Geographic Dispersion of Economic Shocks: Evidence from the Fracking Revolution

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Abstract

The combining of horizontal drilling and hydrofracturing unleashed a boom in oil and natural gas production in the US. This technological shift interacted with local geology to create exogenous shocks to income and employment. We measure the effects of these shocks within the county where production occurs and track their geographic and temporal propagation. Every million dollars of new oil and gas extracted produces $80,000 in wage income, $132,000 in royalty payments and business income, and 0.85 jobs within the county in the year production occurs. Within the region, the economic impacts are approximately three times larger. Within 100 miles of the new production, one million dollars generates $257,000 in wages, $286,000 in royalties and business income, and 2.13 jobs. Thus, over half of the fracking revenue stays within the regional economy. The impacts of new production on wages are relatively persistent over time. Roughly 2/3 of the wage income increase persists two years after the initial shock. New oil and gas extraction increased aggregate US employment by as many as 640,000, implying a 0.43 percentage point decrease in the unemployment rate during the Great Recession.

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1 Introduction

The technological innovation of combining horizontal drilling with hydrofracturing has created an oil and natural gas boom within the United States. The interaction of technological change and preexisting geology has generated large income shocks in many areas of the country. Employment in the mining industry grew by 60% during a period when overall US unemployment reached 10%. We use the fracking revolution to study how income and employment shocks propagate over time and across geography and industries.

We use a comprehensive data set of oil and natural gas production to calculate the value of production from new wells in any county in a given year. As firms may select the exact location within a region to drill, we instrument using the geological presence of shale deposits. Using data from the Bureau of Labor Statistics (BLS) and the Internal Revenue Service (IRS), we measure the effect of new oil and gas production on income and employment. In particular, we ask: how much of the value of new production stays within the county and region where the production occurs?

These income effects take several forms. First, wages of workers in the resource extraction and transportation industries are directly impacted through participation in the extraction process. Second, landowners are paid royalties on the value of production taken from their land.[1] Finally, wages and employment in industries not directly related to oil and gas production may be affected.

The county may not be the ideal level of observation because workers and landowners may be located in counties adjacent to where new production is occurring. By examining the impact of new production at increasing distances, we track the propagation of the shocks over space. This spatial analysis is important because we are interested in how fracking impacts the entire region, not just the immediate county. This is particularly

[1] In some states land rights and mineral rights may be held separately. All references to land owners in the paper should be interpreted as the owner of the mineral rights.

important since substantial new fracking activity occurs in sparsely populated counties.

Two major results emerge from our analysis. First, the counties where extraction occurs enjoy significant economic benefits. Second, the effects grow larger as we widen the geographic area being examined. The regional impact on jobs and income is approximately three times as large as the immediate county effect with most of the impact happening within 100 miles of the drilling sites.

Each million dollars of new oil and gas production is associated with a $80,000 increase in wage income and 0.85 new jobs within the county in that year. Roughly 40% of the income increase is in industries not directly related to oil and gas extraction such as construction, hospitality, and local government. Of the $80,000 increase in local wages, $48,000 are wage payments to oil and gas industry workers, including trucking, and another $31,000 are wage spillovers to workers in other industries. In addition, we find $132,000 in royalty payments and increased business income within the county. The direct effects imply that roughly 20 percent of the total value of gas and oil extracted remains in the county in the form of wages, royalty payments and business income.

Within a 100 mile radius, each million dollars in new production is associated with wage increases of $257,000 and 2.13 jobs, about three times as large as the effects at the county level. Each million dollars also generates almost $286,000 in royalty payments and increased business income within a 100 mile radius. Overall, we conclude that 54 percent of the value of new production shows up in households within commuting distance of the drilling locations during that year.

The impacts of new production on wages and employment are relatively persistent over time. Approximately 2/3 of their increase persists two years after the initial shock. However, royalty and business income is ephemeral. Across industries, we find that mining wages dissipate within two years while wages in other industries see continued increases over time. This suggests that the fracking activity spills over to the rest of the economy.

Our results also provide some insight into the aggregate impact of the fracking boom. A significant portion of the increase in oil and gas production occurred during the depths of the Great Recession. With the national economy operating at significantly less than full employment, the increased demand for labor generated by the fracking boom almost certainly increased overall employment. Our estimates suggest that new oil and gas extraction between 2005 and 2012 increased employment by 640,000. Assuming no displacement in employment from other locations, this suggests that the fracking boom lowered aggregate US unemployment by 0.43 percentage points during the Great Recession.

2 Literature Review

The impact of natural resources on economic performance has generated a large and growing literature. There are several papers focusing on the US that suggest that fossil fuels create a resource curse in a region by raising wages in one sector and crowding out other sectors.[2] Other work finds overall benefits to regional economies.[3]

The recent fracking revolution in the United States provides significant variation in new production. Several recent papers have focused on the fracking revolution. Some focus on particular states or sectors.[4] Other papers use indirect measures of production.[5] Our paper differs from the literature in several ways: we use detailed measures of production from

[2]Jacobsen and Parker (2014) find that the oil bust in the 1980s harmed manufacturing employment more than the boom in the 1970s helped employment in this sector. This is analogous to the Black, McKinnish and Sanders (2005) finding that the coal bust hurt income and employment more than the boom helped.

[3]Allcott and Keniston (2014) find that energy extraction benefits, rather than harms, local manufacturing employment by using exposure to national shocks (as measured by proven reserves) as an instrument. Similarly, Weber (2013) and Fetzer (2014) find that non-mining jobs increase with mining activity. Over a long time horizon (1890 to 1990), Michaels (2011) finds that oil abundant counties in the US South saw higher population growth and higher income per capita growth than counties without oil.

[4]Weber (2012) examines county level direct effects of gas production in three states from 1998 to 2008.

[5]Fetzer (2014) examines the county level direct effect of any drilling activity after 2007 by instrumenting with the presence of shale. Maniloff and Mastromonaco (2014) study the effect of the number of wells (and a similar instrument) as a measure of production. Other papers related to this topic include Bartik, Currie, Greenstone and Knittel (2016), Considine, Watson and Considine (2011), Deller and Schreiber (2013), Marchand (2012), Wang and Krupnick (2013), and Weber (2013).

new wells for all states; we study the effect during the Great Recession; and we examine the spatial and temporal propagation of economic spillovers.

Our work has implications beyond an understanding of the local effects of oil and gas fracking. We are studying a large and arguably exogenous shock that can teach us about the size and breadth of geographic spillovers from localized economic activity. Our estimates contribute to the literature on the economic responses to local shocks in the spirit of Blanchard and Katz (1992), Black et al. (2005) and Shoag (2015).[6]

It is worth noting that the increase in drilling activity is not universally viewed as positive. The regions where this activity is taking place tend to be rural and drilling activities generate significant local impacts.[7] Several recent papers have examined the environmental concerns with shale gas and oil, including water quantity, water quality, local air pollution, methane leakages, and earthquakes.[8] These concerns have led to many communities questioning whether the local benefits exceed the costs. New York State has placed a moratorium on fracking while several counties in Colorado have done the same. Our paper may provide useful guidance on quantifying the benefits.

3 Local Geology and the Technology of Fracking

Domestic oil production increased every year from 2008 to 2015, reversing a decline that began in 1986. In 2013, the Energy Information Administration (EIA) projected that

[6]Black et al. (2005) find that each coal mining job added to a county during the coal boom created an additional 0.17 jobs in other industries.

[7]Newell and Raimi (2015) find significant heterogeneity in the impact on local government finance. Media reports have noted increases in crime and congestion that have accompanied increased economic activity. See, for example, see these *New York Times* articles: Healy (2013), "As Oil Floods Plains Towns, Crime Pours In"; Galbraith (2012), "In Oil Boom, Housing Shortages and Other Issues"; and Urbina (2011b), "A Tainted Water Well and Concern There May Be More."

[8]Howarth, Ingraffea and Engelder (2011) debate many of these concerns and risks. Muehlenbachs, Spiller and Timmins (2015) find that homes relying on wells for drinking water have fallen in value because of drilling activity in Pennsylvania. Olmstead, Muehlenbachs, Shih, Chu and Krupnick (2013) find increases in chloride concentrations downstream of treatment plants processing shale gas waste and increased concentrations of total suspended solids in watersheds with new shale gas wells.

the US would soon exceed 1970s levels of oil production of 11.5 million barrels per day (EIA 2013a).[9] As a result, the US oil and gas industries added about 300,000 jobs from 2004 to 2012.[10] Fuel prices have responded to this supply shock: domestic natural gas prices fell by two thirds between 2005 and 2012 while global oil prices fell by half in the fall of 2014.[11]

Shale gas and oil refer to fossil fuels trapped in shale formations. While these resources have been known for decades, it was not until the early 2000s that they began to be developed in earnest (EIA 2013b). Industry combined the use of several technological innovations in horizontal drilling, hydrofracturing, and three dimensional seismic imaging.[12] High natural gas prices enabled some firms to risk experimenting with the new technique. In many US locations, favorable conditions exist including geology, property rights, market structure, pipeline infrastructure, and water availability.[13]

Over the past decade, the share of US petroleum production coming from shale resources has increased dramatically. Figure 1 shows oil and gas production separately for vertically and horizontally drilled fuels. In 2000, the amount of fuel produced from vertically drilled wells greatly exceeded that from horizontal wells. By 2013, this pattern reversed and aggregate production has increased dramatically. This trend is not expected to end soon (EIA 2013a). EIA estimates that the United States has 223 billion barrels of shale oil and 2,431 trillion cubic feet of shale natural gas, over a third of the world's recoverable shale

[9] Global oil prices collapsed starting in the summer of 2014. US weekly production peaked at 9.6 mmbpd in June 2015 (https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=WCRFPUS2&f=W).

[10] Employment in the natural resources and mining sector grew from 1.68 million in 2004 to 1.98 million in 2012 (BLS Quarterly Census of Employment and Wages).

