1-m11 t tsq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model7, title(Const.)

*** OLS Regression - Manufacturing Sector
gen dempmann = empman - empman[!n-1]
quietly reg dempmann newrv m1-m11 t tsq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model8, title(Man.)
*** OLS Regression - Mining Sector
\[ \text{empmnl} = \text{empoth} - \text{empmnl}[\_n-1] - \text{empoth}[\_n-1] \]
\[ \text{quietly reg dempmnl newrv m1-m11 t tsq, robust estat dwatson estadd scalar r\_dw = r(dw) estimates store model9, title(Mining)} \]

*** OLS Regression - Transport & Utilities
\[ \text{emptru} = \text{emptru}[\_n-1] \]
\[ \text{quietly reg demptru newrv m1-m11 t tsq, robust estat dwatson estadd scalar r\_dw = r(dw) estimates store model10, title(TransUtil.)} \]

*** OLS Regression - Whole Trade
\[ \text{empwtr} = \text{empwtr}[\_n-1] \]
\[ \text{quietly reg dempwtr newrv m1-m11 t tsq, robust estat dwatson estadd scalar r\_dw = r(dw) estimates store model11, title(Whole Trade)} \]

*** OLS Regression - Retail Trade
\[ \text{emprtr} = \text{emprtr}[\_n-1] \]
\[ \text{quietly reg demprtr newrv m1-m11 t tsq, robust estat dwatson estadd scalar r\_dw = r(dw) estimates store model12, title(Retail Trade)} \]

*** OLS Regression - Information
\[ \text{empinf} = \text{empinf}[\_n-1] \]
\[ \text{quietly reg dempinf newrv m1-m11 t tsq, robust estat dwatson estadd scalar r\_dw = r(dw) estimates store model13, title(Info.)} \]

*** OLS Regression - Prof. Bus. Svc.
\[ \text{emppbs} = \text{emppbs}[\_n-1] \]
\[ \text{quietly reg demppbs newrv m1-m11 t tsq, robust estat dwatson estadd scalar r\_dw = r(dw) estimates store model14, title(ProfSvc.)} \]

*** OLS Regression - Lei. & Hsp.
\[ \text{emplhs} = \text{emplhs}[\_n-1] \]
\[ \text{quietly reg demplhs newrv m1-m11 t tsq, robust estat dwatson estadd scalar r\_dw = r(dw) estimates store model15, title(Lei. & Hosp.)} \]

*** OLS Regression - Other Svc.
\[ \text{empots} = \text{empots}[\_n-1] \]
\[ \text{quietly reg dempots newrv m1-m11 t tsq, robust estat dwatson} \]
estadd scalar r Dw = r(dw)
estimates store model16, title(Other Svc.)

*** OLS Regression - Gov.
gen dempgov = empgov- empgov[-n-1]
quietly reg dempgov newrv m1-m11 t tsq, robust
estat dwatson
estadd scalar r Dw = r(dw)
estimates store model17, title(Gov.)

*** OLS Regression - Fin & R Est.
gen dempfin = empfin- empfin[-n-1]
quietly reg dempfin newrv m1-m11 t tsq, robust
estat dwatson
estadd scalar r Dw = r(dw)
estimates store model18, title(FinReal.)

*** OLS Regression – Education
/gen dempedu = empedu- empedu[-n-1]
quietly reg dempedu newrv m1-m11 t tsq, robust
estat dwatson
estadd scalar r Dw = r(dw)
estimates store model19, title(Education)

*** Table 5a
estout model7 model8 model9 model10 model11 using Table5a.rtf, ///
cells(b(star fmt(2)) se(par fmt(2))) ///
legend label varlabels(_cons Constant newrv Shale) ///
stats(r2 bic r Dw, fmt(3) label(R-sqr BIC DW)) ///
drop(m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 t tsq _cons) ///
note (Monthly dummies and trend terms not reported)

*** Table 5b
estout model12 model13 model14 model15 model16 using Table5b.rtf, ///
cells(b(star fmt(2)) se(par fmt(2))) ///
legend label varlabels(_cons Constant newrv Shale) ///
stats(r2 bic r Dw, fmt(3) label(R-sqr BIC DW)) ///
drop(m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 t tsq _cons) ///
note (Monthly dummies and trend terms not reported)

*** Table 5c
estout model17 model18 model19 using Table5c.rtf, ///
cells(b(star fmt(2)) se(par fmt(2))) ///
legend label varlabels(_cons Constant newrv Shale) ///
stats(r2 bic r Dw, fmt(3) label(R-sqr BIC DW)) ///
drop(m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 t tsq _cons) ///
note (Monthly dummies and trend terms not reported)

*** OLS Regression – Northeast
quietly reg dempne newrvne m1-m11 t tsq, robust
estat dwatson
estadd scalar r Dw = r(dw)
estimates store model20, title(Northeast)
*** OLS Regression – Central
quietly reg dempcn newrcn m1-m11 t tsq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model21, title(Central)

*** OLS Regression – Southwest
quietly reg dempsw newrvsw m1-m11 t tsq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model22, title(Southwest)

*** Table 6
estout model20 model21 model22 using Table6.rtf, cells(b(star fmt(2)) se(par fmt(2))) ///
legend label varlabels(_cons Constant newrv Shale) ///
stats(r2 bic r_dw, fmt(3) label(R-sqr BIC DW)) ///
drop(m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 t tsq _cons) ///
note (Monthly dummies and trend terms not reported)
Appendix C

