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WHO NEEDS A FRACKING EDUCATION? THE EDUCATIONAL RESPONSE TO LOW-SKILL BIASED TECHNOLOGICAL CHANGE

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Who Needs a Fracking Education? The Educational Response to Low-Skill Biased Technological Change

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ABSTRACT

Over the past decade, a technological breakthrough – hydraulic fracturing or “fracking” – has fueled a boom in oil and natural gas extraction by reaching shale reserves inaccessible through conventional technologies. We explore the educational response to fracking, taking advantage of the timing of its widespread introduction and the spatial variation in shale oil and gas reserves. We show that local labor demand shocks from fracking have been biased toward low-skilled labor and males, reducing the return to high school completion among men. We also show that fracking has increased high school dropout rates of male teens, both overall and relative to females. Our estimates imply that, absent fracking, the male-female gap in high school dropout rates among 17- to 18-year-olds would have narrowed by about 11% between 2000 and 2013 instead of remaining unchanged. Our estimates also imply an elasticity of high school completion with respect to the return to high school of 0.47, a figure below historical estimates. Explanations for our findings aside from fracking’s low-skill bias – changes in school inputs, population demographics, and resource prices – receive less empirical support.

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I. Introduction

A defining feature of the U.S. labor market since the 1970s has been a rise in the premium for skill, or rising wage inequality. A favored explanation for this trend, known as skill-biased technological change (SBTC), is that new technologies tend to complement skilled labor, generating increases in the relative demand for skilled labor that outpace increases in its relative supply (Katz and Murphy, 1992). Growth in the relative supply of skilled labor appears to have kept pace with SBTC-induced growth in relative demand until the 1970s, when growth in educational attainment stalled (Goldin and Katz, 2008). This observation suggests that the supply elasticity of education with respect to the skill premium today is low, both in absolute terms and by 20th century standards. Yet, there is a dearth of credible micro-level evidence on the educational response to SBTC.

In this paper, we attempt to inform this question by estimating the educational response to a recent *low*-skilled biased technological breakthrough in a specific industry – oil and gas extraction. By pumping large quantities of fluids at high pressure down a wellbore and into a target rock formation, a technology known as hydraulic fracturing – or “fracking” – has made it possible to extract oil and natural gas from horizontal wells in shale plays unreachable through conventional technologies (U.S. Environmental Protection Agency, 2013). In his 2012 State of the Union address, President Obama stated that fracking could generate more than 600,000 jobs by 2020 and supply natural gas for almost 100 years (Obama, 2012). Industry projections have suggested that 63% of new jobs are to be blue collar jobs, suitable for those without higher education (IHS Global Inc., 2014).

Recent research suggests that the employment impacts of fracking have already been sizable, with substantial job growth occurring in both mining and non-mining sectors intensive in less-educated labor, such as construction (Brown, 2014; Fetzer, 2014; Feyrer, Mansur, and Sacerdote, 2014; Maniloff and Mastromonaco, 2014; Weber, 2012, 2014). By increasing the relative demand for *low*-skilled labor, fracking thus has the potential to *slow* growth in educational attainment. Such a phenomenon would work against broader economic trends both at the local level – where incomes may be rising due to fracking, especially among families whose children are more at risk of dropping out – and nationally – where technological change in other industries continues to favor the highly educated.

Despite the considerable recent research on the local economic effects of fracking, only Weber (2014) has attempted to estimate its impacts on educational attainment. However, given his focus on the resident adult population, aged 25 and over, his estimates are arguably driven by changes in the location decisions of less-educated workers, rather than decisions about schooling *per se*.[1] A related literature (Black, McKinnish, and Sanders, 2005; Emery, Ferrer, and Green, 2012; Morissette, Chan, and Lu, 2015) addresses this concern by estimating the impacts of resource booms and busts on school enrollment in younger populations. The educational responses to (permanent) technological advances in resource extraction could nevertheless be fundamentally different from those in response to (temporary) price shocks. For example, while price shocks increase the opportunity cost of remaining enrolled in school, they arguably have less impact on expectations of lifetime earnings, and hence smaller effects on educational attainment.[2] Estimating the long-term consequences of oil abundance in the U.S. South, Michaels (2011) could capture the educational impacts of structural change in resource extraction, but again, a focus on educational attainment in the resident adult population makes it difficult to rule out migration as the driving factor.

We take an empirical approach similar to that of Michaels (2011), exploring the evolution of educational outcomes across areas with different shale oil and gas endowments as fracking has spread. However, we attempt to isolate educational choices separately from locational ones by focusing on high school dropout rates among teenagers, rather than the educational attainment of adults. Our use of

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[1] Weber's results are also geographically limited, pertaining only to non-urban counties in 4 natural gas rich states (Arkansas, Louisiana, Oklahoma, and Texas). Using the share of a county with shale gas reserves as an instrument, he finds that natural gas fracking has reduced the county adult population share that has less than a high school degree and increased the county adult population share with a high school degree only.

[2] Consistent with this idea, Emery, Ferrer, and Green (2012) find that while the 1970s oil boom reduced school enrollment while it was happening, it did not impact ultimate educational attainment.

microdata also allows us to explore directly the possible influence of migration on our estimates. Relative to studies considering younger populations, moreover, our source of identifying variation abstracts from fluctuations in oil and gas prices, and we present evidence that price changes are not a driving factor behind our estimates. Further, our empirical approach is demanding, as we compare local markets with different shale oil and gas reserves *within* states over time. Doing so, we remove bias from unobserved common shocks to dropout rates – e.g., from state policies or economic conditions – across markets within the same state. We also exploit the fact that fracking has had greater impacts on the employment prospects of men.

Our empirical approach is therefore essentially a triple-difference one, exploiting variation in the potential effect of fracking across space, time, and gender. We find considerable empirical support for its identifying assumptions. For example, local labor markets with higher per-capita shale oil and gas reserves look quite similar along observed dimensions as those with lower reserves in the same state prior to the introduction of fracking, suggesting that they would not otherwise have been on different educational trajectories. Further, the within-state relationships between predicted per-capita shale reserves and the outcomes of interest remain relatively stable through the early 2000s – before fracking was widespread but as oil and gas prices were rising. Moreover, local markets with higher per-capita shale reserves have not experienced large increases in *conventional* oil and gas production since fracking began – another finding suggesting that the effects we estimate are driven by technological innovation, not price changes.

Using microdata from the 2000 Census and the 2005 through 2013 American Community Surveys and defining local labor markets using commuting zones (CZs), we find that fracking has increased the high school dropout rates of male teenagers, but not of female teenagers.[3] Our estimates

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[3] Commuting zones are collections of contiguous counties (possibly crossing state boundaries) that were strongly linked on the basis of commuting patterns in the 1990s (Tolbert and Sizer, 1996). Like metropolitan areas, CZs have been used in past research to define local labor markets (e.g., Autor and Dorn, 2013; Autor, Dorn, and Hanson,

imply that, instead of remaining constant, the male-female gap in high school dropout rates among 17- to 18-year-olds would have narrowed by about 11% between 2000 and 2013 in the absence of fracking. Consistent with prior research, we also find that higher-reserve CZs have experienced greater growth in both shale oil and gas production and overall employment in the oil and gas industry compared to lower-reserve CZs in the same state. Formally combining the impacts on dropout and on oil and gas employment using an instrumental variables approach, we estimate that each 0.1 percentage point fracking-induced increase in the local male oil and gas employment rate has increased the dropout rate of male teens by around 0.3 to 0.35 percentage points.[4] Only a quarter of this estimate can possibly be accounted for by in-migration of existing dropouts; the lion's share of the dropout effect is thus driven by the schooling decisions of local teens.

We also present direct evidence that the effects of fracking on the decision to drop out of high school have been driven by local labor demand shocks that favor the least-educated workers, as well as try to rule out alternative explanations. Here, we show that the most affected industries are intensive in dropout labor. We also find that the wages of adult male high school dropouts in relatively high-reserve CZs have increased, relative to the wages both of adult female high school dropouts and of adult males with higher levels of education. On the other hand, we find little evidence to suggest that school inputs have fallen in response to fracking. Likewise, it is unlikely that changes in the race, ethnicity, or family background of the teenage population can explain the results. Our use of high-frequency data gives us further confidence in our conclusions regarding mechanisms: we find that the timing of the initial increase in dropout wages corresponds neatly with that of increases in dropout rates while the timing of the few small changes in school and demographic characteristics do not.

2013a, 2013b; Chetty et al., 2014), but they have the relative advantage of covering the entire United States, including rural areas. CZs are thus ideal for our analysis: fracking is largely a rural phenomenon, and the resulting labor demand shocks need not necessarily respect county boundaries.

[4] Our estimates imply that the average CZ with any shale oil or gas reserves experiences a 0.10 percentage point (about 10%) increase in the male oil and gas employment rate.

A back-of-the-envelope calculation based on our estimates yields an elasticity of high school completion with respect to the high school graduate-dropout wage premium of around 0.47 – below the lower bound on the range of elasticities estimated by Black, McKinnish, and Sanders (2005) in their study of the 1970s coal boom and 1980s coal bust. We might have expected if anything a stronger educational response to technological change in resource extraction than to even long-lived resource price shocks. Yet, these findings are consistent with a low supply elasticity of educated labor today (Goldin and Katz, 2008), and provide some of the first credible micro-level evidence that a weak educational response to SBTC may be contributing to widening wage inequality.

II. Empirical Approach and Data

A. Identification Strategy

Shale oil and gas deposits are unevenly distributed across the United States, resulting in geographic variation in the fracking potential of different CZs. At the same time, these reserves have only become exploitable with the spread of fracking. Our basic identification strategy takes advantage of the interplay between these geographic and temporal factors: if this technological advance has truly increased the propensity of teens to drop out of school, dropout rates should have increased more (or declined less) in CZs with more reserves as fracking spread. Further, if local labor demand shocks are indeed the mechanism linking fracking to dropout – and these labor demand shocks have been biased toward men – we should also expect these dropout effects to be larger for males. Incorporation of this additional comparison across gender essentially converts our baseline difference-in-differences approach into a triple-difference one.

Implementing our identification strategy is not straightforward, however. The first challenge comes in measuring shale oil and gas deposits in a CZ, as there are no existing local (e.g., county-level) estimates. Instead, we must predict a CZ's reserves based on the location of shale plays and estimates of play-specific reserves, which change annually as new discoveries are made. As a result, our local reserve measures are blunter than they would ideally be and have the potential to be endogenous. Information on oil and gas reserves must also be combined using a common metric, as oil and gas are naturally measured in different units (in barrels and in thousands of cubic feet, respectively). And using a common metric, such as the heat energy that the reserves could produce or their dollar value, may not allocate weights to oil and gas reserves that are consistent with their "exploitability" due to fracking.

Our preferred approach to predicting CZ reserves relies on the most recent estimates of oil and gas reserves (from 2013) published by the Energy Information Administration (EIA) and the most recent maps of shale plays (from 2011), also published by the EIA.[5] We overlay these maps to counties, separately for oil and gas, and allocate 2013 reserves to counties based on the fraction of each play that they contain, following a process similar to that of Maniloff and Mastromonaco (2014), who study the local economic impacts of fracking.[6] A given CZ's oil (gas) reserves are then the sum of these prorated oil (gas) reserves across all counties the CZ contains.[7] To combine oil and gas reserves, we convert these predicted reserves into millions of British Thermal Units (MMBTUs), which capture the amount of heating energy that they contain.[8] Finally, we normalize each CZ's combined predicted oil and gas reserves by its 2000 population to arrive at predicted shale reserves per capita. We test the robustness of our results to changing various aspects of the prediction later in the paper.

Figure 1 shows the geographic distribution of the energy content of predicted shale oil and gas reserves per capita across the 722 CZs in the lower 48 states, with positive-reserve CZs grouped into

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[5] Reserves by play are reported at http://www.eia.gov/naturalgas/crudeoilreserves/pdf/table_2.pdf and http://www.eia.gov/naturalgas/crudeoilreserves/pdf/table_4.pdf. The shapefiles for play boundaries can be found at http://www.eia.gov/pub/oil_gas/natural_gas/analysis/publications/maps/shalegasplay.zip.

[6] Thus, we assign a county *x*% of a shale play's estimated reserves if it accounts for *x*% of its land area. Unlike Maniloff and Mastromonaco (2014), we use more frequent data, CZs rather counties, and only one instrument. We use the estimated reserves rather than the fraction of each CZ with reserves (the instrument used in prior research) to better capture fracking potential. For example, two CZs with very different reserves would look identical under the latter measure. The latter measure also cannot easily accommodate the fact that some labor markets lie atop multiple shale plays.

[7] We allocate counties to CZs (1990 boundaries) using the crosswalk provided by David Dorn: http://www.ddorn.net/data/cw_cty_czone.zip.

[8] We use the production conversion factors reported for 2012 by the EIA (http://www.eia.gov/forecasts/aeo/pdf/appg.pdf): 1,022 BTUs per cubic foot of gas and 5.85 MMBTUs per barrel of oil.

quartiles. There is considerable regional variation in reserves, with clusters of high-reserve areas in the Western (Montana, North Dakota), Southern (Louisiana, Oklahoma, and Texas), and mid-Atlantic (Pennsylvania and West Virginia) regions. These CZs lie atop different shale plays: the Bakken (in Montana and North Dakota), the Barnett, Eagle Ford, Fayetteville, Haynesville-Bossier, and Woodford (in Louisiana, Oklahoma, and Texas), and the Marcellus (in Pennsylvania and West Virginia). However, there is also variation in the magnitude of reserves across CZs that are geographically proximate. This variation allows us to include state-by-year fixed effects in our baseline specification, and thus to identify the effects of fracking from within-state variation across CZs over time. These state-by-year fixed effects helpfully account for the shared effects of other state-level shocks, such as changes in state education policy or other aggregate economic developments. They also mitigate the influence of outliers in the reserve distribution, which are concentrated in particular states (Montana, North Dakota, and Texas).[9]

A second challenge to implementing our empirical strategy comes in dating the widespread introduction of fracking. Figure 2 plots aggregate trends in monthly oil and gas production by well type – vertical (or conventional) versus horizontal or directional (unconventional) – using production data from DrillingInfo.[10] The graph shows that gas production from unconventional drilling began rising slowly from early 2000, but dramatically picked up around the start of 2006. For oil and gas alike, monthly production from unconventional drilling more than quadrupled between early 2006 and early 2013. For the purposes of our analysis, we thus date the introduction of fracking to 2006.[11] To support this choice, we present transparent event-study estimates, which trace out the pattern of response over time and do not privilege 2006 as the first year that fracking was widespread.

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[9] We explore the robustness of our findings to outliers below in Table 4.

[10] To be conservative, we group unknown well types with vertical wells in the conventional category. This graph is identical to Figure 1 in Feyrer, Mansur, and Sacerdote (2014).

[11] We use the same start date for fracking across all CZs, despite the fact that not all shale plays appear to have been first fracked in 2006.

Our baseline difference-in-differences model thus compares the difference in teenage dropout rates from 2005 and earlier to 2006 and later between CZs with higher predicted per-capita shale oil and gas reserves and those with lower predicted per-capita shale reserves in the same state. Two aspects of our research design help us mitigate the influence of price fluctuations on our estimates, as our goal is to isolate the educational response to technological change. First, we use no price information to predict local reserves. Second, aside from the event-study models described above, our empirical strategy assumes that all years from 2006 to 2013 are equally "treated" by fracking, despite the price changes that occurred over that period shown in Figure 3. More importantly for our identification strategy, Figure 3 shows that the difference in average prices between 2000 to 2005 and 2006 to 2013 is opposite-signed for oil and gas: oil prices increase, but gas prices fall. Thus, there is not a strong reason to believe *ex ante* that the effects we estimate, which are based on pooling the predictions of shale oil and gas reserves, are picking up responses to price variation. We further explore the potential role of price in our estimates below.