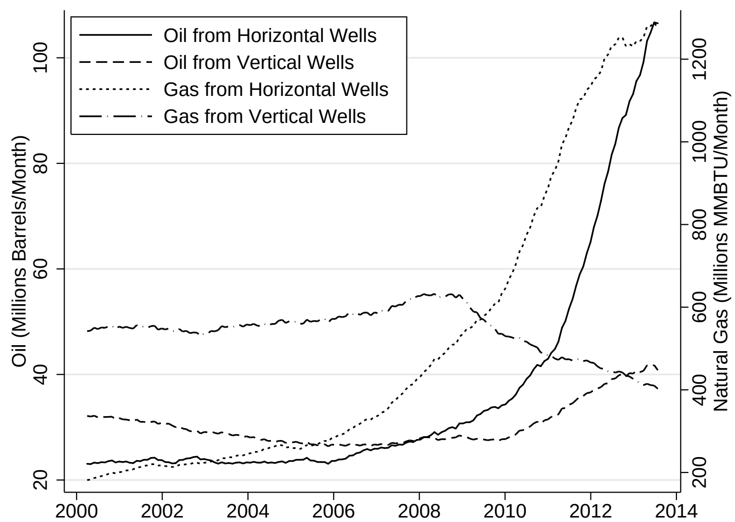
[11] Gas prices fell from $10 per million British Thermal Units (MMBTU) in October 2005 to $3.35 by the end of 2012 (see http://www.eia.gov/dnav/ng/hist/n9190us3m.htm). The oil price drop occurs after our sample period and was due to a number of factors in addition to US crude supply. Below, we examine whether there are asymmetric responses to prices rising or falling.

[12] Wang and Krupnick (2013) point to several culminating events that lead to the shale revolution starting in the mid-2000s. New seismic imaging technology allows geologists to better understand the structure and properties of the subsurface rocks (Bohi 1999). From one location, the company can drill eight horizontal wells and access the same reservoir volume as sixteen vertical wells (DOE 2009). By injecting a high pressure fluid into the well bore, cracks and fractures develop allowing the hydrocarbons to be extracted.

[13] Joskow (2013) discusses the importance of deregulation in the recent developments in the gas industry.

resources (EIA 2013b). The locations of this activity are geographically specific. For each county, Figure 2 shows the cumulative value of new fossil fuel extraction per capita between 2004 and 2012.

Figure 1: Production By Drill Type



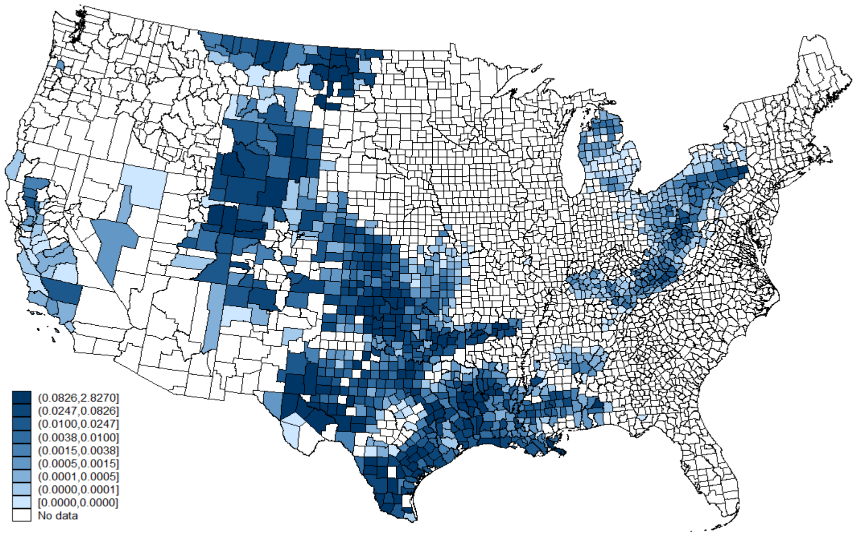
Notes: We report aggregate barrels of oil produced in a given month from wells with a drilling type of vertical or horizontal (including directional). These totals differ from other national reports as we exclude wells with unknown drilling types. There are 5.6 MMBTU per barrel of crude oil. Data source is drillinginfo.com.

4 Data Description

From the BLS, we use the Quarterly Census of Employment and Wages, which has information on the annual average of total employment and wages by county. These data come from employers reporting economic activity in the county and are disaggregated by sector.[14] This disaggregation allows us to see if the income and employment effects are restricted to

[14]The sectors are as follows: natural resources and mining; trade, transportation and utilities (hereafter transportation); construction; manufacturing; education and health services; government (we aggregate local, state, and federal); and other services (we combine leisure and hospitality, financial activities, information, professional and business services, other services, and unclassified).

Figure 2: New Production from Fracking



Notes: This figure plots each county's cumulative value of new production per capita from 2004 to 2012. Data sources are drillinginfo.com and BLS.

sectors that are directly employed in oil and gas extraction (mining and transportation) or whether these effects are seen in other sectors.

The IRS Statistics of Income data have county level information on annual AGI, wages and salaries, dividends, interest, and capital gains. We define *IRS Other Income* to be the difference between AGI and the other categories.[15] We are interested in the other income category because this is where royalties to land holders should appear. These royalties typically are from 1/8 to 1/4 of the value of production (Urbina 2011a, Fitzgerald 2015). This category also includes non-wage business income such as rental income.

The BLS and IRS data differ in their reporting of the location of income. The BLS data are reported in the county where the employer is located. We should note that the employer's location may not perfectly correlate with the location of the work being performed, particularly for workers in the field.[16] Because the BLS reporting is related

[15]Regressions on dividends, interest, and capital gains show no significant relationship with new oil and gas production and are therefore not included in our tables.

[16]According to the BLS, "Workers should be reported at the permanent main or branch office, terminal, etc., that is directly responsible for their supervision, or reported at the base from which they operate to

to unemployment insurance filings, the state information should be accurate. The IRS data are reported in the county where individuals file their taxes. This may create a differential when there are workers that commute or relocate to a county without changing the address from which they file taxes. Therefore, BLS data better reflect the economic activity happening within the county while IRS data reflect the impact on tax filers that reside within the county.

Drillinginfo collects oil and natural gas production information from various state agencies for each well and month.[17] We focus only on wells that begin producing oil or gas in a given year. We use fuel prices from the EIA to determine values.[18] BLS and Drillinginfo data span 2004 to 2014. The IRS data are only available to 2012, so we focus on the period with complete data.[19] All values are converted to 2014 dollars using the CPI.

Our identification comes from the counties that have seen new production from the fracking boom. The most active counties producing oil are in California, Colorado, Kansas, Louisiana, New Mexico, North Dakota, Ohio, Oklahoma, and Texas. The most active gas producing counties are in Arkansas, Colorado, Louisiana, New Mexico, Pennsylvania, Utah, Texas, West Virginia, and Wyoming. From 2005 to 2012, the new production in our sample is valued at $81 billion in oil and $136 billion in gas.

Our county level analysis excludes the smallest two percent of counties.[20] There are a few counties with significant new production of oil and natural gas and our results are

carry out their activities." http://www.bls.gov/cew/cewmwr01.htm

[17]Drillinginfo has information on over one million wells that were active during our sample. We define oil wells as those wells with a well type classification of Oil or O&G, and gas wells as those classified as Gas. New oil wells account for nine percent of the oil produced in the US during our sample. New gas wells account for 13 percent of natural gas. We aggregate these data by county and year.

[18]We use the West Texas Intermediate monthly spot oil price (http://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm) and the U.S. natural gas monthly wellhead price (http://www.eia.gov/dnav/ng/hist/n9190us3m.htm). If transportation costs exist, then local well prices will be lower than these benchmarks that would suggest our estimates are conservative lower bounds.

[19]As Section 5 describes, we first difference income and employment data so our estimates are for new production from 2005 to 2012. In an online appendix, we report results using all the available data where possible. The 2012 to 2014 period does not provide much of the useful identifying variation since the largest increases in drilling activity occur before then.

[20]This threshold excludes counties with 446 or fewer people employed in 2004.

sensitive to their inclusion. To take one extreme example, in 2007, Loving County Texas had 44 workers and produced $761 million in new oil per capita. The new production in these low population counties is included in all our aggregated results including the state, commuting zone and distance results.[21] Our balanced panel consists of seven years, 3,078 counties, and 21,546 county-year observations for each industry.

We construct instruments using data on the presence of shale in a region (*i.e.*, plays) from the EIA.[22] We assign each county to a specific play. Small plays with less than ten counties are combined into a single "other" category, resulting in 23 designations of plays such as the Utica, Marcellus, Devonian, Antrim, New Albany, Barnett, and Bakken shale plays (see Appendix Figure A1).[23]

5 Empirical Framework

5.1 Econometric Model

One of the challenges in evaluating the impact of new fracking activity is deciding how to measure the intensity of that activity. Millions of dollars of new production in a very low population county (like Loving County, Texas) is going to have a significantly different impact than the same amount of new production in a county with a much larger population. Our solution to this problem is to scale production and our outcome variables by one year lagged employment.[24] This works well at the county level and allows small and large population counties to be handled consistently in the same regression.[25] Scaling by

[21] Commuting zones are defined by the USDA 1990 definition. `http://www.ers.usda.gov/datafiles/Commuting_Zones_and_Labor_Market_Areas/czlma903.xls`.

[22] These data are from the shape files for the EIA "Major Tight Oil and Shale Gas Plays in Lower 48 States" (see `http://www.eia.gov/special/shaleplays/` and the files at `http://www.eia.gov/maps/map_data/TightOil_ShaleGas_Plays_Lower48_EIA.zip)`.

[23] Some counties are in multiple plays. On average each play contains 32 counties.

[24] All references to per capita refer to scaling by the lagged annual average of total employment levels.

[25] All regressions are unweighted. Results weighted by population are qualitatively similar.

employment has the additional benefit of being invariant to aggregation. At all levels of aggregation we sum both the value of new production and the level of employment.

Our estimating equation examines the per capita changes in income and employment resulting from the value of new production per capita. The dependent variable, ΔY_{it}, is the one year change in annual income (or the one year change in employment) divided by the one year lag of total employment.

The key independent variable is the total value of oil and natural gas extracted from wells that started producing in the current year measured in million dollars per capita, $NewValue_{it}$. New production is a function of preexisting geology and the newly introduced technology of horizontal drilling combined with fracking. These changes over time may be independent of other shocks occurring within the county and therefore would represent exogenous shocks to county income.[26]

We control for geography fixed effects (county, commuting zone or state where appropriate), α_i, and year fixed effects, ω_t. In order to deal with the potential for dynamic effects, we also include the one year lag of new production as an additional control. For region i in year t, we estimate:

$$\Delta Y_{it} = \beta_1 * NewValue_{i,t} + \beta_2 * NewValue_{i,t-1} + \alpha_i + \omega_t + \epsilon_{i,t} \tag{1}$$

Initially we focus on β_1 that represents the contemporaneous income or employment effects of new production. These results only condition on a single lag of production while Section 7.2 uses multiple lags in order to examine the dynamic effects explicitly.[27] We report two-way clustered standard errors by geography and year. The geographic clustering addresses

[26] Appendix Table A1 shows that counties with fracking are historically similar to other areas based on 2004 population, income, and wage rates. This also shows that early adopting counties are similar to late adopting counties. Section 5.3 discusses how we address any possible endogeneity.

