# The Fracking Boom, Local Labor Market Opportunities, and College Attainment*

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**Abstract**

This paper examines the college educational, earnings, and employment responses to local labor demand shocks brought about by recent innovations in horizontal drilling and hydraulic fracturing. I find that a boom in fracking production within a county causes a reduction in college enrollment rates at four-year institutions, an increase in earnings, and an increase in employment for both men and women, with stronger effects for men. The decline in college enrollment during a boom is largely reversed as fracking production slows within a county. Educational attainment, however, remains persistently low for cohorts who experience the biggest enrollment declines. Workers who never attend college experience relatively larger earnings and employment gains, when compared to college-educated workers. These findings reveal that fracking-induced shifts in labor demand raise the opportunity cost of, and reduce the relative returns to, college.

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# 1 Introduction

Models of human capital investment predict that an increase in the earnings of less-educated workers relative to the earnings of more-educated workers will, *ceteris paribus*, reduce investments in schooling. The reason is that the increased earning potential among the less-educated will raise the opportunity cost of schooling and, thus, reduce the returns to education. In this paper, I study this phenomenon empirically, using county-level data to identify the effects of labor demand shocks caused by the fracking boom.

Since the early 2000s, innovations in horizontal drilling and hydraulic fracturing ("fracking") have created oil and natural gas booms in many counties in the United States. Technological change, together with preexisting deposits of oil and natural gas, created large shocks to income and employment in these counties. Between 2005 and 2015, average annual earnings per worker increased by 22.1 percent in fracking boom counties, but by only 4.4 percent in counties from non-fracking states. Over the same period, employment increased by 20.7 and 4.3 percent in fracking boom counties and counties from non-fracking states, respectively.[1] Although the fracking boom provides an ideal setting to study the college educational response to local earnings and employment shocks, it has received little attention in the literature.

An important feature of the boom is that fracking production expanded and contracted over a relatively short time period in many counties. Because people can go back to school later in life, sharp changes in short-run economic conditions might not have an effect on ultimate educational choices (Card and Lemieux, 2001). Temporary shocks to income could even provide a source of financing that leads to higher levels of educational attainment, especially for students facing considerable financial constraints on

[1] Statistics are derived from employment count and average annual earning measures from the Quarterly Workforce Indicators. Feyrer et al. (2017) document that fracking resulted in increased earnings and employment in the oil and natural gas industry as well as non-oil and natural gas industries. They find that within a county, each million dollars of new fracking production produces $80,000 in wage income and $132,000 of royalty and business income. They also claim that on aggregate, U.S. employment increased by as many as 640,000 as a result of fracking.

educational investment.

To estimate the short and long run effects of fracking-induced labor demand shocks on college investment, earnings, and employment, I first use a comprehensive data set of oil and natural gas production from all wells drilled in the United States to identify which oil and gas producing counties experienced a boom in fracking production, and in what year the boom began in each county. For each boom county, I then construct a synthetic control of counties from non-fracking states that most resemble the boom county based on pre-boom characteristics. The period-specific effects of fracking estimated using the synthetic control method offer a way to examine how the educational and labor market outcomes evolve over time as fracking production expands and contracts within a boom county. Averaging these dynamic effects over time provides a measure of the overall average effects of fracking.

Over the course of a boom cycle, college enrollment is lower on average in fracking boom counties relative to their synthetic controls. There is no significant difference, however, in graduation rates between the two sets of counties. Using data from the American Community Survey (ACS) and the Integrated Postsecondary Education Data System (IPEDS), I find specifically that the proportion of young men enrolled in college is about 4.7 percentage points smaller on average in fracking boom counties relative to the proportion enrolled in their respective synthetic control counties; a reduction of 12.5 percent relative to the mean proportion enrolled of 37.6 percent. Similarly, the proportion of young women enrolled is about 3.9 percentage points smaller, a reduction of 8.7 percent relative to the mean proportion enrolled of 44.6 percent. The reduction in enrollment is driven by reductions in enrollment rates at four-year institutions. Indeed, I find a contrasting result for two-year enrollment rates. If anything, they may have increased in fracking boom counties, particularly for women.

The observed effects of fracking-induced labor demand shocks on college attainment are consistent with traditional models of human capital investment, including the model

I present in Section 3, because fracking causes a large proportional increase in the earnings of non-college-educated workers. Panel (a) of Figure 1 shows the average value of fracked oil and gas production in boom counties five years prior to, and five years following, the start of a boom. Panel (b) shows the corresponding trends in the natural log of average annual earnings in boom counties and their synthetic controls over these same years, by educational attainment. Prior to the boom, earnings in boom counties and their synthetic controls are identical. As fracking production increases, earnings in boom counties increase for both non-college and college-educated workers relative to their synthetic controls, with the effects being proportionately larger for non-college-educated workers. Using data from the Quarterly Workforce Indicators (QWI), I find that the average annual earnings of non-college-educated men in boom counties are about $5,467 (16.2 percent) larger than those in their synthetic control counties during the ten year period following the start of a boom, while average annual earnings of college-educated men are about $7,045 (11.3 percent) larger. Average annual earnings are about $1,985 (9.4 percent) and $2,034 (5.3 percent) larger for non-college-educated and college-educated women, respectively. The college premium in boom counties, as measured by the *ratio* of college-educated worker earnings to non-college-educated worker earnings, decreases by 0.12 (6.7 percent) for men and 0.04 (1.9 percent) for women relative to the college premiums in their synthetic control counties. I also find positive effects of fracking on the employment-to-population ratio in boom counties, with the employment effect being relatively larger for non-college-educated workers than college-educated workers.

One benefit of using the synthetic control method in this study is the ability to capture the dynamic effects of a fracking boom as fracking production expands and contracts in a county. The dynamic effects of fracking on labor market outcomes and fracking production following the start of a boom are positively correlated. Thus, the changes in earnings and employment are largest in magnitude when fracking production is at its peak, about five years following the start of a boom. This positive correlation is most pronounced for the employment effects, and appears regardless of gender or educational attainment.

The dynamic effects of fracking on college enrollment and fracking production following the start of a boom are negatively correlated. This implies that decreases in college enrollment are largest in magnitude during the peak of the boom, but any effect tends to be nullified after fracking production slows down in a boom county. Although the decline in college enrollment is generally reversed as fracking production slows in a boom county, I find that college enrollment and attainment remains persistently low for particular cohorts. Specifically, I find that individuals aged 16 to 19 at the start of a boom are less likely to be enrolled throughout the duration of the boom, and no more likely to be enrolled after the boom. Moreover, I find that 10 years following the start of a boom, individuals in these cohorts living in boom counties have less educational attainment than those of the same cohorts in the synthetic control counties, despite having similar levels of attainment prior to, and at the start of, the boom. These results suggest that reduced educational attainment is an enduring effect of the fracking booms, despite the transitory nature of the booms.

The average and period-specific effects of fracking on earnings and employment are consistently larger in magnitude for men than for women. If an increase in the opportunity cost of college attendance and a corresponding decrease in the relative returns to college are important mechanisms through which fracking affected college investment, then a relatively larger effect on male college enrollment rates is also expected. I find that on average, the effect of fracking on college enrollment rates is relatively larger for men than for women, with this disparity being particularly pronounced during the peak years of a boom.

The model I present in Section 3 explores other potential channels through which fracking may affect college investment. Increases in tax revenues in a boom county that get channelled into school spending, for example, might alter teacher quality and student productivity, as well as provide more opportunity for scholarship funding. Additionally, college educational attainment may be influenced by rising parental income in boom counties (Blanden and Gregg, 2004). With these factors considered, the net effect on educational attainment is theoretically ambiguous. My empirical evidence, however, supports the conclusion that an increase in the opportunity cost of college is the dominant channel through which booms in fracking production affected college educational attainment.

Although labor market opportunities resulted in migration into these boom counties, particularly in North Dakota and the Bakken region (Wilson, 2016), changes in the composition of the population are not driving my results. The estimated effects of fracking on college enrollment rates remain robust to restricting the ACS sample to include only those who had not changed their residence since prior to any boom in fracking production.

In the next section I provide a brief literature review on fracking and other economic booms. In section 3, I present a theoretical model of human capital investment. In Section 4, I offer a brief background on fracking production, discuss how I define booms and identify boom counties, and outline the various data sources used in this study. Section 5 explains my empirical strategy and method for conducting inference. In Section 6, I present results. Section 7 concludes.

## 2 Literature Review

My work is most directly related to the growing literature on the effects of the fracking boom. Scholars have looked at the effect of the fracking boom on a variety of outcomes, to which I add an examination of the long-term effects on college enrollment and graduation.[2]

[2]Outcomes shown to have been possibly affected by the fracking boom include income and employment (Weber, 2014; Bartik et al., 2019; Feyrer et al., 2017; Krupnick and Echarte, 2017; Maniloff and Mastromonaco, 2017), high school attainment (Cascio and Narayan, 2017; Rickman et al., 2017; Niekamp, 2019), migration (Wilson, 2016, 2017), crime (James and Smith, 2017; Street, 2018; Andrews and Deza, 2018), school finance, teacher quality and student achievement (Marchand et al., 2015), as well as marriage, divorce, and birth rates (Kearney and Wilson, 2018).

Researchers have shown consistently that the earnings and employment effects of the fracking boom are not only substantial, but extend beyond the mining industry to construction, transportation, and other industries dominated by less-educated men (Feyrer et al., 2017; Bartik et al., 2019). Consequently, fracking-induced labor demand shocks have largely favored men without a college degree (Kearney and Wilson, 2018; Cascio and Narayan, 2017). My findings on the local labor market effects of the fracking boom are consistent with other findings in the literature.

Despite several studies regarding the relationship between historic resource extraction and human capital investment, estimates of the educational effects of resources are scarce and inconclusive (Marchand and Weber, 2018).[3] Even less attention has been paid to the effects of the recent fracking boom on educational attainment, with several notable exceptions. Cascio and Narayan (2017), Rickman et al. (2017), and Niekamp (2019) find that in general, fracking had a negative effect on educational outcomes. Specifically, fracking increased high school dropout rates of male teens, both overall and relative to females throughout the U.S. (Cascio and Narayan, 2017), though perhaps not in North Dakota (Niekamp, 2019). In North Dakota, enrollment rates at four-year colleges decreased significantly in core-oil producing counties relative to non-oil counties (Niekamp, 2019). There is evidence that high school and college attainment decreased in Montana and West virginia as well (Rickman et al., 2017).

Considering the existing literature as a whole, this paper provides three key contributions. First, I document the dynamic effects of the fracking boom over a relatively long period of time. Importantly, this allows me to see what happens to labor market and educational outcomes within a county not only while fracking production is booming, but also when production slows. Second, I track college enrollment and attainment of the cohorts most likely to be affected by the boom as they age. This allows me to analyze

[3]For studies regarding the relationship between historic resource extraction and human capital investment, see for example Black et al. (2005), Papyrakis and Gerlagh (2007), Michaels (2011), Emery et al. (2012), Haggerty et al. (2014), Morissette et al. (2015), Douglas and Walker (2017), and Kumar (2017).

whether individuals are simply delaying their college going, or foregoing it altogether. Third, this paper analyzes the effect of the fracking boom on college educational outcomes across the entirety of the United States. Previous research focuses almost purely on high school attainment, and the few studies that analyze college attainment focus on a particular state or subset of states.

## 3 Theoretical Model

To guide my empirical analysis, I model the essential factors linking fracking to educational attainment. My approach draws heavily on existing models of human capital investment (Becker, 1964; Cascio and Narayan, 2017; Charles et al., 2018). Following Charles et al. (2018), individuals will invest in human capital until the marginal benefit equals the marginal cost. The marginal benefit consists of the expected lifetime earnings associated with the investment. The marginal cost consists of direct costs of education, such as tuition, books, and fees; indirect, or "psychic" costs of college enrollment, relative to those of working; and the implicit opportunity cost, or foregone earnings as a result of going to college instead of working. Fracking can affect college enrollment decisions through any one of these channels, and the purpose of this model and empirical work to follow is to not only understand whether it has an overall effect, but the channels through which that effect arises.

The individuals in my framework are young adults, who are aged $a_t$ in year $t$ and live until age $T$. These young adults decide whether to immediately participate in the labor market, or attend college before participating in the labor market. Students differ in their academic ability $\theta_i$, distributed according to a Uniform distribution over [0,1]. Let $Z$ denote the direct costs of college, and $b$ the interest rate at which students can borrow. College students incur indirect or psychic costs $z(\theta_i) = \psi(1 - \theta_i)$ from attending college.[4] Labor market participants with and without college training receive labor market incomes $\omega_t^c$ and $\omega_t^{nc}$ in year $t$, respectively.

Given the model setup above, then with current information $\Lambda_i$, the value of not going to college, $V_{it}^{nc}(\theta_i)$, is simply the discounted present value of expected lifetime earnings without college training

$$V_{it}^{nc}(\theta_i) = \sum_{k=0}^{T-a_t} \frac{1}{(1+r)^k} E\left[\omega_{t+k}^{nc} | \Lambda_i\right], \tag{1}$$

and the value of going to college, $V_{it}^{c}(\theta_i)$, is the discounted present value of lifetime earnings with a college degree, net the direct and indirect costs

$$V_{it}^{c}(\theta_i) = \sum_{k=1}^{T-a_t} \frac{1}{(1+r)^k} E\left[\omega_{t+k}^{c} | \Lambda_i\right] - (1+b)Z - \psi(1-\theta_i)\,. \tag{2}$$

Letting $\pi_k^c = \omega_k^c - \omega_k^{nc}$ denote the college income premium in some year $k$, then the expected lifetime premium that a person of ability $\theta_i$ gets from attending college in year $t$, $R_{it}^c(\theta_i)$, is

$$R_{it}^c(\theta_i) = V_{it}^{c}(\theta_i) - V_{it}^{nc}(\theta_i) = \sum_{k=1}^{T-a_t} \frac{1}{(1+r)^k} E\left[\pi_{t+k}^{c} | \Lambda_i\right] - (1+b)Z - \psi(1-\theta_i) - \omega_t^{nc}\,. \tag{3}$$

The first term in equation (3) is individual $i$'s discounted present value of the expected future lifetime college income premium at time $t$, or the sum of their expectations of the college income premium for every year of their future working life, given their current information $\Lambda_i$. The middle two terms are the direct and indirect costs of going to college, and the last term is the labor market earnings foregone in year $t$ as a result of enrolling in college and not working, or the opportunity cost of going to college. An individual with ability $\theta_i$ will go to college if their expected lifetime premium from attending college in year $t$ is greater than zero. In other words, when $V_{it}^{c}(\theta_i) > V_{it}^{nc}(\theta_i)$.

[4] The linear functional form of $z$ is imposed for graphical simplicity only.

Figure 2 provides a graphical representation of this equilibrium. $\theta^*$ is the threshold ability level such that individuals with $\theta_i < \theta^*$ will not go to college, individuals with $\theta_i > \theta^*$ will go to college, and individuals with $\theta_i = \theta^*$ are indifferent between college or not.

Equation (3) formalizes the main channels through which fracking can influence the decision to attend college. Fracking may have resulted in an immediate increase in the local labor market income of non-college graduates, thus increasing the opportunity cost of going to college. As can be seen in Figure 3, this would increase the threshold ability level to $\theta'$, resulting in fewer college attendees. Furthermore, the technological innovation resulting in the fracking boom may have had enduring effects on the labor market incomes of both college graduates and non-college graduates. If fracking increased the expected lifetime labor market income of non-graduates relatively more than for graduates, then the college income premium would decrease, further increasing the threshold ability level to $\theta''$, resulting in even fewer college attendees.[5] The fracking boom could have also affected the indirect costs of going to college. For example, fracking may have resulted in increased resources in the homes and high schools of prospective college students, perhaps decreasing the psychological costs associated with attending school. If this is relatively more beneficial for low ability individuals than high ability individuals, the

[5]These points can be more formally illustrated by considering a simple constant elasticity of substitution production function for aggregate output $Q$ with two types of labor inputs, college-educated ($c$), and non-college-educated ($nc$),

$$Q = \left[\alpha(A_c L_c)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)(A_{nc}L_{nc})^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

where $L_c$ and $L_{nc}$ are the quantities employed of college-educated and non-college-educated workers, $A_c$ and $A_{nc}$ represent college and non-college educated labor-augmenting technological change, $\alpha$ is a technology parameter indexing the share of work activities allocated to college-educated workers, and $\sigma$ is the elasticity of substitution between college and non-college-educated labor. Under the assumption that workers are paid their marginal products,

$$ln\left(\frac{\omega^c}{\omega^{nc}}\right) = ln\left(\frac{\alpha}{1-\alpha}\right) + \left(\frac{\sigma-1}{\sigma}\right) ln\left(\frac{A_c}{A_{nc}}\right) - \frac{1}{\sigma}\left(\frac{L_c}{L_{nc}}\right).$$

Thus if $\sigma > 1$ and technological innovations in fracking acted to allocate a larger share of work activities to non-college-educated workers (a decrease in $\alpha$), or otherwise resulted in a relative increase in non-college-educated worker productivity (a decrease in $\frac{A_c}{A_{nc}}$), then this would result in a decrease in the college premium.

upward sloping line will shift up and become less steep, resulting in a threshold ability level $\theta'''$.[6]

A well identified reduced-form estimate of the effect of fracking captures the college educational response to all of these channels. In other words, the net college enrollment effect for the average area with fracking would be $\theta''' - \theta^*$. The reduced form effect can be broken up into the three channels described above,

$$\theta^{RF} = \theta''' - \theta^* = (\theta''' - \theta'') + (\theta'' - \theta') + (\theta' - \theta^*), \tag{4}$$

where $(\theta''' - \theta'')$ is the indirect cost channel, $(\theta'' - \theta')$ the college income premium channel, and $(\theta' - \theta^*)$ the opportunity cost channel.

While the reduced form effect is interesting and important, distinguishing among these channels is key to understanding the causal relationship between fracking and college attainment. There is a problem however, in attempting to identify multiple channels with one exogenous shock – the introduction of fracking. Suppose there are two distinct groups in the population, group $f$ and group $m$, and that group $f$ does not experience the college premium and opportunity cost effects ($\theta''_f - \theta'_f = 0$ and $\theta'_f - \theta^*_f = 0$) but group $m$ does. Suppose further that the indirect cost effect is the same for the two groups ($\theta'''_m - \theta''_m = \theta'''_f - \theta''_f$). Under these conditions, differencing the reduced form effects across these two groups will identify the effects of fracking working through the two labor market channels,

$$\theta^{RF}_m - \theta^{RF}_f = (\theta''_m - \theta'_m) + (\theta'_m - \theta^*_m). \tag{5}$$

In the empirical strategy to follow, I will incorporate this idea by verifying that fracking has larger impacts on the expected earnings of men than women, and by estimating the

[6] By reducing student-to-teacher ratios, increasing teacher salaries, making school years longer, or altering any other school input, increases in school spending can lead to higher educational attainment (Jackson et al., 2015). Marchand et al. (2015) find however, that school districts in Texas responded to the fracking-caused tax base expansion by spending more on capital projects, but not on teachers. As a result, fracking led to high teacher turnover and more inexperienced teachers, ultimately leading to slightly lower student achievement in these districts.

difference in effects of fracking on educational outcomes of men and women. Hence, empirically, males represent group $m$ and females represent group $f$.

# 4 Context and Data

## 4.1 Fracking Production

Shale rock formations far below the surface of the earth hold enormous deposits of natural gas and oil (often referred to as shale gas and shale oil). Hydraulic fracturing is a well stimulation technique involving high-pressure injection of fracking fluid, primarily consisting of water, sand, and other thickening agents, to create and maintain fractures in the shale rock allowing the shale oil and gas to be released. In a review of the economic, policy, and technology history of shale gas development, Wang and Krupnick (2013) suggest that a number of factors converged in the early 2000s that made it profitable for firms to produce large quantities of shale gas, but that the most important factor was innovations in technology.[7] The review of Wang and Krupnick (2013) finds that some of the key innovations in fracking technology came from government research and development and private entrepreneurship aimed at developing unconventional natural gas (for example, shale gas), and some of the innovations in fracking technology (for instance, horizontal drilling and three-dimensional seismic imaging) came from the oil industry where firms sought to explore and produce unconventional oil instead of unconventional gas.

These technological innovations made it more cost-effective to produce shale oil and gas, and as a result the share of natural gas and oil production coming from shale resources has increased dramatically since the early 2000s. Figure 4 shows the aggregate annual level of oil and gas production by drill type of wells that first started producing oil and gas in the year 2000 or later. Production from traditional vertically drilled wells

[7] Some other factors suggested include high natural gas and oil prices in the 2000s (see Figure 5), government policy, private entrepreneurship, private land and mineral rights ownership, market structure, favorable geology, water availability, and natural gas pipeline infrastructure.

exceeded that of horizontally drilled (fracked) wells in the early 2000s and remained relatively constant between 2000 and 2017. Starting between 2006 and 2010 however, shale oil and gas production increased tremendously across the U.S., with horizontally drilled production far surpassing production from traditional vertically drilled wells.