B. Data

The final challenge in implementing our approach is in acquiring the necessary data to implement it. Ideally, we would have high-frequency (e.g., annual) data at the CZ level on dropout rates spanning the introduction of fracking, separately by gender. We would also have similarly frequent and high-quality data on production (by well type) and employment in the oil and gas industry, to confirm that the CZs we classify as having higher fracking potential (per Figure 1) are indeed the ones where the industry has expanded more rapidly as fracking has spread. The best available data do not meet all of these ideals, but come close.

B.1. Data on Dropout

The 2000 Census and the 2005 through 2013 American Community Survey (ACS) Public Use Microdata Samples (PUMS) (Ruggles et al., 2010) provide individual-level data on gender, age, school enrollment, and educational attainment, and identify local geography down to the Public Use Microdata Area (PUMA) level. PUMAs are not the same as CZs, but can be allocated to CZs based on the division of county population across PUMAs and the mapping between CZs and counties.[12] Thus, we are able to estimate sex-specific dropout rates of teenagers at the CZ level for two pre-fracking years (2000 and 2005) and eight consecutive post-fracking years (2006 through 2013). Unfortunately, no data are available for 2001 through 2004.[13]

We define dropouts as those who have not recently been enrolled in school and do not have a high school degree and limit attention to 17- to 18-year olds in our main analysis.[14] We focus on the population that is of high school age to mitigate bias from selective migration. That is, by including 19-year-olds or older adults, we would be more concerned that what might appear to be an impact of fracking on education decisions is really an impact of fracking on location choices of existing dropouts.[15] As discussed above, we are interested in how fracking has affected the level of dropout in the economy, not how it has affected the geographic distribution of existing dropouts. Fortunately, by using individual-level microdata, we are able to explore the influence of migration of estimates directly. We do so below in Section V.C.

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[12] The crosswalk between 2000 PUMAs and CZs (relevant for the 2000 Census and the 2005-2011 ACS) is available on David Dorn's website: http://www.ddorn.net/data/cw_puma2000_czone.zip. We create an analogous crosswalk between 2010 PUMAs and CZs (relevant for the 2012 and 2013 ACS) using data on the division of 2010 county population across 2010 PUMAs from the Missouri Census Data Center (http://mcdc.missouri.edu) and the county-CZ crosswalk (http://www.ddorn.net/data/cw_cty_czone.zip).

[13] PUMA codes are not reported in the public-use ACS files for these years. As for other potential data sources, although all school districts have been required to report dropout rates as a result of the No Child Left Behind Act, no consistent dropout rate measure exists for the years of our study. Further, the National Center for Education Statistics does collect dropout data for each district, but finalized consolidated data are only available from 2003 to 2010. Additionally, data are often missing or suppressed, especially for more rural districts. State administrative data exist, but definitions and reporting guidelines differ from state to state and across years.

[14] The reporting period for school enrollment is the prior three months in the ACS (which is conducted in all months of the year) and February 1 in the Census (which is conducted on April 1). School years generally last 180 days, starting in September and ending in May. This leaves some potential that we misclassify ACS respondents interviewed in the late summer as dropouts, since we do not observe the interview date in the public-use data. Because our analysis includes state-by-year fixed effects, it will account for any resulting bias provided that it does not vary within states over time.

[15] Consistent with this possibility, Allcott and Keniston (2014) find substantial migration associated with energy booms since the 1960s.

B.2. Data on the Spread of Fracking

While dropout is our ultimate outcome of interest, our analysis begins with a “first stage” demonstrating that the oil and gas industry has expanded more in the post-fracking period in areas with higher fracking potential. We rely on two data sources for this purpose. First, we use the 2000 Census and the 2005 through 2013 ACS PUMS to measure the percent of 25 to 64 year-olds in the civilian labor force working in oil and gas extraction, separately by gender.[16] Second, we use CZ-by-year aggregates of monthly well-level production data licensed to us under a special agreement with DrillingInfo, a private firm. The aggregate data give production (thousands of cubic feet of natural gas or barrels of oil) by type of well (horizontal or directional versus vertical or unknown). Following prior research (Feyrer, Mansur, and Sacerdote, 2014), we classify production from horizontal and directional wells as fracking, or as coming from shale. As with our instrument, we combine oil and gas production using the conversion to MMBTUs. However, we also consider the value of production (converted to real 2012 dollars using the energy CPI) as an outcome. To reduce imprecision in the estimates arising from some extreme outliers in these data, we follow Maniloff and Mastromonaco (2014) in also taking the inverse hyperbolic sine (IHS) of these measures. The IHS effectively allows us to take the natural logarithm of production – and coefficients can be interpreted much as they would be in a log-linear model as production levels grow – but retain observations with zero production in the estimation sample.[17]

C. Descriptive Statistics

Table 1 presents descriptive statistics on baseline (year 2000) values of key variables for all CZs in the lower 48 states (column 1) and CZs in the 30 states with any reserves (column 2), which will be the focus of our analysis. In column 3, we show the relationship between predicted reserves per capita

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[16] We focus on ages 25 and older to capture those individuals who are not actively making education decisions.

[17] The inverse hyperbolic sine of y is $\sinh^{-1}(y)=\ln\left(y+\sqrt{y^2+1}\right)$. Thus, $\sinh^{-1}(0)=0$ and $\partial\sinh^{-1}(y)/\partial x=\left(1/\sqrt{y^2+1}\right)(\partial y/\partial x)$ $\rightarrow(1/y)(\partial y/\partial x)$ as $y\rightarrow\infty$. We obtain substantively similar coefficients with less precision when we use instead a log-linear dummy model (Pakes and Griliches, 1980), which substitutes a zero for the log of production when the value of production itself is zero and includes a dummy to indicate such observations in the regression. We prefer the IHS approach, since it does not require controlling for a potentially endogenous variable.

(Figure 1) and these baseline characteristics from a model including state fixed effects, reflecting our identification which will ultimately rely on within-state variation across CZs. Here, and in all analyses to follow, standard errors are clustered on state, and each CZ is given equal weight, unless noted.[18]

The statistics in Panel A show that CZs in our analysis sample on average have higher employment shares in the oil and gas industry in 2000. They also have higher levels of oil and gas production overall. Within states, however, there is not a statistically significant relationship between predicted per-capita shale oil and gas reserves and either baseline oil and gas employment rates or production. Thus, while CZs with shale reserves tend to be in states with more oil and gas overall, they are not producing significantly more oil and gas than other CZs in the same state in 2000. This finding provides preliminary evidence that our reserve prediction isolates fracking potential, since there were technological constraints on tapping into shale reserves at this time. The average CZ in the analysis sample is predicted to lie atop around 7,000 MMBTUs of shale reserves per capita – nearly enough oil and natural gas to heat 70,000 American homes for a year.[19] The average positive-reserve CZ also has nearly 16,000 MMBTUs of reserves per capita. We will use these figures to scale our estimates.

Aside from these differences in baseline oil and gas penetration, the CZs under study look much like a random draw. As shown in Panel B, the year 2000 dropout rates of 17- to 18-year olds are quite similar in the analysis sample and the lower 48 states overall. Dropout rates for males exceed those for females by around 1.5 percentage points, consistent with findings from Murnane (2013). Murnane (2013) also finds that dropout rates decreased in the 2000s, a trend worth noting moving forward and one that we see in our sample as well.[20] Panel C shows that the CZs under study also look similar to the typical CZ in the country at large in terms of all of other demographic and economic characteristics

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[18] Recall that CZs can span state borders. For the purposes of the fixed effects and the inference, we assign CZs to the states in which the majority of their population resides.

[19] The conversion is made using information from the American Gas Association available at http://www.aga.org/KC/ABOUTNATURALGAS/ADDITIONAL/Pages/HowtoMeasureNaturalGas.aspx.

[20] In the average CZ in our analysis sample, male dropout rates decreased from about 10.2% in 2000 to about 5.4% in 2013. Female dropout rates also decreased from about 8.8% to 4.0%.

measured in 2000, though they are slightly poorer and more racially diverse.[21] As shown in Panel D, they also had similar levels of per-pupil school revenues during the 1999-2000 school year (as reported in the Common Core of Data (CCD)), as well as a similar distribution of revenues across different levels of government. They are also similar in terms of pupil-teacher ratios (as also reported in the CCD) and the CZ-mean income-adjusted test scores constructed by Chetty et al. (2014).

But more importantly for our analysis, column 3 shows that CZs with more shale oil and gas reserves per capita on average look quite similar on baseline observables to those with less within the same state. In particular, they have similar year 2000 teenage dropout rates, racial and ethnic compositions, unemployment rates, poverty rates, rates of single parenting and English-speaking, as well as similar population densities and levels of local and federal per-pupil school revenue. Further, where relationships between observables and per-capita shale reserves are statistically significant, they are small in magnitude. For example, the estimates in column 3 imply that the difference in median annual household income between a positive-reserve CZ at the 25th percentile of the reserve distribution and one at the 75th percentile is only about $281 – only 3.6% of the inter-quartile range in median household income for positive-reserve CZs in the analysis sample. By a similar calculation, the differences in child disability rates, per-pupil state revenue, class size, and test scores across CZs with different shale oil and gas reserves, though statistically significant, are small in magnitude.[22]

These findings support the identifying assumptions of our empirical approach. In order for our strategy to identify the effects of fracking on high school dropout, it must be the case that higher-reserve CZs did not experience other shocks to dropout rates as fracking began to diffuse. If higher-reserve CZs looked systematically different than lower-reserve CZs at the outset, it might be different

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[21] The characteristics summarized in Panel C have been aggregated to the CZ level from county-level tabulations of the 2000 Census, which should be more precisely estimated than comparable variables calculated from the PUMS.

[22] For child disability rates, per-pupil state revenue, class size, and test scores, the predicted differences between a positive-reserve CZ at the 25th percentile of the distribution and its counterpart at the 75th percentile (as a percent of the variable's inter-quartile range) are 0.046 percentage points (2.8%), $42 (3.2%), 0.6 pupils (2.2%), and 0.28 percentile points (2.3%), respectively.

trajectories associated with those characteristics – rather than with fracking potential – that are responsible for changes in dropout rates. Finding that CZs looked similar along many dimensions prior to the spread of fracking thus helps to mitigate concerns about this source of bias. However, because there are some statistically significant differences, we control for interactions between baseline characteristics and time dummies in our preferred specifications.

III. The Spread of Fracking and the Geography of the Oil and Gas Industry

A. Difference-in-Differences Estimates

We begin our analysis by examining how the spread of fracking has affected the geographic distribution of oil and gas employment and production in the United States. We start with a simple difference-in-differences specification:

$$(1) \qquad y_{zst} = \theta\, reserves_z after2005_t + \left(after2005_t \cdot X_{z,pre}\right)' \beta + \lambda_{st} + \delta_z + \varepsilon_{zst},$$

where y_{zst} represents an industry outcome measure in CZ z in state s in year t; reserves_z represents predicted per-capita oil and gas reserves in CZ z (measured in 1000s of MMBTUs and normalized by 2000 population); $after2005_t$ is a dummy variable set to one if t>2005, zero otherwise; and $X_{z,pre}$ is a vector of CZ-level observables measured in the pre-fracking period. Our preferred estimates include in $X_{z,pre}$ all of those variables listed in Table 1, Panel C.[23] λ_{st} then represents a vector of state-by-year fixed effects, which sweep out bias from unobserved factors that are common to all CZs in a state at a given point in time. Likewise, δ_z represents a vector of CZ fixed effects, which account for unobserved determinants of outcomes that are common to the same CZ over time. ε_{zst} represents all remaining unobserved determinants of outcomes.

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[23] We thus exclude interactions with the variables in Panel D. Income-adjusted test scores are not available for all CZs, and are also not pre-determined. We explore the changes school revenues and class size as candidate causal mechanisms for the relationship between fracking and dropout (Table 7), and thus opt to exclude the interactions with baseline levels.

The coefficient of interest in model (1) is that on the first interaction term, θ. We expect this coefficient to be positive for measures of industry penetration: in 2006 and later, relative to 2000 and 2005, places with higher predicted shale oil and gas reserves should have seen greater growth in the oil and gas industry. For least squares regression to identify this parameter, it must be the case that other within-state shocks (aside from fracking) to the outcomes of interest in CZs with higher fracking potential do not coincide with the introduction of fracking.

Table 2, Panel A presents estimates of θ for our measures of the size of the oil and gas industry: the percentage of 25-64 year olds working in the sector, separately by gender (columns 1 and 2); the male-female difference in these percentages (a triple-difference estimate; column 3); and the level and IHS of production, measured both in terms of value (in thousands of real 2012 dollars) and thousands of MMBTUs (columns 4 through 7). Estimates are presented without and with controlling for differential trends by other CZ pre-existing characteristics. As in Table 1, the regressions give each CZ equal weight, and standard errors are clustered on state.

Consider first the estimates in the upper part of the panel, which include state-by-year and CZ fixed effects but exclude the interactions between pre-fracking CZ observables and the post-fracking dummy. These estimates imply that the average CZ in our analysis sample (with 7,000 MMBTUs of reserves; Table 1) experienced a statistically significant 0.05 percentage point (0.0066 x 7) increase in the percent of men employed in oil and gas extraction as a result of fracking. Among those with any reserves, the estimates imply that fracking resulted in almost a 0.11 percentage point (0.0066 x 16) rise. Due to little impact on the employment of females (column 2), the magnitude of the difference-in-differences coefficient on the male-female differential in oil and gas employment is just slightly smaller than that for men alone (column 3).

To compare to existing literature, it is useful to re-express our difference-in-differences estimates for oil and gas employment rates into a prediction of the number of jobs created in the industry due to fracking. Aggregating across the employment effects for men and women and using estimates from the model with additional controls in the lower part of the panel, we arrive at a prediction of 618,000 jobs created – a figure comparable to that reported by Maniloff and Mastromonaco (2014) using a fairly similar empirical approach. Like them, our estimates also imply the largest increases in jobs in Texas (approximately 233,000 jobs) and Pennsylvania (approximately 73,000 jobs) (Appendix Table 1). Unlike them, but consistent with other research (e.g., Feyrer, Mansur, and Sacerdote, 2014), we also see significant effects of the spread of fracking on the construction sector (Appendix Table 2), amounting to around 315,500 new jobs nationwide (Appendix Table 1). Interestingly, however, the effects on total employment – aggregating across all industries – are much more muted (Appendix Tables 1 and 2), suggesting that fracking has shifted the industrial composition of local employment more than it has raised employment in the aggregate.

In the next columns, we confirm that production of oil and natural gas has also risen more quickly in CZs with higher fracking potential as fracking has spread. While estimates for production levels (columns 4 and 6) are quite noisy, working with the IHS of production (columns 5 and 7) improves precision. Here, we predict that the average CZ in the analysis sample experienced a statistically significant 3.9% (0.0056 x 7 x 100%) increase in the value of shale oil and gas extracted per capita and a marginally statistically significant 2.4% increase in production when measured in MMBTUs (0.0034 x 7 x 100%).[24] In general, the estimates are also only slightly reduced in magnitude when we account for differential trends in employment rates by other CZ pre-existing characteristics.