[27] One lag captures most of the dynamics while keeping most of our sample.

time series correlations while the year clustering addresses spatial correlation.[28]

5.2 Spatial Propagation

The BLS provides data on wages and employment as reported by establishments within a county. Workers at job sites are reported as employed in the county from which they are supervised. If physical wells are located in a different county than their supervisory unit this may understate the impact of new oil and gas production in the county where the well is located. In addition, workers may not live and shop in the counties where the new extraction is taking place. This will result in spillovers of economic activity in neighboring counties that will not be picked up in the county level analysis. Aggregating to the commuting zone and state level allows us to explore the extent of these spillovers.

We further extend our county level analysis to look at the impacts at arbitrary distances from new production. We sum the value of new production, employment, and income within a fixed radius of the centroid of a county. As in our county analysis, we scale the new production and the change in employment and income by the one year lag of total employment. We are essentially creating artificial commuting areas of varying sizes around the centroid of each county.[29] We estimate Equation 1 for areas with distances ranging from 20 to 200 miles. The changes in these estimates with increasing distance shows the geographic propagation of income and employment as we get farther from the sources of the new production.

Because these analyses are run at the county level, aggregation results in new pro duction

[28]See Cameron, Gelbach and Miller (2011). One-way clustering by geography, time, or state-year produces similar standard errors to those reported in Table 1. Footnote 31 discusses using Conley (1999) spatial adjustment standard errors.

[29]There are potentially other ways of estimating effects at different distances. For example, we could run the change in employment per capita in a county against a set of right hand side variables measuring new production in increasing donuts around the county centroid. This type of analysis would work well in an environment with uniform population density but runs up against scaling issues (see Section 4). Oil found in a low population neighboring county will have a different impact than oil found in a high population neighboring county. Our aggregation method deals with this in a consistent manner.

being included in the regression for multiple county groups.[30] Clustering by year deals with this artificially-induced spatial correlation in a flexible way.[31] In addition, Section 6.1 reports results for data aggregated by commuting zone or state where spatial correlation should be less of an issue.

5.3 Instrumental Variables

New production depends on both the availability of the resource and firms deciding to extract it. While the former is clearly exogenous, the latter may not be. Some areas may be fracked earlier because the cost of gaining leases is low due to low land values or because wages are low due to high unemployment. For this reason we instrument for new production in each county using geological formations.

We use a two step process to generate instruments. Resource availability depends on geography and a county's area. First we model production as a function of a county's shale play and common technological temporal shocks. As some counties have larger area, we treat these shocks as multiplicative. We generate predictions for aggregate new production in each county for each year by estimating:

$$ln(NewValue_{it} + 1) = \alpha_i + \lambda_{jt} + \epsilon_{it} \quad (2)$$

where α_i is a dummy for each county and λ_{jt} represents a set of dummy variables for each play-year combination. The predictions from Equation 2 incorporate the timing of new production from the play dummies while controlling for the idiosyncratic level of

[30] If a county is included in multiple observations, then it will receive more weight in the regression. Our results are robust to weighting by the inverse of the number of counties included in each group.

[31] Conley (1999) spatial adjustment deals directly with spatial correlation, taking the distances between counties into effect. It has the limitation of being available only for OLS. For our OLS results, two-way clustering by county and year typically results in larger standard errors than the Conley method. We model the Conley adjustment assuming a one year serial correlation and a Bartlett spatial weighting kernel over 300 miles. Hsiang (2010) provides Stata code.

production in each county.[32]

Second, we transform these predictions into a form consistent with the main independent variable in the paper. We generate a prediction for new production *per capita* for each county year pair:

$$New\hat{V}alue_{it} = (e^{\hat{\alpha_i}+\hat{\lambda_{jt}}} - 1)/pop_{it} \tag{3}$$

This approach uses the time series of productivity in a geological region (i.e., a play) to predict county level production. The predicted values for new production per capita are based on the timing of new production for all the counties within a particular play. Each individual county represents a small part of the play's production so that the instrument is exogenous with respect to the idiosyncratic roll out of fracking within individual counties.[33]

6 Results

6.1 Income

Table 1 shows the results of estimating Equation 1 for aggregate wages from the BLS, and adjusted gross income (AGI), wages, and other income from the IRS. Each entry in the table represents the coefficient from a different regression. In Panel A, the OLS estimates suggest that one million dollars of new oil and gas production in associated with a BLS wage increase of $34,000 within the county. The impact increases substantially when we expand the geographic area of interest. At the commuting zone level, wages increase by $50,000 per million of new production. At a 100 mile radius from the county centroid, this

[32]Suppose that production is uniformly distributed in a play but that the amount of land in each county corresponding to the play differs. The log specification allows each county to scale the play productivity by the relative area within the play.

[33]In order to test this assumption we construct an alternative instrument for each county that omits that county from the initial regression. These instruments do not generate significantly different results. The results are also robust excluding counties within 50 miles from the initial regressions (see Table A2).

increases to $221,000.[34] The state level effects are $239,000. As described in Section 5.3, these results may be biased because the choice of counties for drilling may be non-random. For this reason, the remainder of the paper focuses on the IV results (though all tables also report OLS results) where we instrument using the regional geology.

Panel B of Table 1 reports our IV results.[35] These estimates suggest that one million dollars of new oil and gas production is associated with a BLS wage increase of $80,000 within the county. Again, our estimates increase substantially as we look more regionally. At a 100 mile radius from the county centroid each million dollars of new production is associated with wage increases of $257,000.[36]

Results using IRS data suggest smaller wage effects, with one million of new production associated with $42,000 in increased wages at the county level and $130,000 within a 100 mile radius. These point estimates are about one half of the corresponding BLS wage results. This suggests that itinerant workers are capturing a substantial portion of the wage increase in comparison with the long time residents.

Our results for IRS other income suggest that one million dollars of new production leads to $132,000 at the county level and $286,000 at the 100 mile level. This almost certainly represents more than just royalty payments. Drillinginfo provides some information on royalty rates and they tend to vary from 1/8 to 1/4 of production value with an average closer to 15%.

Combining the BLS wage results with the IRS other income estimates, we find that about 20 percent of the value of new production remains in the county of production and

[34] Commuting zones as defined by the USDA tend to be smaller than this. Consequently our estimates based on these commuting zone definitions tend to lie between the county and 100 mile radius results.

[35] The first stage results are reported in Table A3. Separate estimates are reported for oil values, natural gas values, and the combined values. For our preferred 100 mile results, all first stage F-stats are greater than 10, the threshold suggested by Staiger and Stock (1994) and Stock and Yogo (2005) for weak instruments. The state level regressions have the weakest first stages. Weak instruments will bias the results toward OLS, which in our case is a downward bias.

[36] As in Panel A, the commuting zone estimates lie between the county and 100 mile radius effects ($114,000) and the state estimates are similar to the 100 mile radius effect ($301,000) but with larger standard errors. We focus on the county and 100 mile radius effects for the remainder of the paper.

54 percent stays within a 100 mile radius.

6.2 Industry Level Income

Table 2 breaks down the BLS income results by industry. We will focus on the IV results in Panel B. The first column repeats the results of Table 1 for all industries: one million dollars of new production is associated with $80,000 of additional wages at the county level. Table 2 shows that most of these gains occur in mining ($29,000) and transportation ($20,000). Added together, roughly 60% of the increased wages are in sectors directly involved in extracting new gas and oil. Of the remainder, the largest impact is in construction.

At the 100 mile level, each million dollars of new production is associated with $257,000, with $156,000 in mining and $61,000 in transportation. Again, most of the wage increases in the year of new production occur in sectors directly related to extraction. Interestingly, we see a contemporaneous drop in manufacturing that is consistent with a 'resource curse' as discussed in Section 2.

6.3 Employment

We find similar patterns in employment.[37] Each million dollars of additional oil or gas production generates an employment increase of 0.85 at the county level. Of this, 0.29 is in mining and 0.24 in transportation. At the 100 mile level we find an employment increase of 2.13 with 1.39 in mining and 0.60 in transportation.[38] As with the income results, we find that the majority of the increase is in mining and transportation. Of the remaining categories construction sees the largest gains.

The income and employment effects are extremely similar and are consistent with each new job in a county paying roughly $100,000. However, we cannot say with certainty

[37]Table A4 reports the results of regressions using BLS employment by industry.

[38]Figure A2 shows the results of a series of regressions of county level employment changes against the value of new production within a radius of the centroid of the county that mirror the income results.

whether this is the correct interpretation. It seems likely that the increased activity led to a combination of new jobs along with higher wages for existing jobs within the county and region. We cannot distinguish between these two effects.

6.4 Robustness

Here we summarize robustness checks that we discuss in detail in the online appendix. First we examine characteristics of the production process. We consider whether the number of new wells has predictive power independent of production. This did not turn out to be the case (Table A5). It is also possible that new oil drilling and new gas drilling have different impacts. For example, natural gas is almost always transported by pipeline while oil may be shipped by rail or truck. Though point estimates suggest that oil has a larger impact than gas, these differences are not statistically significant (Table A6). We are therefore comfortable aggregating the two fuels. We may worry that our results are being driven by price changes. We split our sample by periods of rising and falling prices. Our main results do not seem to be affected by the direction of prices (Table A7).

Our analysis has focused on the period 2005-2012 due to availability of the IRS data. The BLS data are available through 2014. Table A8 presents our results for this extended sample using the BLS data. Adding these additional data increases the magnitude of our coefficients in our preferred IV specification. All coefficients remain highly significant. Tables A9 and A10 present the OLS and IV results across three time periods: 2005-2008, 2009-2011, and 2012-2014. The second period has the largest effects and the tightest standard errors, suggesting that the period during the Great Recession is providing a lot of the identification. IV results are extremely noisy for the 2012-2014 period.