Stata Program for Estimation of Annual Panel Models

clear all
set more off
**Set Working Directory
cd "~/Users/timconsidine/Documents"

**Import Data
use PA_Annual_Panel_data.dta, clear

xtset cnum year

** OLS Estimation Employment Model with Fixed County & Time Effects
estimates store m1, title(Em_FixT)

** OLS Estimation Employment Model with Fixed County Effects & Nonlinear Trend
quietly xtreg demppc newrvtpc time timeqr if year > 2004, vce(cluster countyear) fe nonest
estimates store m2, title(Em_NLT)

** Estimation of Instrumental Variable for Shale Spending by County
gen lnewrvt = log(newrvt + 1)
quietly tabulate cnum, generate(dum)
reg lnewrvt d2006-d2015 dum1-dum66 if year > 2004, robust
predict fit, xb
gen newrvtpc2 = exp(fit - 1) / cpilfe / pop

** IV Estimation Employment Model with Fixed County & Time Effects
estimates store m3, title(Em_FixT_IV)

** IV Estimation Employment Model with Fixed County Effects & Nonlinear Trend
quietly xtreg demppc newrvtpc2 time timesqr if year > 2004, vce(cluster countyear) fe nonest
estimates store m4, title(Em_NL_IV)

** Table 6: County Employment Impacts
estout m1 m3 m2 m4 using table7.rtf, ce
\ cells(b(star fmt(3)) se(par fmt(3))) \ ///
legend label varlabels(_cons Constant)          
\ ///
\ stats(r2 df_r bic, fmt(3 0 1) label(R-sqr dfres BIC))

** Real Income per Capita

gen rincpc = income / cpile / pop
** OLS Estimation Income Model with Fixed County & Time Effects
estimates store m5, title(Em_FixT)
** OLS Estimation Income Model with Fixed County Effects & Nonlinear Trend
quietly xtreg rincpc newrvtpc time timesqr if year > 2004, vce(cluster countyear) fe nonest
estimates store m6, title(Em_NLT)

** IV Estimation Income Model with Fixed County & Time Effects
estimates store m7, title(Em_FixT_IV)

** IV Estimation Income Model with Fixed County Effects & Nonlinear Trend
quietly xtreg rincpc newrvtpc2 time timesqr if year > 2004, vce(cluster countyear) fe nonest
estimates store m8, title(Em_NL_IV)

** Table 7: County Income Impacts
estout m5 m7 m6 m8 using table8.rtf, cells(b(star fmt(3)) se(par fmt(3))) ///
legend label varlabels(_cons Constant)          ///stats(r2 df_r bic, fmt(3 0 1) label(R-sqr dfres BIC))

Appendix D

Stata Program & Data for Estimation of VAR Models

clear all
set more off
**Set Working Directory
cd "~/Users/timconsidine/Documents"
**Import Data
use quarterly_data_final, clear
**Generate Month/year variable
gen int date = yq(year, quarter)
format date %tq
**Set Time Series
tsset date
** Estimation of VAR
gen dgdp = gdp - L.gdp
gen demp = emp - L.emp
gen inc = income / cpilfe
gen dinc = inc - L.inc
gen newrv = newrv / 1000
var newrv dgdp demp dinc, lags(1/1) dfk small exog(q1 q2 q3 time timesq)
** Granger Causality Tests
vargranger
** Impulse Response Functions
** irf create tcqvar3, step(20) set(tcqirf3**) replace
** irf graph oirf, impulse(newrevt dgdp demp dinc) response(newrv dgdp demp dinc)
** Re-Estimation of VAR with Exogenous Shale Investment & New Production
var dgdp demp dinc, lags(1/1) dfk small exog(newrevt q1 q2 q3 time timesq)
** OLS Regression
reg dgdp L.dgdp L.demp L.dinc newrevt q1-q3 time timesq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model1, title(GDP)
list dgdp demp dinc newrevt q1 q2 q3 time timesq
reg demp L.dgdp L.demp L.dinc newrevt q1-q3 time timesq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model2, title(Employ)
reg dinc L.dgdp L.demp L.dinc newrevt q1-q3 time timesq, robust
estat dwatson
estadd scalar r_dw = r(dw)
estimates store model3, title(Income)
** VAR Estimates Table
** estout model1 model2 model3 using Table9.rtf, ///
** cells(b(star fmt(2)) se(par fmt(2))) ///
** legend label varlabels(_cons Constant newrv Shale Spending) ///
** stats(r2 bic r_dw, fmt(3) label(R-Sqr bic Durbin-Watson))
** Simulation of Multipliers
forecast create basesim, replace
forecast estimates model1
forecast identity gdp = dgdp + L.gdp
forecast estimates model2
forecast identity emp = demp + L.emp
forecast estimates model3
forecast identity inc = dinc + L.inc
gen shock = 0
gen newrevex = newrevt
forecast identity newrevt = newrvex + shock
forecast exogenous q1 q2 q3 newrvex time timesq shock
forecast solve, prefix(b_) begin(tq(2014q1))
list b_gdp b_emp b_inc if year > 2013
replace shock = 1 in 37
list shock
forecast solve, prefix(sh_) begin(tq(2014q1))
list sh_gdp sh_emp sh_inc if year > 2013
gen gdpm = (sh_gdp - b_gdp) / 1000
gen empm = sh_emp - b_emp
ngen incm = (sh_inc - b_inc) / 1000
list gdpm empm incm