If the run-up in oil prices shown in Figure 3 were driving our estimates, we would expect our empirical approach to uncover an impact on conventional production, which should be responsive to price. The coefficient of interest for the IHS of value of conventional production, shown in column 8, is negative, zero up to three decimal places, and not statistically significant. In addition to helping rule out

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[24] The average positive reserve county experienced a 9.0% increase in value, which contributes significantly to the 30% increase in oil and gas production – weighting by the same value measure – between 2000 and 2013.

price fluctuations as a causal mechanism, this result provides further evidence that our shale reserve prediction captures fracking potential, rather than potential for oil and gas production more generally.

B. Event-Study Estimates

As a further test of whether our reserve measure elicits the true effects of fracking, rather a response to price fluctuations or to unobservables, we turn to the "event-study" model:

$$(2) \qquad y_{zst} = \sum_{\tau \neq 2005} \theta_\tau \, reserves_z yr_t^\tau + \sum_{\tau \neq 2005} \left(yr_t^\tau \cdot X_{z,pre} \right)' \beta_\tau + \lambda_{st} + \delta_z + \varepsilon_{zst} \, ,$$

where yr_t^τ represents a dummy that is set to one when t=τ, zero otherwise, and all other terms remain as previously defined. The interaction with a dummy for the year 2005 – what we consider to be the immediate pre-fracking year – is omitted so that the model is identified. Thus, we normalize θ_{2005} – the gradient of outcomes in per-capita reserves as of 2005 – to zero. As a result, θ_τ represents the difference in the value of that gradient between τ and 2005.

Relative to the simple difference-in-differences specification in (1), model (2) thus allows for an "impact" of fracking before widespread diffusion of the technology (θ_{2000}). Evidence of such an impact would suggest that higher-reserve CZs have other, unobserved characteristics that have made them amenable to industry expansion. Such characteristics would include endowments of oil and gas that can be reached through conventional technologies. If shale and other reserves were positively correlated, for instance, we might expect higher shale CZs to experience systematically higher growth in oil and gas employment prior to due to the introduction in fracking, reflecting the increases in oil and gas prices between 2000 and 2005 (Figure 3). Thus, if estimates from model (1) isolate the impact of fracking, it should be the case that θ_{2000}=0, or that the relationship between per-capita shale oil and gas reserves and employment remained unchanged between 2000 and 2005. Model (2) has the additional benefit of allowing us to trace out the impacts of fracking in the post-fracking period.

Figure 4 plots estimates of the θ_τ for four key outcomes in Table 2 – the percent of men employed in oil and gas and the male-female difference in these percentages (Panel A) and the IHS of the value and energy content of shale oil and gas production (Panel B); the capped vertical lines around the estimates represent 90% confidence intervals. For employment and the energy content of production, there was no significant change, statistically or economically, in the relationships with per-capita shale reserves between 2000 and 2005. In addition to providing further evidence that our empirical approach is isolating the effects of fracking, these findings support our working assumption that widespread fracking began in 2006.

With the exception of the small and statistically insignificant employment estimates for 2010, the pattern of coefficient estimates in the post-fracking period is also one of increasing effects over time, consistent with the production trends shown in Figure 2. We summarize the event-study estimates by estimating a version of model (2) that imposes several restrictions that roughly match the patterns in the data: no difference in the relationship between per-capita reserves and industry penetration in 2000 and 2005 (θ_{2000}=0) and constant effects within three groups of consecutive years in the post-fracking period: 2006-08 ($\theta_{2006}= \theta_{2007}= \theta_{2008}$), 2009-11 ($\theta_{2009}= \theta_{2010}= \theta_{2011}$), and 2012-13 ($\theta_{2012}= \theta_{2013}$). Estimates of this restricted event-study model, shown in Panel B of Table 2, show that the impacts of fracking on male employment in oil and gas extraction nearly doubled over the post-fracking period (column 1), the male-female employment differential in the industry grew by nearly 50% (column 3), and effects on production grew by a factor of five or more (columns 5 and 7). Though statistically significant, the impacts on conventional production are an order of magnitude smaller and do not exhibit the same pattern of increasing effects (column 8). Moreover, conventional production appears to shrink over time in the post-fracking period, suggesting that, if anything, sectoral price shocks may be biasing our estimates downward.

The pattern of increasing effects on employment and shale production suggests that fracking did not begin everywhere at the same time. With this in mind, we exploit this pattern of increasing effects as an additional source of identifying variation in the dropout models presented in the next section.

IV. Fracking and High School Dropout

The findings presented above make a strong case that our measure of a labor market's fracking potential carries a significant signal, as high-reserve labor markets experienced greater expansion of the oil and gas industry in 2006 and later, but not before. The event-study estimates also serve to reinforce our choice of 2006 as the start of the "post-fracking" period. If fracking has had an impact on high school dropout, trends in dropout should follow much the same pattern: little change in the relationship between per-capita reserves and dropout through 2005, but with an abrupt change between 2005 and 2006 that is sustained – and possibly grows – through the end of the period of study. In this section, we investigate whether this has been the case, quantify the magnitude of the effects, and explore the robustness of the estimates to various changes in specification.

A. Baseline Estimates

The event-study estimates will be the starting point for our dropout analysis. These estimates, based on model (2) and presented in Figure 5, correspond to the preferred specification, which includes the full set of interactions between year 2000 CZ characteristics and year effects. Recall that the baseline specification also includes CZ fixed effects and state-by-year fixed effects. These fixed effects account for unobservables that may also affect the outcomes of interest, such as fixed school and area characteristics related to facility and teacher quality (in the case of the CZ fixed effects) as well as common shocks from changes in state educational policies (in the case of the state-by-year fixed effects). As in Figure 4, the capped vertical lines represent 90% confidence intervals, and inference is robust to heteroskedasticity in the error terms and error correlation within states over time.

Figure 5 suggests that fracking has increased male teenage (ages 17 to 18) high school dropout rates (represented by the triangles), as well as the male-female gap in teenage high school dropout rates (represented by the diamonds). For both measures, the gradient of dropout in per-capita shale reserves actually declined between 2000 and 2005, implying that teenage male dropout rates were declining faster in CZs with higher fracking potential over the pre-fracking period. This trend reversed sharply between 2005 and 2006. As was the case with employment, the gains relative to 2005 are sustained through 2013, though not all coefficient estimates are statistically different from zero. There is also less evidence of monotonically increasing effects here than there was for employment or for oil and gas production.

The first three columns of Table 3 present the corresponding estimates from the more restrictive specifications – difference-in-differences (Panel A) and the restricted event-study model (Panel B).[25] The difference-in-differences estimates (Panel A) are quite similar across the specifications without and with additional controls, predicting that in the average CZ, the teenage male dropout rate is now about 0.14 percentage points higher (≈0.0196 x 7) and male-female teenage dropout rate differential about 0.16 percentage points higher (≈0.0228 x 7) due to fracking. To put these figures in perspective, recall that both male and female teenage dropout rates declined over the sample period – by 4.8 percentage points for each group (from 10.2% to 5.4% for males and from 8.8% to 4.0% for females). The male-female *gap* in dropout rates was thus unchanged (at 1.4%) over the sample period. Our estimates therefore imply that, in the absence of fracking, the male-female gap would have actually narrowed between 2000 and 2013, by about 11%.

While using the average is helpful for thinking about the aggregate impact of fracking, scaling the dropout estimates by the corresponding estimates for the size of the oil and gas industry in Table 2

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[25] If the counterfactual is truly one where male dropout rates in higher-reserve CZs would have continued their convergence to female dropout rates during the post-fracking period, both models underestimate the impacts of fracking on dropout rates.

gives us a better sense of the variation in effect sizes across CZs. For example, focusing on our preferred difference-in-differences specification (with the additional controls), our estimates imply that each additional percentage point increase in a CZ's adult male oil and gas industry employment rate from fracking has on average generated about a 3 percentage point increase in its male teen dropout rate ($0.0189/0.0062 \approx 3$). Put differently, a fracking-induced increase in the male oil and gas employment rate of 0.1 percentage points – roughly the gain experienced in the average CZ with any reserves – has led to a 0.3 percentage point increase in the dropout rate of male teens. We formalize this calculation in columns 4 and 6 of the first panel of Table 3 by instrumenting for the male oil and gas employment rate and the male-female gap in oil and gas employment rates with $reserves_z \times after2005_t$.[26] The TSLS estimate for males (column 4) is not much affected by the additional controls, though it is slightly more precise. The TSLS estimates for the male-female difference in teenage dropout rates (column 6) are also larger than those for males alone.

This normalization of the difference-in-differences impact on the teenage dropout rate is helpful for two other reasons. First, TSLS provides a useful way to compare the implications of the difference-in-differences and restricted event-study specifications. That is, instead of instrumenting for CZ oil and gas employment rates with $reserves_z \times after2005_t$, as we do in Panel A, we can instrument with the interactions between per-capita reserves and each of the three time dummies in the restricted event-study. Ideally, this over-identified TSLS model would generate similar estimates as the just-identified model in Panel A. The TSLS estimates in Panel B are pretty similar, though noisier.

Second, TSLS estimates can be usefully compared to their OLS counterparts – in this case, the partial correlation between adult oil and gas employment rates and teen dropout rates. The OLS

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[26] In estimating this model, we thus assume that any differential changes in dropout rates between higher- and lower-reserve CZs over time are working through changes in employment rates, rather than other factors. Doubtless there are other industry metrics not perfectly correlated with employment that we could use to scale the estimates. We are therefore interpreting these estimates more as indirect least squares estimates of the impact of oil and gas employment, rather than instrumental variables estimates in the strictest sense.

estimates would be biased if oil and gas employment rates are correlated with unobserved determinants of high school dropout – for instance, if dropout rates in CZs that have ultimately "fracked more" would have been declining over time less quickly for other unobserved reasons. However, the OLS estimates could be unbiased estimates of a different parameter: the educational response to temporary, but exogenous fluctuations in oil and gas employment rates, e.g., due to price shocks. By contrast, the TSLS estimates identify the educational response to more permanent, structural changes in oil and gas employment rates due to the spread of fracking – a local average treatment effect (LATE).

We present these OLS estimates in columns 5 and 7 of Table 3. Regardless of inclusion of the additional controls, the OLS estimates are quite similar to one another – positive, but much smaller than TSLS, and not statistically different from zero.[27] Though we may have expected endogeneity to bias the estimates upward because of the unobservable characteristics of communities that have chosen to frack, the finding that the TSLS estimates exceed OLS are instead strongly suggestive of the second interpretation – that school enrollment decisions are less likely to be influenced by temporary economic shocks than more permanent changes in the role of oil and gas in the local economy.[28]

B. Specification Checks

Yet another advantage of TSLS is that it provides a useful benchmark for comparing across specifications. With this in mind, in Table 4, we use TSLS as a basis of comparing the results across a battery of specification checks. In Panel A, we repeat the estimates from our preferred specification, which includes the additional controls, for the purposes of comparison. We keep the additional controls of the preferred model throughout the table. We present the reduced-form difference-in-differences estimates and the TSLS estimates for both males and the male-female difference.[29]

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[27] The finding that TSLS estimates exceed OLS is found in studies of the local employment effects of fracking as well (Brown, 2014; Maniloff and Mastromonaco, 2014; and Weber, 2012, 2014).

[28] TSLS might also exceed OLS due to attenuation bias from measurement error in oil and gas employment rates.

[29] We omit the OLS estimates to conserve on space. Throughout the table, they are positive, but much smaller than TSLS, and generally not statistically significant (results available on request).

In Panel B, we explore the robustness of our conclusions to how we predict shale reserves. We redo the prediction in four different ways. The first two approaches weight oil and gas reserves by price rather than energy content in the aggregate reserve prediction under extreme assumptions. First, we use price forecasts that were quite different from what truly occurred (based on the 2003 EIA *Annual Energy Outlook*'s "Rapid Technological Progress" price predictions for 2010), and second, we use the most recently available data on actual prices (from 2012). Though the second approach delivers slightly larger point estimates for males and slightly smaller ones for the male-female difference, they are statistically indistinguishable from those at baseline. Our third change to the prediction – using the earliest available shale play reserve estimates (from 2011) – also generates fairly comparable estimates to baseline that are more precise. Our final approach is to weight oil and gas reserves by their respective least squares coefficients when their industry employment impacts are estimated separately in equation (1).[30] This specification generates estimates that are fairly similar to those at baseline.

For each of these alternative instruments, it remains the case that some CZs have much higher reserves than the rest, raising the concern that the estimates are influenced by outliers. We address this concern in several ways. First, in the remaining part of Panel B, we re-estimate our models using different functional forms of our original reserve prediction – first, by using the IHS of our original reserve measure, and second, by creating a dummy for CZs with reserves in the top quartile of those with reserves (=1 if a CZ has reserves at or above 7,820 MMBTUs per capita). The resulting estimates are fairly similar to what we found at baseline, though they are generally less precise, reflecting weaker first-stage relationships with oil and gas employment rates.[31]

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[30] More specifically, we regress the total employment rate in the oil and gas industry on *gas_reserves*, *oil_reserves*, CZ fixed effects, state-by-year fixed effects, and the vector of additional controls, where *gas_reserves* represents per-capita gas reserves (in millions of cubic feet) and *oil_reserves* represents per-capita oil reserves (in thousands of barrels). Letting $\hat{\theta}_{gas}$ represent the coefficient on *gas_reserves* and $\hat{\theta}_{oil}$ represent the coefficient on *oil_reserves* from this regression, our employment-based reserve measure for CZ *z* is then $\hat{\theta}_{gas} gas\_reserves_z + \hat{\theta}_{oil} oil\_reserves_z$.

[31] The stability of the TSLS coefficients across these two specifications helps to validate our baseline approach of assuming that the effects of reserves are linear.

Our second approach to addressing outliers is to re-estimate our models on a restricted subsample of the data. In Panel C, we show how estimates from our preferred specification change when we exclude from the sample the three states that contain the highest-reserve CZs – Montana, North Dakota, and Texas. The reduced-form estimates get much larger in magnitude – and the one for males remains marginally significant – but only the over-identified TSLS estimates are statistically significant. This finding suggests that having Montana, North Dakota, and Texas in the estimation sample is helpful for obtaining precise results. However, though a bit smaller, the TSLS estimates are in the same ballpark of what we found at baseline.[32]

Our final approach is to weight CZs by population, as the highest per-capita reserve CZs tend to be small. Like the estimates in Panel C, the TSLS estimates weighted by year 2000 CZ population, presented in Panel D, are universally smaller than their unweighted counterparts presented in Panel A. However, they remain statistically significant. An alternative interpretation of these findings is that larger local labor markets have responded differently to fracking than smaller ones, and that our baseline estimates thus misrepresent how fracking has affected dropout in the population at large.[33] Viewed in this light, our results suggest that dropout rates in more populous CZs have responded less to fracking, possibly because teenagers in urban areas are less aware of nearby rural job opportunities than rural teenagers would be.

We also consider several different outcome variables to assess the sensitivity of our estimates to the choice of age group (Panel E) and to migration (Panel F). As shown in Panel E, we find no evidence of an effect of fracking on slightly younger individuals, ages 15 and 16.[34] One explanation for this null

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[32] Montana, North Dakota, and Texas are also the three states with the most shale oil per capita. The similarity of the original TSLS estimates to the TSLS estimates when these states are dropped therefore suggests that the impacts of oil fracking and of natural gas fracking on dropout have been similar.

[33] As Haider, Solon, and Wooldridge (forthcoming) point out, however, weighting by population does not truly identify the population average partial effect.

[34] The mean dropout rate of 15-16 year olds in the year 2000 was 3.031% – 0.425 percentage points above the female rate in the same age group.

finding is that compulsory schooling laws restrict dropout rates at younger ages. We explore this possibility by limiting the sample of 17-18 year olds to the 12 states where kids are legally permitted to leave school at age 16 or earlier.[35] If compulsory schooling laws constrained dropout choices, we would expect the dropout effects for 17-18 year olds to be larger here than in the sample overall. If anything, the estimates are smaller, suggesting that our main findings hold regardless of compulsory schooling regulations.