7 Dispersion over Space and Time

7.1 Geographic Dispersion

The choice of a 100 mile radius for Table 1 is not random. Figure 3 shows the results of a series of regressions of income changes against the value of new production within a radius of the centroid of the county.[39] As the distance is increased, production, income, and employment in other counties is included in the analysis. The coefficients at zero represent the impact of production located within the county (these coefficients are identical to those in Table 1). Between zero and 50 miles, very few adjacent counties are being included. As we move from 50 to 100 miles, production in adjacent counties becomes significant and the coefficients rise. From 100 to 200 miles, the coefficient on wages flattens while the coefficient on IRS other income continues to rise modestly. This distance pattern is consistent with a commuting distance of 100 miles being the most appropriate unit of observation. The continued rise of IRS other income past 100 miles may indicate that land or mineral right ownership is more geographically dispersed than employment though we cannot reject that the impacts at 100 and 200 miles are the same.

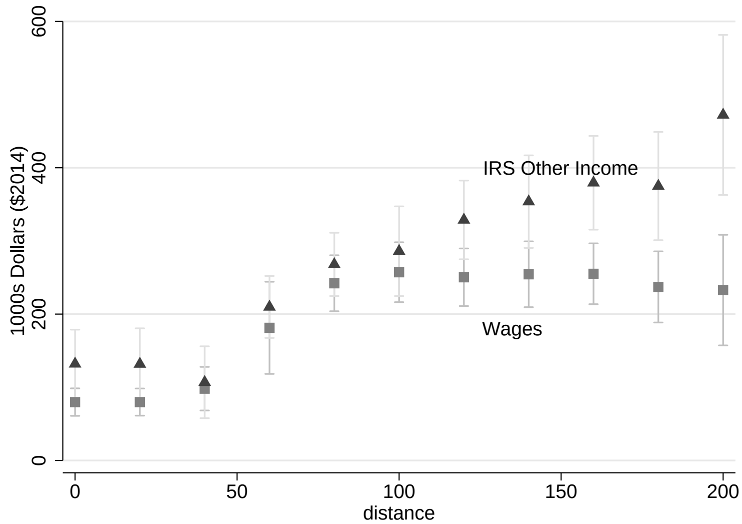
Splitting the results by county size provides additional evidence on the propagation of shocks.[40] We bin counties in our sample into six equally-sized deciles by initial employment and estimate the main coefficient separately for each. Counties above the median (8,361 workers) see significantly larger effects of new production that are statistically similar to the state results.[41] This suggests that counties with larger populations are more likely to see the income and employment gains remain within the county while smaller counties will draw on surrounding counties for workers.

[39]This figure reports IV results while Figure A3 reports OLS results.

[40]See Table A11.

[41]A pooled regression found that counties above the median were significantly different from small counties ($T = 3.8$) and a Hausman test between the effect for these larger counties and that for the state aggregates to be similar ($\chi^2 = 0.47$).

Figure 3: Wage Income (BLS) and Other Income (IRS) Effects Including Neighbors within a Given Distance (IV)



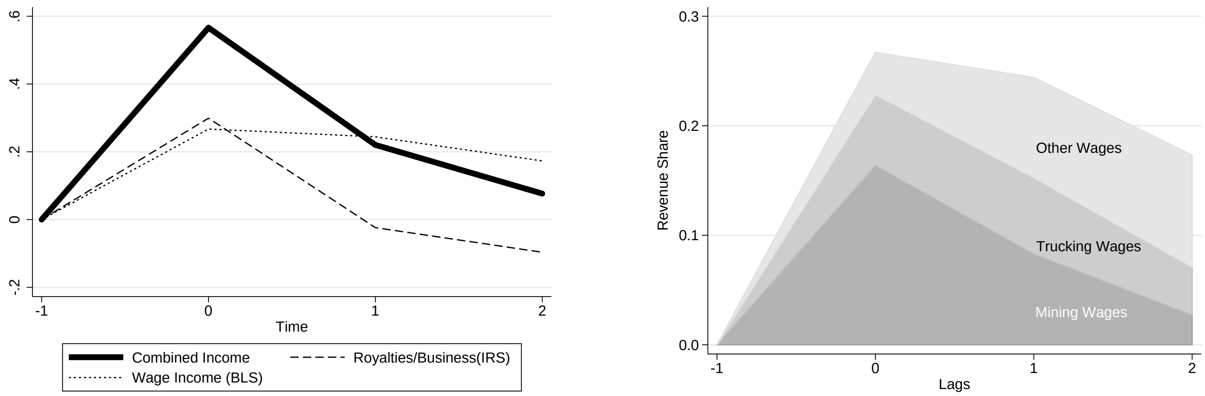
Notes: We regress the one year change in annual income per capita against the total value of new production aggregated within circles of various radii around county centroids. We control for county and year fixed effects and a single lag of production. Standard errors are clustered by county and year, error bars show the 95 percent confidence interval.

7.2 Persistence

How permanent are changes in economic activity as a result of new production? The preceding results show the contemporaneous impact of new production but it is not hard to imagine that some of this activity will persist into the future. For example, new wells may result in several years of production and royalty payments as well as employment maintaining the wells and trucking product to market. All the preceding regressions include a one year lag of new production to control for the ongoing impact of past production so the reported coefficients already control for this. In this section, we look specifically at lagged coefficients using our preferred 100 mile specification.

Ideally we would have sufficient data to specify a full impulse response function from a shock to production. The brief time series that we have available does not allow for this.

Figure 4: BLS and IRS Income Increases From New Production Over Time



Notes: The figure shows the wage income gains from new production in the BLS data over a three year horizon resulting from a one unit shock to new production. These estimates correspond to our 100 Mile IV regressions in Tables A12 and A13. See text for details.

We can, however, learn quite a lot by including two lags for our main 100 mile results.[42]

The results over time are represented by the summation of the initial coefficients with the lags. The left panel of Figure 4 shows the impulse response for BLS wage income, IRS other income, and the sum of the two for a one unit shock.[43] We see two general patterns.

First, for the BLS data the impact gets smaller over the next two years but is still significant two full years after new production occurs. Each dollar of new production generates a wage increase of 0.27 in the initial year that shrinks to 0.17 two years later. After two years, we find that 2/3 of the initial effect persists.

Second, for the IRS royalty and business income the large 0.30 impact in the first year is completely wiped out by a negative coefficient in the first lag. Surprisingly, this suggests that this income boost is a one year affair. Summing the IRS and BLS data we see fairly modest impacts two years after new production.

There is interesting heterogeneity in the industry level effects. The right panel of Figure

[42]The contemporaneous results are relatively insensitive to the inclusion of one or two lags of production so we limit ourselves to one lag in the regressions focusing on contemporaneous effects to maximize sample size. We could also include leads of production. When we do so, none of the leads are economically significant and their inclusion does not change the other coefficients substantially.

[43]Table A12 shows the full impulse response regressions for Figure 4.

4 summarizes the industry results.[44] Mining wage increases are largely gone two years after new production while the transportation industry sees further wage increases in the year after new production.

Wages in industries not directly related to extraction (Other Wages) also rise over time. Within this group, manufacturing wages drops in the year of new production but recovers in the following year resulting in a net positive effect. This result helps explain why some of the literature discussed in Section 2 on the resource curse find negative effects for manufacturing while others find the opposite. Government wages sees the largest increase in the year after new production. The hospitality industry, finance, and business services collectively see very small increases in wages in the initial year of production but increasing income over the next two years.

This paints a nuanced picture over time. Initially, income increases are concentrated in sectors directly related to production. Mining income increases largely disappear once production has started. However other sectors see income increases with a one or two year lag. Increases in the service sector and manufacturing offset the loss in mining income, leaving roughly 2/3 of the initial increase intact two years after production.[45]

7.3 Effects over Time and Distance

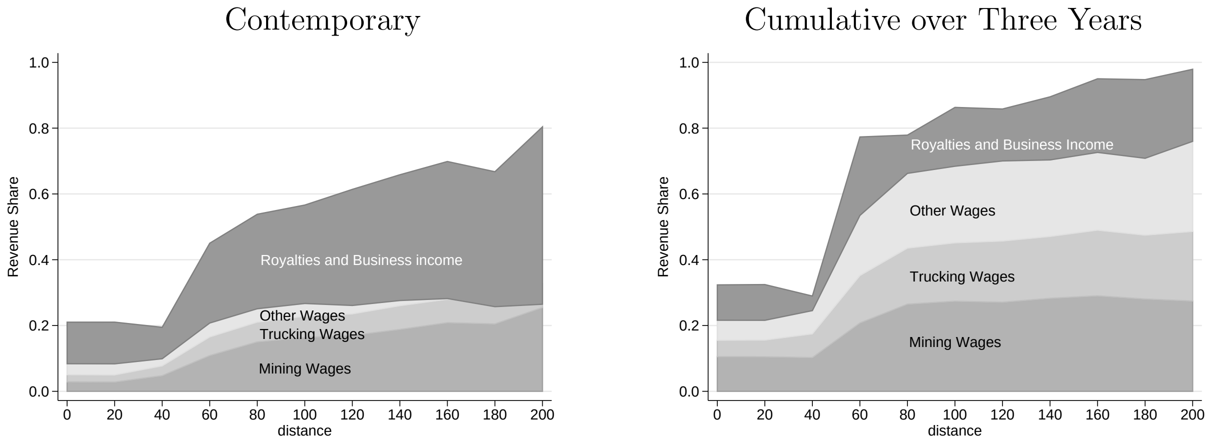
Finally, we examine the joint effects over time and distance. Figure 5 shows the share of revenue that flows to mining wages, transportation wages, other wages, and royalties and other business income.[46] The first panel reports just the contemporaneous effects with mining wages and royalties and business income accounting for the majority of the regional effects.

[44] Table A13 shows the full impulse response regressions for this panel.

[45] The time pattern and relative magnitude for employment follow the income results (see Table A14).

[46] These calculations are based on the two-year lag model summarized in Tables A12 and A13. The one-year lag model, like in our main results, yields similar findings (see Figure A5).