Data on local level oil and gas production come from DrillingInfo, a private firm that collects lease, permit, and production data on all wells drilled in the United States.[8] The data indicate drill date, monthly production amount, drilling direction (vertical or non-vertical), and county.[9] The sample consists of monthly production of oil, measured in barrels, and gas, measured in thousands of cubic feet (MCF), on properties that began producing either oil, gas, or oil and gas at some point after January 1st, 2000.

To convert oil and gas production into comparable dollar amounts, I use average annual national prices for oil and gas, recorded by the Energy Information Administration (EIA), and create a measure of the value of fracked oil and gas produced.[10] I then use the Consumer Price Index to adjust all dollar amounts to 2010 dollars.

For consistency across samples, I aggregate all oil and gas production data to the county-year level. To take into account the relative size of a county, I use the annual intercensal county resident population estimates from the U.S. Census Bureau to create a per capita measure of the total value of oil and gas production. Specifically, I define $Production_{cy}$ to be the total value of fracked oil and gas production per capita in county $c$ in year $y$. Figure 6 shows the total value of fracked oil and gas production by county between 2000 and 2017. In all, there were 745 counties in 27 states where at least some

[8]The use of these data were provided by DrillingInfo through an academic use agreement.

[9]Similar to Feyrer et al. (2017) and Kearney and Wilson (2018), I consider oil and gas produced from non-vertical wells as fracked oil and gas.

[10]For natural gas, I use the reported average annual citygate prices, which represent the total cost paid by gas distribution companies for gas received at the point where the gas is physically transferred from a pipeline company or transmission system. This price is intended to reflect all charges for the acquisition, storage, and transportation of gas as well as other charges associated with the local distribution company's obtaining the gas for sale to consumers. For crude oil, I use the reported West Texas Intermediate (WTI) average annual price. Prices of WTI are often listed in oil price reports, alongside other important oil markers, like UK Brent or the OPEC basket. WTI crude oil is also the underlying commodity of the Chicago Mercantile Exchanges oil futures contracts. The price of other crude oils, such as UK Brent crude oil, the OPEC crude oil basket, and Dubai Fateh oil, can be compared to that of WTI crude oil.

shale oil and gas production occurred between 2000 and 2017. Fracking production was most heavily concentrated in Texas, North Dakota, Oklahoma, Louisiana, Pennsylvania, and Wyoming.

Averaging $Production_{cy}$ over 2000 to 2017, the average county's value of fracked oil and gas per capita was $9,150, while the median was only $220. Figure 7 shows the average annual value of fracked oil and gas production over time by quintile of this distribution. Although fracking occurred in almost 750 counties over the sample period, the vast majority of fracked oil and gas came from a relatively small number of counties. The highly skewed distribution of fracking production highlights the importance of identifying and analyzing the effects of fracking in these select few counties that experienced a boom.

## 4.2 Boom County Identification

Consider the statistical model

$$Production_{cy} = \lambda_c + \phi_y + \varepsilon_{cy} \, , \tag{6}$$

where $Production_{cy}$ is the total value of fracked oil and gas production per capita in county $c$ in year $y$, $\lambda_c$ represents county fixed effects, and $\phi_y$ represents year fixed effects. I use least-square residual variation in $Production_{cy}$, which nets out county and year fixed effects, to identify boom counties. I consider a county a boom county if its residual fracking production is consistently large relative to other counties over the sample period. Specifically, I identify the 75th percentile in the distribution of residual fracking production for each year. If a county is in the upper quartile of these distributions in the majority of years in the sample, it is considered a boom county. 108 of the 745 counties with fracking production were considered boom counties.

The timing of a boom in a boom county varied according to when fracking production began in each individual county. Thus, when analyzing the average or aggregate effects of fracking on educational and labor market outcomes, it is important to do so in event time, where the event is defined to be the year in which fracking production saw a marked increase in each county. Figure 8 gives four examples of counties experiencing booms in different years. The vertical lines represent the event year in each county. In each case, fracking production is relatively stable prior to the event year, but then continues to increase for about five years. This pattern was fairly consistent across boom counties. Indeed, the event year for each county was identified as the year in the sample in which fracking increased the most over the following five year period. Table 1 shows the event year for each of the 108 boom counties in the sample. Figure 9 shows average annual standardized residual fracking production in boom counties and non-boom counties, confirming that I have identified counties which in fact experienced a boom, as well as their respective event timing.

## 4.3 Educational Outcomes

My first source of information on educational outcomes comes from the 2005 to 2017 American Community Survey (ACS) samples. Public Use Microdata Areas (PUMAs) are the most detailed geographic areas available in the ACS Public Use Microdata Samples, and are defined as a group of counties, or tracts within counties, with at least 100,000 people. PUMA boundaries do not overlap and are completely contained within states. I do not use ACS samples prior to 2005 because PUMA codes are not available in these samples. For consistency across data sets, I use a PUMA-to-county crosswalk to convert PUMA-year educational measures from the ACS to the county-year level.

Besides current PUMA and state of residence, the ACS contains individual level data on educational attainment, current enrollment status, state of birth, and migration information. To best capture the effect of fracking induced labor demand shocks on educational outcomes, I restrict the ACS sample to individuals aged 18 to 26, the ages in which educational decisions are most often made. I define $Prop.\ Enrolled_{cy}$ to be the proportion of individuals aged 18 to 26 in county $c$ in year $y$ currently enrolled in school. Similarly, I define $Prop.\ Graduated_{cy}$ to be the proportion with four or more years of completed college.

My second source of information on educational attainment is the Integrated Postsecondary Education Data System (IPEDS). IPEDS is a system of interrelated survey components conducted annually by the National Center for Education Statistics. IPEDS gathers information from every college, university, and technical/vocational institution that participates in the federal student financial aid programs in the United States. Included in this rich administrative data is a measure of first-time, full-year enrollments, as well as total graduations, allowing me to identify the number of individuals enrolling for the first time, or graduating, during the booms. I match colleges and universities to counties, and compute gender and county-specific estimates of first-time, full-year enrollments, as well as graduations in each year between 2000 and 2016. I then adjust these first-time enrollment and graduation totals by the size of the population aged 20 to 25 in each county in order to capture per capita first-time enrollment and graduation rates.[11]

One of the advantages of using the ACS is the ability to test to what extent changes in the composition of the population, notably from migration, affect the observed effects of fracking. This is possible by first restricting the sample to individuals aged 18 to 26, ages during which most human capital investments are made. Second, the ACS contains information on the migration activity of the respondents. By restricting the sample to those who have been living in their current residence since prior to any boom, I can assess whether fracking altered the college investment decisions of long-term residents, or if the effects using the unrestricted sample simply reflect changes in the composition of the population.

One drawback of the ACS is the inability to use samples prior to 2005 due to the lack

[11] The county population estimates were already grouped according to age by the U.S. Census Bureau.

of geographic information of the respondents. Another concern is that ACS data do not distinguish between the type of college a respondent attended or is attending. For example, if an individual reports being enrolled in school, it is unreported whether they are enrolled in a two-year or a four-year college. In addition to data availability before 2005, the IPEDS reports enrollment and graduation totals for different types of colleges separately. Together, the ACS and IPEDS data provide a thorough picture of activity related to college educational attainment before, during, and after county-specific booms in fracking production.

### 4.4 Earnings and Employment

Data on earnings and employment come from the Quarterly Workforce Indicators (QWI). The source data for the QWI is the Longitudinal Employer-Household Dynamics (LEHD) linked employer-employee microdata, covering over 95% of U.S. private sector jobs. The QWI provide local labor market statistics at the county level by industry and worker demographics, such as worker age, gender, educational attainment, and race/ethnicity. These data however, can only be tabulated for two-way groups (for example, by gender and educational attainment of workers). Therefore, for each industry in a county, I have measures of average annual earnings and annual employment counts by gender and educational attainment of workers. I define $Average\ Annual\ Earnings_{cy}$ as the average annual earnings in county $c$ in year $y$ (in 2010 \$), and $Jobs/Population_{cy}$ as the total jobs-to-population ratio in county $c$ in year $y$.

## 5 Empirical Strategy

My empirical work relies on the ability to estimate what would have happened in counties exposed to a boom in fracking had they not experienced the boom. One possible comparison is between boom counties and other fracking counties that are not considered boom counties. Because boom and non-boom counties were both exposed to fracking, they are likely similar along many dimensions. However, it is precisely because fracking occurs in varying degrees in non-boom counties that I elect not to use them as part of a potential control group. To best estimate the effects of fracking on educational and labor market outcomes, I include in my potential control group all counties from states that did not have any fracking production over the sample period. Feyrer et al. (2017) show that the wage and employment effects of fracking production are significant up to 100 miles from where the actual fracking production takes place. By excluding non-fracking counties within fracking states, I limit the possibility of potential control counties experiencing the effects of the boom in a neighboring county within the same state.

Table 2 contains descriptive statistics for the main outcome variables from each data set, as well as population characteristics, for fracking boom counties and non-fracking counties. Although the population characteristics are strikingly similar between the boom counties and non-fracking counties, the outcome variables appear to be quite different, especially the educational outcomes. There could, of course, be a concern for estimation if the outcomes in boom counties were on different trajectories than those in non-fracking counties prior to their respective booms. To address this concern, I use the synthetic control method formally introduced by Abadie and Gardeazabal (2003) and Abadie et al. (2010).

The synthetic control method is often used to evaluate the effects of an intervention in comparative case studies. It is a data-driven approach to constructing a weighted average of untreated units that act as a control, to which the treated unit is compared. In the context of this study, the boom counties identified previously are the treated units, and the counties from non-fracking states make up the pool of potential controls for each boom county. The intervention is the boom in fracking production, which I specify as occurring in the county-specific event years described above for each boom county. An additional benefit of using the synthetic control method is the ability to capture the dynamic effects of fracking on each educational and labor market outcome as fracking production expands and contracts in a county.

To outline my empirical strategy, I will begin by providing some notation to evaluate the effect of the fracking boom in a single county. Then I will discuss how I aggregate the county-specific effects into an average effect, as well as my method for conducting inference.

## 5.1 Synthetic Control Method - One Treated Unit

Following the notation of Abadie et al. (2010), I observe $J + 1$ counties. Without loss of generality, let the first county be the one to experience a fracking boom, so that there are $J$ remaining counties that serve as potential controls. Let $Y_{it}^N$ denote the educational or labor market outcome that would be observed for county $i$ at time $t$ in the absence of fracking, for all counties $i = 1, \ldots, J + 1$, and time periods $t = 1, \ldots, T$. Suppose the intervention occurs in period $T_0$, then $T_0 - 1$ is the number of periods before the start of the boom (the length of the pre-intervention period), with $1 \leq T_0 - 1 \leq T$. Let $Y_{it}^I$ be the educational or labor market outcome that would be observed for county $i$ at time $t$ if county $i$ is exposed to a boom from period $T_0$ to $T$. I assume that fracking had no effect on educational or labor market outcomes in the pre-intervention period, so for $t \in \{1, \ldots, T_0 - 1\}$ and all $i \in \{1, \ldots, N\}$, $Y_{it}^I = Y_{it}^N$.

Let $\alpha_{it} = Y_{it}^I - Y_{it}^N$ denote the effect of fracking for county $i$ at time $t$ if county $i$ is exposed to fracking in periods $T_0, T_0 + 1, T_0 + 2, \ldots, T$. Note that this effect is allowed to potentially vary over time. Therefore,

$$Y_{it}^I = Y_{it}^N + \alpha_{it}, \tag{7}$$

and the observed educational or labor market outcome for county $i$ at time $t$ is

$$Y_{it} = Y_{it}^N + \alpha_{it} D_{it}, \tag{8}$$

where $D_{it}$ is an indicator variable taking on the value of 1 if county $i$ is exposed to a fracking boom at time $t$ and 0 otherwise.

The parameters of interest are $\alpha_{1,T_0}, \alpha_{1,T_0+1}, \ldots, \alpha_{1,T}$, which are the post-intervention period-specific effects of fracking on the educational or labor market outcome of interest. For $t \geq T_0$,

$$\alpha_{1t} = Y_{1t}^I - Y_{1t}^N = Y_{1t} - Y_{1t}^N. \tag{9}$$

Note that $Y_{1t}$ is observed. Therefore, to estimate $\alpha_{1t}$, it is only necessary to come up with an estimate for $Y_{1t}^N$. Abadie et al. (2010) suggest using

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \tag{10}$$

for $t \in \{T_0, T_0 + 1, \ldots, T\}$ as an estimator for $\alpha_{1t}$, where $w_j^*$ is the weight given to potential control county $j$. The vector of weights $\mathbf{W} = (w_2, \ldots, w_{J+1})$ where $w_j \geq 0$ for $j = 2, \ldots, J+1$ and $w_2 + w_3 + \cdots + w_{J+1} = 1$ is chosen to provide a linear combination of potential control counties that best match the treated county based on pre-intervention values of the outcome variable, as well as other pre-intervention characteristics. The pre-intervention variables I use to identify the synthetic control for each treated county include the value of the outcome variable in each of the pre-intervention years (Abadie et al., 2010), as well as county-year demographic characteristics including the proportion of males, gender-specific proportions of white individuals, and gender-specific shares of individuals aged 20 to 34, 35 to 49, 50 to 64, and over 65.

To capture the average effect of the fracking boom in the treated county, denoted by $\bar{\alpha}_1$, I average the period-specific estimates of fracking over the entire treatment period.

Thus,

$$\bar{\alpha}_1 = \left(\frac{1}{T - T_0}\right) \sum_{t=T_0}^{T} \hat{\alpha}_{1t} \, . \tag{11}$$

## 5.2 Synthetic Control Method - Multiple Treated Units

Suppose there are $G$ counties that experience a fracking boom in potentially different years. Similar to Cavallo et al. (2013) and Dube and Zipperer (2015), for each treated county $g \in \{1, \ldots, G\}$, I follow the same strategy outlined above to estimate period-specific effects of fracking, denoted by $\hat{\alpha}_{g,l}$, where $l$ represents the number of years since the start of the boom.[12] The estimated average period-specific effects then, are given by

$$\overline{\alpha}_l = \frac{1}{G} \sum_{g=1}^{G} \hat{\alpha}_{g,l}. \tag{12}$$

With multiple treated counties, I estimate the overall average effect of the fracking boom in the treated counties, denoted by $\bar{\alpha}$, by averaging the period-specific average estimates of fracking over the entire treatment period (Dube and Zipperer, 2015). Therefore,

$$\overline{\alpha} = \left(\frac{1}{T - T_0}\right) \sum_{l=T_0}^{T} \bar{\alpha}_l \, . \tag{13}$$

## 5.3 Inference

Large sample inferential techniques are not well suited for comparative case studies such as this, since the number of control counties that receive positive weight and periods in the sample are relatively small. Following Abadie et al. (2010), Dube and Zipperer (2015), and Cavallo et al. (2013), I use exact inferential techniques, similar to permutation tests, to conduct statistical inference. This involves applying the synthetic control method to each of the control counties, finding a large number of average placebo effects, and then

[12]Combining estimated effects using event time is important in this study because the event year varies across the $G$ treated counties.

examining at each period if the effect of fracking in a treated county is large relative to the distribution of average placebo effects. Specifically, I conduct inference for each period-specific effect, $\bar{\alpha}_l$, by computing a $(1-k)$ percent confidence interval according to the following steps.

1. For each period $l$, I compute placebo estimates, $\hat{\alpha}_{j,l}^{PL}$, for all potential control counties $j \in \{2, \dots, J+1\}$.
2. Let $N_{\overline{PL}}$ denote the number of average placebo effects of size $G$, each combination indexed by $c \in \{1, \dots, N_{\overline{PL}}\}$. For each period $l$, I compute an average placebo effect of size G, denoted by $\overline{\alpha}_l^{PL(c)}$, by choosing at random $G$ values of the $J$ placebo estimates, $\hat{\alpha}_{j,l}^{PL}$, and averaging over these estimates. This procedure is repeated with replacement $N_{\overline{PL}}$ times.
3. Let $P_l^{TR} = F^{PL}(\bar{\alpha}_l)$ denote the percentile rank statistic of the period-specific treatment effect $\bar{\alpha}_l$, where $F^{PL}$ is the empirical cumulative distribution function of the $N_{\overline{PL}}$ average placebo effects, $\overline{\alpha}_l^{PL(c)}$. Let $P_{l,(p)}^{PL} = F^{PL}\left(\bar{\alpha}_{l,(p)}^{PL(c)}\right)$ denote the percentile rank statistic of the average placebo effect $\bar{\alpha}_{l,(p)}^{PL(c)}$, which is the $p^{th}$ percentile average placebo effect. Inverting the percentile rank test, the $(1-k)$ percent confidence interval of the period-specific treatment effect $\bar{\alpha}_l$ is given by

$$\left(\bar{\alpha}_l - \bar{\alpha}_{l,(1-\frac{k}{2})}^{PL(c)}, \bar{\alpha}_l + \bar{\alpha}_{l,(\frac{k}{2})}^{PL(c)}\right). \tag{14}$$

In step 1 above, I compute period-specific placebo estimates for each of the $J$ untreated counties following the same procedure outlined above for the $G$ actual treated counties. This involves considering each control county as "treated," and finding a synthetic control using the remaining $J-1$ control counties. Because the event year varies across the $G$ treated counties, I randomly assign the fraction of control counties to each event year that corresponds to the fraction of the actual treated counties in each event year. Because $\bar{\alpha}_l$ is an average of the $G$ treated counties in each period, step 2 involves computing $N_{\overline{PL}}$

average placebo effects of that same size. I compute $N_{\overline{PL}} = 1,000$ average placebo effects of size $G$, to which I compare the actual estimated treatment effect. Steps 1 and 2 ensure that the average period-specific placebo effects were found in an identical way as the actual period-specific effects, allowing for meaningful comparisons between the two.

Similar to the procedure taken by Dube and Zipperer (2015), Step 3 involves examining if the average period-specific treatment effect is large relative to the distribution of average period-specific placebo effects. Since the percentile rank statistic is approximately uniformly distributed, I determine whether the percentile rank of the period-specific treatment effect $P_l^{TR}$ lies within the tails of the uniform distribution. Given a statistical significance level of $k$ percent, I cannot reject the null hypothesis that $\bar{\alpha}_l = 0$ precisely when $\frac{k}{2} \leq P_l^{TR} = F^{PL}(\bar{\alpha}_l) \leq 1 - \frac{k}{2}$. A $(1-k)$ percent confidence interval can then be found by inverting this test, asking for what values of $\nu$ does the adjusted effect $\bar{\alpha}_l - \nu$ appear free from treatment: when does $\frac{k}{2} \leq F^{PL}(\bar{\alpha}_l - \nu) \leq 1 - \frac{k}{2}$? The $(1-k)$ percent confidence interval for $\bar{\alpha}_l$ is the set of $\nu$ not rejected using the critical values $\frac{k}{2}$ and $1 - \frac{k}{2}$, precisely the interval given in equation (14).[13]

I follow steps analogous to those above to conduct inference for $\bar{\alpha}$, the overall average effect of the fracking boom. This involves examining how large $\bar{\alpha}$ is relative to the distribution of the $N_{\overline{PL}}$ corresponding overall average placebo effects $\bar{\alpha}^{PL(c)}$. Specifically, the $(1-k)$ percent confidence interval of the overall average effect, $\bar{\alpha}$, is given by

$$\left(\bar{\alpha} - \bar{\alpha}^{PL(c)}_{(1-\frac{k}{2})}, \bar{\alpha} + \bar{\alpha}^{PL(c)}_{(\frac{k}{2})}\right). \tag{15}$$

# 6 Results

In this section I test my theoretical model's predictions by first analyzing the effects of the fracking boom on educational outcomes, and then exploring potential mechanisms driving these effects.

[13] Figure 10 illustrates graphically step 3 of this procedure.

## 6.1 College Educational Attainment - Repeated Cross Sections

Table 3 reports the average effects of fracking, $\bar{\alpha}$, on college educational outcomes from the ACS and IPEDS separately for men in panel A and women in panel B. In fracking boom counties, the proportion of men aged 18 to 26 enrolled in college decreases by 4.7 percentage points relative to their synthetic control over a ten year period following the start of a boom, a decrease of about 12.5 percent compared to the mean proportion enrolled of 37.6 percent. Women aged 18 to 26 in boom counties see a similar but slightly smaller reduction in the proportion enrolled in college. As a result of the fracking boom, the proportion of woman enrolled in college decreases by about 3.9 percentage points, a decrease of about 8.7 percent relative to the mean proportion enrolled of 44.6 percent.

Although the estimates of the effect of the boom on the proportion graduated in a county are negative for both men and women, placebo analysis suggests that I cannot reject the null hypothesis that $\bar{\alpha} = 0$ for either group. Taken together, the evidence on enrollment and graduation is suggestive that the fracking boom likely affected individuals most on the college enrollment margin rather than the completion margin. Individuals near the threshold ability level, $\theta^*$, are those whose educational attainment is most affected by the fracking boom. It is plausible that absent fracking, had they enrolled in college, these individuals are those most likely to drop out of college.