Finally, as described above, one benefit of using microdata is that we can directly examine the influence of migration on our estimates. We do so in Panel F, presenting the impact of fracking on the chance of being *both* a dropout *and* a recent cross-PUMA migrant, as well as the on the chance of being *both* a dropout *and not* a recent migrant. The sum of coefficients across these two outcomes is equal to the total baseline dropout effect reported in Panel A, allowing us to obtain an estimate of the fraction of the overall dropout effect possibly explained by migration. The reduced-form difference-in-differences estimate for the male-female difference in the probability of being both a dropout and a recent migrant is significant at 10% level, suggesting that migration does contribute something to the estimated overall effect of fracking on dropout. However, this contribution is small: When the coefficient is compared to the corresponding one for dropout rates overall, migration can account for only a bit over a quarter of the dropout effect we estimate (0.0068/0.0238≈0.29). Most of the effects we estimate are therefore driven by educational choices rather than residential ones.

V. Why Would Fracking Affect High School Dropout? Evidence on Potential Causal Mechanisms

The evidence presented thus far suggests that the spread of oil and gas fracking has transformed some local economies in the United States over the past decade. CZs with strong fracking potential have seen greater growth in the oil and gas industry and in construction, consistent with

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[35] These states are Georgia, Indiana, Kentucky, Maryland, Michigan, Missouri, Montana, New Jersey, New York, North Dakota, West Virginia, and Wyoming. We obtained compulsory schooling ages from NCES at: https://nces.ed.gov/programs/statereform/tab5_1.asp.

recent research on the local economic impacts of fracking. However, this structural transformation has had the additional consequence of increasing the chances that teenagers, namely male teens, decide to drop out of high school. This section presents evidence in favor of our preferred explanation – that fracking has generated increases in the relative demand for less-educated labor – and attempts to rule out other explanations.

A. Human Capital Theory: Increases in Relative Demand for Dropouts

As discussed above, the chief candidate for a causal mechanism linking fracking to high school dropout derives from human capital theory (Becker, 1964): rational economic agents will choose to drop out of high school, rather than continue to attain a degree, if the net present discounted value (PDV) of dropout exceeds that of high school completion. The net PDV of dropout is traditionally modeled as the PDV of lifetime earnings as a high school dropout. The net PDV of high school completion is the PDV of lifetime earnings with a high school degree, less the costs – both "psychic" costs and the opportunity cost of foregone income – of remaining in school. Thus, fracking can make dropout more attractive through two channels: by increasing the opportunity cost of remaining enrolled in high school today (it may be possible to obtain a job in the oil fields right now), and by increasing expectations of a dropout's lifetime earnings. If dropouts are impatient or present-biased (Cadena and Keys, forthcoming; Lavecchia, Lu, and Oreopoulos, 2014), the job opportunities from fracking may seem even more enticing.

Both of these channels rely on fracking being a low-skill biased technology, or a technology whose diffusion raises the relative demand for least skilled workers in the labor market. As preliminary evidence on this point, Table 5 gives the educational distribution of adult employment in the post fracking period (2006-2013), overall and separately for the two industries most affected by the spread of fracking – oil and gas extraction and construction. Educational attainment is divided into four mutually-exclusive (and exhaustive) categories – high school dropout, high school graduate (only), some college (only), and college graduate. While only 5.8% of the workforce consists of high school dropouts,

dropouts are nearly twice as common among those employed in the oil and gas industry (9.3%) and nearly three times as common among those employed in construction (13.3%). Both industries are also heavily male (84% for oil and gas and 90% for construction, compared to 52.6% of employed workers overall). Employee characteristics for five occupations that encompass more than half (52.4%) of employment in the oil and gas industry further show how heavily the industry relies on males and on dropouts. For example, nearly 20% of employment in oil and gas is in extractive occupations (i.e., drilling) and 18.3% of these workers are high school dropouts.

Table 6 provides further evidence on this point, presenting estimates of the impact of fracking on the CZ mean natural log of hourly wages for 25- to 64-year-olds in the civilian labor force, separately by gender and the four categories of educational attainment introduced above.[36] Panel A presents the differences-in-differences estimates, whereas Panel B presents the restricted event study results. Figure 6 presents the full event-study (model (2)) estimates; as in the earlier figures, we plot 90% confidence intervals around the estimates. All models include the interactions between pre-existing CZ characteristics and year dummies.

If the relative demand for dropouts has risen, it should be the case that the spread of fracking has increased wages more in higher-reserve CZs, and more so among high school dropouts than individuals with a high school degree or more. Considering the difference-in-differences estimates for men, we see a pattern of declining wage effects as education increases – and significant differences in effect sizes across the four education categories (column 5) – but we cannot rule out equal wage effects for high school dropouts and high school graduates (p=0.932 in Panel A). The wages of women in higher-fracking CZs also appear to respond only weakly to fracking and do so fairly evenly across education

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[36] Following Card (2001) and Lewis (2011), who explore the relative wage impacts of immigration on local labor markets (metropolitan areas), we windsorize individual hourly wages at $2 and $200 (in real 1999 dollars), and adjust CZ-specific means for a quartic in age, years of education (with separate effects for cohorts born before versus after 1950), and dummies for black race and Hispanic ethnicity.

levels. Still, these small wage effects could reflect differences in unobserved local labor demand shocks between higher- and lower-reserve CZs.

With this possibility in mind, we believe that the effect of fracking on the male-female wage gap – and on the male-female gap in high school dropout – may produce less biased estimates. Using the wage gap as the outcome of interest (bottom of the panel), we find stronger evidence that the wage impacts of fracking have been concentrated among the least educated workers – paralleling our earlier finding of larger effects for the male-female dropout gap than for males alone. However, we still cannot rule out that increases in demand for dropouts have had the same wage effects as increases in demand for high school graduates (p=0.413).

The event-study estimates in Figure 6 – where all vertical axes have the same range – provide more compelling visual evidence that fracking has increased in the relative wages of dropouts. The male-female wage gap among dropouts in higher-reserve CZs experienced a marginally significant decline between 2000 and 2005, but increased sharply between 2005 and 2006. With the exception of the coefficient for the year 2009 – when both oil and gas prices were exceptionally low (at $61.95 per barrel and $3.67 per thousand cubic feet, respectively) – the male-female wage gap among dropouts remained at a similar if not higher level through 2011, implying much larger wage effects than the difference-in-differences estimates in Table 6. Impacts on the male-female wage gap among higher-education workers over these same years (Panels B, C, and D of Figure 6) are much smaller in magnitude and generally not statistically significant. As shown in Panel A of the figure, the relationship between per-capita shale reserves and the male-female dropout wage gap reverted (relative to the state trend) to its 2005 value in 2012 and even shrunk between 2012 and 2013.

The corresponding restricted event-study estimates, given in Panel B of Table 6, are significantly greater in magnitude and significance for the earlier post-fracking years than the difference-in-differences results in Panel A. From 2006 to 2008, for example, the effect of fracking was 8 times larger for dropouts than other populations, and the difference in effects for high school dropouts and graduates is significant at the 5% level (*p*=0.05). This trend continued through 2011 but was reversed in 2012 and 2013, as Figure 6 implied.

It is possible that, by 2012, the dropout premium had begun to be eroded by increases in the relative supply of dropout labor. To explore this explanation, we estimated both difference-in-differences and restricted event-study models for the dropout share in the adult population, ages 25 to 64. Given such a wide age range and our focus on an 8-year time horizon post fracking, these estimates should be little affected by earlier increases in dropout rates of teenagers; instead, they should reflect migration of dropouts into the CZ. We found no evidence of increases in the dropout share of the adult population: while generally positive, all of the estimates were small and statistically insignificant.[37]

This finding suggests that the decline in the dropout wage premium by the end of our sample period has another explanation. One possibility is that the demand for dropout labor may have fallen due to the decline in natural gas prices by 2012 (Figure 3), but oil prices remained high during these years. Another possible explanation is that the increase in relative demand for male dropouts evident for 2006 through 2011 was truly temporary, or that this most recent decline is temporary itself. Regardless, increases in the relative demand for dropouts could still rationalize impacts on high school dropout in 2012 and 2013, and possibly even further into the future, if individuals base their educational choices on information from the recent past.

We can use the estimates in Table 6 to do a back-of-the-envelope calculation of the elasticity of high school completion with regard to the high school premium. Consider the impacts of fracking on wages between 2006 and 2008: our estimates imply that fracking reduced the high school graduate-dropout wage premium by 1.12 (0.07*16) percentage points in the average CZ with any shale reserves,

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[37] By contrast, Weber (2014) finds that fracking has reduced local dropout rates among adults and increased their likelihood of having a high school degree. However, our estimates are not strictly comparable, since Weber (2014) focuses only on four states and natural gas fracking and uses a different empirical approach.

narrowing the pre-existing (year 2000) high school graduate-dropout wage gap (of 15.7%) by 7.13%. In turn, male teenage dropout rates in the average CZ with any shale reserves increased by 0.3424 percentage points (using the corresponding event-study estimates from the column 3 of Table 3, Panel B) – 3.36% of the year 2000 mean male teenage dropout rate. Together, these calculations imply an elasticity of high school completion with respect to the high school premium of 0.47. This elasticity is below the lower bound of the elasticity range of 0.54 to 0.72 estimated by Black, McKinnish, and Sanders (2005).

B. School Resources

Reductions in school resources associated with fracking might also have led to a more rapid rise in dropout rates in higher-reserve CZs. Disamenities from fracking – environmental or otherwise – might have reduced property values by more in higher-reserve CZs, possibly shrinking the local tax base to support public education.[38] In the absence of offsetting increases in local property tax rates, such declines in property values would reduce local property tax revenues, possibly resulting in reductions in school spending. Reductions in school spending could, in turn, make it more difficult to keep marginal students from dropping out. We wouldn't necessarily expect any such effects to differ across males and females, but it is worthwhile to try to rule out any effect, regardless of gender.

To this end, Table 7 presents estimates of the impacts of fracking on the natural log of per-pupil school revenues by source (local, state, or federal government) as well as the natural log of total spending and the natural log of total revenue. We estimate our preferred specification using data from the CCD for the 1999-2000 and 2004-05 to 2012-13 school years, so as to align with the estimates

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[38] There is some evidence that fracking has reduced property values. Muehlenbachs, Spiller, and Timmins (2014) find large negative impacts on nearby groundwater-dependent house prices, though at a broader geographic scale, they find positive impacts that diminish over time. Gopalakrishnan and Klaiber (2013) also find negative impacts on property values. Relatedly, Hill (2013) finds that fracking has increased infant mortality.

presented thus far.[39] All of the spending and revenue estimates are small in magnitude and none are statistically significant. The corresponding event-study estimates, shown in Figure 7, Panel A, are if anything consistent with the positive effects of fracking on local income found in recent research: by the end of the sample period, per-pupil local revenues were increasing somewhat faster in higher-reserve CZs, and both per-pupil state and federal revenues (distributed progressively on the basis of wealth and income, respectively) were falling. On net, these revenue changes led to a reduction in per-capita school spending by 2012 to 2013, but neither this estimate nor any of the revenue estimates in the restricted event-study specifications (Table 7, Panel C) are statistically significant. In any case, the fact that possible changes in school funding from fracking did not emerge until 2012 or 2013 – well after the impacts on high school dropout began – suggests that they are not driving our dropout estimates.

Nevertheless, it is possible that, faced with rapidly growing enrollments as a result of fracking, public schools in highly affected labor markets may not have been able to hire teachers so quickly, putting upward pressure on pupil-teacher ratios. We present some evidence that this indeed happened in the last column of Table 7. But the effects are small. To see this, suppose that the effects on dropout were working entirely through increases in class size. Our estimates then imply that each additional student per teacher would on average increase the male teenage dropout rate by 4.725 percentage points. Such an effect size is well outside the range of the best available estimates of class size impacts.[40] Moreover, the effects of fracking on class size again emerged gradually – not immediately as was the

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[39] It is important to present revenues from each level of government, because state and federal grants have the capacity to offset reductions in local revenue. State governments often redistribute local tax revenue across school districts in an effort to narrow spending differences between more and less wealthy districts (Hoxby, 2001). Relatedly, the federal government's primary grants program (Title I) is distributed on the basis of child poverty. If fracking has increased child poverty rates, any educational impacts for local students may have eventually been buffered by Title I funds.

[40] This evidence is from the Tennessee STAR experiment. Unfortunately, due to data limitations, there are no credible estimates from this experiment of the impact of class size on high school dropout. However, Dynarski, Hyman, and Schanzenbach (2013) find that being randomly assigned to attend a small class in kindergarten (with 13 to 17 students) instead of a regular-sized class (with 22 to 25 students) – so on average having 5 to 12 fewer students in the same class – increased the probability of attending college by 2.7 percentage points.

case with the wage and dropout effects. There is also reason to believe that any increases in class size would have increased girls' likelihood of dropout as well, as noted above, but we find no such effect.[41]

C. Changes in the Composition of the Population

The dropout effects we estimate may also simply reflect changes in the composition of the population. For example, if new migrants to higher-reserve CZs were negatively selected, their children might have had higher propensities to drop out of school. In Table 8 Panel A, we present difference-in-differences estimates of the impact of fracking for the limited demographic information that we have on the age group of interest – race and ethnicity. In Panel B, we present estimates for several observable measures of family background for younger children, ages 11 to 14.[42] We work with our preferred specification, with the full set of controls.

The estimates provide little evidence that fracking changed the composition of the student population. For example, effects on the racial and ethnic composition of 17- and 18-year olds are similar in magnitude across gender and not statistically significant. Likewise, there is no consistent pattern of effects on several family background characteristics of 11- to 14-year-olds. For instance, the relationship between fracking and maternal dropout rates is positive and statistically significant for 11- to 14-year-old girls, though the effects for girls and boys are not significantly different. The coefficient signs are also consistent with a relative decrease in the dropout rates of males – an effect working in the opposite direction of what we find. On the other hand, the relationship between fracking and paternal employment in oil and gas is positive, statistically different from zero, and larger in magnitude for boys than girls. However, the difference between the male and female coefficients is not statistically

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[41] We would like to explore how fracking has affected the output of public schools, particularly as measured by test scores. However, there is no source of data on test scores that is geographically disaggregated enough and spans enough years to apply our empirical approach. The National Assessment of Educational Progress (NAEP) spans the period of interest, but reports data only for states and selected large school districts. Since passage of the No Child Left Behind Act, states have been required to test children in grades 3 through 8 in math and science and publicly report the test results since 2002-03. Unfortunately, the tests differ across states.

[42] Unfortunately, the Census and ACS only provide detailed family background information about individuals who still reside with their parents – an increasingly selected group over the age range of dropouts that we study.

significant.[43] On net, there appears to be no effect of fracking on household income of 11- to 14-year-olds. The corresponding event-study estimates, shown in Panels B through D of Figure 7, also yield little evidence of a relationship between fracking and family background.

VI. Conclusion

Over the past decade, the advent of horizontal drilling and hydraulic fracturing has (quite literally) fueled a structural transformation of local economies across diverse swaths of the United States – from Pennsylvania to North Dakota – increasing local incomes and helping to set the U.S. on a path toward energy independence. By using high-frequency outcomes data and information on shale reserves to take advantage of variation in the timing and location of fracking, we have produced new evidence of this structural transformation. We have also demonstrated that it has had the additional consequence of generating higher high school dropout rates among teenagers, particularly the young males whose employment prospects it has more greatly affected. We find the most empirical support for the explanation that fracking represents low-skill biased technological change. In particular, our identification strategy also uncovers evidence that fracking has increased the relative wages of male dropouts, relative to both female dropouts and males with higher levels of education.