Figure 5: Income Effects Over Time and Distance



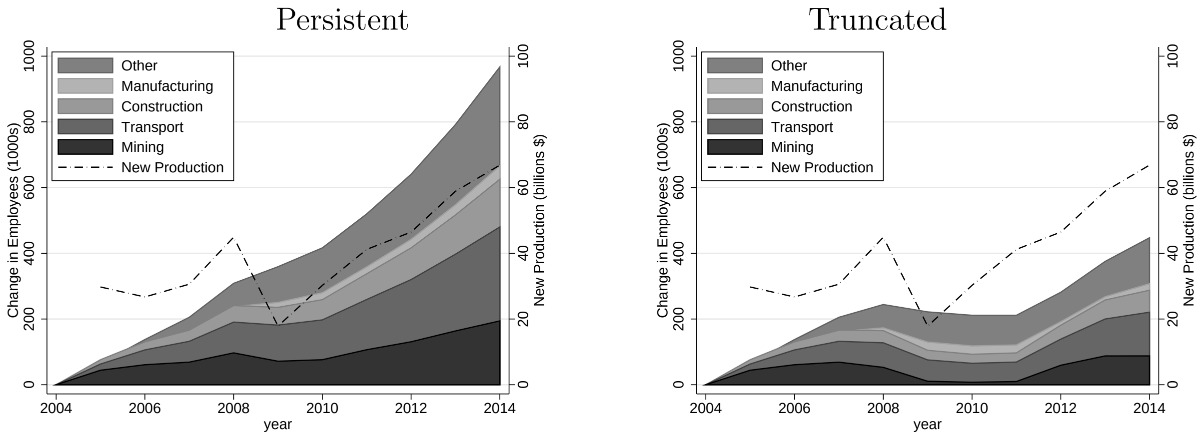
Notes: The left panel decomposes the contemporaneous income gains from new production combining the IRS and BLS income results over various distances. The right panel sums the effect over three years using the estimates from our main results. See text for details.

The second panel reports the cumulative effect on the wealth in a region over the first three years after production begins. This equals the change in income in the year of new production plus the new income the following year from that initial production, as well as the new income two years later. We find that each of the four categories (mining, transportation, other labor income, and royalties) account for approximately equal shares. In the county alone, the cumulative effect equals about a third of the revenue from the initial production. The effect exceeds 80% of the revenue in a 100 mile radius. This large share may seem high for a capital intensive activity. This suggests that local multiplier effects make an important contribution.

8 Discussion

During the Great Recession, unemployment rates exceeded 10% at times. Our estimates can help understand the degree that fracking dampened this effect. From 2005 to 2014, the oil and gas industry extracted $393 billion worth of new production (see Figure 6). One million in new production results in 2.18 jobs in the year of new production, 2.71 one

Figure 6: Aggregate Employment Effects from Total New Production



Notes: The left panel assumes a persistent employment effect after three years. The right panel assumes no impact after three years. See text for details.

year later and 2.27 two years later.[47] We use these coefficients and observed production to generate a predicted change in employment by county and year and aggregate to the nation level.[48]

Ideally, impulse response functions include enough lags to clarify the long run impact. Our seven-year panel only allow us to estimate a few lags. Therefore, we need to make assumptions of the impact of new production beyond two years. We make two extreme assumptions to set upper and lower bounds. The left panel of Figure 6 assumes that the jobs that resulted from new production after two years will persist forever. The right panel assumes that the impact goes to zero three years after production. Given that the impact is not falling steeply between years one and two this is a very conservative assumption.

We find an employment increase of between 210-420 thousand in 2010 compared to a world with no new production. By 2012 employment is 280-640 thousand higher. In a full employment economy we would expect that this increase in local employment would

[47]Table A14 reports the impulse response function coefficients for the employment effects. The results mirror the wage effects that we show in Figure 4.

[48]We estimate the change in employment per capita using the 100 mile radius specification and multiply by lagged county employment to get the county specific employment change.

be offset by decreases in employment in other parts of the economy. During our sample period, labor markets in the US were at their weakest point since the Great Depression. As an upper bound, we assume that employment increases during our sample period were not offset by decreases in the rest of the economy. Given a labor force of approximately 150 million, our results suggest a 0.43 percentage point increase in aggregate employment due to new production of oil and natural gas from 2005-2012, with an identical reduction of the unemployment rate.

Looking at the industry-level results, we find that mining jobs dominate the initial increase in employment but are less important over time. Mining wage and employment gains are concentrated around the time of new production while transportation, construction and other impacts tend to emerge with a lag. In 2012 20% of the overall increase in employment is in the mining sector, 30% is in the transportation sector, and roughly half the increase is in sectors not directly related to extraction.

What does this mean for the typical county that has fracking activity? This question is complicated by the extremely skewed distribution of production within the counties where fracking is taking place. There are 1,023 counties that had some new production between 2005 and 2012. The top 10% of these counties accounted for almost 80% of overall new production during our sample and the top 5% accounted for about 60%. The top 1% alone accounted for almost 30%, while the bottom 50% produced less than 1%.

On average, *each* county in the top 5% produced approximately 1% of total US new production.[49] Each of these counties would have an additional 6,400 workers in 2012.[50] From Section 6.3, we know that roughly 1/3 of these jobs will be within the county and 2/3 will be nearby within a 100 mile radius.

[49]These counties have a median employment level of 10,000 so this represents roughly $30,000 annually in new production per capita or about $250,000 over our sample period.

[50]This assumes that these counties' production patterns mimic that of the national aggregate. As the nationwide employment effect is 640,000 in 2012, each county would account for about 1% of that.

9 Conclusion

Our analysis is among the first comprehensive examinations of the effects of fracking on income and employment. Fracking is particularly interesting because we know the exact location of the wells and are able to measure the impacts at ever widening levels of geography. New production in our data is being driven by new drilling technology interacted with the preexistence of appropriate geography. Our new production is therefore exogenous to economic conditions at the time of the new drilling. This allows us to study how income shocks propagate through local and regional economies.

While county impacts are substantial, the regional effects are several times larger. As we move out to 100 miles, 54 percent of the new value extracted remains within the region in the year of the new production. About half of the income increase is in the form of higher wages and the other half as royalties and business income. Mining accounts for 60 percent of the wage increase, transportation 25 percent, with the remainder in other industries. Royalty and business income are ephemeral but the impacts of new production on wages are relatively persistent over time. Approximately 2/3 of wage increases persist two years after the initial shock, especially outside of mining.

We find substantial increases in regional employment due to fracking. Each million dollar of new production generates a contemporaneous increase in employment of 0.85 workers at the county level and 2.13 within 100 miles. Aggregating to the national level we conclude that aggregate employment rose by 640,000 jobs due to fracking, causing a reduction in the US unemployment rate of 0.43 percentage points during the Great Recession. This almost certainly understates the impact as it only takes into account the direct impact of the value of new extraction. For much of the nation the main impact of the fracking boom was lower natural gas prices which do not play a role in our analysis.[51]

[51] Hausman and Kellogg (2015) examine the economic consequences of lower fuel prices over this period.

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Table 1: Effects of Fracking on Income

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions) from Wells Opened in Current Year Per Capita

	(1) BLS Wages	(2) IRS AGI	(3) IRS Wages	(4) IRS Other Inc
	Panel A: OLS			
County	33,957***	81,088***	16,891***	64,094***
	(9,655)	(11,215)	(4,901)	(7,136)
Commuting Zone	50,175***	86,273***	29,342***	57,820***
	(12,560)	(24,474)	(8,921)	(19,025)
County +100 miles	221,153***	314,936***	92,165***	225,002***
	(26,154)	(32,571)	(12,915)	(27,190)
State	238,645***	513,384***	66,845	417,812***
	(66,761)	(116,643)	(82,472)	(44,861)
	Panel B: IV			
County	79,751***	176,600***	42,064***	132,016***
	(9,394)	(22,828)	(6,291)	(23,358)
Commuting Zone	114,148***	206,737***	75,727***	134,964***
	(18,480)	(28,207)	(14,479)	(25,519)
County +100 miles	257,252***	417,275***	129,926***	285,999***
	(20,455)	(38,174)	(13,915)	(30,632)
State	301,119***	586,074***	160,263	409,964***
	(71,630)	(82,527)	(112,278)	(123,692)

*** p<0.01, ** p<0.05, * p<0.10

Notes: Each coefficient represents a separate regression with standard errors in parentheses. Regressions control for geography and year fixed effects as well as the lag of new production per capita. AGI is adjusted gross income. The county and county +100 miles regressions have 21,546 observations and standard errors are clustered by county and year. The commuting zone and state regressions have 5,187 and 357 observations, respectively, and standard errors are clustered by geography and year.

Table 2: Effects of Fracking on Wages and Salaries by Industry

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) Total	(2) Mining	(3) Transport	(4) Construct	(5) Manufact	(6) Ed & Health	(7) Govern	(8) Other Serv
				Panel A: OLS				
County	33,957***	16,932***	7,980***	4,304**	-758	-1,255	3,227***	3,227***
	(9,655)	(2,220)	(2,691)	(1,937)	(1,369)	(1,524)	(1,004)	(1,004)
County +100 miles	221,153***	126,364***	54,244***	27,897***	-13,520***	1,080	14,020**	11,068***
	(26,154)	(19,876)	(7,818)	(3,628)	(3,332)	(938)	(6,663)	(2,348)
State	238,645***	158,877***	64,465***	50,536***	-27,486**	21,856***	-42,409**	12,807
	(66,761)	(29,271)	(4,861)	(19,007)	(11,460)	(2,562)	(21,615)	(8,340)
				Panel B: IV				
County	79,751***	28,643**	19,691***	10,070***	-2,455	1,682**	6,998***	15,122
	(9,394)	(13,361)	(4,648)	(3,573)	(2,749)	(800)	(880)	(15,333)
County +100 miles	257,252***	155,886***	61,374***	36,201***	-16,006***	1,433	10,346	8,018**
	(20,455)	(14,546)	(8,073)	(3,413)	(3,256)	(1,651)	(6,822)	(3,471)
State	301,119***	190,664***	70,313***	76,703*	-35,149***	21,922***	-45,502	22,169
	(71,630)	(15,447)	(5,525)	(41,886)	(12,493)	(4,304)	(38,095)	(16,004)

*** p<0.01, ** p<0.05, * p<0.10

Notes: Each coefficient represents a separate regression with standard errors in parentheses. The county and county +100 miles regressions have 21,546 observations and standard errors are clustered by county and year. These counties are includes in the state aggregates. The state regressions have 357 observations and standard errors are clustered by area and year.

Appendix - For Online Publication

A1 Robustness Checks

A1.1 Wells versus Production

Our preferred specifications use the new value of oil and gas production per capita on the right hand side. There are several alternative measures of fracking activity that were also considered. The value of production is a combination of the number of wells, the average production of each well, and the price of oil and gas during the production period. Because we include time effects in all regressions, changes in oil and gas prices play a minor role.

In Table A5, we consider whether the number of wells that began producing that year has predictive power independent of new production because the process suggests a fixed labor cost to creating a well regardless of the well's productivity. This did not turn out to be the case. In regressions including both the value of production and well data, we find that production data have greater predictive power. Part of the explanation may be that productive wells are re-fracked more often and involve more trucking and more extensive horizontal drilling. It may also be that the willingness to invest in new wells is proportional to the expected production from these wells, leading to a strong correlation between the costs of opening a well and the value of new production. Because the well and production data are highly correlated with each other it is not possible to separate out the effects.