I capture how the effects of the fracking boom on these educational outcomes evolve over time in Figures 11 and 12. Panel (a) in both figures show the trends in the proportion enrolled and the proportion graduated in the boom counties and their synthetic control, while panel (b) illustrates the gap between the outcome variable in the boom counties and that of their synthetic control in each period. In other words, panel (b) shows the period-specific effects, $\bar{\alpha}_l$, of the fracking boom on the outcome variables of interest from five years before the start of the boom to ten years after. The average value of fracking production per capita tends to increase dramatically for about five years after the start of a boom, at which point it hits a peak and then proceeds to steadily decline (see Figures

8 and 9). The negative effect of the fracking boom on the proportion of males enrolled follows a strikingly similar pattern, increasing in magnitude and reaching a low between three and five years following the start of a boom. During the peak producing years of a boom, the proportion of males enrolled is about 8 percentage points lower than the proportion enrolled in the synthetic control. A similar but less pronounced pattern can be seen for women. Another insight from the dynamic effects captured in these figures is that the large decline in male college enrollment three to five years after the start of the boom is followed by a decline of graduation rates six to nine years after the start of the boom. The overall average effects reported previously mask these lagged effects on male graduation rates.

Using only the ACS data, it would be unclear whether this reduction in college enrollment was driven by lower enrollment in four-year institutions, two-year institutions, or some combination of both. Identifying which individuals are most affected by fracking is important, and the IPEDS data are useful in this regard. Column three of Table 3 reports the effect of the fracking boom on the enrollment rate at four-year institutions. The fracking boom resulted in a 1.3 percentage point decrease in the male enrollment rate at four-year institutions, about an 11.6 percent reduction relative to the mean male enrollment rate of 11.2 percent. The estimated effect for the female enrollment rate at four-year institutions is larger in magnitude, a decrease of about 2 percentage points (about 15 percent relative to the mean female enrollment rate of 13.5 percent). The distribution of placebo estimates for the female enrollment rate has a relatively larger variance however, so despite the larger estimated effect, I cannot reject the null hypothesis that $\bar{\alpha} = 0$. I find no effect of fracking on graduation rates at four-year institutions for either men or women. In contrast to the negative enrollment effects at four-year institutions, the point estimates of the fracking boom on both enrollment and graduation rates at two-year institutions are positive for men and women, though the effects are smaller in magnitude and not statistically significant for men.

Figures 13, 14, 15, and 16 show the trends in male and female enrollment and graduation rates by level of institution, as well as the lead and lag specific effects of the fracking boom, $\bar{\alpha}_l$, on these outcomes. Enrollment rates at four-year institutions follow a similar pattern to those measured using the ACS for both men and women. Specifically, enrollment rates in boom counties decreased for several years relative to their synthetic control, this pattern reversing with the slow in fracking production. Although less pronounced, the enrollment and graduation rates at two-year institutions appear to move in tandem with fracking production during a boom as well.

Taken together, the evidence suggests that county-specific fracking booms acted to decrease college enrollments rates for both men and women, with the effects being relatively larger in magnitude for men. These negative effects on enrollment are driven primarily by decreases in enrollment rates at four-year institutions. Indeed, the evidence is suggestive that individuals, especially women, may have substituted away from four-year institutions and attended two-year institutions in these boom counties.

My findings complement those from Charles et al. (2018) on the housing boom and bust. Similar to Charles et al. (2018), I find that within areas experiencing a boom, college enrollment declines only temporarily. They find, however, that the effects of the housing boom on college enrollment are concentrated at two-year institutions. Apparently the source, locations, and type of industry-specific economic booms matter for their effect on educational attainment. The human capital required for jobs in the oil and gas industry can be highly specialized, and although many jobs related to construction, drilling, and extraction of oil and gas do not require a formal degree, a certificate or two-year degree can increase the likelihood of employment as well as the compensation associated with employment.

## 6.2 College Educational Attainment - Affected Cohorts

The transitory effect of fracking on enrollment rates within a county is not indicative of whether those that substituted away from college remained out of college or eventually attended. To analyze whether fracking had enduring effects on educational attainment, I redefine my sample to include only individuals aged 16 to 19 at the start of a boom, and then follow these cohorts as they age over the boom cycle. I choose these cohorts because they are of prime college going ages during the rapid increase in production phase of a boom.

The results in Table 4 show that on average over the ten year period following the start of a boom, men and women of these cohorts are less likely to enroll in college in boom counties relative to synthetic control counties. Figures 17 and 18 capture the dynamic effects of the fracking boom on enrollment and educational attainment of men and women from these cohorts. As these individuals age, they are less likely to enroll in college regardless of living in a boom county or not. On a given year during the peak years of a boom however, men and women in boom counties are significantly less likely to be enrolled than their counterparts in the synthetic control counties. Men and women aged 16 to 19 at the start of the boom are less likely to be enrolled throughout the duration of the boom, and no more likely to be enrolled after the boom. Following a drop in enrollment, one might expect to see fewer years of educational attainment as these cohorts age. Although the effects of the fracking boom on educational attainment are imprecisely estimated, I find evidence that these individuals end up with fewer years of completed schooling than they otherwise would have absent the fracking boom. Taken together, these results suggest that the effects of fracking on these affected cohorts appear to be permanent, despite the transitory nature of the booms.

## 6.3 Mechanisms

### 6.3.1 Shocks to Local Labor Demand

I find strong evidence consistent with my theoretical model's prediction that increasing the opportunity cost of attending college and decreasing the relative returns to college will reduce educational attainment. The opportunity cost of going to college refers to the potential foregone earnings of a worker without a college degree, which I measure using the average annual earnings of non-college-educated individuals. As a measure of the expected future college premium, I use the ratio of average annual earnings of college to non-college-educated workers. In this section I provide evidence that both the demand for college-educated and non-college-educated labor increased in fracking boom counties, with the shock to non-college-educated labor being relatively larger than to college-educated labor. This implies that there was not only an increase in the opportunity cost of going to college, but that the expected future college premium decreased in these areas. Both of these findings are consistent with the findings related to educational attainment in the previous section.

Table 5 reports separately for both men and women, the average effects of fracking, $\bar{\alpha}$, on average annual earnings and the jobs-to-population ratio. The fracking boom increased male earnings by a substantial 15.5 percent, and female earnings by about 6.5 percent. The effect is larger for non-college-educated men and women (16.2 and 9.4 percent) than for college-educated men and women (11.3 and 5.3 percent). The average earnings for non-college-educated workers in the sample is $33,745. Therefore, average earnings of non-college-educated workers increased by an average of nearly $5,500 per year over the ten years following the start of a boom. The fracking boom also increased the jobs-to-population ratio for men and women, with the effect again being larger in magnitude for men (13 percent) than for women (3.1 percent). These effects on employment were also especially large for non-college-educated workers relative to college-educated workers, regardless of gender.

Figures 19, 20, and 21 show the trends in the natural log of average annual earnings and the natural log of the jobs-to-population ratio of all, college-educated, and non-college-educated male workers in fracking boom counties and their synthetic controls, as well as the lead and lag specific effects of fracking, $\bar{\alpha}_l$, on these two outcomes. For all three groups of men, the effect on earnings increased steadily for the first five years following the boom, then remained relatively constant at that level over the remaining five years. The figures indicate that there was a boom in male employment that moved congruent with the boom in fracking production; increasing substantially for about five years, then decreasing over the following couple of years. Here again we see that in each period during the treatment period, the lag specific effects on earnings and employment are relatively larger for non-college-educated males than college-educated males. Though less pronounced, similar dynamic effects can be seen for women in Figures 22, 23, and 24. One exception in Figure 23 is the null effect on the jobs-to-population ratio of college-educated women. Importantly, my measures of earnings and employment of college-educated individuals refer to those with at least a bachelor's degree. Thus, this null result is not necessarily surprising given the observed increase in female two-year college enrollment rates in these counties.

The effects of the fracking boom on earnings and employment were consistently larger for non-college-educated workers than college-educated workers. In Table 6 and Figures 25 and 26, I look directly at the overall average effect of the fracking boom, $\bar{\alpha}$, on the college premium and college-to-non-college-educated employment ratio. I find that due to the fracking boom, the male college premium decreased by 6.7 percent and the male employment ratio decreased by 10.7 percent. The female college premium and college-to-non-college employment ratio also decreased, though the effects are again less pronounced. In addition to the considerable increase in the opportunity cost of going to college, the reduction in the expected future returns of a college degree disincentivized investment in a college education.

My theoretical model provides guidance on how to identify empirically the extent to which the fracking boom affected educational outcomes through these labor market channels specifically. This involved identifying two groups that experienced the same effects of fracking on the indirect costs of going to college, with only one group experiencing the opportunity cost and college premium effects of fracking. By differencing the reduced from effects across these two groups, the effects of fracking working through these two labor market channels would be identified (see Equation (5)). Although women did experience the labor market effects of fracking, these effects were consistently smaller in magnitude than the labor market effects for men. This fact, together with smaller-in-magnitude effects of fracking on educational outcomes of women compared to men provide convincing evidence that an increase in the opportunity cost of going to college, as well as a reduction in the expected future college premium are important channels through which fracking affected college educational outcomes.

#### 6.3.2 Migration

One important alternative is that my estimated effects are simply picking up a change in the composition of the population due to in-migration. By restricting the ACS sample to individuals aged 18 to 26, I remove the possibility that my estimated effects are being driven by individuals not of the common college going ages. Suppose however, that there is a group of individuals aged 18 to 26 who moved into fracking boom counties as a result of the boom. Suppose further that these individuals would not have attended college even if there was no boom. If these individuals migrated from potential control counties, then all else equal the proportion of individuals enrolled in the boom county would decrease and the proportion of individuals enrolled in the potential control county would increase. To identify the extent to which changes in the composition of the population influence my estimated effects, I restrict the ACS sample further to only include individuals who reported not having moved since prior to any fracking boom. By restricting the sample in this way, I identify the effects of fracking on the college educational attainment decisions of long-term residents of the boom counties, compared to those of the long-term residents of the potential control counties.

Figures 27 and 28 show trends in the proportion of long-term resident men and women aged 18 to 26 enrolled and graduated in boom counties and their synthetic control counties, as well as the lead and lag specific effects of fracking, $\bar{\alpha}_l$, on these outcomes. In fracking boom counties, the proportion of long-term resident men and women enrolled in college decreased by 4.7 and 2.4 percentage points, respectively, relative to their synthetic controls over a ten year period following the start of the boom (see Table 7). These overall average effects on college enrollment, as well as the dynamic effects are very similar to those from the unrestricted sample of all individuals aged 18 to 26. The average and dynamic effects of fracking on graduation rates are also very similar between the restricted sample of long-term residents and the unrestricted sample. Table 4, Figure 29, and Figure 30 also show that the average and dynamic effects of fracking on the educational outcomes of long-term residents aged 16 to 19 at the start of the boom are very similar to those from the unrestricted sample of all individuals aged 16 to 19 at the start of the boom. This evidence supports the conclusion that previous results are not simply a reflection of changes in the composition of the population as the booms in fracking unfolded, but rather a consequence of fracking booms influence on individuals' decisions to attend college.

# 7 Conclusion

To identify the ways that the fracking boom has affected educational attainment, I use a comprehensive data set of oil and natural gas production to identify which counties experienced a boom and in what year the boom began in each county. I then use the synthetic control method to estimate the average and dynamic effects of these county-specific fracking booms on college investment decisions. I find that a boom in fracking production within a county causes a reduction in college enrollment, with the effect being concentrated among individuals at four-year institutions. Although the decline in college enrollment during a boom was generally reversed as fracking production slowed in a county, college attainment remained persistently low for cohorts in their early 20s during the rise and peak of a boom.

My theoretical model illustrates mechanisms through which the fracking boom would affect educational outcomes. I find evidence in support of that model's predictions. A boom in fracking production increases the earnings and employment of both non-college and college-educated workers, with relatively larger effects for non-college-educated workers. The fracking booms thus not only increase the opportunity cost of additional years of schooling, but also decrease the expected relative returns to additional years of schooling.

The literature on resource and other localized economic booms suggest a variety of plausible causal links to educational attainment. Although I focus primarily on the college premium, two other relevant routes are migration and changes in parental and government resources. The estimated effects of the fracking boom on college educational attainment in this paper are not being driven by changes in the composition of the population. Instead, I find that fracking decreased college investment of long-term residents in boom counties by increasing the opportunity cost of, and decreasing the relative returns to, schooling. If fracking did result in more financial resources for education, then that does not dominate the effects of the increased opportunity cost of education.

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## Table 1: Boom County Event Years

| County | State | Event Year | County | State | Event Year |
|---|---|---|---|---|---|
| Conecuh | AL | 2008 | Seminole | OK | 2003 |
| Cleburne | AR | 2009 | Stephens | OK | 2010 |
| Conway | AR | 2006 | Washita | OK | 2005 |
| Faulkner | AR | 2006 | Bradford | PA | 2009 |
| Van Buren | AR | 2006 | Clinton | PA | 2007 |
| White | AR | 2005 | Tioga | PA | 2009 |
| Garfield | CO | 2003 | Harding | SD | 2003 |
| Rio Blanco | CO | 2005 | Andrews | TX | 2009 |
| Bossier | LA | 2006 | Borden | TX | 2003 |
| Caddo | LA | 2006 | Calhoun | TX | 2002 |
| Cameron | LA | 2003 | Colorado | TX | 2009 |
| De Soto | LA | 2006 | Denton | TX | 2003 |
| Evangeline | LA | 2007 | Ector | TX | 2006 |
| Lafourche | LA | 2003 | Freestone | TX | 2000 |
| Plaquemines | LA | 2002 | Frio | TX | 2009 |
| Red River | LA | 2006 | Gaines | TX | 2009 |
| St Mary | LA | 2003 | Grimes | TX | 2003 |
| Vermilion | LA | 2001 | Hardeman | TX | 2000 |
| Webster | LA | 2001 | Harrison | TX | 2006 |
| Jasper | MS | 2003 | Hemphill | TX | 2006 |
| Lincoln | MS | 2003 | Jack | TX | 2003 |
| Wayne | MS | 2006 | Jasper | TX | 2006 |
| Blaine | MT | 2003 | Jefferson | TX | 2005 |
| Dawson | MT | 2001 | Johnson | TX | 2003 |
| Fallon | MT | 2003 | Leon | TX | 2005 |
| Richland | MT | 2003 | Lipscomb | TX | 2003 |
| Roosevelt | MT | 2008 | Live Oak | TX | 2009 |
| Sheridan | MT | 2003 | Montague | TX | 2009 |
| Wibaux | MT | 2003 | Nacogdoches | TX | 2007 |
| Eddy | NM | 2009 | Ochiltree | TX | 2009 |
| Rio Arriba | NM | 2006 | Orange | TX | 2000 |
| Billings | ND | 2009 | Panola | TX | 2009 |
| Bottineau | ND | 2009 | Parker | TX | 2003 |
| Bowman | ND | 2003 | Pecos | TX | 2012 |
| Burke | ND | 2009 | Roberts | TX | 2009 |
| Divide | ND | 2008 | Robertson | TX | 2001 |
| Dunn | ND | 2009 | Rusk | TX | 2009 |
| Golden Valley | ND | 2009 | San Augustine | TX | 2006 |
| Grand Forks | ND | 2009 | Shelby | TX | 2006 |
| McLean | ND | 2007 | Terry | TX | 2005 |
| Mountrail | ND | 2007 | Tyler | TX | 2003 |
| Renville | ND | 2003 | Ward | TX | 2009 |
| Stark | ND | 2008 | Webb | TX | 2009 |
| Williams | ND | 2009 | Willacy | TX | 2000 |
| Blaine | OK | 2012 | Wise | TX | 2003 |
| Canadian | OK | 2009 | Carbon | UT | 2007 |
| Carter | OK | 2009 | Duchesne | UT | 2009 |
| Coal | OK | 2005 | Uintah | UT | 2009 |
| Dewey | OK | 2008 | Upshur | WV | 2006 |
| Ellis | OK | 2007 | Carbon | WY | 2003 |
| Hughes | OK | 2003 | Hot Springs | WY | 2003 |
| Johnston | OK | 2009 | Park | WY | 2003 |
| Marshall | OK | 2009 | Sublette | WY | 2003 |
| Pittsburg | OK | 2006 | Sweetwater | WY | 2009 |

*Notes*: The event year for each county is defined as the year in the sample in which fracking increased the most over the following five year period.

Table 2: Descriptive Statistics

| | Fracking Boom Counties | | | Non-Fracking Counties | | |
|---|---|---|---|---|---|---|
| | Mean | S.D. | Median | Mean | S.D. | Median |
| **ACS** | | | | | | |
| Prop. Enrolled (%) | 33.8 | 12.6 | 33.7 | 37 | 16.2 | 18 |
| Prop. Graduated (%) | 7.5 | 4.2 | 7.2 | 8.7 | 5.6 | 8.1 |
| Observations: | | 1,404 | | | 16,412 | |
| **IPEDS** | | | | | | |
| Two-Year Colleges | | | | | | |
| Enrollment Rate (%) | 15.6 | 15.2 | 10 | 9.6 | 19.7 | 5.2 |
| Graduation Rate (%) | 4.5 | 4.5 | 2.9 | 3.2 | 6.4 | 1.2 |
| Observations: | | 475 | | | 6,948 | |
| Four-Year Colleges | | | | | | |
| Enrollment Rate (%) | 13.6 | 8.6 | 14.4 | 13.1 | 10.6 | 10.8 |
| Graduation Rate (%) | 5.3 | 4.3 | 4 | 6.1 | 4.8 | 4.8 |
| Observations: | | 280 | | | 6,717 | |
| **QWI** | | | | | | |
| All Workers | | | | | | |
| Ave. Earnings | 34,077 | 6,557 | 33,158 | 32,585 | 6,887 | 31,253 |
| Jobs/Population | .333 | .120 | .308 | .340 | .127 | .327 |
| Non-college Workers | | | | | | |
| Ave. Earnings | 30,207 | 6,489 | 28,904 | 27,375 | 4,350 | 26,890 |
| Jobs/Population | .135 | .052 | .124 | .130 | .043 | .127 |
| College Workers | | | | | | |
| Ave. Earnings | 50,278 | 10,058 | 49,869 | 50,496 | 11,117 | 48,555 |
| Jobs/Population | .056 | .020 | .053 | .066 | .038 | .056 |
| Observations: | | 1,916 | | | 22,520 | |
| **Population Characteristics** | | | | | | |
| Prop. Male (%) | 50.3 | 2 | 49.7 | 49.8 | 2 | 49.5 |
| Prop. White Male (%) | 85.7 | 13.2 | 90.9 | 85.9 | 16.3 | 93 |
| Prop. White Female (%) | 85.7 | 14 | 91.8 | 85.8 | 17.3 | 93.9 |
| Prop. Male Aged 20 to 34 (%) | 18.7 | 3.4 | 18.4 | 18.6 | 4.2 | 17.9 |
| Prop. Female Aged 20 to 34 (%) | 17 | 3.1 | 17.1 | 17.2 | 3.5 | 16.8 |
| Observations: | | 1,916 | | | 22,520 | |

*Notes*: The unit of observation is county-year. Average annual earnings are in 2010 dollars. Data sources: 2005-2017 American Community Survey (ACS), 2000-2016 Integrated Postsecondary Education Data System (IPEDS), 2000-2016 Quarterly Workforce Indicators (QWI), and the 2000-2017 U.S. Census Population Estimates.

Table 3: Overall Average Effects of Fracking on Educational Outcomes

| | ACS | | IPEDS | | | |
|---|---|---|---|---|---|---|
| | Proportion Enrolled (1) | Proportion Graduated (2) | Four-Year Enrollment Rate (3) | Four-Year Graduation Rate (4) | Two-Year Enrollment Rate (5) | Two-Year Graduation Rate (6) |
| ***Panel A.* Males** | | | | | | |
| Average Effect $\bar{\alpha}$ (p.p.) | -4.69 | -0.71 | -1.30 | -0.02 | 0.50 | 0.52 |
| 95% Confidence Interval | [-7.01,-1.69] | [-1.25,0.43] | [-3.03,0.01] | [-0.62,0.54] | [-0.57,1.13] | [-0.55,1.15] |
| Baseline Average (%) | 37.60 | 7.72 | 11.23 | 5.27 | 9.71 | 3.05 |
| ***Panel B.* Females** | | | | | | |
| Average Effect $\bar{\alpha}$ (p.p.) | -3.87 | -0.13 | -2.02 | 0.15 | 1.15 | 0.96 |
| 95% Confidence Interval | [-6.43,-1.16] | [-0.89,1.34] | [-5.07,1.29] | [-0.88,0.83] | [0.52,1.70] | [0.33,1.51] |
| Baseline Average (%) | 44.61 | 12.46 | 13.50 | 7.34 | 10.81 | 3.36 |

*Notes*: This table reports overall average effects of fracking on educational outcomes ($\bar{\alpha}$), measured in percentage points (p.p.), from equation (13). The 95 percent confidence intervals are estimated using equation (15) following the steps outlined in section 5.3. Also reported are the baseline average values, measured in percentages, of the various educational outcome variables. Data sources: 2005-2017 American Community Survey (ACS) and 2000-2016 Integrated Postsecondary Education Data System (IPEDS).