Our findings have several important implications. First, they point to another potential negative side effect of fracking aside from the potential environmental consequences. The decision to drop out of school could well be a rational one in the face of increases in the relative wages of dropouts. Nevertheless, some students could be making mistakes by perhaps putting more weight on the present than they should be (Cadena and Keys, forthcoming; Levecchia, Lu, and Oreopoulos, 2014). Furthermore, by the end our sample period – when the price of oil remained (and hence labor demand should have remained) high – the labor demand shocks from fracking no longer appear to favor dropouts, pointing to the possibility that that fracking-induced relative wage boosts for dropouts were

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[43] A further caveat on this finding is that there is a significant difference between boys and girls in the effect of fracking on the likelihood that 11- to 14-year-olds have a father present in the household.

only temporary. Either way, fracking may be generating sub-optimally low levels of education among some individuals who would already be near the bottom of the skill distribution, with possible implications for future productivity and the social safety net.[44]

Second, and more broadly, we present new evidence on the relationship between technology and educational attainment. With fracking, we appear to have a technology that complements low-skilled labor and one whose use is geographically constrained in a way that allows for credible identification of its impacts on educational attainment. We find evidence of reductions in educational attainment at the bottom of the skill distribution despite broader economic trends. However, if there are positive income effects of fracking on education, we are underestimating the structural parameter of interest – the educational response to technological change. The effects of technological change on education may also be heterogeneous across the skill distribution. Thus, although our results support the notion that elasticity of education with respect to the skill premium today is low, future understanding of this relationship may benefit from exploration of other episodes of industry-specific technological change, particularly ones favoring the highly skilled.

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[44] Although those students who drop out may re-enroll later in their lives (Emery, Ferrer, and Green (2012) do find some evidence for such re-enrollment in British Columbia), we cannot investigate this possibility with Census data.

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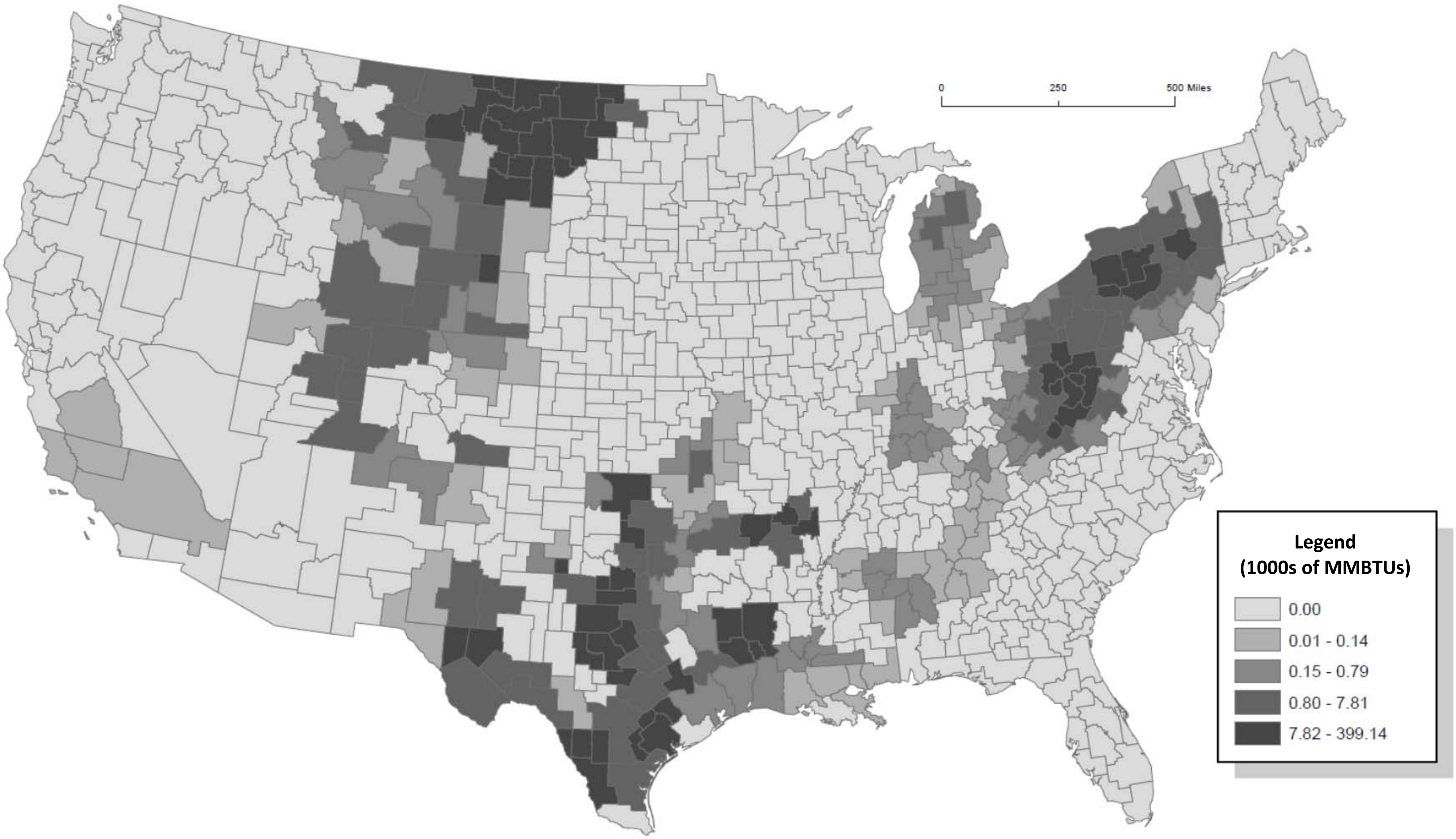
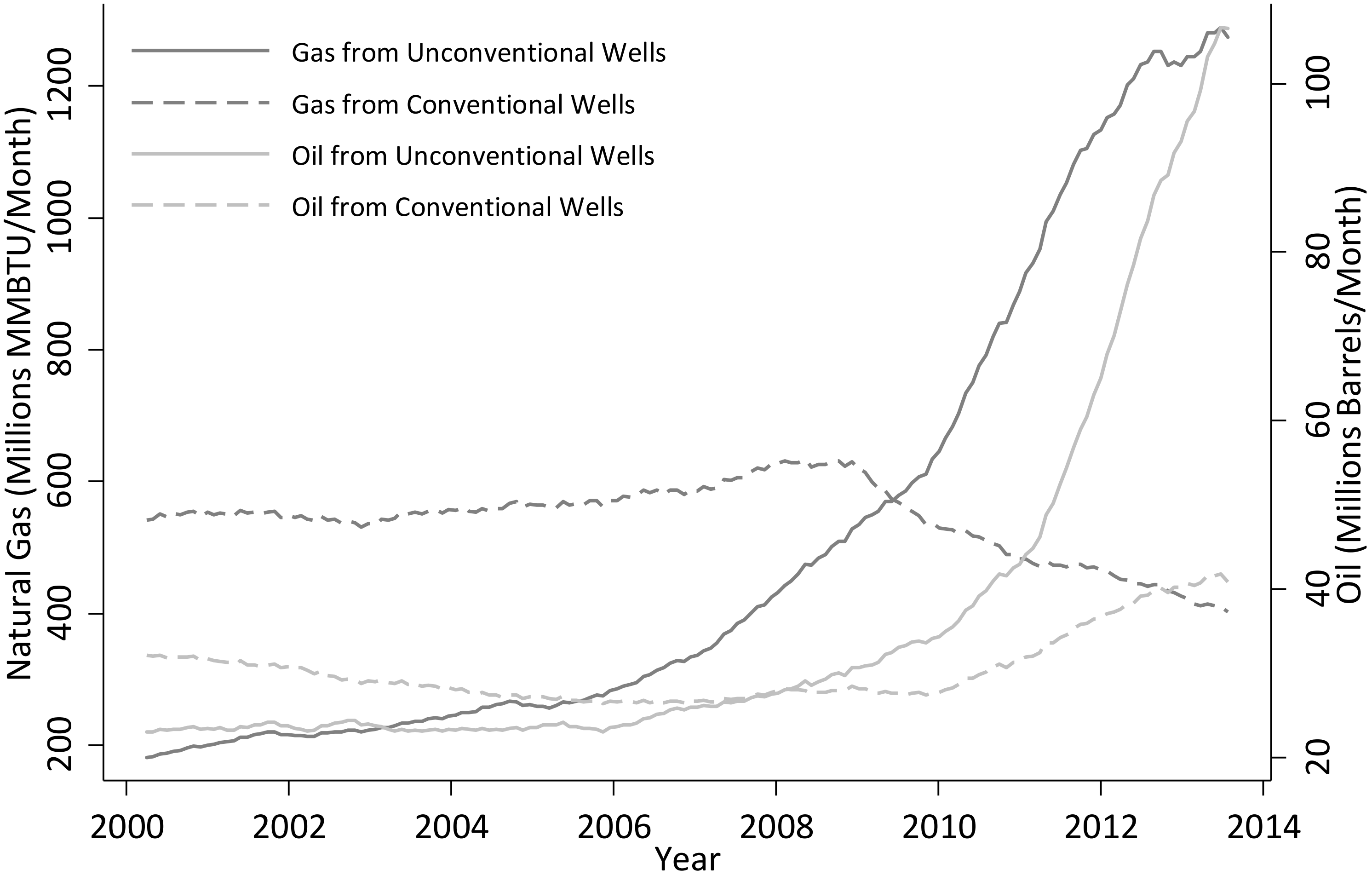
Figure 1 -
Predicted Per-Capita Shale Oil and Gas Reserves by Commuting Zone
(Thousands of MMBTUs in 2013 per Person)



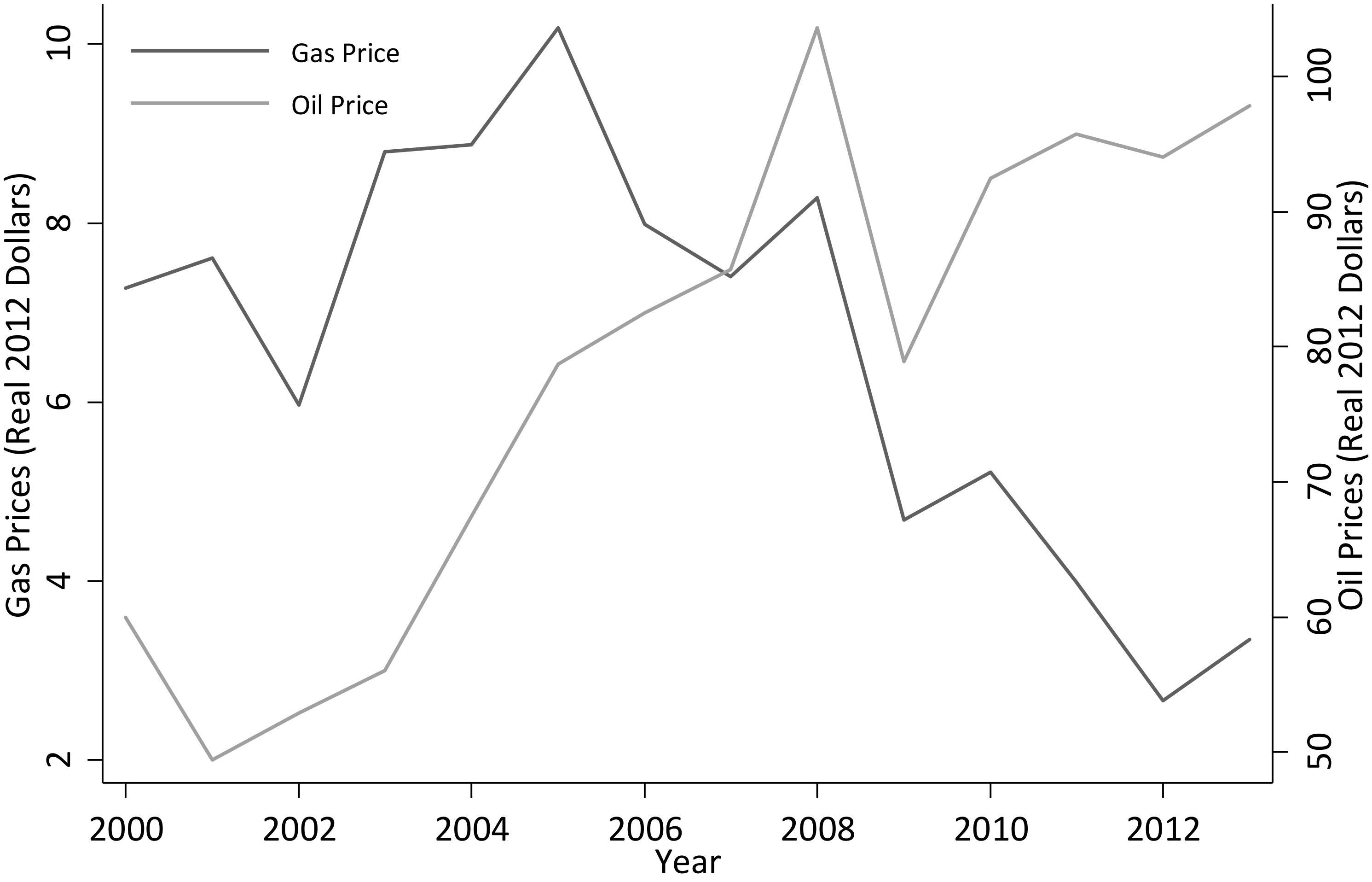
Notes: Figure gives estimated shale oil and gas reserves divided by 2000 population for commuting zones (1990 definition). Estimates of shale oil and gas reserves were derived by overlaying recent (2011) EIA maps of shale plays to commuting zones, separately for oil and gas, and allocating 2013 EIA estimates of play reserves to commuting zones based on the fraction of each play that they contain.