A1.2 Oil versus Gas

It is possible that new oil drilling and new gas drilling have different impacts. For example, natural gas is almost always transported by pipeline while oil may be shipped by rail or truck. The point estimates when we estimate new oil extraction and new gas production separately suggest that oil has a larger impact on wages than natural gas ($260,000 in wages per million for oil production versus $180,000 for gas production for our preferred specification of county plus 100 miles using instrumental variables), but that these differences are not statistically significant (Table A6).

Figure A4 shows the results split by oil and gas at varying distances from the county centroid. Between 0 and 100 miles the impact of natural gas and oil are very similar. The impact of oil flattens out at distances larger than 100 miles while natural gas continues to have marginal effect out to 200 miles, though the standard errors are quite large.

A1.3 Rising versus Falling Fossil Fuel Prices

Oil prices have played a role in the timing of the fracking boom, with high prices between 2005 and 2008, followed by a collapse during the Great Recession. We may worry that our results are being driven by periods of high oil prices in ways not captured by time dummies. We therefore split our sample by periods of rising and falling prices. Oil and natural gas prices generally move together, but there are a few periods where they diverge. We therefore split the sample based on whether a county sees rising or falling prices for the dominant fuel in that county. Both the rising and falling price samples include all the non-producing counties as a control group. Table A7 shows our main results for each of these samples. The results do not seem to be affected by the direction of prices.

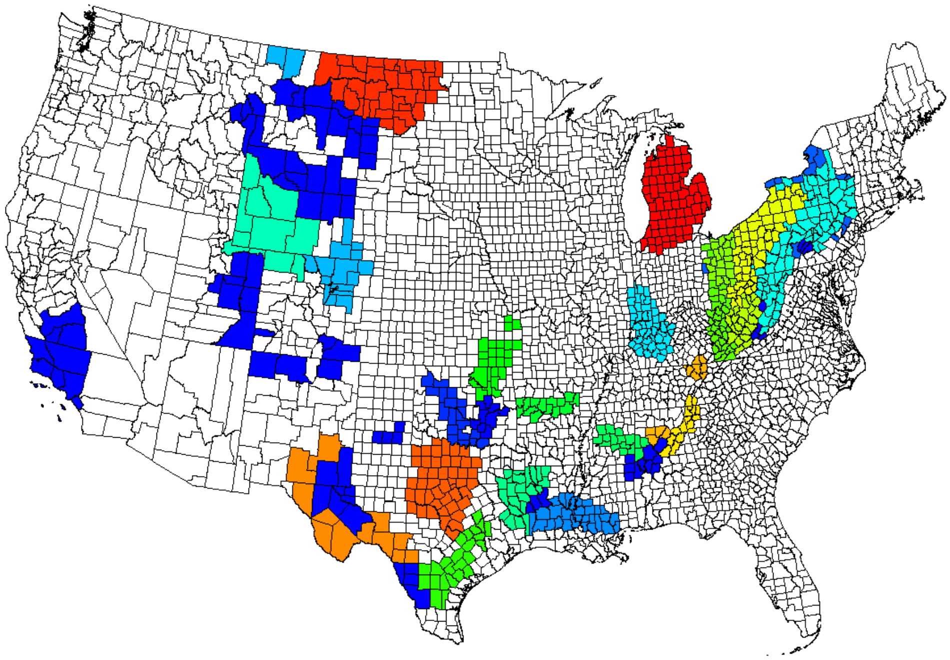
A1.4 More Recent Data

Our analysis has focused on the period 2005-2012 due to availability of the IRS data. The BLS data is available through 2014. Table A8 presents our results for this extended sample using the BLS data. Adding these additional data increases the magnitude of our coefficients in our preferred IV specification.

In order to explore this further we split the sample into three periods. The first period, 2005 to 2008, includes the early years of the fracking boom but does not include the Great Recession. The second period, 2009 to 2011 is during the Great Recession and ends with our IRS sample. For the final period, 2012 to 2014, we only have BLS data. This is a period with falling unemployment and a more mature fracking industry. Tables A9 and A10 present the OLS and IV results across these three time periods. The second period has the largest effects and the tightest standard errors, suggesting that the period during the Great Recession is providing a lot of the identification. IV results are extremely noisy for the 2012-2014 period.

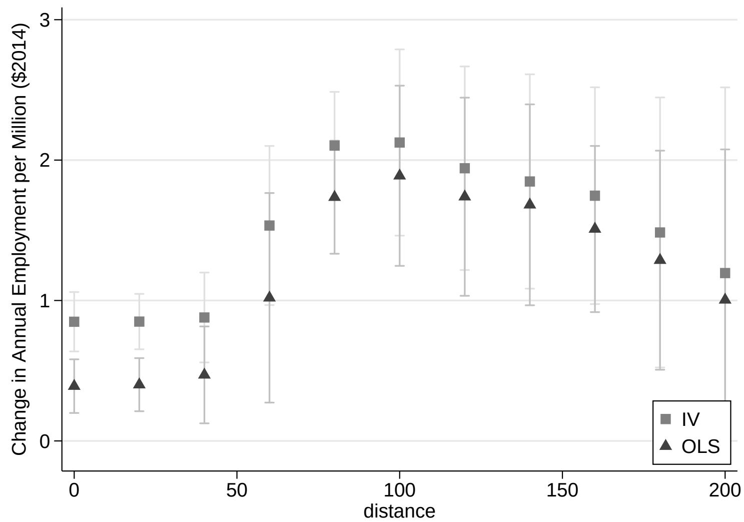
A2 Additional Figures

Figure A1: Shale Plays



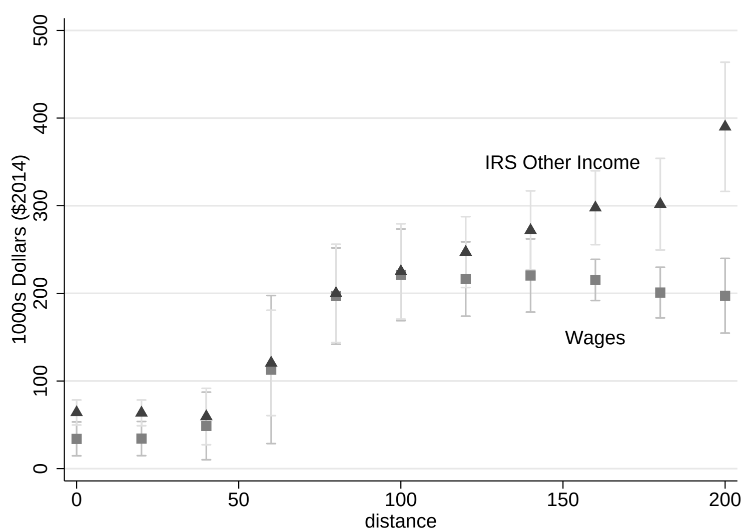
Source: EIA "Major Tight Oil and Shale Gas Plays in Lower 48 States". See text for details.

Figure A2: Employment Effects Including Neighbors within a Given Distance



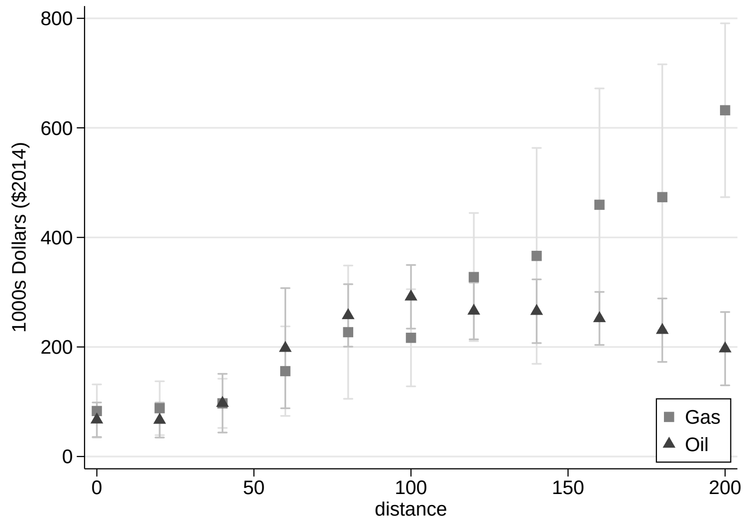
Notes: We regress the one-year change in employment per capita against the total value of new production aggregated within circles of various radii around county centroids. We control for county and year fixed effects and a single lag of production. Standard errors are clustered by county and year, error bars show the 95 percent confidence interval.

Figure A3: Wage Income and Other Income Effects within a Given Distance (OLS)



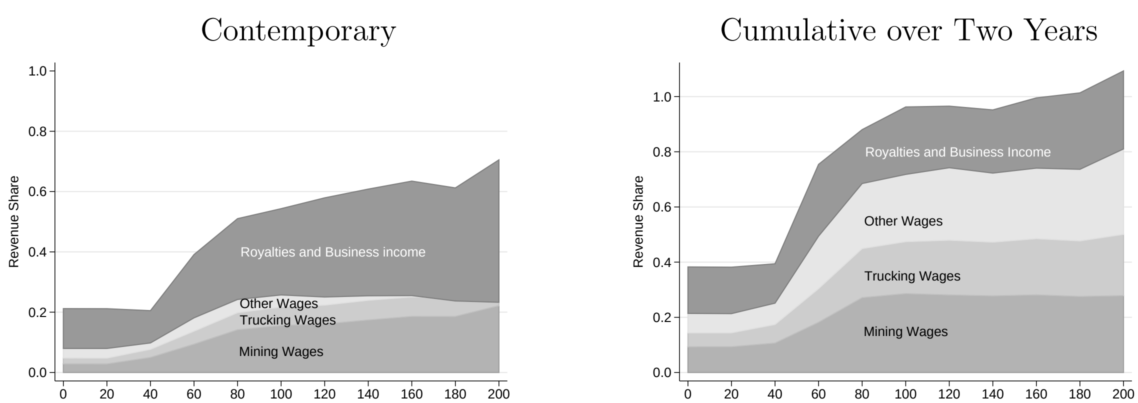
Notes: We regress the one-year change in employment per capita against the total value of new production aggregated within circles of various radii around county centroids. We control for county and year fixed effects and a single lag of production. Standard errors are clustered by county and year, error bars show the 95 percent confidence interval.