Table 4: Overall Average Effects of Fracking on Educational Outcomes (Individuals Aged 16 to 19 at the Start of the Boom)

| | *Prop. Enrolled*$_{cy}$ | | *Educational Attainment*$_{cy}$ (*Years Completed*) | |
|---|---|---|---|---|
| | Males | Females | Males | Females |
| | (1) | (2) | (3) | (4) |
| ***Panel A.* All Individuals** | | | | |
| Average Effect $\bar{\alpha}$ | -3.92 | -3.67 | -0.11 | -0.10 |
| 95% Confidence Interval | [-5.51,-1.70] | [-5.42,-1.78] | [-0.31,0.29] | [-0.30,0.28] |
| Baseline Average | 55.08 | 59.96 | 11.14 | 11.44 |
| ***Panel B.* Long-Term Residents** | | | | |
| Average Effect $\bar{\alpha}$ | -3.63 | -2.66 | -0.16 | -0.11 |
| 95% Confidence Interval | [-5.20,-1.59] | [-4.34,-0.71] | [-0.38,0.23] | [-0.32,0.24] |
| Baseline Average | 55.83 | 61.11 | 11.07 | 11.40 |

*Notes*: This table reports overall average effects of fracking on college enrollment and educational attainment $\bar{\alpha}$, measured in percentage points and years of completed education, from equation (13). Long-term residents are those who have been in the same residence since prior to any boom in fracking production. The 95 percent confidence intervals are estimated using equation (15) following the steps outlined in section 5.3. Also reported are the baseline average values of college enrollment and educational attainment, measured in percentages and years of completed education. Data source: 2005-2017 American Community Survey.

Table 5: Overall Average Effects of Fracking on Labor Market Outcomes

| | *Average Annual Earnings$_{cy}$* | | | *Jobs/Population$_{cy}$* | | |
|---|---|---|---|---|---|---|
| | All | College Educated | Non-College Educated | All | College Educated | Non-College Educated |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| ***Panel A.* Males** | | | | | | |
| Average Effect $\bar{\alpha}$ (%Δ) | 15.47 | 11.32 | 16.18 | 12.99 | 6.46 | 15.54 |
| 95% Confidence Interval | [14.04,16.82] | [9.27,12.95] | [14.93,17.50] | [11.37,16.37] | [5.29,10.03] | [13.64,18.82] |
| Baseline Average | 39,639 | 62,349 | 33,745 | 0.34 | 0.062 | 0.14 |
| ***Panel B.* Females** | | | | | | |
| Average Effect $\bar{\alpha}$ (%Δ) | 6.47 | 5.32 | 9.40 | 3.07 | -1.26 | 5.51 |
| 95% Confidence Interval | [5.23,7.39] | [3.74,6.08] | [7.93,10.25] | [2.11,5.71] | [-1.92,1.93] | [4.37,8.32] |
| Baseline Average | 25,353 | 38,227 | 21,121 | 0.33 | 0.033 | 0.12 |

*Notes*: This table reports overall average effects of fracking, $\bar{\alpha}$ from equation (13), on the average annual earnings (measured in 2010 dollars) and jobs-to-population ratios of all, college educated, and non-college educated men and women. The 95 percent confidence intervals are estimated using equation (15) following the steps outlined in section 5.3. Also reported are the baseline average values of the average annual earnings and the jobs-to-population ratios for each group. Data source: 2000-2016 Quarterly Workforce Indicators.

Table 6: Overall Average Effects of Fracking on the College Premium and the College-to-Non-College Educated Employment Ratio

| | *College Premium*$_{cy}$ | | *College / Non College Employment*$_{cy}$ | |
|---|---|---|---|---|
| | Males | Females | Males | Females |
| | (1) | (2) | (3) | (4) |
| Average Effect $\bar{\alpha}$ (%Δ) | -6.70 | -1.94 | -10.74 | -7.39 |
| 95% Confidence Interval | [-6.31,-9.94] | [-1.88,-4.24] | [-11.53,-8.53] | [-7.40,-4.83] |
| Baseline Average | 1.85 | 1.82 | 0.44 | 0.55 |

*Notes*: This table reports overall average effects of fracking, $\bar{\alpha}$ from equation (13), on the college premium (measured in 2010 dollars) and the employment ratio of college-to-non-college educated men and women. The 95 percent confidence intervals are estimated using equation (15) following the steps outlined in section 5.3. Also reported are the baseline average values of the college premiums and employment ratios. Data source: 2000-2016 Quarterly Workforce Indicators.

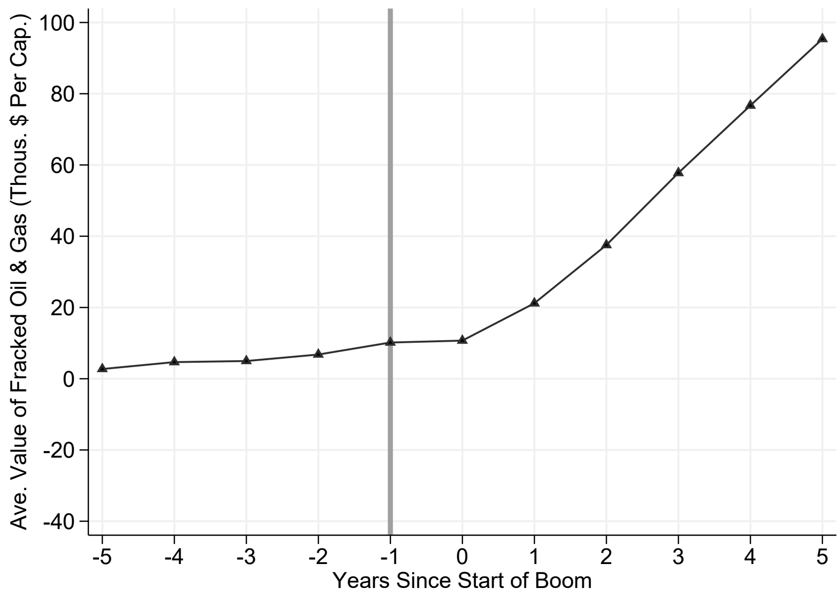
Table 7: Overall Average Effects of Fracking on Long-Term Resident Educational Outcomes

| | *Prop. Enrolled*$_{cy}$ | | *Prop. Graduated*$_{cy}$ | |
|---|---|---|---|---|
| | Males | Females | Males | Females |
| | (1) | (2) | (3) | (4) |
| Average Effect $\bar{\alpha}$ (p.p.) | -4.9 | -2.79 | -0.93 | -0.06 |
| 95% Confidence Interval | [-7.22,-1.89] | [-5.35,-0.08] | [-1.47,0.21] | [-0.82,1.41] |
| Baseline Average | 41.14 | 48.97 | 5.78 | 10.62 |

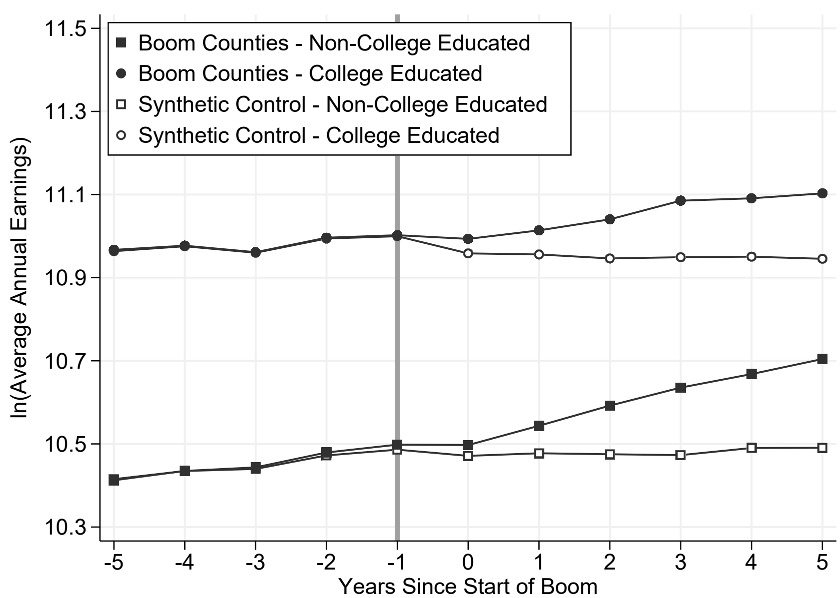
*Notes*: This table reports overall average effects of fracking on educational outcomes of long-term residents $\bar{\alpha}$, measured in percentage points (p.p.), from equation (13). Long-term residents are those who have been in the same residence since prior to any boom in fracking production. The 95 percent confidence intervals are estimated using equation (15) following the steps outlined in section 5.3. Also reported are the baseline average values, measured in percentages, of the various educational outcome variables. Data source: 2005-2017 American Community Survey.

Figure 1: Fracking Production and Earnings by Educational Attainment

(a) Average Value of Fracking Production Per Capita in Boom Counties

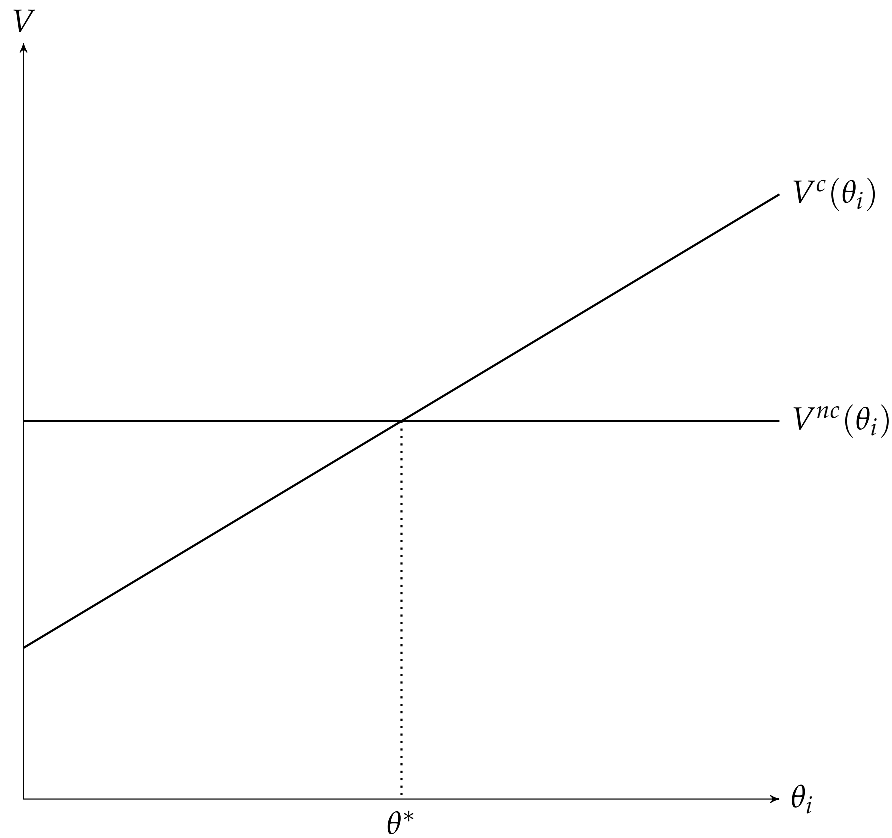



(b) Earnings by Educational Attainment in Boom Counties and Their Synthetic Controls



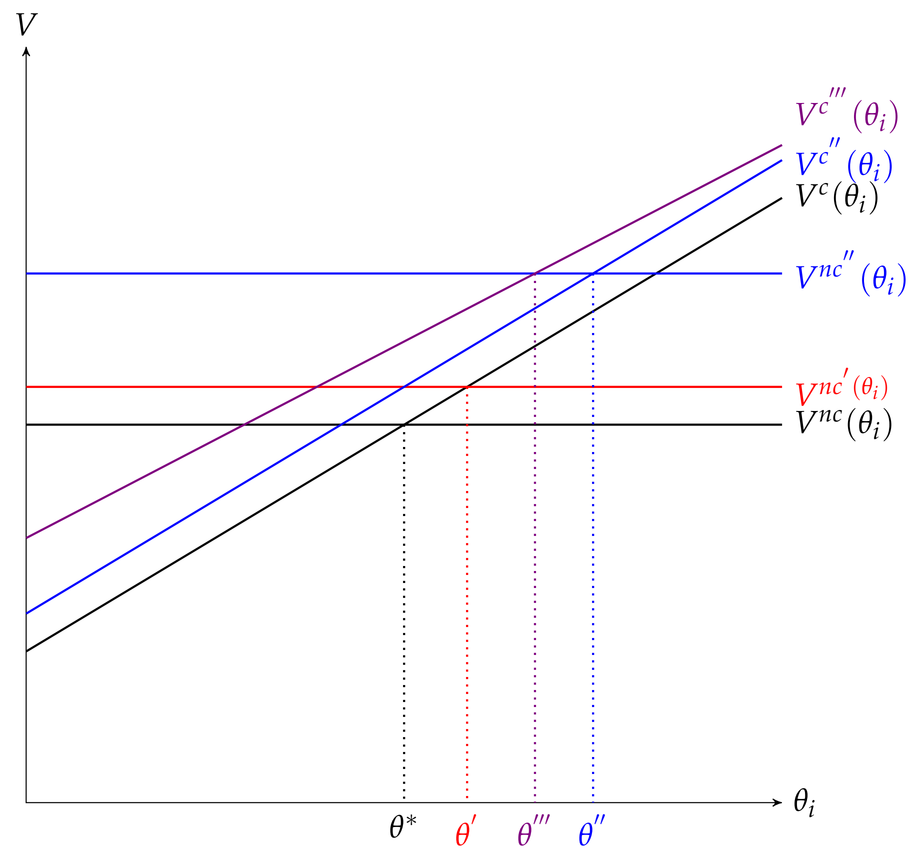

*Notes*: This figure contains the average value of fracked oil and gas production, measured in thousands of dollars per capita, in boom counties (panel (a)). Panel (b) shows the natural log of average annual earnings of non-college-educated and college-educated workers, in boom counties and their synthetic controls. The synthetic control counties are estimated according to the methodology outlined in Section 5. Data sources: DrillingInfo and the 2000-2016 Quarterly Workforce Indicators.

Figure 2: Graphical Representation of Model Equilibrium



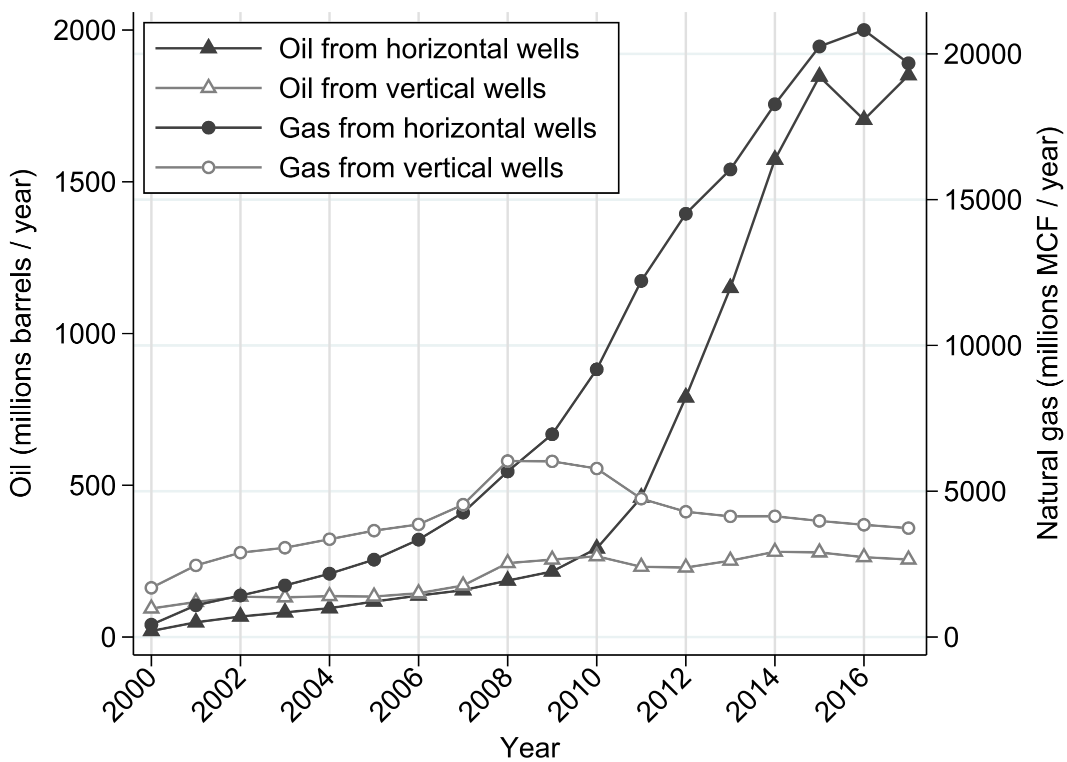

*Notes*: $\theta^*$ is the threshold ability level such that individuals with $\theta_i < \theta^*$ will not go to college, individuals with $\theta_i > \theta^*$ will go to college, and individuals with $\theta_i = \theta^*$ are indifferent between college or not.

Figure 3: Graphical Representation of Model Equilibrium with Fracking-Induced Shocks



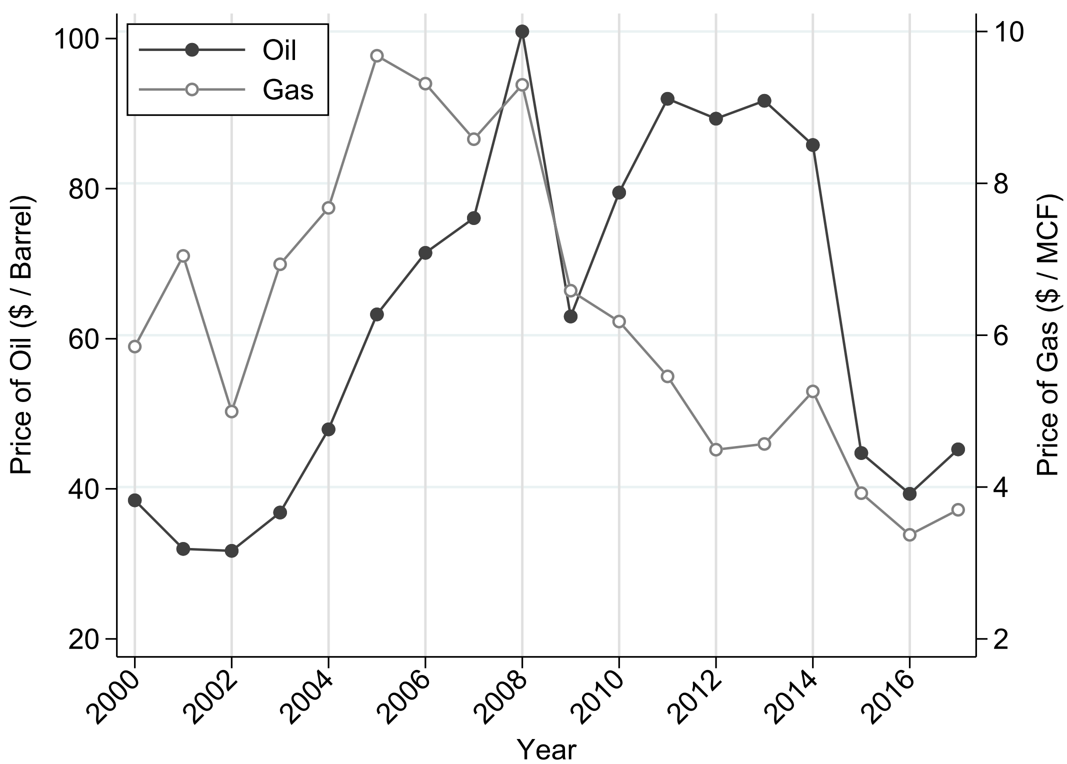

*Notes*: An increase in the opportunity cost of going to college would increase the threshold ability level to $\theta'$, resulting in fewer college attendees. A larger increase in the expected lifetime labor market income of non-graduates relative to graduates would lead to a decrease in the college income premium, further increasing the threshold ability level to $\theta''$, resulting in even fewer college attendees. A relatively larger decrease in indirect costs for low ability individuals than high ability individuals would decrease the threshold ability level to $\theta'''$.