Figure 2 -
Oil and Gas Production from 2000 to 2013 by Well Type



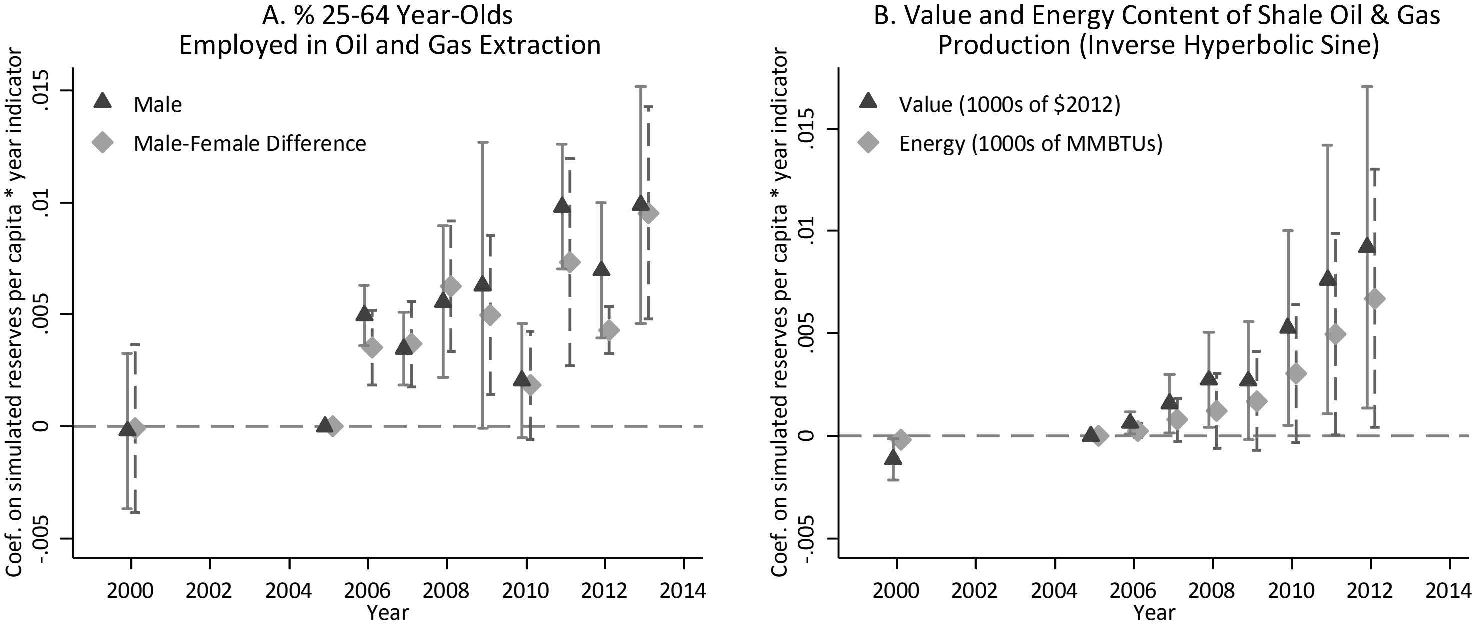
Notes: Data from DrillingInfo.com. Unconventional production is defined as production from horizontal and directional wells. Conventional production is defined as production from vertical and unknown wells. Sample consists of all 48 contiguous states. This graph is identical to Figure 1 in Feyrer, Mansur, and Sacerdote (2014).

Figure 3 -
Oil and Gas Prices from 2000 to 2013



Notes: Graph plots yearly prices for oil and gas in real 2012 dollars. Gas prices are US natural gas wellhead prices measured in dollars per thousand cubic feet (MCF). 2013 wellhead prices were discontinued, so the December 2012 wellhead price is used in its place. Oil prices are spot prices from Cushing, Oklahoma for WTI grade crude oil measured in dollars per barrel. Real 2012 dollars are normalized using energy CPIs. Data are from the Energy Information Administration.

Figure 4 -
Impacts of Fracking on Employment and Production in the Oil and Gas Industry

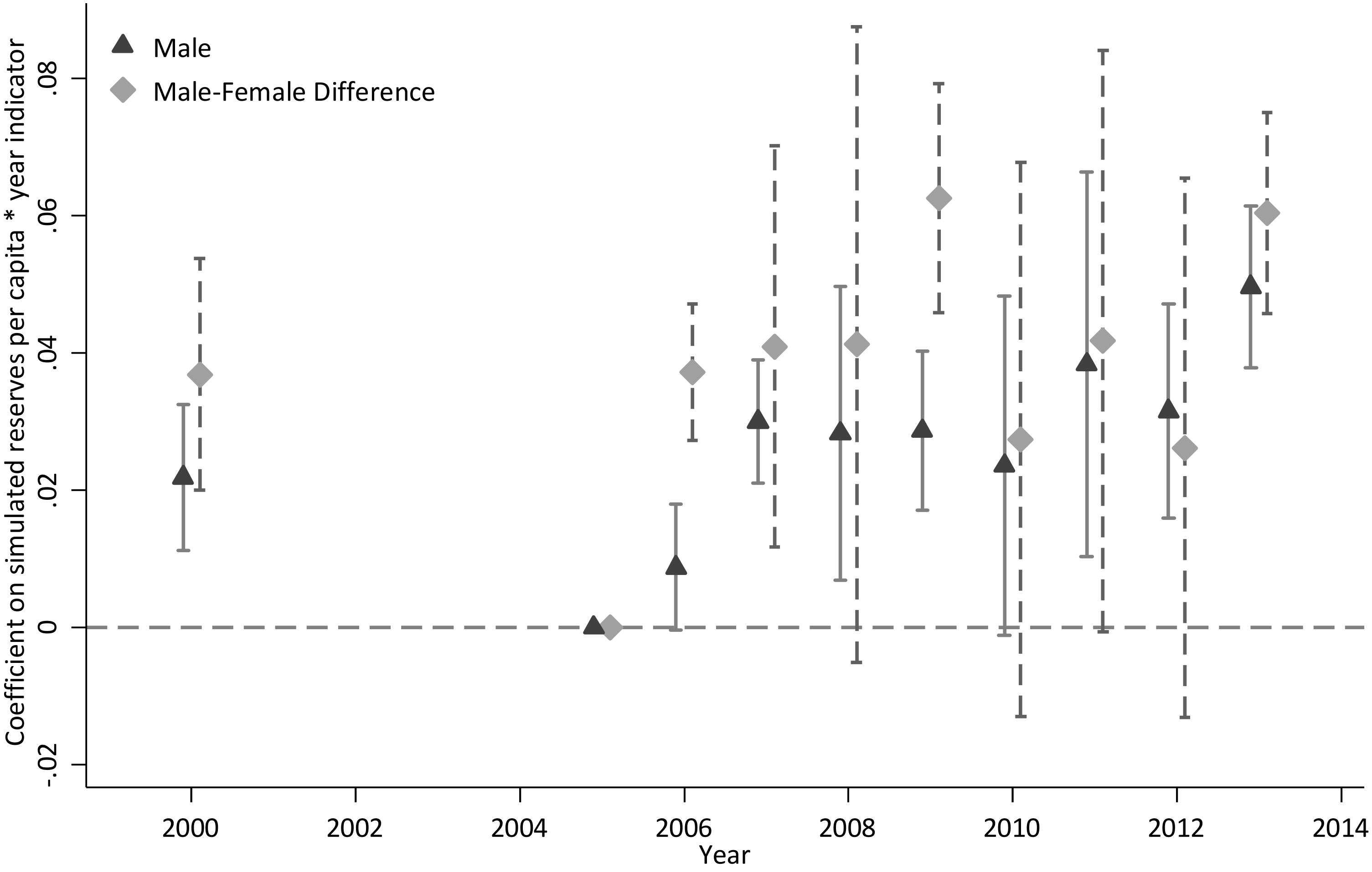


A. % 25-64 Year-Olds Employed in Oil and Gas Extraction

B. Value and Energy Content of Shale Oil & Gas Production (Inverse Hyperbolic Sine)

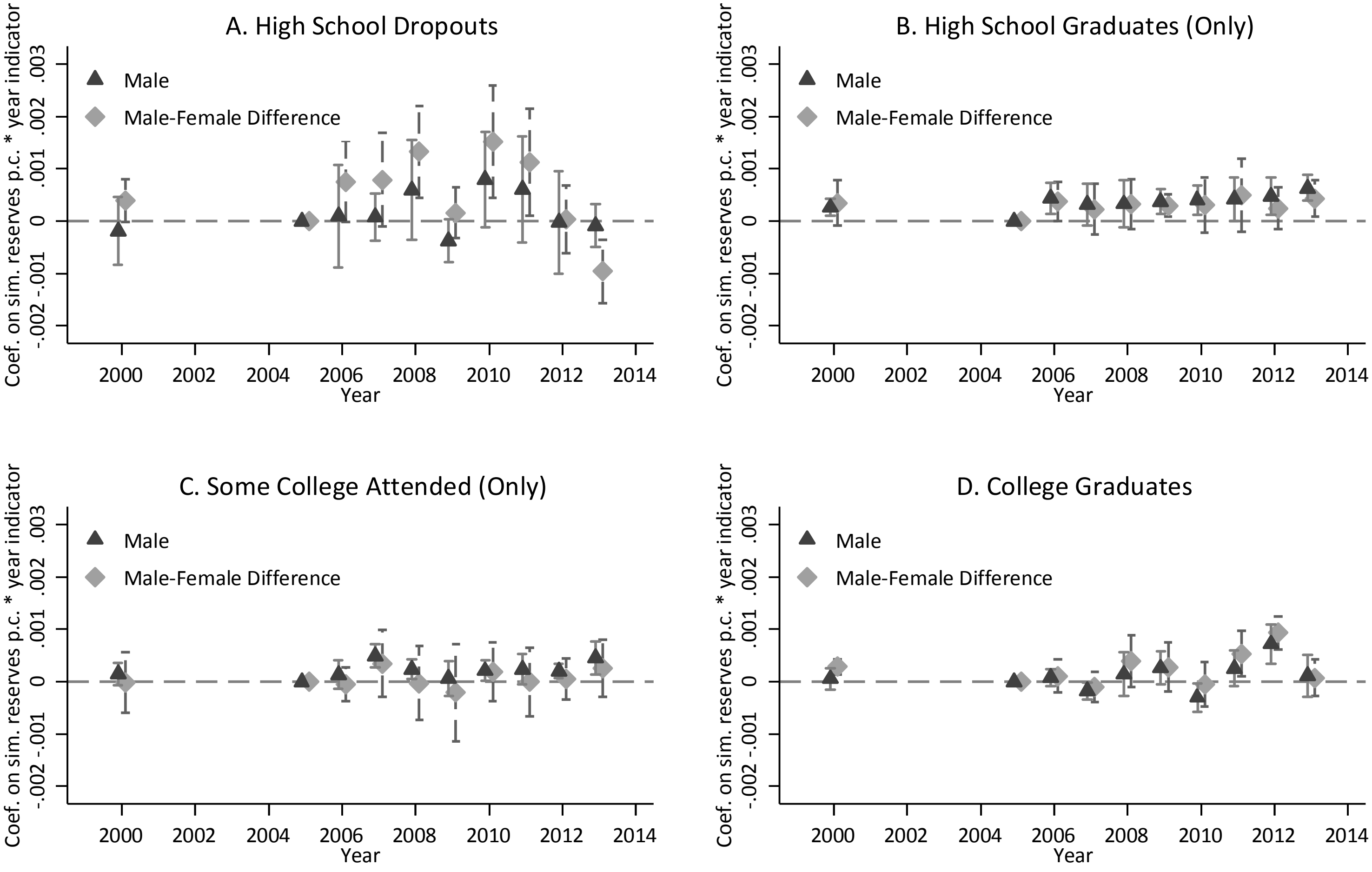
Notes: Graphs plot coefficients on interactions between year dummies and predicted shale oil and gas reserves per capita (measured in 1000s of MMBTUs and normalizing by year 2000 CZ population) from regressions that also include state-by-year fixed effects, commuting zone fixed effects, and interactions between year dummies and each of the year 2000 CZ characteristics summarized in Table 1, Panel C. The interaction between predicted reserves and the 2005 dummy is excluded to identify the model. Each commuting zone is given equal weight in the estimation, and inference is robust to heteroskedasticity and error correlation within states over time. Capped vertical lines represent 90 percent confidence intervals on the coefficient estimates. Data are from the 2000 Census and 2005-2013 ACS PUMS (Panel A) and DrillingInfo (Panel B). The DrillingInfo span 2000-2012, but we exclude data from 2001-2004 for consistency with the Census and ACS. Sample is limited to the 553 CZs in the 30 of the lower 48 states with any shale oil or gas reserves.

Figure 5 -
The Effect of Fracking on High School Dropout Rates



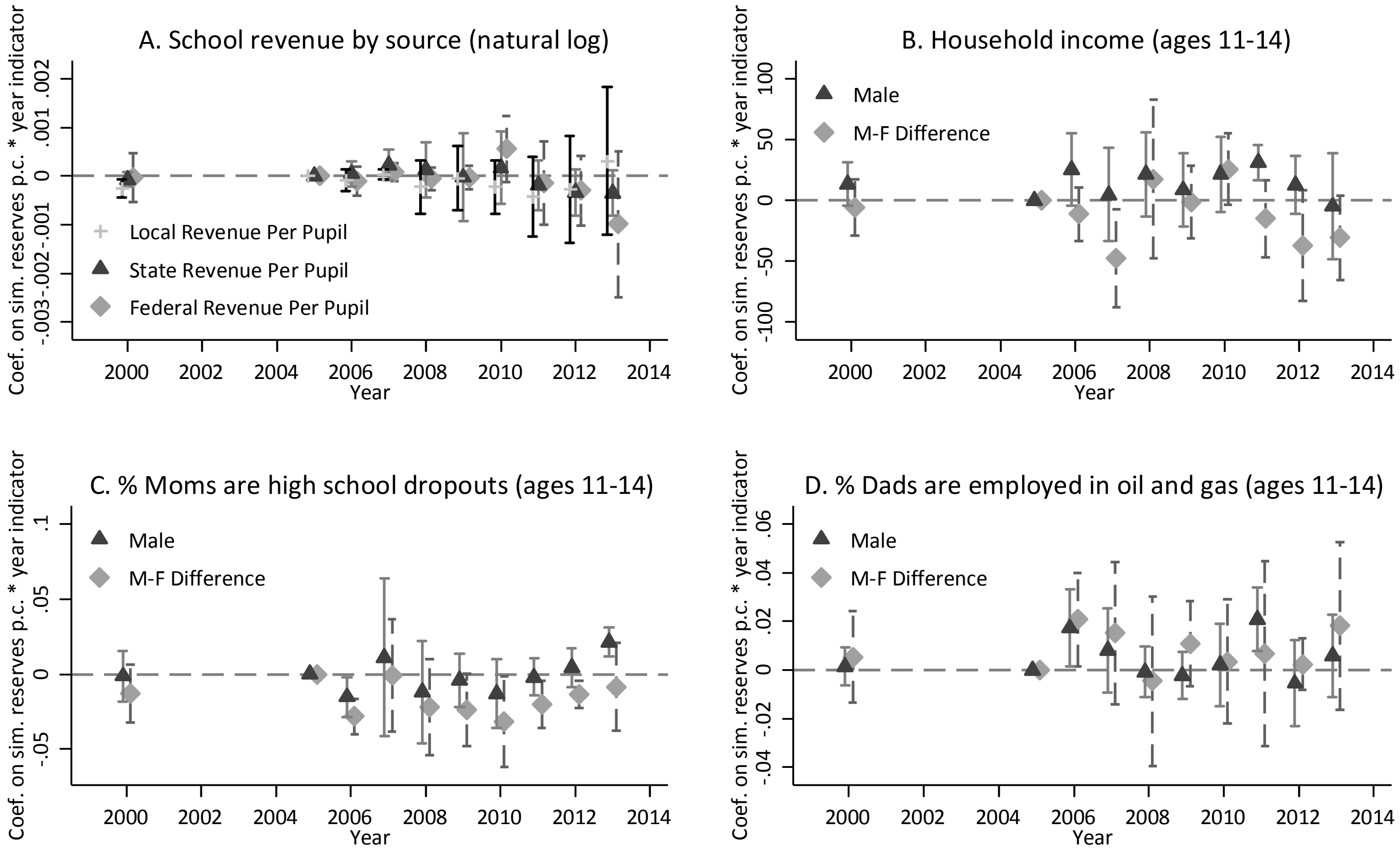
Notes: Graph plots coefficients on interactions between year dummies and predicted shale oil and gas reserves per capita (measured in 1000s of MMBTUs and normalizing by year 2000 population) from regressions that also include state-by-year fixed effects, commuting zone fixed effects, and interactions between year dummies and each of the year 2000 CZ characteristics summarized in Table 1, Panel C. The interaction between predicted reserves and the 2005 dummy is excluded to identify the model. Each commuting zone is given equal weight in the estimation, and inference is robust to heteroskedasticity and error correlation within states over time. Capped vertical lines represent 90 percent confidence intervals on the coefficient estimates. Data are from the 2000 Census and 2005-2013 ACS PUMS; sample is limited to the 553 CZs in the 30 of the lower 48 states with any shale oil or gas reserves. The dependent variable is the percent of 17- and 18-year-old males not currently enrolled in school and without a high school degree (triangles) or the difference in this percentage and the analogous percentage for females (diamonds).