Figure A4: Wage Income Effects within a Given Distance by Fuel Type



Notes: We regress the one-year change in annual income per capita against the total value of new production aggregated within circles of various radii around county centroids. We control for county and year fixed effects and a single lag of production. Standard errors are clustered by county and year, error bars show the 95 percent confidence interval.

Figure A5: Cumulative Effects Over Time for One-Lag Regressions



Notes: The left panel decomposes the contemporary income gains from new production combining the IRS and BLS income results over various distances. The right panel sums the effect over two years using the estimates from our main results. See text for details.

A3 Additional Tables

Table A1: Comparison of Historic Population and Income by Group

Panel A: Summary Statistics for 2004 by Group

Group	Observations	Population	Income (millions)	Wage Rate
1	2,113	42,609	$1,680	$38,310
		(126,956)	(6,540)	(12,762)
2	827	35,118	$1,300	$39,576
		(175,911)	(7,820)	(12,828)
3	116	54,576	$2,450	$38,885
		(182,231)	(9,560)	(12,963)
4	23	67,572	$2,570	$41,417
		(143,066)	(5,930)	(14,152)

Panel B: T-Statistics of Differences in Means across Groups

Population	2	3	4
1	-1.29	0.96	0.92
2		1.11	0.87
3			0.31
Income	2	3	4
1	-1.35	1.19	0.64
2		1.44	0.77
3			0.05
Wage Rate	2	3	4
1	2.42	0.47	1.14
2		-0.54	0.66
3			0.82

Notes: Panel A reports the sample mean by group. Standard deviations are shown in parentheses. Groups are defined as follows: group 1 is the control group without any drilling; group 2 is early drillers starting in 2005 or 2006; group 3 is mid adopters starting in 2007-2010; and group 4 is late adopters starting in 2011 or 2012. Panel B shows the t-statistics of the differences between means for each pair of groups.

Table A2: Jackknifed Effects

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) BLS Wages	(2) IRS AGI	(3) IRS Wages	(4) IRS Other Inc
	Panel A: Omit Own County			
County	87,629***	191,190***	45,633***	142,431***
	(9,254)	(28,240)	(6,127)	(28,143)
Commuting Zone	118,915***	214,357***	78,888***	139,766***
	(19,542)	(31,315)	(15,113)	(27,698)
County +100 miles	260,736***	428,309***	132,684***	294,523***
	(20,608)	(42,071)	(14,255)	(33,182)
State	300,459***	606,608***	162,120	433,794***
	(78,311)	(85,129)	(117,382)	(131,964)
	Panel B: Omit Counties Within 50 miles			
County	115,387***	229,008***	54,964***	169,030***
	(27,554)	(61,636)	(9,635)	(52,836)
Commuting Zone	149,248***	244,465***	91,731***	157,115***
	(52,294)	(45,848)	(20,527)	(37,285)
County +100 miles	262,291***	463,052***	137,476***	322,347***
	(18,372)	(55,852)	(16,482)	(41,278)
State	280,750***	664,154***	139,634	473,835***
	(76,742)	(111,590)	(112,877)	(96,152)

*** p<0.01, ** p<0.05, * p<0.10

Notes: See Table 1.

Table A3: Instrumental Variables First Stage Results

Dependent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita
Main Independent Variable: Instrumented Oil and Natural Gas Value ($Millions)

	(1) Main Sample	(2) All Years	(3) Pre-Recession	(4) Recession	(5) Post-Recession
County	1.57***	1.09*	1.00**	3.63***	1.20**
	(0.53)	(0.64)	(0.49)	(0.40)	(0.56)
	[10.06]	[9.630]	[4.111]	[82.19]	[5.774]
County +100 miles	2.72***	1.58	1.52***	3.87***	0.68*
	(0.55)	(0.96)	(0.39)	(0.14)	(0.39)
	[24.48]	[15.13]	[15.79]	[735.2]	[3.779]
Commuting Zone	3.00***				
	(0.59)				
	[25.81]				
State	2.40**	1.79***	2.01***	4.10***	-2.39***
	(1.05)	(0.67)	(0.51)	(0.25)	(0.39)
	[5.264]	[8.812]	[15.67]	[414.8]	[441.6]

*** p<0.01, ** p<0.05, * p<0.10

Notes: First-stage regressions for Tables 1 and A10. See text for a description of the instruments. Standard errors are two-way clustered by geography and year. F-Stats are in brackets.

Table A4: Effects of Fracking on Employment by Industry

Dependent Variable: One-Year Change in Employment per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) Total	(2) Mining	(3) Transport	(4) Construct	(5) Manufact	(6) Ed & Health	(7) Govern	(8) Other Serv
Panel A: OLS								
County	0.39***	0.20***	0.11***	0.05**	-0.03	-0.04	0.05**	0.05
	(0.10)	(0.02)	(0.03)	(0.02)	(0.03)	(0.04)	(0.02)	(0.07)
County +100 miles	1.89***	1.11***	0.52***	0.31***	-0.31***	-0.05*	0.09	0.21***
	(0.32)	(0.17)	(0.08)	(0.06)	(0.10)	(0.03)	(0.11)	(0.04)
State	1.32***	1.44***	0.42***	0.49*	-0.56***	0.07	-0.65*	0.12
	(0.31)	(0.21)	(0.10)	(0.26)	(0.14)	(0.07)	(0.37)	(0.25)
Panel B: IV								
County	0.85***	0.29*	0.24***	0.12**	-0.10	0.03	0.10***	0.17
	(0.11)	(0.16)	(0.06)	(0.05)	(0.07)	(0.03)	(0.02)	(0.24)
County +100 miles	2.13***	1.39***	0.60***	0.43***	-0.35***	-0.07*	0.00	0.13*
	(0.33)	(0.14)	(0.08)	(0.06)	(0.09)	(0.04)	(0.08)	(0.07)
State	2.21**	1.77***	0.60***	0.87	-0.75***	0.02	-0.58	0.29
	(1.07)	(0.12)	(0.12)	(0.62)	(0.15)	(0.11)	(0.57)	(0.36)

*** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Each coefficient represents a separate regression with standard errors in parentheses. The county and county +100 miles regressions have 21,546 observations and standard errors are clustered by county and year. These counties are includes in the state aggregates. The state regressions have 357 observations and standard errors are clustered by area and year.

Table A5: Effects of Wells Versus Value of Production

Dependent Variable: One-Year Change in Wages and Salaries per Capita

	1	2	3
Value of Production	33,957***		33,972***
	(9,655)		(10,248)
Lagged Production	4,718		3,437
	(10,496)		(10,185)
Number of Wells		67,090***	372
		(20,793)	(14,912)
Lagged Number of Wells		29,868	9,213
		(21,185)	(11,817)

*** p<0.01, ** p<0.05, * p<0.10

Notes: Production is the total value of oil and natural gas ($Millions) from wells opened in the current year per capita. Wells is the number of these wells per capita. Standard errors, clustered by state-year, are in parentheses. There are 21,546 observations in each regression.

Table A6: Effects of Fracking on Income by Fuel Type

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil or Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) BLS Wages	(2) IRS AGI	(3) IRS Wages	(4) IRS Other Inc
	Panel A: Oil (OLS)			
County	28,775**	83,474***	15,197***	68,822***
	(12,179)	(14,518)	(4,809)	(9,784)
County +100 miles	240,822***	333,046***	81,951***	256,435***
	(36,894)	(40,781)	(14,475)	(36,451)
State	153,498***	347,509***	-86,445	442,842***
	(38,326)	(92,253)	(65,435)	(100,550)
	Panel B: Gas (OLS)			
County	39,456***	93,152***	24,915**	66,169***
	(12,188)	(22,537)	(9,959)	(13,048)
County +100 miles	218,707***	377,844***	159,922***	222,056***
	(57,242)	(80,907)	(29,745)	(54,000)
State	446,895***	281,372	275,472***	-9,163
	(35,720)	(195,146)	(98,334)	(151,120)
	Panel C: Oil (IV)			
County	67,101***	141,884***	37,237***	105,641***
	(15,771)	(21,230)	(7,382)	(16,951)
County +100 miles	291,567***	422,760***	118,314***	313,641***
	(29,038)	(43,004)	(24,248)	(36,212)
State	97,708***	499,036	-128,512	628,294
	(32,109)	(608,985)	(115,031)	(485,346)
	Panel D: Gas (IV)			
County	83,072***	253,513***	53,736***	186,526***
	(24,283)	(14,711)	(14,627)	(59,805)
County +100 miles	216,750***	531,377***	193,129***	323,945***
	(44,307)	(98,386)	(33,173)	(71,612)
State	570,888***	594,452***	396,575***	202,556*
	(63,988)	(65,007)	(27,425)	(106,798)

*** p<0.01, ** p<0.05, * p<0.10

Notes: See Table 1.

Table A7: Effects on Income by Direction of Price Shock

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) BLS Wages	(2) IRS AGI	(3) IRS Wages	(4) IRS Other Inc
	Panel A: Rising Prices (OLS)			
County	18,440**	61,683***	12,825***	49,098***
	(7,660)	(16,402)	(2,564)	(14,068)
County +100 miles	195,423***	259,629***	71,420***	198,120***
	(37,569)	(36,177)	(14,020)	(36,446)
State	147,310	-114,768	-114,521	-32,661
	(151,724)	(264,157)	(190,935)	(181,850)
	Panel B: Falling Prices (OLS)			
County	46,512***	92,621***	19,946***	72,616***
	(9,505)	(10,493)	(5,948)	(7,234)
County +100 miles	215,058***	353,144***	105,942***	245,587***
	(25,927)	(24,674)	(8,594)	(20,039)
State	252,545***	864,367***	102,658**	778,803***
	(59,768)	(117,006)	(45,196)	(123,675)
	Panel C: Rising Prices (IV)			
County	38,695	223,780**	37,359***	181,188**
	(27,190)	(89,511)	(13,505)	(78,273)
County +100 miles	219,697***	425,128***	96,320***	336,227***
	(43,518)	(54,355)	(24,201)	(46,749)
State	78,583	27,982	-225,095	73,321
	(69,901)	(305,646)	(182,925)	(297,212)
	Panel D: Falling Prices (IV)			
County	81,438***	170,245***	43,419***	124,323***
	(13,001)	(40,974)	(10,451)	(30,972)
County +100 miles	230,421***	400,645***	119,388***	278,811***
	(29,247)	(32,005)	(16,389)	(26,040)
State	309,298*	964,606***	147,157	823,447***
	(170,115)	(91,198)	(121,939)	(136,683)

*** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Each coefficient represents a separate regression with standard errors in parentheses. AGI is adjusted gross income. Standard errors are clustered by area and year.