Figure 4: U.S. Production by Drill Type



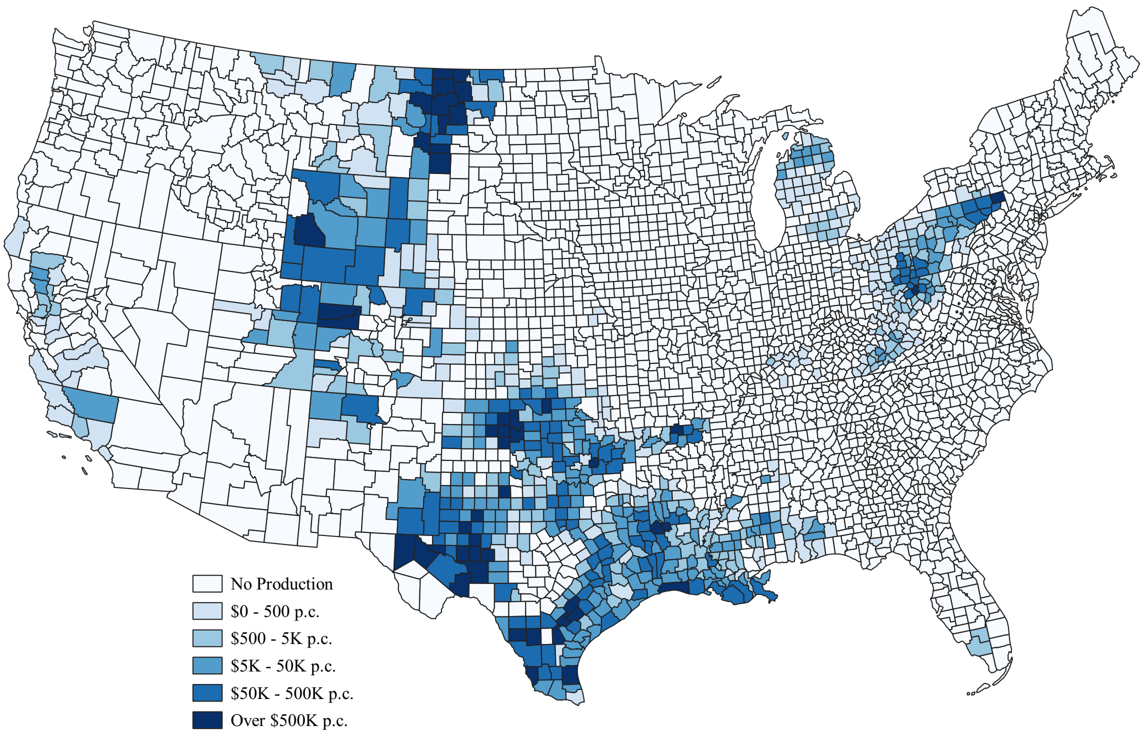

*Notes*: This figure contains yearly aggregates of oil and gas production with a drilling type of vertical or horizontal (including directional). These aggregates come from wells with first production date in the year 2000 or later. Data source: Drillinginfo.

Figure 5: Real Oil & Gas Prices



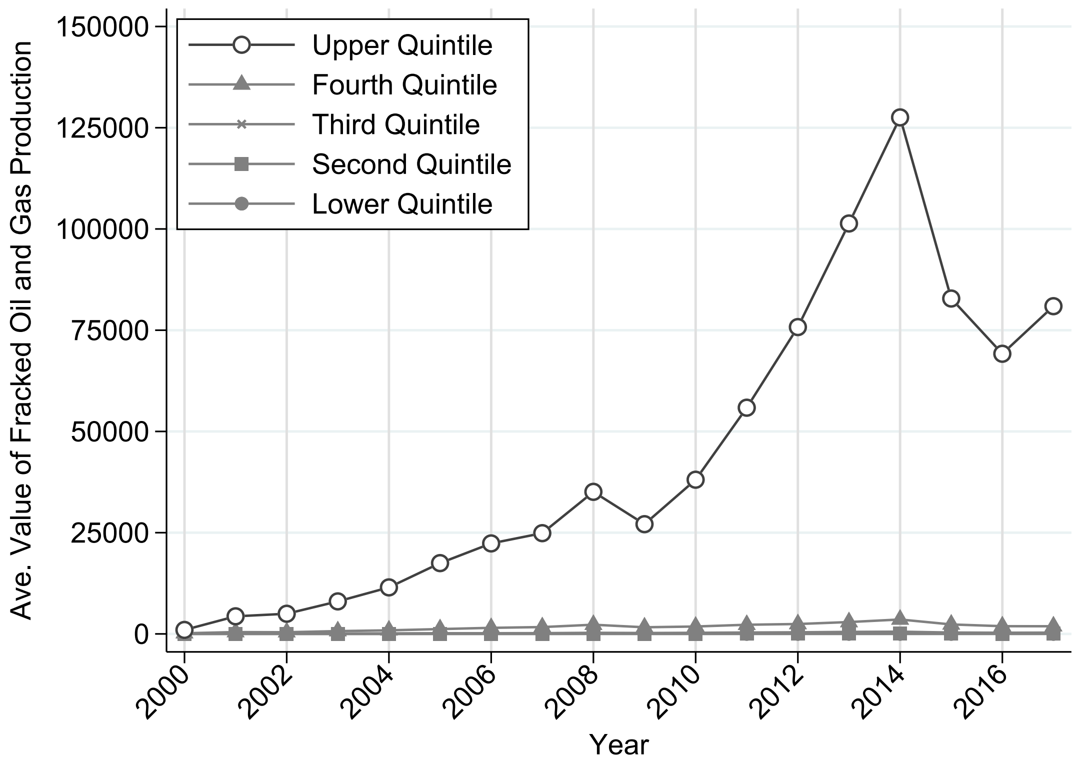

*Notes*: This figure contains average annual real prices of oil and gas production (in 2010 $). Data source: Energy Information Administration (EIA).

Figure 6: U.S. Fracking Production by County (2000 - 2017)




*Notes*: This figure contains the total value per capita of fracked oil and gas production by county from 2000 to 2017. Data source: Drillinginfo.

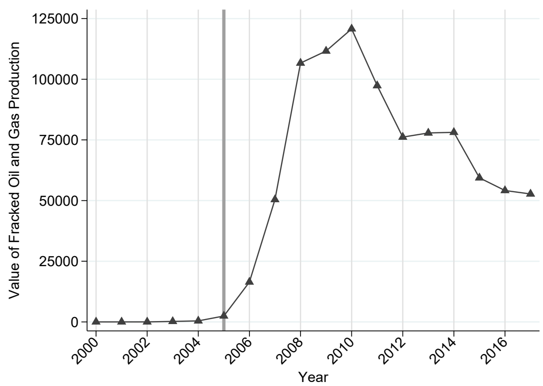
Figure 7: Annual Value of Fracked Oil and Gas Production by Quintile (2000 - 2017)



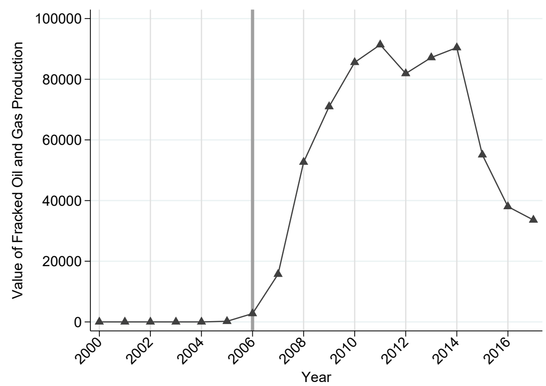

*Notes*: This figure contains the annual value of fracked oil and gas production per capita by quintile from 2000 to 2017. Data source: Drillinginfo.

Figure 8: Boom County Event Year Examples

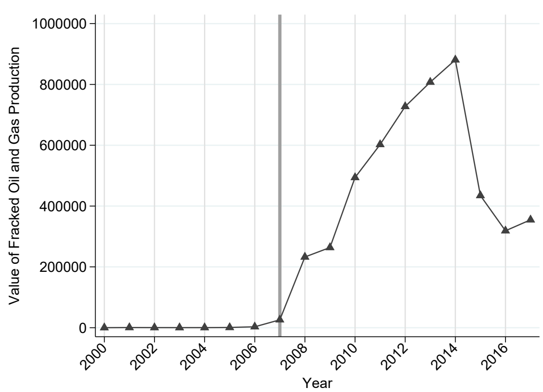
(a) Coal County, OK



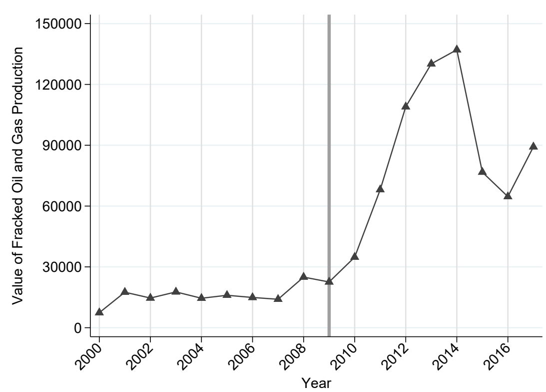

(b) Van Buren County, AR




(c) Mountrail County, ND

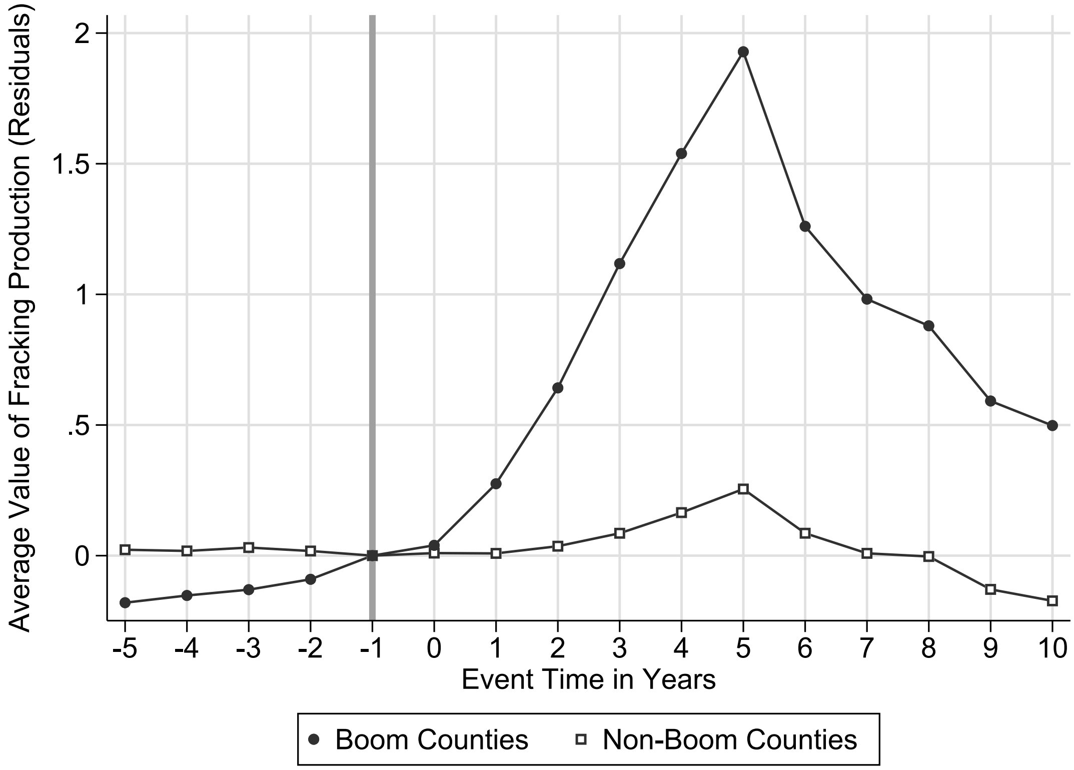



(d) Ward County, TX



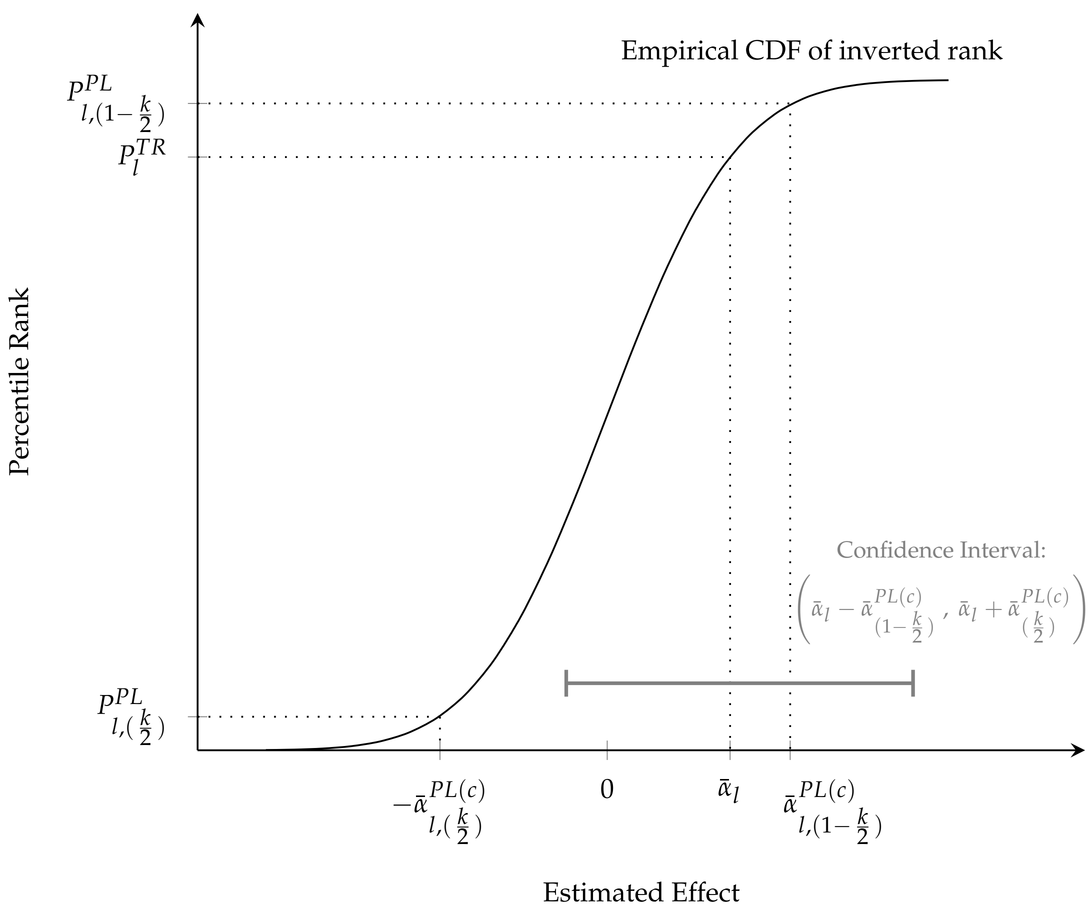

*Notes*: The vertical lines indicate the event year, defined as the year in the sample in which fracking increased the most over the following five year period. The event years for all boom counties can be found in Table 1.

Figure 9: Residual Fracking Production in Boom Counties and Non-Boom Counties




*Notes*: This figure contains the average residual value of fracked oil and gas production per capita from equation (6), in boom counties and non-boom counties. Residuals have been standardized and are shown relative to the year prior to the start of the boom. Data source: Drillinginfo.

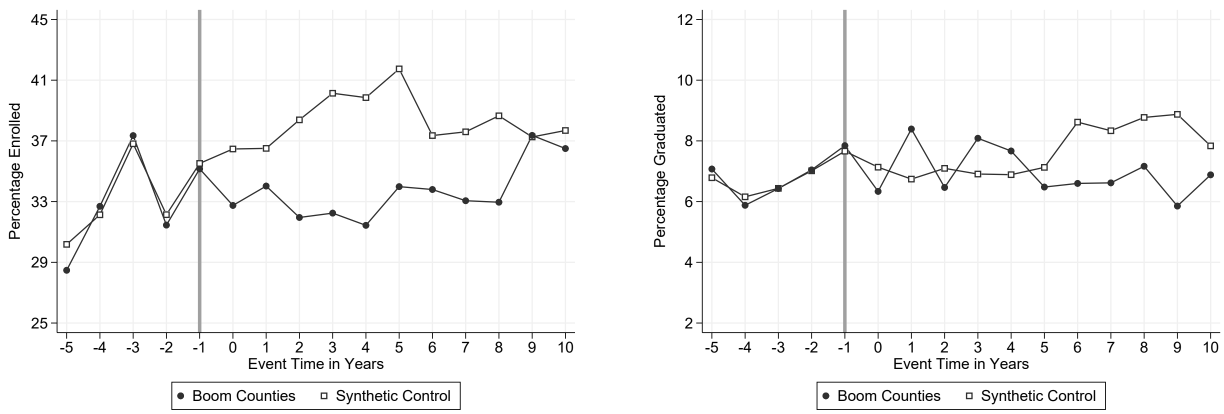
Figure 10: Formulation of Confidence Intervals by Inverting the Percentile Rank



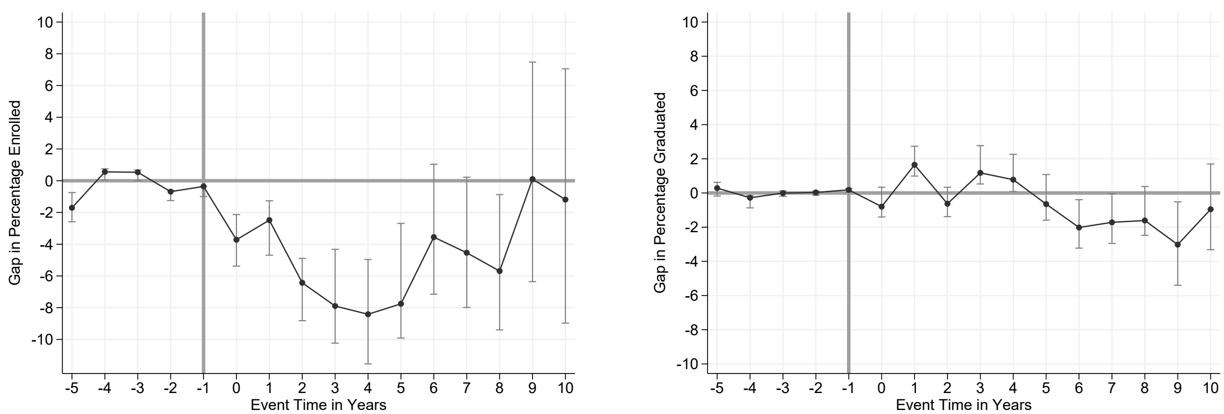

*Notes*: This figure illustrates how I calculate a $(1-k)$ percent confidence interval by inverting the percentile rank and determining for what values of $\nu$ the adjusted effect $(\bar{\alpha}_l - \nu)$ appears free from treatment. The $(1-k)$ percent confidence interval for $\bar{\alpha}_l$ is the set of $\nu$ not rejected using the critical values $\frac{k}{2}$ and $1-\frac{k}{2}$.

Figure 11: College Enrollment and Graduation Rates of Males Aged 18 to 26

(a) Trends



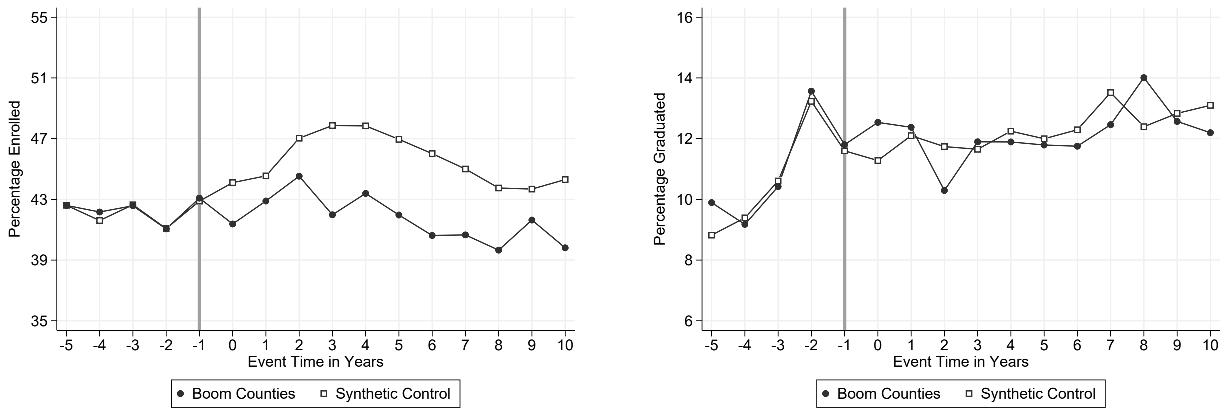

(b) Gap Between Boom Counties and their Synthetic Control



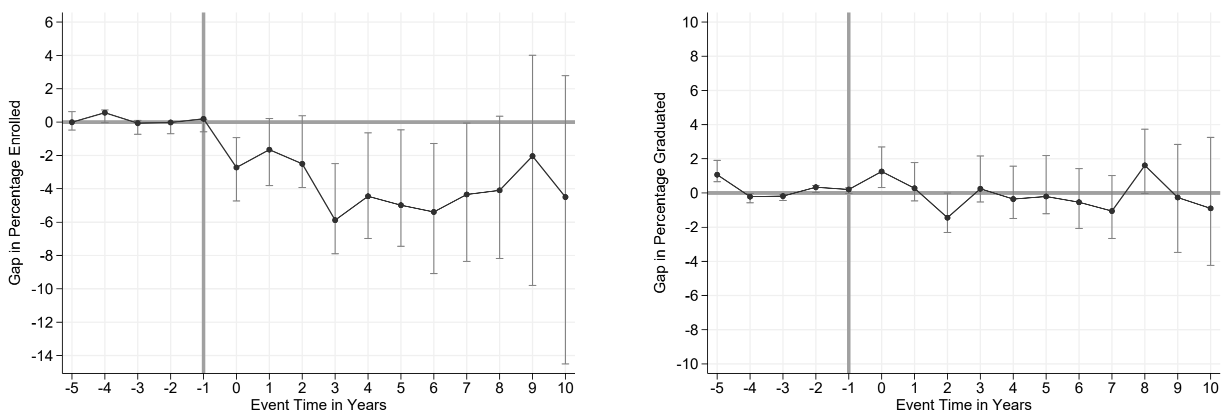

*Notes*: Panel (a) shows trends in the proportion of men enrolled in and graduated from college in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on the proportion of men enrolled in and graduated from college, $\bar{\alpha}_l$, measured in percentage points (p.p.), from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).