Figure 6 -
Impacts of Fracking on Hourly Wages by Educational Attainment



Notes: Graphs plot coefficients on interactions between year dummies and predicted shale oil and gas reserves per capita (measured in 1000s of MMBTUs and normalizing by year 2000 population) from regressions that also include state-by-year fixed effects, commuting zone fixed effects, and interactions between year dummies and each of the year 2000 CZ characteristics summarized in Table 1, Panel C. The interaction between predicted reserves and the 2005 dummy is excluded to identify the model. Each commuting zone is given equal weight in the estimation, and inference is robust to heteroskedasticity and error correlation within states over time. Capped vertical lines represent 90 percent confidence intervals on the coefficient estimates. Data are from the 2000 Census and 2005-2013 ACS PUMS; sample is limited to the 553 CZs in the 30 of the lower 48 states with any shale oil or gas reserves. The dependent variable in all panels is the mean adjusted log hourly wage of 25-64 year olds with the stated educational attainment. See notes to Table 6 for description of the wage adjustment.

Figure 7 -
Other Candidate Mechanisms for the Dropout Effects of Fracking:
School Funding and the Composition of the Population



Notes: Graphs plot coefficients on interactions between year dummies and predicted shale oil and gas reserves per capita (measured in 1000s of MMBTUs and normalizing by year 2000 population) from regressions that also include state-by-year fixed effects, commuting zone fixed effects, and interactions between year dummies and each of the year 2000 CZ characteristics summarized in Table 1, Panel C. The interaction between predicted reserves and the 2005 dummy is excluded to identify the model. Each commuting zone is given equal weight in the estimation, and inference is robust to heteroskedasticity and error correlation within states over time. Capped vertical lines represent 90 percent confidence intervals on the coefficient estimates. Data are from the Common Core of Data (Panel A) and the 2000 Census and 2005-2013 ACS PUMS (Panels B-D); sample is limited to the 553 CZs in the 30 of the lower 48 states with any shale oil or gas reserves.

Table 1 -
Baseline Commuting Zone Characteristics and their Association with the Presence and Intensity of Shale Oil and Gas Reserves

	Mean (sd)		Coef (se) on P.C. Reserves (1000s of MMBTUs)
	Lower 48 States	States with Any Shale Oil or Gas	
	(1)	(2)	(3)
	A. Oil and Gas Industry Characteristics, 2000		
Shale oil & gas reserves per capita (1000s of MMBTUs)	5.420	7.076	-
	(27.56)	(31.31)	
Shale oil & gas per capita (1000s of MMBTUs)	0.073	0.095	-0.000
	(0.474)	(0.540)	(0.000)
Conventional oil & gas per capita (1000s of MMBTUs)	0.405	0.528	0.002
	(1.612)	(1.824)	(0.002)
Employed in oil or gas extraction, male ages 25-64 (%)	0.859	1.111	0.003
	(1.888)	(2.093)	(0.003)
Employed in oil or gas extraction, female ages 25-64 (%)	0.106	0.137	0.000
	(0.250)	(0.278)	(0.000)
Male-female difference (%)	0.754	0.975	0.003
	(1.673)	(1.856)	(0.002)
	B. Educational Characteristics, 2000		
High school dropout, male ages 17-18 (%)	10.186	10.225	-0.002
	(4.500)	(4.524)	(0.006)
High school dropout, female ages 17-18 (%)	8.624	8.780	-0.003
	(3.618)	(3.566)	(0.004)
Male-female difference (%)	1.562	1.445	0.001
	(4.078)	(4.136)	(0.003)
	C. Demographic Characteristics, 2000		
Black population share (%)	8.019	8.413	-0.014
	(12.37)	(12.58)	(0.008)
Hispanic population share (%)	7.694	8.386	0.048
	(13.58)	(15.00)	(0.044)
Unemployment rate (%)	3.565	3.545	0.001
	(1.267)	(1.294)	(0.003)
Child poverty rate (%)	17.36	18.49	0.024
	(7.657)	(7.907)	(0.015)
Median annual household income ($2012)	46,135	44,834	-36.637**
	(9,209)	(9,069)	(15.625)
Child disability rate (%)	7.874	7.860	-0.006***
	(1.425)	(1.438)	(0.001)
Single parent population share (%)	11.65	11.77	0.000
	(2.956)	(3.132)	(0.005)
English-speaking only share (%)	90.16	89.87	-0.038
	(11.92)	(12.95)	(0.040)
Population density	227.9	232.3	-0.865
	(1,013)	(1,135)	(0.561)

Table 1 (continued) -
Baseline Commuting Zone Characteristics and their Association with the Presence and Intensity of Shale Oil and Gas Reserves

	Mean (sd)		Coef (se)
	Lower 48 States	States with Any Shale oil or gas	on P.C. Reserves (1000s of MMBTUs)
		D. School Characteristics	
Local revenue per pupil (1999-00, $2012)	3,741	3,696	-1.708
	(1,759)	(1,749)	(4.752)
State revenue per pupil (1999-00, $2012)	5,124	4,946	5.473***
	(1,389)	(1,317)	(1.400)
Federal revenue per pupil (1999-00, $2012)	782.8	816.8	0.937
	(517.1)	(555.3)	(0.661)
Pupil-teacher ratio	15.00	14.78	-0.008**
	(2.408)	(2.411)	(0.004)
Income-adjusted test score	0.252	-0.166	-0.031**
(2004, 2005, and 2007, residual percentiles)	(7.987)	(8.388)	(0.014)
N (Commuting Zones)	722	553	553

Notes: Data were drawn from the 2000 Census PUMS (Panel A employment measures and Panel B), 2000 Census county-level tabulations (Panel C), the Common Core of Data (Panel D revenue measures) and Chetty et al. (2014) (Panel D income-adjusted test score). Due to missing data, the numbers of observations for class size and test scores (Panel D) are 692 and 693 in column 1 and 527 and 528 in columns 2 and 3.

***, **, and * designate statistical significance at the 1%, 5%, and 10 % levels, respectively.

Table 2 -
The Effect of Shale Oil and Gas Reserves and the Introduction of Fracking on Employment and Production in the Oil and Gas Industry

	% 25-64 Year Olds Employed in Oil or Gas Industry			Per-capita Shale Oil and Gas Production				IHS‡ of value of per-capita conventional production
Dependent Variable:	Male	Female	Male-Female Difference	in 1000s of real $2012	IHS‡ of value	in 1000s of MMBTUs	IHS‡ of energy	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				A. Difference-in-Differences				
No additional controls								
Per-capita shale reserves	0.0066***	0.0012*	0.0054***	0.1992	0.0056**	0.0156	0.0034*	-0.0004
x After 2005 (=1)	(0.0020)	(0.0007)	(0.0014)	(0.1469)	(0.0023)	(0.0108)	(0.0018)	(0.0002)
With additional controls†								
Per-capita shale reserves	0.0062***	0.0010	0.0052***	0.1903	0.0056**	0.0152	0.0034*	-0.0003
x After 2005 (=1)	(0.0019)	(0.0007)	(0.0012)	(0.1457)	(0.0024)	(0.0107)	(0.0019)	(0.0002)
				B. Restricted Event-Study				
With additional controls†								
Per-capita shale reserves	0.0048***	0.0002	0.0045***	0.0045	0.0022**	0.0005	0.0008	0.0005***
x Years 2006-2008 (=1)	(0.0014)	(0.0003)	(0.0011)	(0.0105)	(0.0009)	(0.0007)	(0.0007)	(0.0001)
Per-capita shale reserves	0.0061***	0.0014	0.0048***	0.1355	0.0058**	0.0108	0.0033	-0.0006*
x Years 2009-2011 (=1)	(0.0018)	(0.0011)	(0.0008)	(0.1246)	(0.0026)	(0.0090)	(0.0020)	(0.0003)
Per-capita shale reserves	0.0085**	0.0016**	0.0070***	0.5513	0.0103**	0.0437	0.0073*	-0.0010**
x Years 2012-2013 (=1)	(0.0031)	(0.0007)	(0.0024)	(0.3935)	(0.0046)	(0.0294)	(0.0039)	(0.0005)

Notes: Underlying sample consists of 553 commuting zones in the 30 of the lower 48 states with any shale gas or oil reserves observed in 2000 and 2005 through 2013 inclusive. The unit of observation is a commuting zone-year, so each regression thus contains 5530 observations. Data on employment by gender of 25-64 year olds in the oil and gas extraction industry (columns 1 through 3) was drawn from the 2000 Census and the 2005 through 2013 ACS PUMS. Data on oil and gas production (columns 4 through 8) was drawn from DrillingInfo and converted into 2012 dollars using the energy CPI and MMBtus using 2012 conversion factors reported by EIA. All regressions include state-by-year fixed effects and commuting zone fixed effects, and each commuting zone is given equal weight in the estimation. Shale oil and gas reserves are measured in thousands of MMBtus. Standard errors (in parentheses) are clustered on state.

***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

† The additional controls include each of the 2000 Census commuting zone characteristics listed in Panel C of Table 1 interacted with After 2005 (=1) (in Panel A) or interacted with Years 2006-08 (=1), Years 2009-11 (=1), and Years 2012-13 (=1) (in Panel B).

‡ Inverse hyperbolic sine (IHS). $\sinh^{-1}(y)=\ln(y+\text{sqrt}(y^2+1))$. Taking the IHS, rather than the natural log, allows us to retain zeros in the estimation sample, but coefficients can be interpreted much as they would be in a log-linear model.

Table 3 -
The Effect of Shale Oil and Gas Reserves and the Introduction of Fracking on High School Dropout Rates of 17- and 18-Year-Olds

Dependent variable:	% 17- and 18-Year-Olds Not Enrolled, No High School Degree							
	Male	Female	Male-Female Difference		Male		Male-Female Difference	
	RF	RF	RF		TSLS	OLS	TSLS	OLS
	(1)	(2)	(3)		(4)	(5)	(6)	(7)
			A. Reduced-Form is Difference-in-Differences					
No additional controls								
Per-capita shale reserves	0.0196***	-0.0032	0.0228***	% 25-64 Year Olds	2.974***	0.126	4.218***	0.156
x After 2005 (=1)	(0.0035)	(0.0078)	(0.0058)	in Oil and Gas Industry	(0.807)	(0.114)	(1.179)	(0.269)
R-square	0.386	0.320	0.270	Root MSE	6.263	5.522	8.620	7.572
				First-stage partial *F* on inst.	11.04	-	15.38	-
With additional controls†								
Per-capita shale reserves	0.0189***	-0.0049	0.0238***	% 25-64 Year Olds	3.040***	0.118	4.553***	0.157
x After 2005 (=1)	(0.0031)	(0.0089)	(0.0082)	in Oil and Gas Industry	(0.802)	(0.112)	(1.475)	(0.275)
R-square	0.387	0.321	0.271	Root MSE	6.287	5.519	8.756	7.574
				First-stage partial *F* on inst.	10.81	-	18.02	-
			B. Reduced-Form is Restricted Event-Study					
With additional controls†								
Per-capita shale reserves	0.0114***	-0.0100	0.0214*	% 25-64 Year Olds	3.428**	0.090	3.960**	0.106
x Years 2006-2008 (=1)	(0.0036)	(0.0093)	(0.0114)	in Oil and Gas Industry	(1.371)	(0.113)	(1.819)	(0.240)
Per-capita shale reserves	0.0193**	-0.0062	0.0255**	Root MSE	6.431	5.512	8.515	7.566
x Years 2009-2011 (=1)	(0.0094)	(0.0080)	(0.0123)	First-stage partial *F* on inst.	5.129	-	17.88	-
Per-capita shale reserves	0.0297***	0.0048	0.0248**					
x Years 2012-2013 (=1)	(0.0057)	(0.0115)	(0.0112)					
R-square	0.392	0.324	0.275					

Notes: Underlying sample consists of 17- and 18- year-olds residing in the 553 commuting zones of the 30 of the lower 48 states with any shale gas or oil reserves, based on data from the 2000 Census and the 2005 through 2013 ACS PUMS. The unit of observation is a commuting zone-year, so each regression contains 5530 observations. Each commuting zone is given equal weight in the estimation. Shale oil and gas reserves are measured in thousands of MMBtus. Standard errors (in parentheses) are clustered on state.

***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

†Additional controls include each of the 2000 Census commuting zone characteristics listed in Panel C of Table 1 interacted with After 2005 (=1) (in Panel A) or interacted with Years 2006-08 (=1), Years 2009-11 (=1), and Years 2012-13 (=1) (in Panel B).

Table 4 -
Specification Checks on the Ages 17-18 Dropout Results

Dependent variable:	% 17- and 18-Year-Olds Not Enrolled, No High School Degree					
	Male			Male-Female Difference		
	RF	TSLS (Just ID)	TSLS (Over ID)	RF	TSLS (Just ID)	TSLS (Over ID)
	(1)	(2)	(3)	(4)	(5)	(6)
	A. Baseline Model (N=5530)					
Preferred specification	0.0189***	3.040***	3.428**	0.0238***	4.553***	3.960**
(includes additional controls†)	(0.0031)	(0.802)	(1.371)	(0.0082)	(1.475)	(1.819)
		[10.81]	[5.129]		[18.02]	[17.88]
	B. Alternative Instruments (N=5530)					
Value of reserves using 2003 price	0.0026***	3.098***	3.538**	0.0031**	4.494***	3.929**
forecast for 2010 (1000s of $2012)	(0.0004)	(0.834)	(1.465)	(0.0012)	(1.454)	(1.867)
		[9.470]	[4.488]		[16.10]	[15.76]
Value of reserves using 2012 prices	0.0013***	3.302***	3.889**	0.0014**	4.293***	3.811*
(1000s of $2012)	(0.0002)	(1.005)	(1.871)	(0.0006)	(1.369)	(2.008)
		[6.574]	[3.026]		[11.42]	[11.66]
Simulated reserves in 2011	0.0319***	2.633***	2.578**	0.0448***	4.735***	3.504***
(1000s of MMBTUs)	(0.0075)	(0.666)	(1.181)	(0.0097)	(1.267)	(1.018)
		[19.10]	[8.987]		[21.31]	[14.66]
Employment impact of oil and gas	2.3689***	2.788***	2.918**	3.3639***	4.812***	4.071**
reserves separately	(0.8177)	(0.738)	(1.081)	(0.5924)	(1.553)	(1.585)
		[13.12]	[9.984]		[13.76]	[8.164]
IHS of main instrument	0.5984***	3.511**	3.530*	0.7515***	5.308	3.814
	(0.1842)	(1.608)	(1.944)	(0.1605)	(3.273)	(2.481)
		[3.023]	[4.545]		[2.993]	[4.271]
Dummy for top quartile of	1.5908	2.506***	2.792**	2.2437***	4.053**	2.571
main instrument	(0.9484)	(0.841)	(1.322)	(0.6710)	(1.834)	(1.588)
		[2.978]	[5.543]		[3.539]	[5.922]
	C. Restricted Sample (N=4470)					
Dropping MT, ND, and TX	0.0502*	2.527	1.544*	0.0478	2.580	2.970**
	(0.0294)	(2.164)	(0.817)	(0.0488)	(3.198)	(1.079)
		[4.564]	[3.461]		[4.138]	[3.802]
	D. Weighted Estimation (N=5530)					
Weighting by 2000 CZ population	0.0253**	1.991***	2.081***	0.0373***	3.483***	2.305***
	(0.0122)	(0.640)	(0.511)	(0.0078)	(0.958)	(0.739)
		[10.77]	[29.63]		[9.417]	[21.30]