Table A8: Effects of Fracking on Wages and Salaries by Industry: Full Sample

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) Total	(2) Mining	(3) Transport	(4) Construct	(5) Manufact	(6) Ed & Health	(7) Govern	(8) Other Serv
Panel A: OLS								
County	27,345***	12,927***	6,827***	4,110***	-649	-832	2,665***	2,665***
	(7,205)	(2,577)	(2,222)	(1,592)	(1,028)	(1,116)	(746)	(746)
County +100 miles	185,129***	101,781***	48,655***	21,963***	-10,111**	450	13,945	8,445
	(61,236)	(29,420)	(15,932)	(7,694)	(4,557)	(708)	(9,307)	(6,071)
State	220,949***	137,122***	69,665**	53,010***	-25,929	16,488**	-40,176	10,770
	(85,100)	(21,203)	(31,914)	(18,212)	(17,216)	(7,085)	(32,403)	(21,903)
Panel B: IV								
County	79,955***	27,365*	21,110***	8,130**	-3,028	1,268*	6,952***	18,158
	(14,408)	(14,234)	(7,061)	(3,589)	(3,182)	(720)	(1,972)	(11,570)
County +100 miles	344,966***	177,865***	85,628***	44,281***	-9,797	1,644	24,671	20,673
	(91,144)	(25,571)	(26,338)	(9,608)	(6,699)	(1,425)	(16,116)	(12,612)
State	430,044***	219,549***	97,503***	95,408***	-26,549	26,527***	-22,587	40,193*
	(122,313)	(16,539)	(33,294)	(17,010)	(20,061)	(8,887)	(47,883)	(23,072)

*** p<0.01, ** p<0.05, * p<0.10

Notes: Each coefficient represents a separate regression with standard errors in parentheses. AGI is adjusted gross income. The county and county +100 miles regressions have 21,546 observations and standard errors are clustered by county and year. The state regressions have 357 observations and standard errors are clustered by state and year.

Table A9: Effects on Income by Period (OLS)

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) BLS Wages	(2) IRS AGI	(3) IRS Wages	(4) IRS Other Inc
	Panel A: Years 2005 to 2008			
County	11,636***	44,906***	7,470***	37,807***
	(3,079)	(6,575)	(1,458)	(5,347)
County +100 miles	110,142***	236,237***	83,461***	153,258***
	(12,079)	(25,097)	(12,974)	(20,922)
State	261,055***	448,601**	251,194***	171,507
	(66,764)	(204,811)	(49,732)	(170,081)
	Panel B: Years 2009 to 2011			
County	57,190***	115,945***	25,314***	91,085***
	(9,429)	(19,863)	(5,101)	(18,650)
County +100 miles	266,150***	366,360***	95,173***	275,086***
	(13,974)	(20,343)	(13,520)	(15,220)
State	139,269***	420,441***	-29,958	420,418***
	(47,528)	(148,312)	(51,761)	(106,705)
	Panel C: Years 2012 to 2014			
County	9,389*			
	(5,390)			
County +100 miles	157,240**			
	(61,265)			
State	52,522			
	(71,596)			

*** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Each coefficient represents a separate regression. AGI is adjusted gross income. County +100 miles includes all economic activity from counties within 100 miles radius. Standard errors, clustered by state-year (or state), are in parentheses. There are 12,324, 9,239, and 9,237 (204, 153, and 153) observations for Panels A, B, and C, respectively. The county sample excludes counties with 446 or fewer employees in 2004 (2 percent of all counties).

Table A10: Effects on Income by Period (IV)

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) BLS Wages	(2) IRS AGI	(3) IRS Wages	(4) IRS Other Inc
	Panel A: Years 2005 to 2008			
County	30,314*	235,815*	6,399	232,977*
	(16,811)	(132,174)	(11,212)	(136,338)
County +100 miles	104,148*	220,555	144,285*	69,005
	(56,027)	(331,267)	(77,775)	(285,963)
State	480,311*	175,806	108,254	99,552
	(251,678)	(449,014)	(171,493)	(464,549)
	Panel B: Years 2009 to 2011			
County	86,979***	129,277***	37,120***	93,508***
	(6,639)	(19,734)	(5,255)	(18,266)
County +100 miles	285,555***	386,268***	110,554***	279,544***
	(13,453)	(14,166)	(14,066)	(18,899)
State	129,052*	300,075	-481	299,187***
	(65,989)	(284,029)	(85,525)	(110,082)
	Panel C: Years 2012 to 2014			
County	154,318			
	(113,811)			
County +100 miles	-44,611,953			
	(1349510505)			
State	280,231			
	(332,827)			

*** p<0.01, ** p<0.05, * p<0.10

Notes: Each coefficient represents a separate regression. AGI is adjusted gross income. County +100 miles includes all economic activity from counties within 100 miles radius. Standard errors, clustered by state-year (or state), are in parentheses. There are 12,324, 9,239, and 9,237 (204, 153, and 153) observations for Panels A, B, and C, respectively. The county sample excludes counties with 446 or fewer employees in 2004 (2 percent of all counties).

Table A11: Effects on Wages by Population Size

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) OLS Income	(2) IV Income	(3) OLS Employment	(4) IV Employment
Population: 447 to 2,265	37,991***	68,115***	0.47***	0.84***
	(7,834)	(9,878)	(0.09)	(0.10)
Pop: 2,268 to 4,546	30,660***	57,729***	0.39***	0.66***
	(8,667)	(7,522)	(0.10)	(0.10)
Pop: 4,558 to 8,354	20,697***	147,979	0.34***	1.68
	(2,934)	(279,855)	(0.05)	(3.01)
Pop: 8,368 to 15,807	253,695***	323,412***	2.75***	3.76***
	(93,466)	(96,930)	(0.86)	(0.68)
Pop: 15,827 to 41,586	104,046	525,302***	1.44**	6.57***
	(64,609)	(132,240)	(0.68)	(1.85)
Pop: 42,006 to 4,043,854	305,123***	307,098**	3.93***	3.84*
	(100,695)	(125,773)	(1.43)	(2.09)

*** p<0.01, ** p<0.05, * p<0.10

Notes: Each coefficient represents a separate regression. Standard errors clustered by county and year are in parentheses. There are 24,624 observations in each regression.

Table A12: Impulse Response Functions of Fracking on Income

Dependent Variable: One-Year Change in Income per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) BLS Wages	(2) IRS AGI	(3) IRS Wages	(4) IRS Other Inc
New Value Per Capita	267,026***	430,434***	134,553***	299,164***
	(22,745)	(48,089)	(13,652)	(38,952)
Lag 1	-22,905	-417,488***	-82,170***	-322,980***
	(30,041)	(46,330)	(14,183)	(42,257)
Lag 2	-71,046*	-85,351	-38,240***	-72,685
	(42,704)	(78,247)	(11,310)	(76,192)
L0+L1	244,122***	12,946	52,383***	-23,816
	(29,977)	(32,476)	(8,530)	(34,315)
L0+L1+L2	173,076***	-72,405	14,143	-96,500
	(32,146)	(59,520)	(11,955)	(58,992)

*** p<0.01, ** p<0.05, * p<0.10

Notes: This table reports results for the county +100 miles IV regressions that have 18,468 observations and standard errors clustered by county and year.

Table A13: Impulse Response Function of Fracking on Income by Industry

Dependent Variable: One-Year Change in Wages and Salaries per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) Total	(2) Mining	(3) Transport	(4) Construct	(5) Manufact	(6) Ed & Health	(7) Govern	(8) Other Serv
New Value Per Capita	267,026***	163,767***	64,463***	36,916***	-16,463***	670	12,776*	4,897**
	(22,745)	(11,509)	(7,650)	(3,919)	(3,314)	(1,717)	(7,527)	(1,956)
L.d100newfossilval_cap	-22,905	-80,827***	5,005	-2,607	22,849***	-354	26,133*	6,897**
	(30,041)	(14,033)	(8,726)	(5,038)	(5,271)	(2,408)	(13,416)	(3,255)
L2.d100newfossilval_cap	-71,046*	-55,789***	-25,863	-2,232	2,983	3,970	-13,593*	19,477***
	(42,704)	(20,884)	(16,597)	(6,554)	(4,998)	(3,039)	(8,121)	(5,473)
L0+L1	244,122***	82,939***	69,467***	34,309***	6,386	316.9	38,909***	11,794***
	(29,977)	(13,586)	(10,450)	(4,889)	(3,998)	(1,322)	(8,044)	(2,355)
L0+L1+L2	173,076***	27,150**	43,604***	32,077***	9,369**	4,287*	25,316***	31,272***
	(32,146)	(13,076)	(10,174)	(6,463)	(3,950)	(2,422)	(5,542)	(4,420)

*** $p<0.01$, ** $p<0.05$, * $p<0.10$

Table A14: Impulse Response Function of Fracking on Employment by Industry

Dependent Variable: One-Year Change in Employment per Capita
Main Independent Variable: Oil and Natural Gas Value ($Millions)
from Wells Opened in Current Year Per Capita

	(1) Total	(2) Mining	(3) Transport	(4) Construct	(5) Manufact	(6) Ed & Health	(7) Govern	(8) Other Serv
New Value Per Capita	2.18***	1.49***	0.64***	0.45***	-0.39***	-0.10***	0.02	0.08*
	(0.40)	(0.14)	(0.07)	(0.06)	(0.09)	(0.04)	(0.10)	(0.04)
L.d100newfossilval_cap	0.53	-0.75***	0.31***	-0.01	0.41***	0.05	0.53***	-0.01
	(0.51)	(0.14)	(0.10)	(0.06)	(0.11)	(0.06)	(0.15)	(0.08)
L2.d100newfossilval_cap	-0.44	-0.61***	-0.31***	-0.13	0.24***	0.14*	-0.14*	0.38***
	(0.49)	(0.21)	(0.11)	(0.10)	(0.08)	(0.08)	(0.07)	(0.11)
L0+L1	2.709***	0.737***	0.952***	0.435***	0.0137	-0.0486	0.549***	0.0703
	(0.299)	(0.0862)	(0.0780)	(0.0680)	(0.0690)	(0.0379)	(0.0783)	(0.0429)
L0+L1+L2	2.273***	0.126	0.637***	0.302***	0.250***	0.0949	0.411***	0.451***
	(0.433)	(0.159)	(0.0979)	(0.0988)	(0.0831)	(0.0610)	(0.0688)	(0.0845)

*** p<0.01, ** p<0.05, * p<0.10