Figure 12: College Enrollment and Graduation Rates of Females Aged 18 to 26

(a) Trends



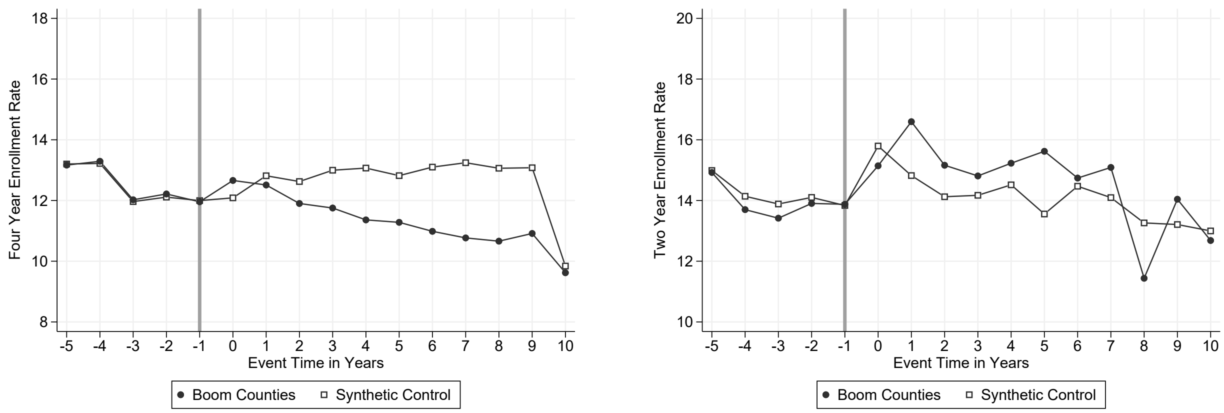

(b) Gap Between Boom Counties and their Synthetic Control



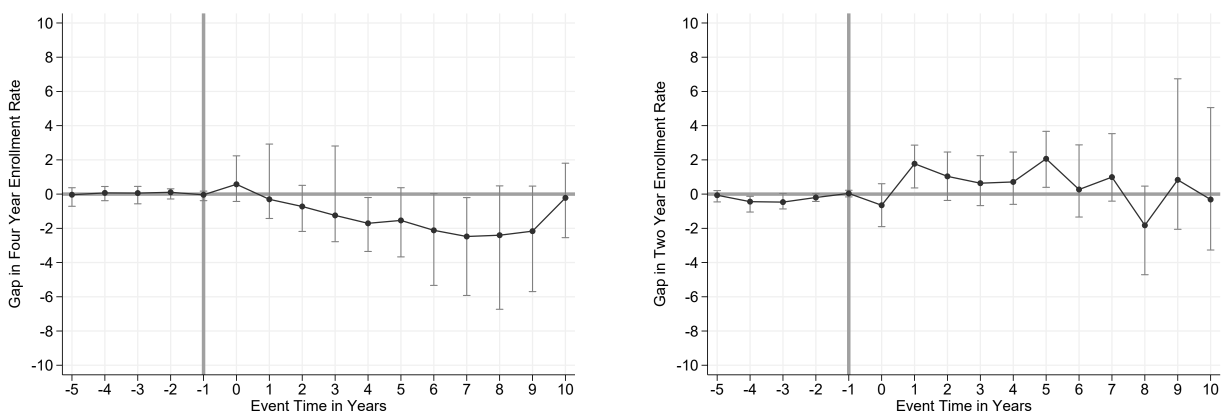

*Notes*: Panel (a) shows trends in the proportion of women enrolled in and graduated from college in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on the proportion of women enrolled in and graduated from college, $\bar{\alpha}_l$, measured in percentage points (p.p.), from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).

Figure 13: Male College Enrollment Rates by Level of Institution

(a) Trends



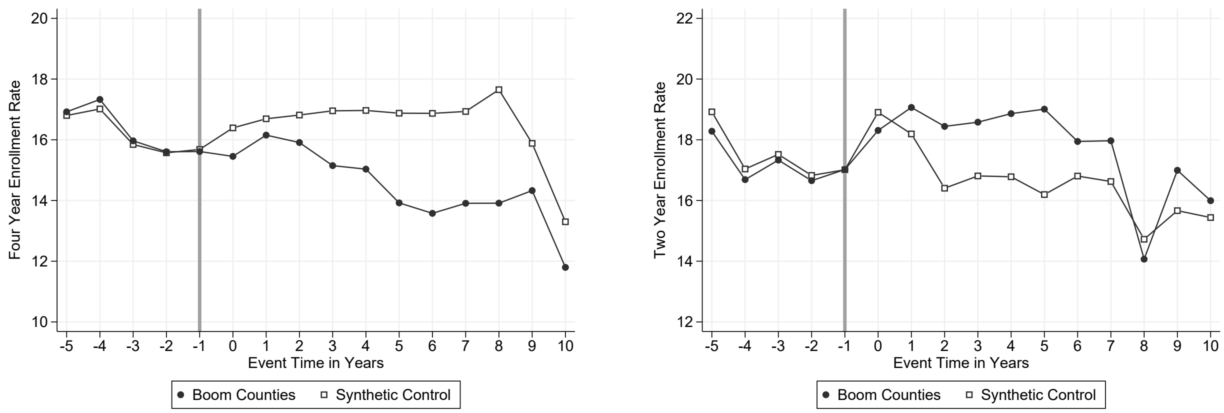

(b) Gap Between Boom Counties and their Synthetic Control



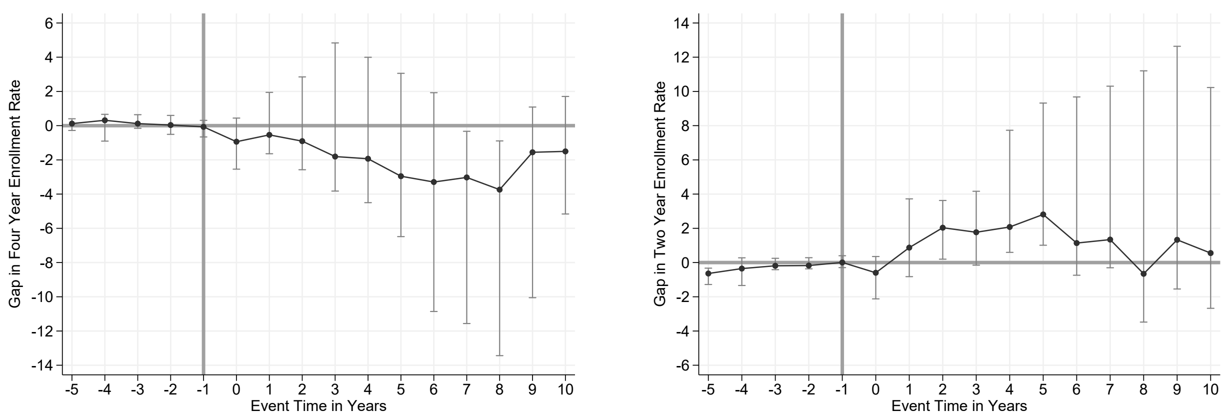

*Notes*: Panel (a) shows trends in male college enrollment rates by level of institution in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on male college enrollment rates, $\bar{\alpha}_l$, measured in percentage points, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2000-2016 Integrated Postsecondary Education Data System (IPEDS).

Figure 14: Female College Enrollment Rates by Level of Institution

(a) Trends



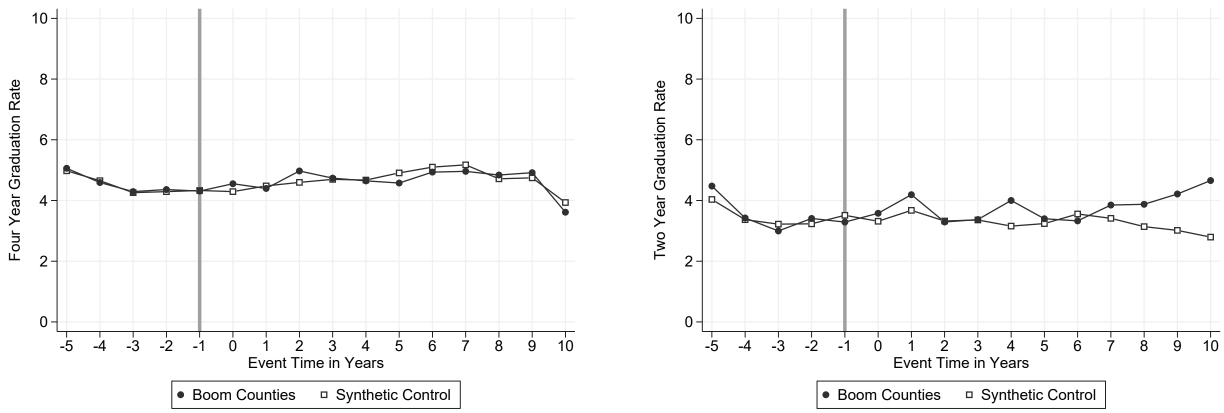

(b) Gap Between Boom Counties and their Synthetic Control



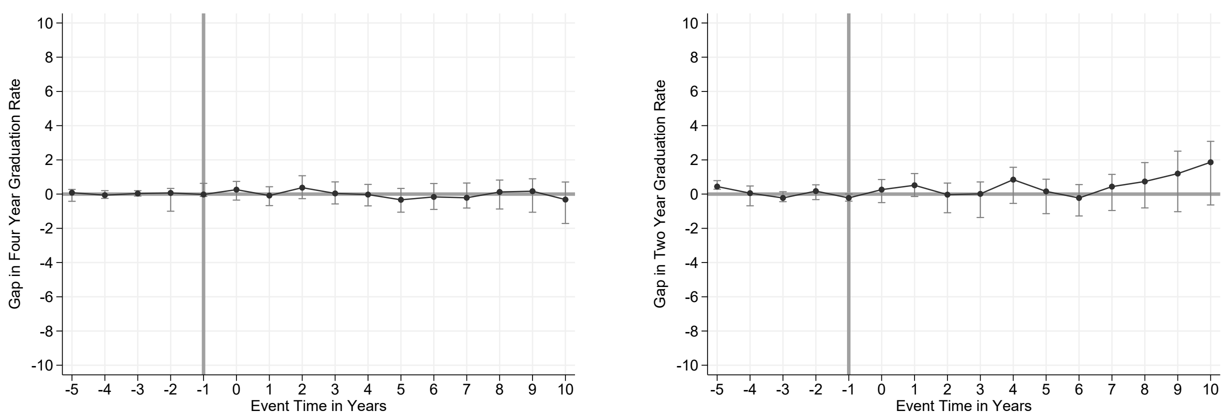

*Notes*: Panel (a) shows trends in female college enrollment rates by level of institution in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on female college enrollment rates, $\bar{\alpha}_l$, measured in percentage points, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2000-2016 Integrated Postsecondary Education Data System (IPEDS).

Figure 15: Male College Graduation Rates by Level of Institution

(a) Trends



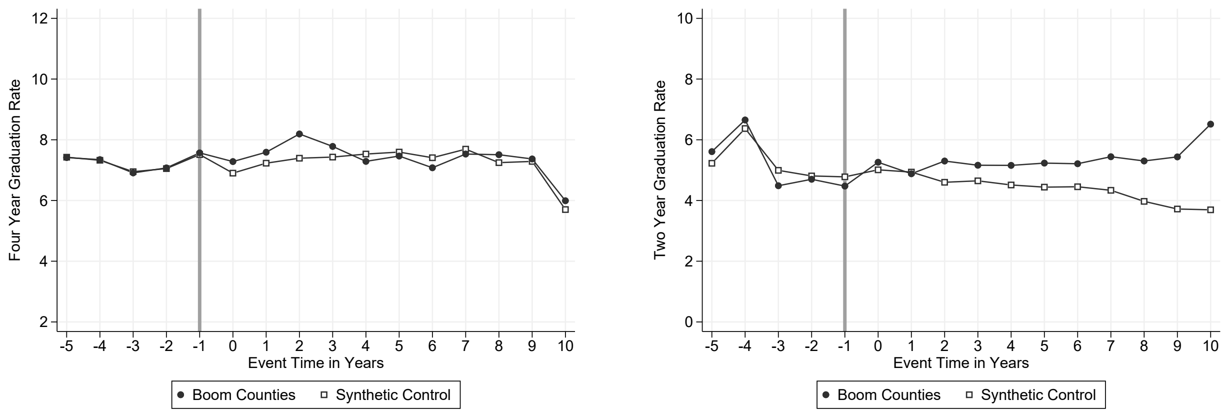

(b) Gap Between Boom Counties and their Synthetic Control



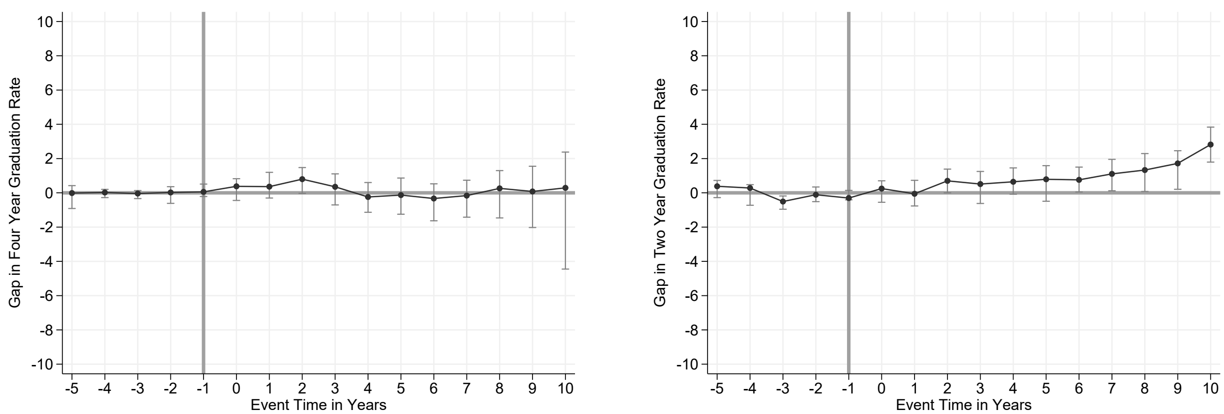

*Notes*: Panel (a) shows trends in male college graduation rates by level of institution in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on male college graduation rates, $\bar{\alpha}_l$, measured in percentage points, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2000-2016 Integrated Postsecondary Education Data System (IPEDS).

Figure 16: Female College Graduation Rates by Level of Institution

(a) Trends



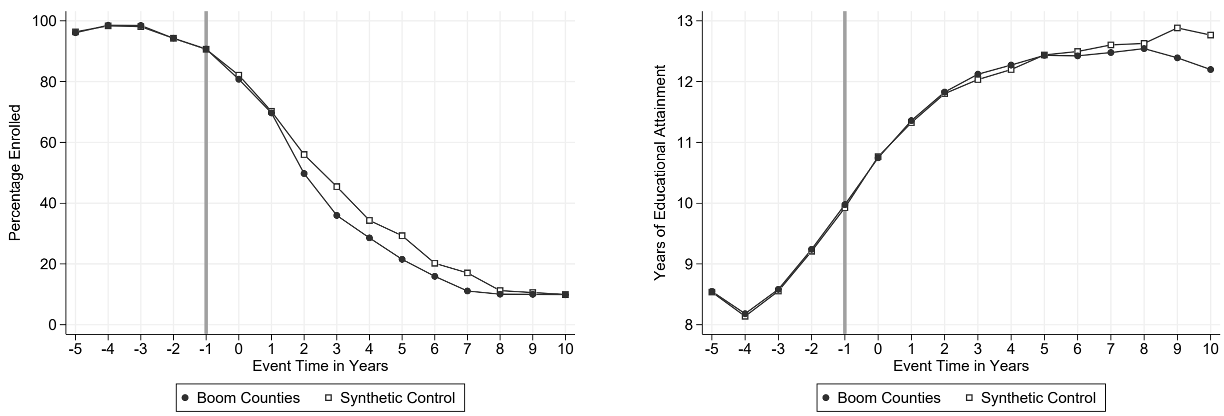

(b) Gap Between Boom Counties and their Synthetic Control



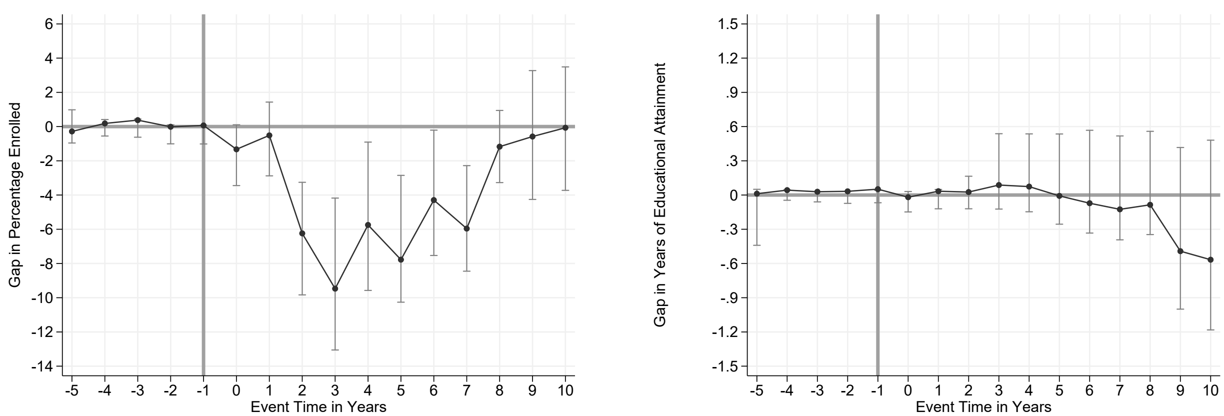

*Notes*: Panel (a) shows trends in female college graduation rates by level of institution in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on female college graduation rates, $\bar{\alpha}_l$, measured in percentage points, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2000-2016 Integrated Postsecondary Education Data System (IPEDS).

Figure 17: College Enrollment Rates and Educational Attainment of Males Aged 16 to 19 at the Start of a Boom

(a) Trends



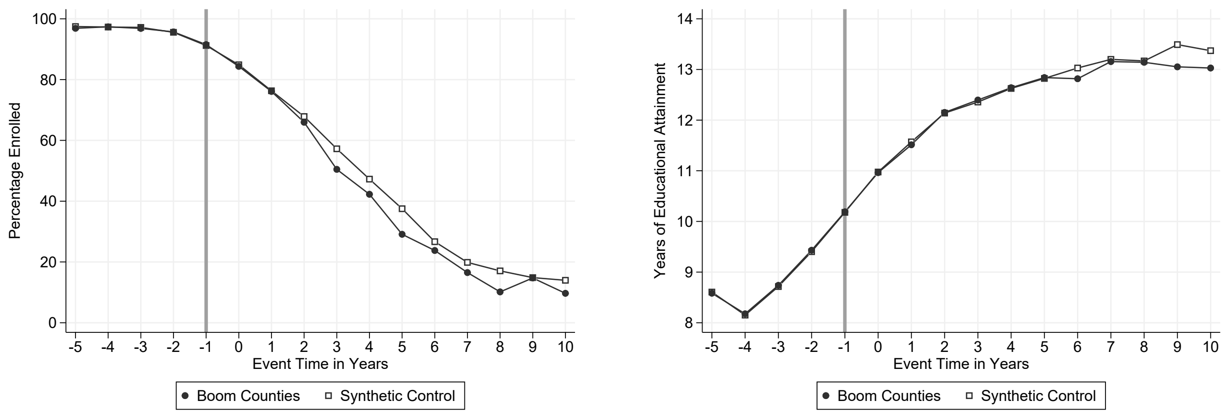

(b) Gap Between Boom Counties and their Synthetic Control



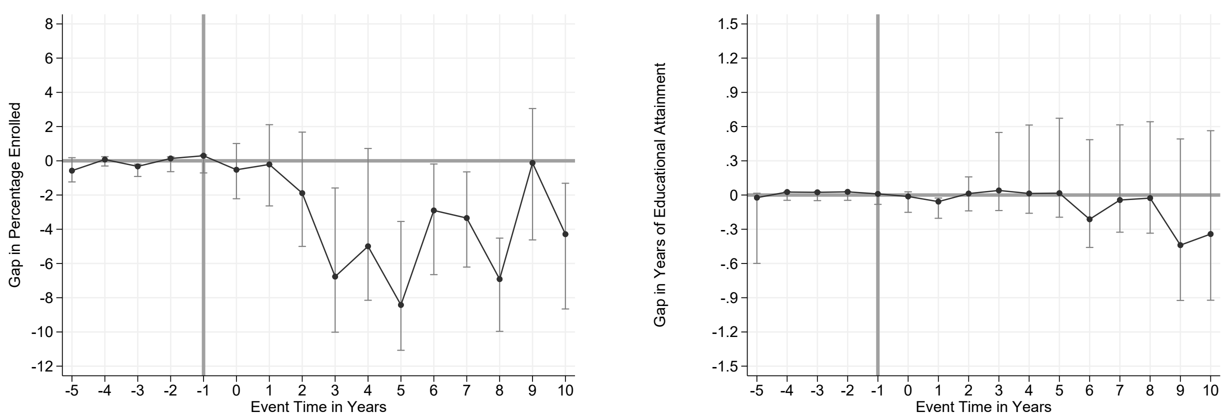

*Notes*: Panel (a) shows trends in the proportion of men aged 16 to 19 at the start of a boom enrolled in college, as well as their educational attainment, in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects, $\bar{\alpha}_l$ from equation (12), of fracking on the proportion of these men enrolled in college, measured in percentage points, as well as on their educational attainment, measured in years of completed schooling. For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).