Table 4 (cont'd) -
Specification Checks on the Ages 17-18 Dropout Results

Dependent variable:	% 17- and 18-Year-Olds Not Enrolled, No High School Degree					
	Male			Male-Female Difference		
	RF	TSLS (Just ID)	TSLS (Over ID)	RF	TSLS (Just ID)	TSLS (Over ID)
	(1)	(2)	(3)	(4)	(5)	(6)
			E. Restricted Age Estimations			
15- to 16-year olds (N=5530)	0.0013	0.210	0.261	0.0001	0.024	0.200
	(0.0019)	(0.320)	(0.398)	(0.0046)	(0.888)	(1.092)
		[10.81]	[5.129]		[18.02]	[17.88]
17- to 18-year olds +	0.0186***	2.837***	3.348*	0.0122	2.195**	1.778**
CSL exit age of ≤ 16 (N=1900)	(0.0057)	(0.754)	(1.682)	(0.0085)	(0.830)	(0.636)
		[4.06]	[8.79]		[6.10]	[39.82]
			F. Effects of Migration (N=5530)			
Outcome is dropout (ages 17-18)	0.0016	0.261	0.174	0.0068*	1.311*	1.160
and recent cross-PUMA migrant	(0.0013)	(0.209)	(0.249)	(0.0040)	(0.770)	(0.895)
		[10.81]	[5.129]		[18.02]	[17.88]
Outcome is dropout (ages 17-18)	0.0173***	2.779***	3.253**	0.0169***	3.242***	2.799**
and not recent cross-PUMA migrant	(0.0027)	(0.733)	(1.206)	(0.0052)	(0.873)	(1.038)
		[10.81]	[5.129]		[18.02]	[17.88]

Notes: Underlying sample consists of 17- and 18-year-olds residing in the 553 commuting zones in the 30 of the lower 48 states with any shale gas or oil reserves, based on data from the 2000 Census and the 2005 through 2013 ACS PUMS. The unit of observation is a commuting zone-year, so each regression contains 5530 observations, unless otherwise noted. All regressions include state-by-year fixed effects, commuting zone fixed effects, and interactions betweeen each of the 2000 Census characteristics listed in Panel C of Table 1 with After 2005 (=1) (in columns 1, 2, 4, and 5) and with with Years 2006-08 (=1), Years 2009-11 (=1), and Years 2012-13 (=1) (in columns 3 and 6). Unless otherwise noted, each commuting zone is given equal weight in the estimation, and shale oil and gas reserves are measured in thousands of MMBtus. Standard errors (in parentheses) are clustered on state. First-stage partial F-statistics on the instrument(s) are given in square brackets under the TSLS coefficient estimates.

Table 5 -
Educational Attainment of Employed Adults Ages 25-64 by Industry and Occupation, 2006-2013

	Percent of Employment (*Industry*)	Percent Male	Percent of Employed Workers			
			High School Dropouts	High School Graduates	College Attendees	College Graduates
All employed workers	100	52.6	5.8	26.6	32.1	35.4
Employed in Oil and Gas Industry	0.38	84.0	9.3	35.6	29.2	25.9
Extractive Occupations	*19.5*	98.2	18.3	50.5	26.1	5.1
Transportation and Material Moving Occupations	*11.2*	96.8	16.0	51.2	27.9	4.9
Construction Trades	*11.7*	98.3	10.7	46.2	33.2	9.8
Mechanic and Repairer Occupations	*6.4*	98.2	13.3	46.3	33.4	7.0
Machine Operators, Assemblers, and Inspectors	*3.5*	95.8	14.2	49.6	31.3	4.9
Employed in Construction Industry	6.79	90.0	13.3	42.7	30.8	13.2

Notes: Data are from the 2006 through 2013 ACS PUMS.

Table 6 -
The Effect of Shale Oil and Gas Reserves and the Introduction of Fracking on Wage Trends, by Educational Attainment and Gender

	Mean Adjusted Log Hourly Wage of:				
Dependent Variable:	High School Dropouts	High School Graduates	College Attendees	College Graduates	p-value: = coefficients
	(1)	(2)	(3)	(4)	(5)
		A. Difference-in-Differences			
Men					
Per-capita shale reserves x After 2005 (=1)	0.0003	0.0003*	0.0002**	0.0001	0.017
	(0.0003)	(0.0002)	(0.0001)	(0.0001)	
	-	[0.932]	[0.542]	[0.295]	
Women					
Per-capita shale reserves x After 2005 (=1)	-0.0001	0.0001	0.0001	-0.0000	0.069
	(0.0001)	(0.0002)	(0.0001)	(0.0000)	
	-	[0.120]	[0.252]	[0.438]	
Male-Female Difference					
Per-capita shale reserves x After 2005 (=1)	0.0004	0.0002	0.0001	0.0001	0.453
	(0.0002)	(0.0001)	(0.0002)	(0.0001)	
	-	[0.413]	[0.140]	[0.154]	
		B. Restricted Event-Study			
Male-Female Difference					
Per-capita shale reserves x Years 2006-08 (=1)	0.0008**	0.0001	0.0001	-0.0000	0.021
	(0.0003)	(0.0001)	(0.0001)	(0.0001)	
		[0.050]	[0.043]	[0.008]	
Per-capita shale reserves x Years 2009-11 (=1)	0.0007*	0.0002	0.0000	0.0001	0.209
	(0.0004)	(0.0001)	(0.0002)	(0.0001)	
		[0.199]	[0.044]	[0.067]	
Per-capita shale reserves x Years 2012-13 (=1)	-0.0007**	0.0002*	0.0002	0.0004***	0.009
	(0.0002)	(0.0001)	(0.0001)	(0.0001)	
		[0.003]	[0.011]	[0.003]	

Notes: Underlying sample consists of the 553 commuting zones in 30 of the the lower 48 states with any shale gas or oil reserves for 2000 and 2005 through 2013 inclusive. The unit of observation is a commuting zone-year, so each regression contains 5530 observations. Data on hourly wages by educational attainment for 25 to 64 year olds in the civilian labor force were drawn from the 2000 Census and the 2005 through 2013 ACS PUMS. Individual hourly wages were windsorized at $2 and $200 (real 1999 dollars), and commuting zone specific means were adjusted for a quartic in age, years of education (with separate effects for cohorts born before versus after 1950), and dummies for black race and Hispanic ethnicity. All regressions include state-by-year fixed effects, commuting zone fixed effects, and interactions between each of the 2000 Census commuting zone characteristics listed in Panel C of Table 1 with After 2005 (=1) (Panel A) and with Years 2006-08 (=1), Years 2009-11 (=1), and Years 2012-13 (=1) (Panel B). Each commuting zone is given equal weight in the estimation. Shale oil and gas reserves are measured in thousands of MMBtus. Standard errors are in parentheses; p-values on a test of the difference in coefficients across education categories (compared to high school dropout) are in square brackets. Inference is robust to heteroskedasticity and error correlation within states over time.
***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 7 -

Alternative Mechanisms: The Effect of Shale Oil and Gas Reserves and the Introduction of Fracking on School Resources

	Natural Log of Per-Pupil (in levels of real $2012):					
Dependent Variable:	Total Spending	Total Revenue	Federal Revenue	State Revenue	Local Revenue	Pupil-Teacher Ratio
	(1)	(2)	(3)	(4)	(5)	(6)
			A. Year 2000 means (levels)			
	9506	9459	816.8	4946	3696	14.78
			B. Difference-in-Differences			
Per-capita Reserves	-0.0001	-0.0001	-0.0001	-0.0000	0.0000	0.0040***
x After 2005 (=1)	(0.0003)	(0.0002)	(0.0001)	(0.0003)	(0.0004)	(0.0011)
			C. Restricted Event-Study			
Per-capita Reserves	-0.0002	-0.0000	-0.0000	0.0002	0.0000	0.0014***
x Years 2006-2008 (=1)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Per-capita Reserves	-0.0001	-0.0000	0.0001	0.0000	-0.0001	0.0045**
x Years 2009-2011 (=1)	(0.0003)	(0.0003)	(0.0002)	(0.0004)	(0.0004)	(0.0018)
Per-capita Reserves	-0.0004	-0.0002	-0.0006	-0.0003	0.0001	0.0070***
x Years 2012-2013 (=1)	(0.0003)	(0.0002)	(0.0005)	(0.0003)	(0.0007)	(0.0021)

Notes: Underlying sample consists of the 553 commuting zones in the 30 of the lower 48 states with any shale oil or gas reserves, based on data from the 1999-2000 and 2004-05 to 2010-11 school years. Data were drawn from the Common Core of Data. The unit of observation is a commuting zone-year. Each regression in columns 1 through 5 contains 5530 observations. Due to missing data, class size regressions (column 6) contain 5457 observations. All regressions include state-by-year fixed effects, commuting zone fixed effects, and interactions between each of the 2000 Census commuting zone characteristics listed in Table 1 with After 2005 (=1) (in Panel B) and Years 2006-08 (=1), Years 2009-11 (=1), and Years 2012-13 (Panel C). Each commuting zone is given equal weight in the estimation. Shale oil and gas reserves are measured in thousands of MMBtus. Standard errors (in parentheses) are clustered on state.
***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 8 -
Alternative Mechanisms: The Effect of Shale Oil and Gas Reserves and the Introduction of Fracking on Population Characteristics

	Male	Female	Male-Female Difference
	A. Characteristics of 17-18 year olds		
% Black			
Year 2000 Mean	10.13	10.05	0.07
Per-capita Reserves	0.0037	0.0018	0.0025
x After 2005 (=1)	(0.0022)	(0.0017)	(0.0030)
% Hispanic			
Year 2000 Mean	10.78	10.19	0.59
Per-capita Reserves	-0.0015	0.0036	-0.0044
x After 2005 (=1)	(0.0023)	(0.0069)	(0.0056)
	B. Characteristics of 11-14 year olds		
Household income (real $2012)			
Year 2000 Mean	69,543	70,031	-488.5
Per-capita Reserves	8.28	17.84	-9.55
x After 2005 (=1)	(7.53)	(14.07)	(7.21)
% Mom is high school dropout			
Year 2000 Mean	15.59	15.57	0.02
Per-capita Reserves	-0.0005	0.0117**	-0.0122
x After 2005 (=1)	(0.0069)	(0.0047)	(0.0078)
% Dad works in oil and gas industry			
Year 2000 Mean	1.44	1.55	-0.11
Per-capita Reserves	0.0050***	-0.0014	0.0064
x After 2005 (=1)	(0.0016)	(0.0078)	(0.0082)

Notes: Underlying sample consists of 17- and 18-year-olds (Panel A) or 11- to 14-year-olds (Panel B) living in the 553 commuting zones in the 30 of the lower 48 states with any shale gas or oil reserves, based on data from the 2000 Census and the 2005 through 2013 ACS PUMS. The unit of observation is a commuting zone-year, so each regression contains 5530 observations. All regressions include year fixed effects, commuting zone fixed effects, and interactions between each of the 2000 Census commuting zone characteristics listed in Panel C Table 1 with After 2005 (=1). Each commuting zone is given equal weight in the estimation. Shale oil and gas reserves are measured in thousands of MMBtus. Standard errors (in parentheses) are clustered on state.

***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix Table 1 -
Predicted Number of Jobs Created by Fracking, by State

	Predicted Jobs Created		
State	in Oil and Gas	in Construction	Overall
Texas	232,793	118,973	62,148
Pennsylvania	72,892	37,226	18,664
North Dakota	63,461	32,331	13,949
New York	56,992	29,069	13,523
West Virginia	44,076	22,550	12,470
Oklahoma	37,155	18,980	9,672
Arkansas	34,910	17,851	9,589
Louisiana	19,343	9,880	5,009
Ohio	18,074	9,232	4,662
Montana	12,535	6,390	2,868
Virginia	4,217	2,156	1,137
New Mexico	3,901	1,998	1,165
Michigan	3,578	1,826	876
Wyoming	3,152	1,610	832
Maryland	2,490	1,270	588
Kentucky	1,981	1,013	546
Colorado	1,602	818	401
Indiana	1,142	583	283
Utah	762	390	216
Mississippi	729	373	196
Kansas	532	272	136
California	434	222	110
Alabama	425	217	119
South Dakota	280	143	61
Georgia	124	63	33
Tennessee	117	60	32
Missouri	116	59	30
Nebraska	14	7	3
Illinois	13	7	3
New Jersey	5	2	1
Total	617,846	315,569	159,325

Notes: CZ-level predictions of jobs created for men were generated by multiplying the male difference-in-differences estimates (with additional controls) by the product of: the CZ's predicted per-capita reserves, the adult male year 2000 CZ employment rate , and the predicted adult male year 2000 population. Population predictions assume that men account for 51% of the adult population. We add across the CZ-level predictions to arrive at the state and national level predictions given in the table.

Appendix Table 2 -

The Effect of Shale Oil and Gas Reserves and the Introduction of Fracking on Employment Overall and By Industry

			% 25-64 Year Olds Employed			
	Overall		In Oil and Gas Industry		In Construction	
Dependent Variable:	Male	Male-Female Difference	Male	Male-Female Difference	Male	Male-Female Difference
	(1)	(2)	(3)	(4)	(5)	(6)
			A. Difference-in-Differences			
No additional controls						
Per-capita shale reserves	0.0020	0.0048**	0.0066***	0.0054***	0.0037***	0.0031*
x After 2005 (=1)	(0.0030)	(0.0021)	(0.0020)	(0.0014)	(0.0011)	(0.0015)
With additional controls†						
Per-capita shale reserves	0.0045	0.0078***	0.0062***	0.0052***	0.0033**	0.0029**
x After 2005 (=1)	(0.0035)	(0.0016)	(0.0019)	(0.0012)	(0.0013)	(0.0014)
			B. Restricted Event-Study			
With additional controls†						
Per-capita shale reserves	0.0031	0.0026	0.0048***	0.0045***	0.0022	0.0026
x Years 2006-2008 (=1)	(0.0028)	(0.0024)	(0.0014)	(0.0011)	(0.0033)	(0.0037)
Per-capita shale reserves	0.0045*	0.0109***	0.0061***	0.0048***	0.0033	0.0033**
x Years 2009-2011 (=1)	(0.0023)	(0.0024)	(0.0018)	(0.0008)	(0.0021)	(0.0016)
Per-capita shale reserves	0.0067	0.0109**	0.0085**	0.0070***	0.0049	0.0027
x Years 2012-2013 (=1)	(0.0076)	(0.0048)	(0.0031)	(0.0024)	(0.0051)	(0.0037)

Notes: Underlying sample consists of 553 commuting zones in the 30 of the lower 48 states with any shale gas or oil reserves observed in 2000 and 2005 through 2013 inclusive. The unit of observation is a commuting zone-year, so each regression thus contains 5530 observations. Data was drawn from the 2000 Census and the 2005 through 2013 ACS PUMS. All regressions include state-by-year fixed effects and commuting zone fixed effects, and each commuting zone is given equal weight in the estimation. Shale oil and gas reserves are measured in thousands of MMBtus. Standard errors (in parentheses) are clustered on state.
***, **, and * designate statistical significance at the 1%, 5%, and 10% levels, respectively.
† The additional controls include each of the 2000 Census commuting zone characteristics listed in Panel C of Table 1 interacted with After 2005 (=1) (in Panel A) or interacted with Years 2006-08 (=1), Years 2009-11 (=1), and Years 2012-13 (=1) (in Panel B).