Figure 18: College Enrollment Rates and Educational Attainment of Females Aged 16 to 19 at the Start of a Boom

(a) Trends



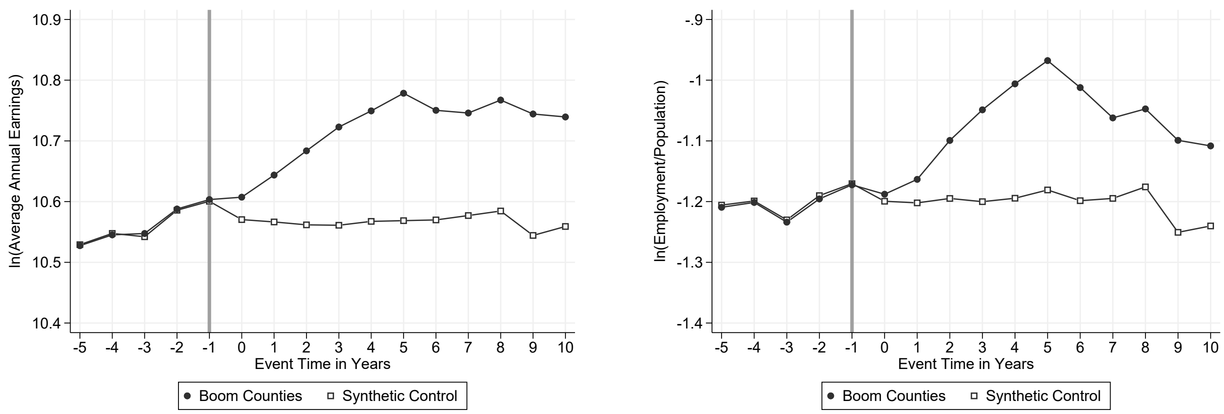

(b) Gap Between Boom Counties and their Synthetic Control



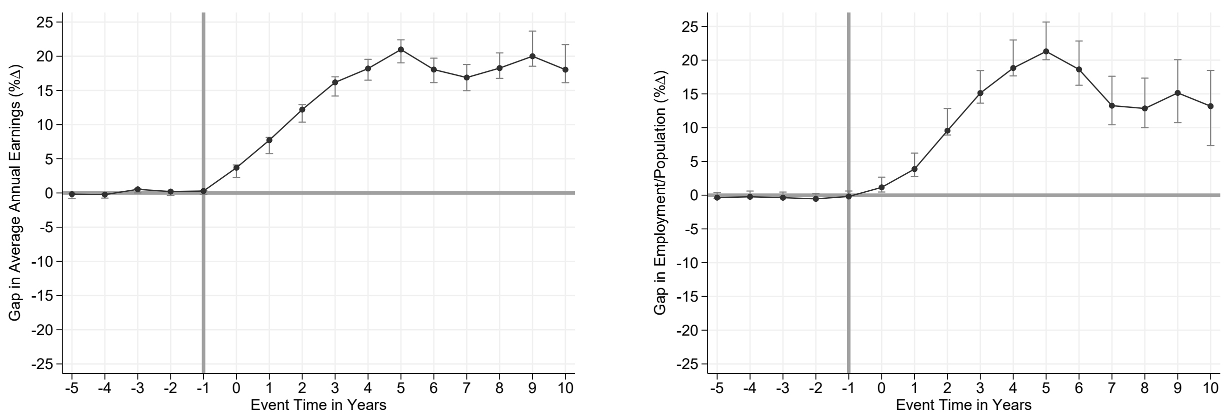

*Notes*: Panel (a) shows trends in the proportion of women aged 16 to 19 at the start of a boom enrolled in college, as well as their educational attainment, in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects, $\bar{\alpha}_l$ from equation (12), of fracking on the proportion of these women enrolled in college, measured in percentage points, as well as on their educational attainment, measured in years of completed schooling. For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).

Figure 19: Average Earnings and Employment-to-Population Ratio of All Males

(a) Trends



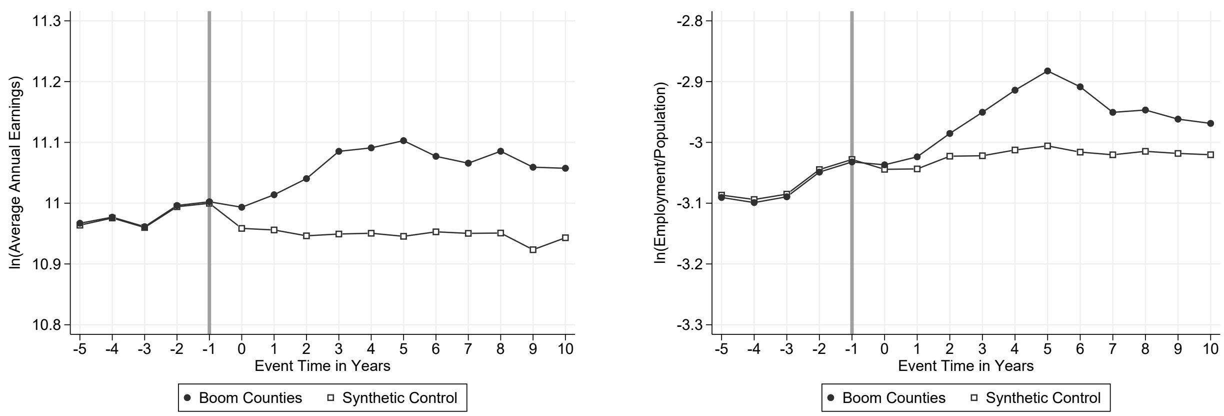

(b) Gap Between Boom Counties and their Synthetic Control



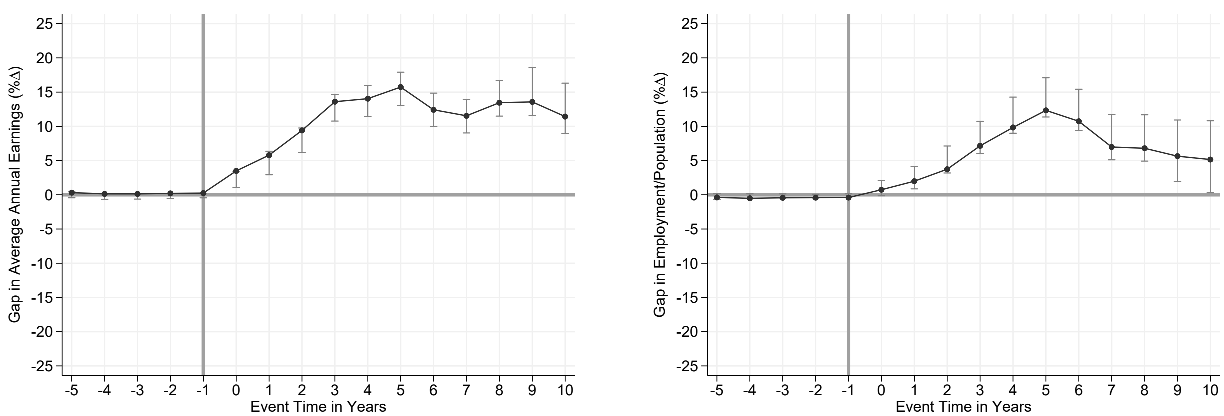

*Notes*: Panel (a) shows trends in the natural log of male average annual earnings and the natural log of the male employment-to-population ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on male average annual earnings and the male employment-to-population ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

Figure 20: Average Earnings and Employment-to-Population Ratio of College-Educated Males

(a) Trends



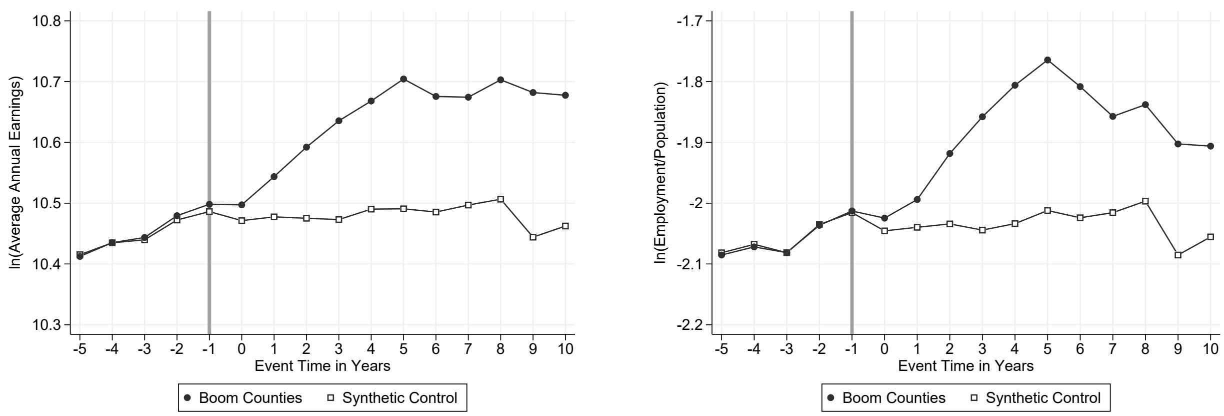

(b) Gap Between Boom Counties and their Synthetic Control



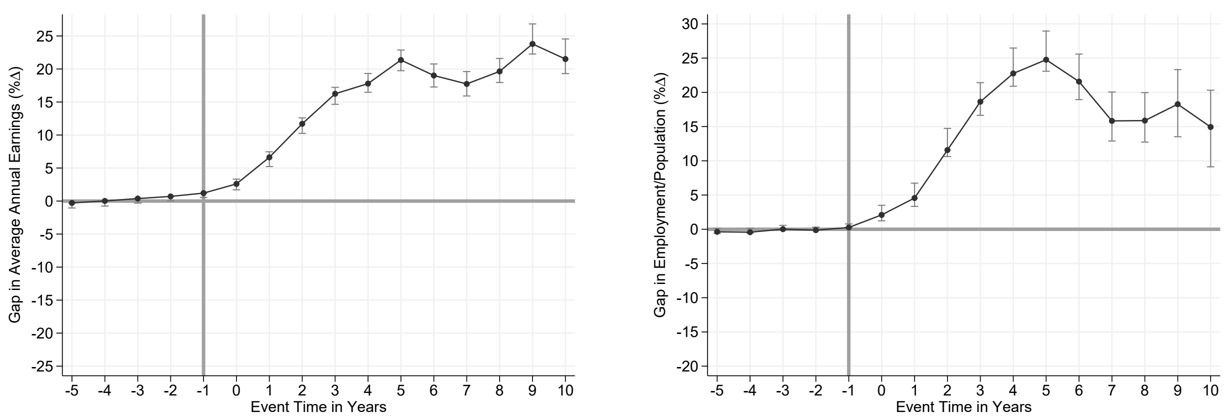

*Notes*: Panel (a) shows trends in the natural log of college-educated male average annual earnings and the natural log of the college-educated male employment-to-population ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on college-educated male average annual earnings and the college-educated male employment-to-population ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

Figure 21: Average Earnings and Employment-to-Population Ratio of Non-College-Educated Males

(a) Trends



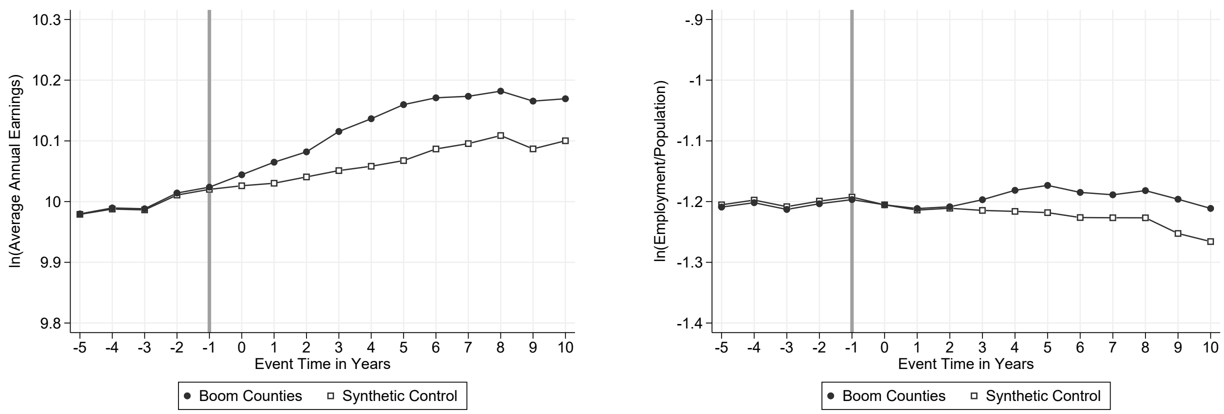

(b) Gap Between Boom Counties and their Synthetic Control



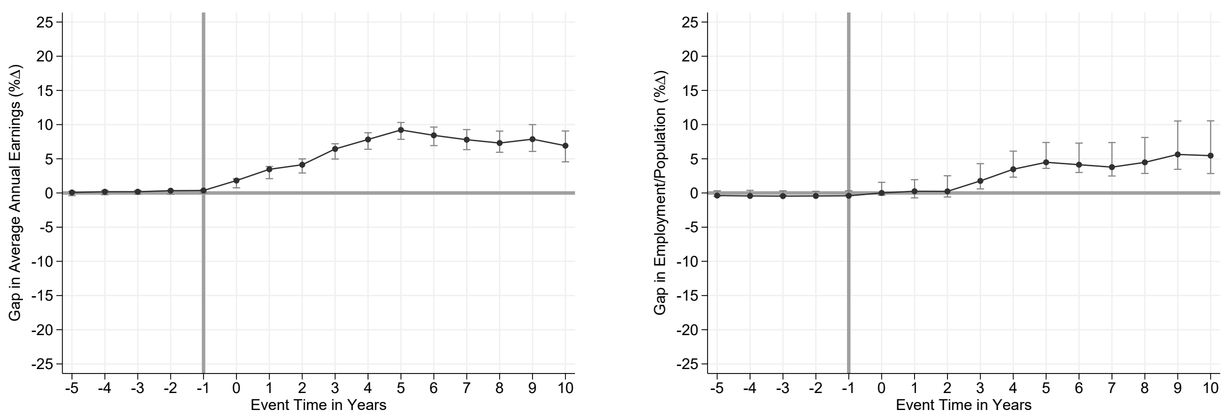

*Notes*: Panel (a) shows trends in the natural log of non-college-educated male average annual earnings and the natural log of the non-college-educated male employment-to-population ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on non-college-educated male average annual earnings and the non-college-educated male employment-to-population ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

Figure 22: Average Earnings and Employment-to-Population Ratio of All Females

(a) Trends



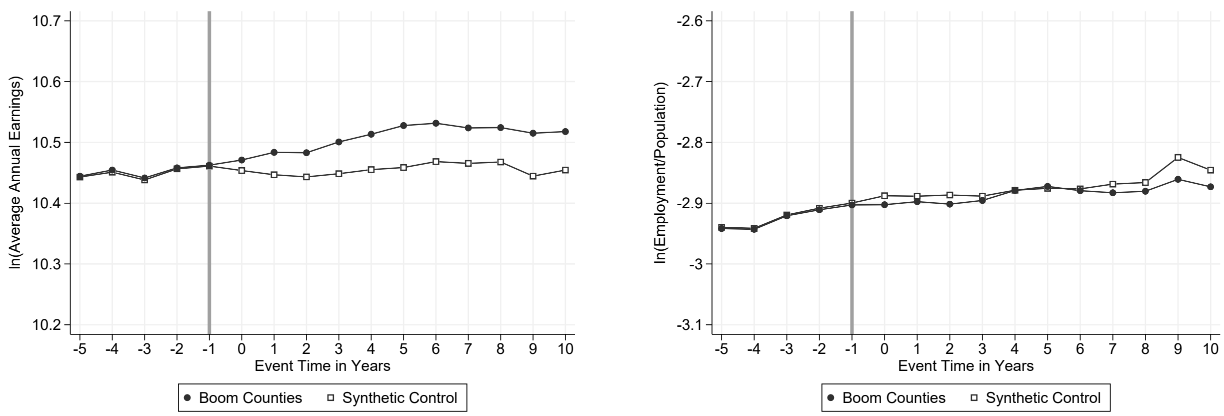

(b) Gap Between Boom Counties and their Synthetic Control



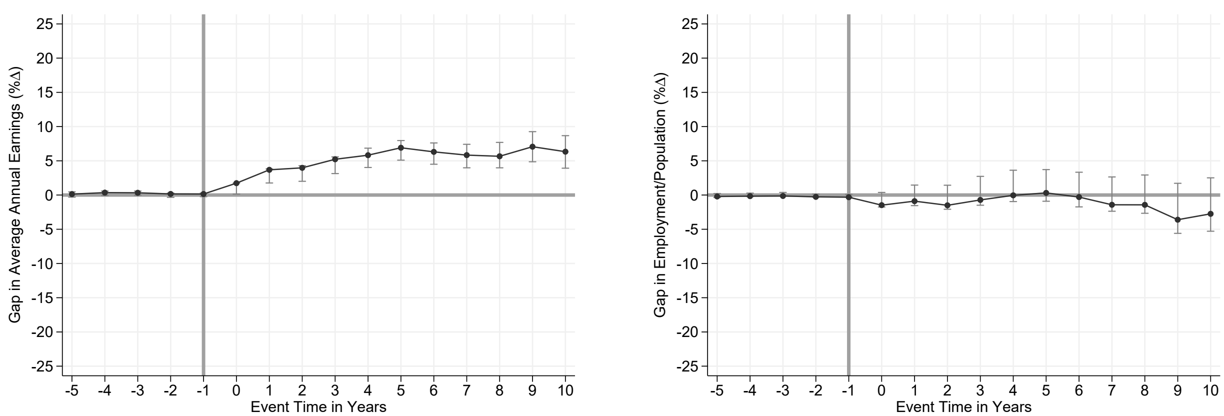

*Notes*: Panel (a) shows trends in the natural log of female average annual earnings and the natural log of the female employment-to-population ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on female average annual earnings and the female employment-to-population ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

Figure 23: Average Earnings and Employment-to-Population Ratio of College-Educated Females

(a) Trends



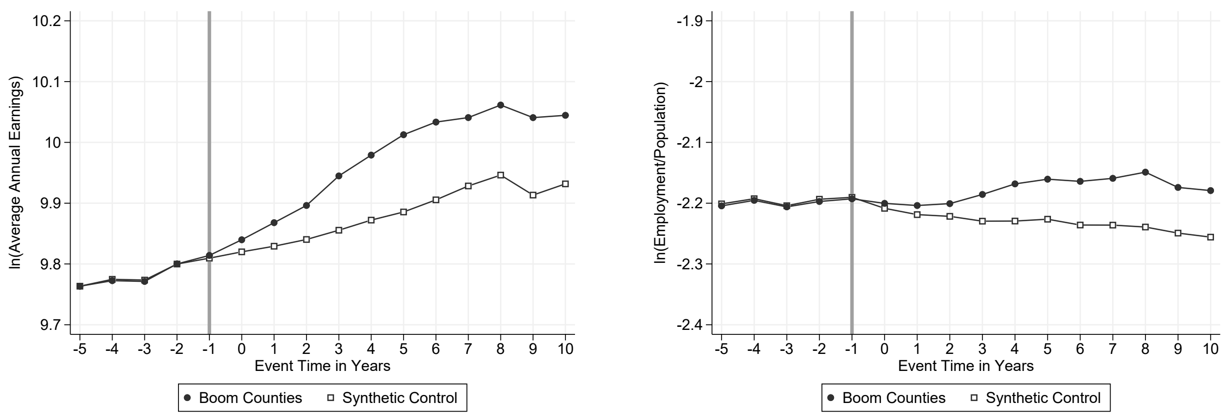

(b) Gap Between Boom Counties and their Synthetic Control



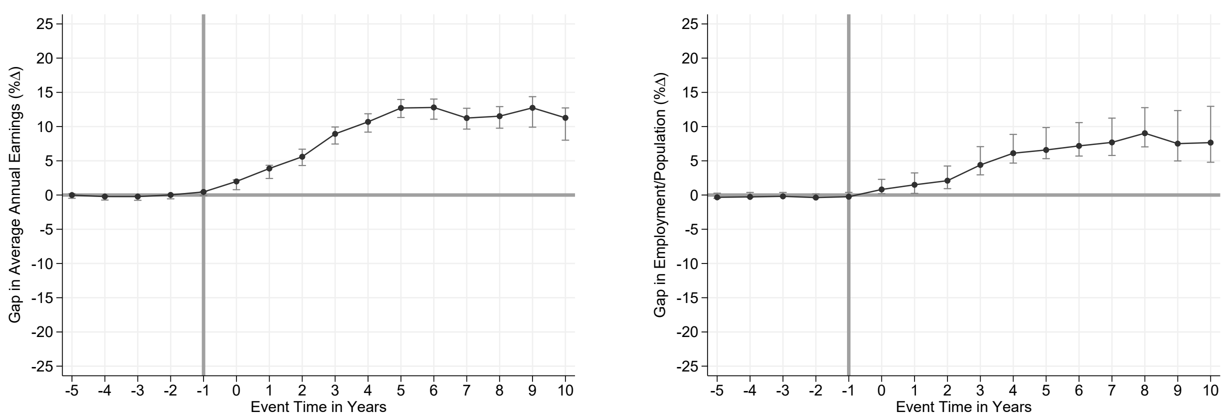

*Notes*: Panel (a) shows trends in the natural log of college-educated female average annual earnings and the natural log of the college-educated female employment-to-population ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on college-educated female average annual earnings and the college-educated female employment-to-population ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

Figure 24: Average Earnings and Employment-to-Population Ratio of Non-College-Educated Females

(a) Trends



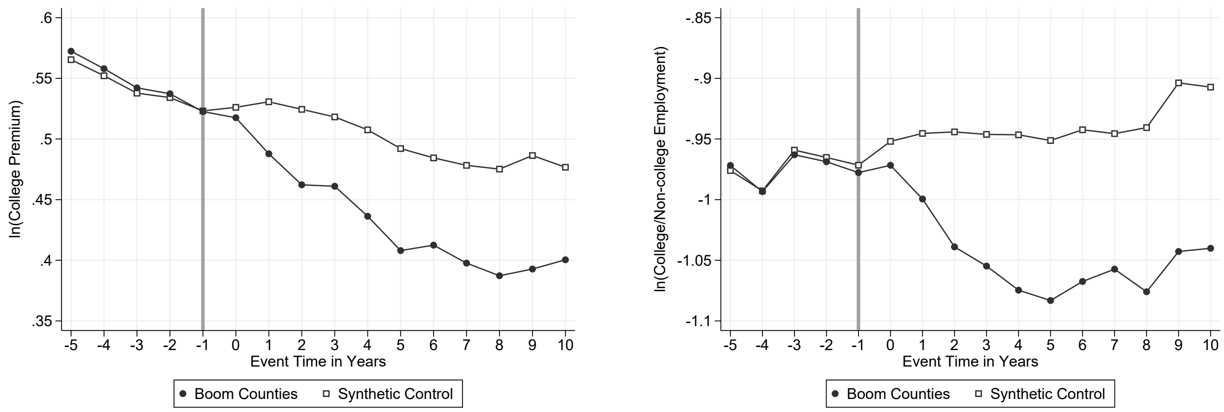

(b) Gap Between Boom Counties and their Synthetic Control



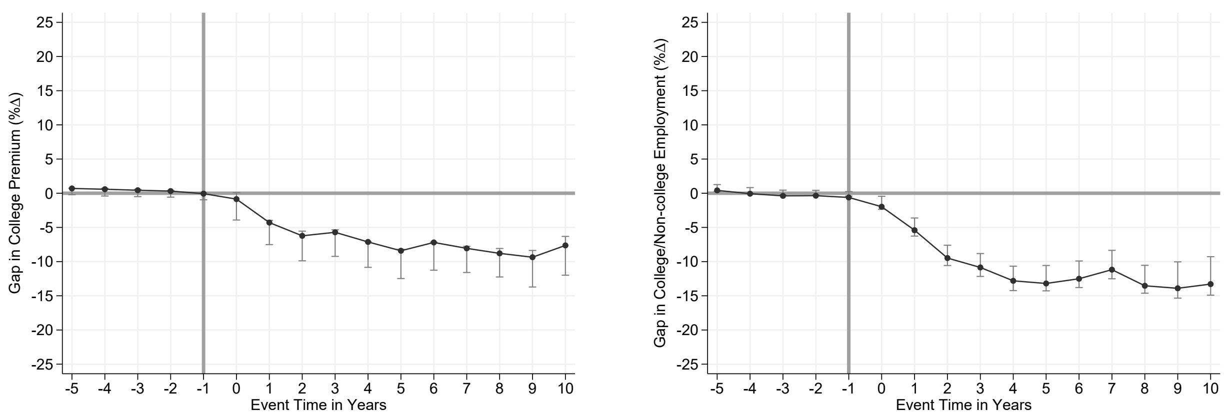

*Notes*: Panel (a) shows trends in the natural log of non-college-educated female average annual earnings and the natural log of the non-college-educated female employment-to-population ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on non-college-educated female average annual earnings and the non-college-educated female employment-to-population ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

Figure 25: Male College Premium and College-to-Non-College-Educated Employment Ratio

(a) Trends



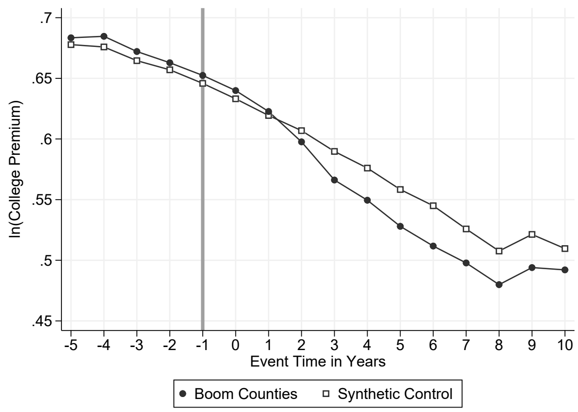

(b) Gap Between Boom Counties and their Synthetic Control

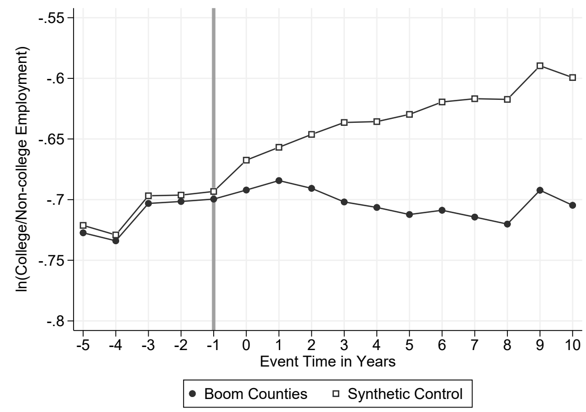



*Notes*: Panel (a) shows trends in the natural log of the male college premium and the natural log of the male college-to-non-college employment ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on the male college premium and college-to-non-college-educated employment ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

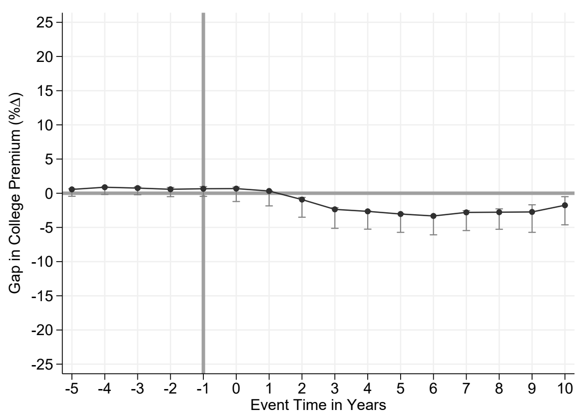
Figure 26: Female College Premium and College-to-Non-College-Educated Employment Ratio

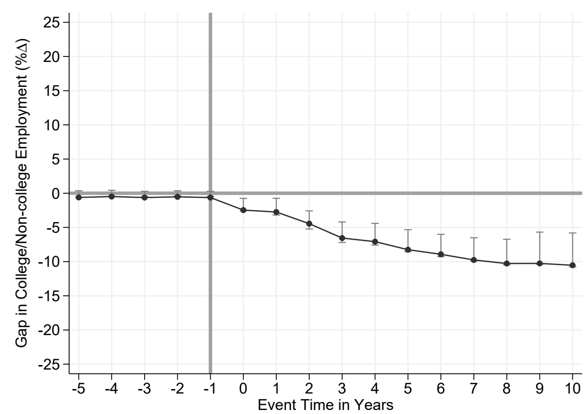
(a) Trends




(b) Gap Between Boom Counties and their Synthetic Control

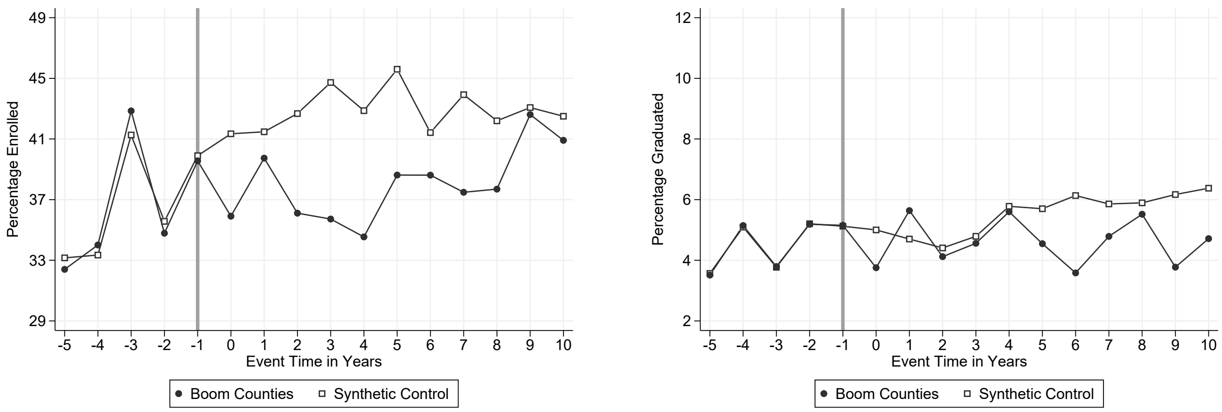


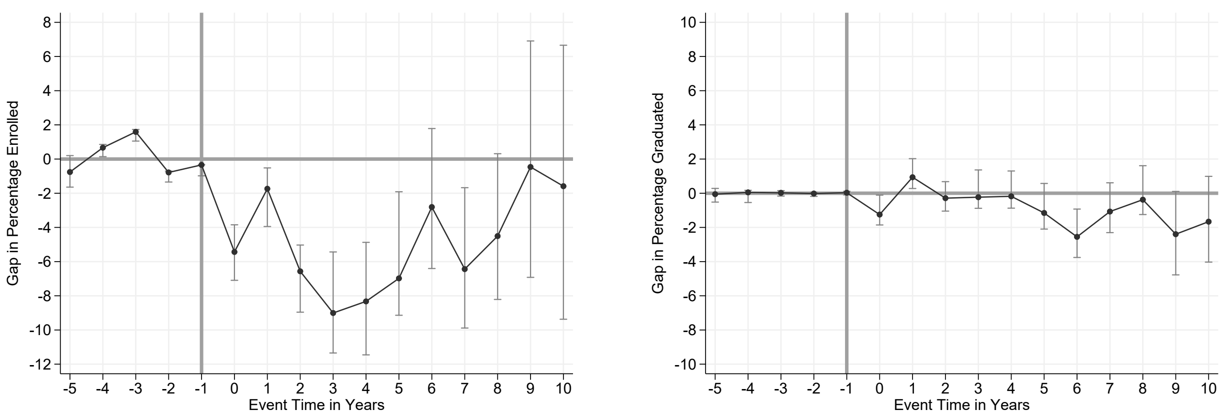

*Notes*: Panel (a) shows trends in the natural log of the female college premium and the natural log of the female college-to-non-college employment ratio in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on the female college premium and college-to-non-college-educated employment ratio, $\bar{\alpha}_l$, measured in percentage changes, from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data Source: 2000-2016 Quarterly Workforce Indicators.

Figure 27: College Enrollment and Graduation Rates of Long-Term Resident Males Aged 18 to 26

(a) Trends



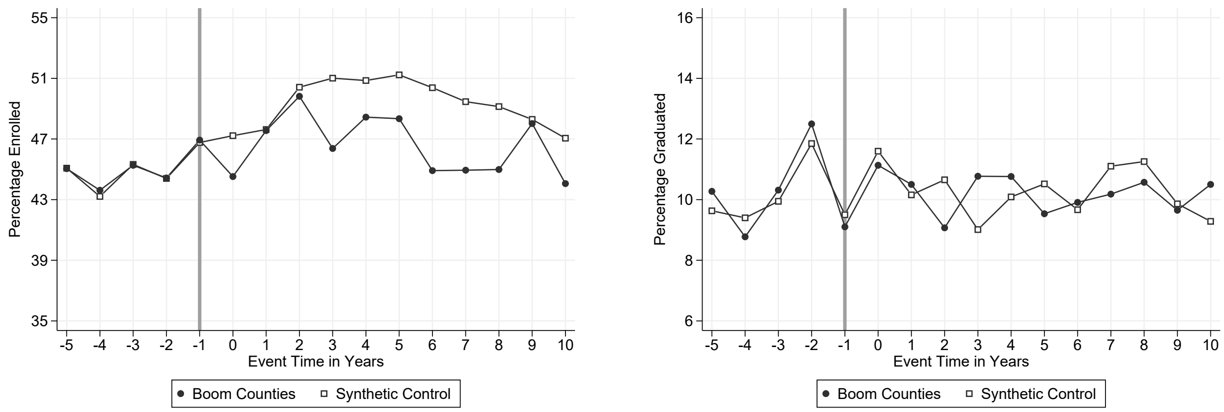

(b) Gap Between Boom Counties and their Synthetic Control



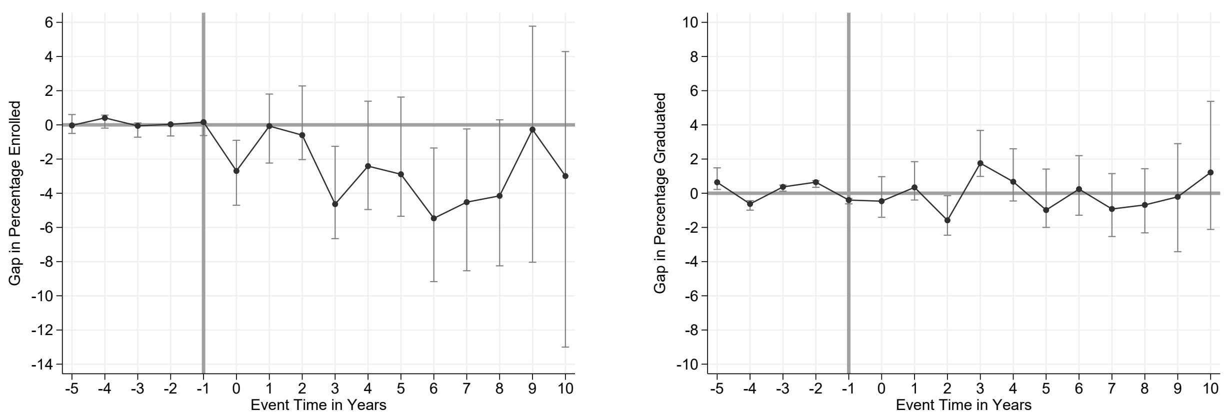

*Notes*: Panel (a) shows trends in the proportion of long-term resident men enrolled in and graduated from college in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on the proportion of long-term resident men enrolled in and graduated from college, $\bar{\alpha}_l$, measured in percentage points (p.p.), from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).

Figure 28: College Enrollment and Graduation Rates of Long-Term Resident Females Aged 18 to 26

(a) Trends



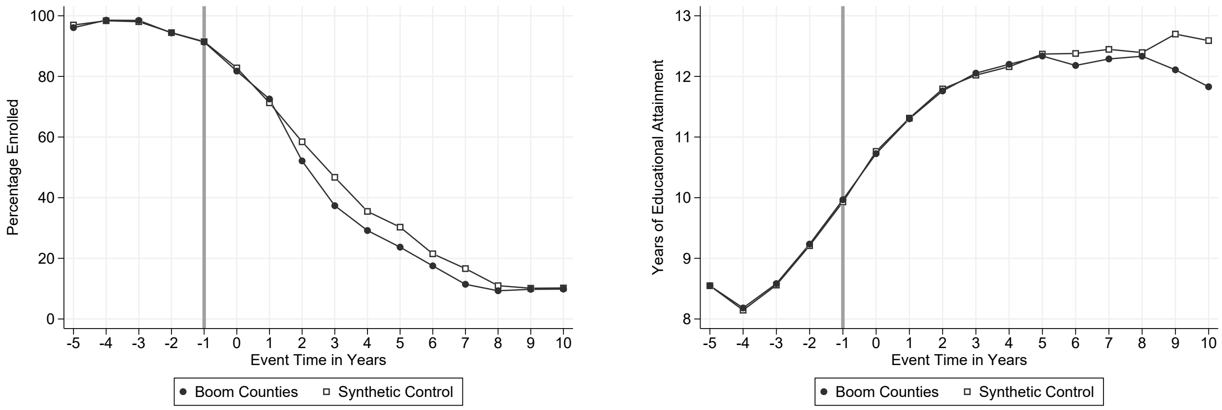

(b) Gap Between Boom Counties and their Synthetic Control



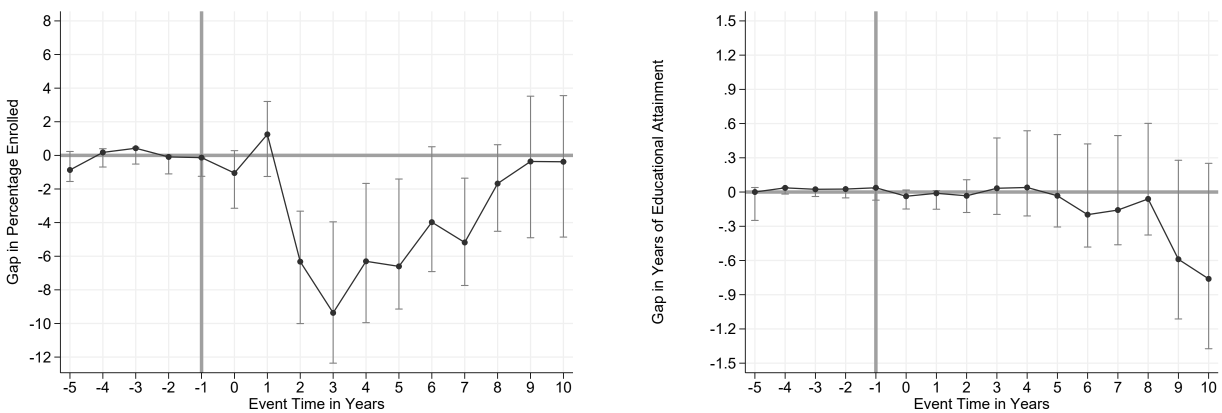

*Notes*: Panel (a) shows trends in the proportion of long-term resident women enrolled in and graduated from college in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects of fracking on the proportion of long-term resident women enrolled in and graduated from college, $\bar{\alpha}_l$, measured in percentage points (p.p.), from equation (12). For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).

Figure 29: College Enrollment Rates and Educational Attainment of Long-Term Resident Males Aged 16 to 19 at the Start of a Boom

(a) Trends



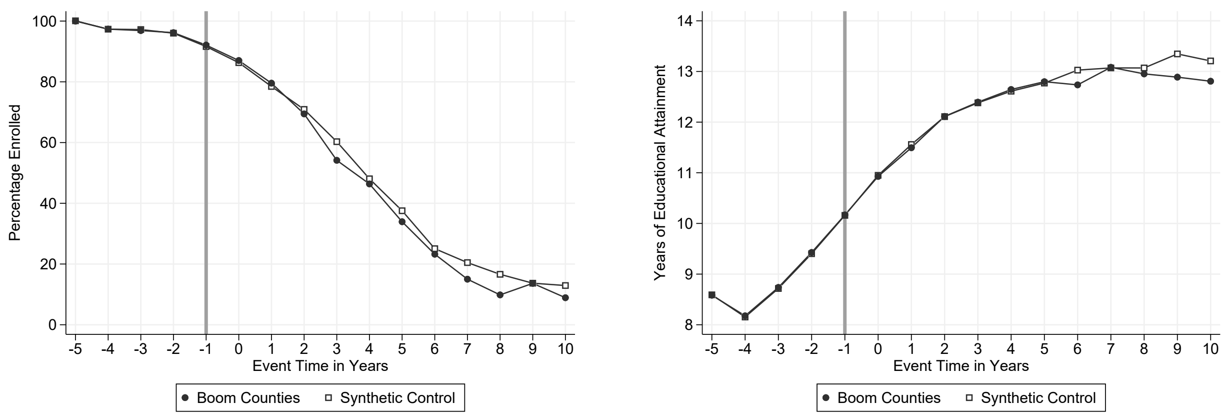

(b) Gap Between Boom Counties and their Synthetic Control



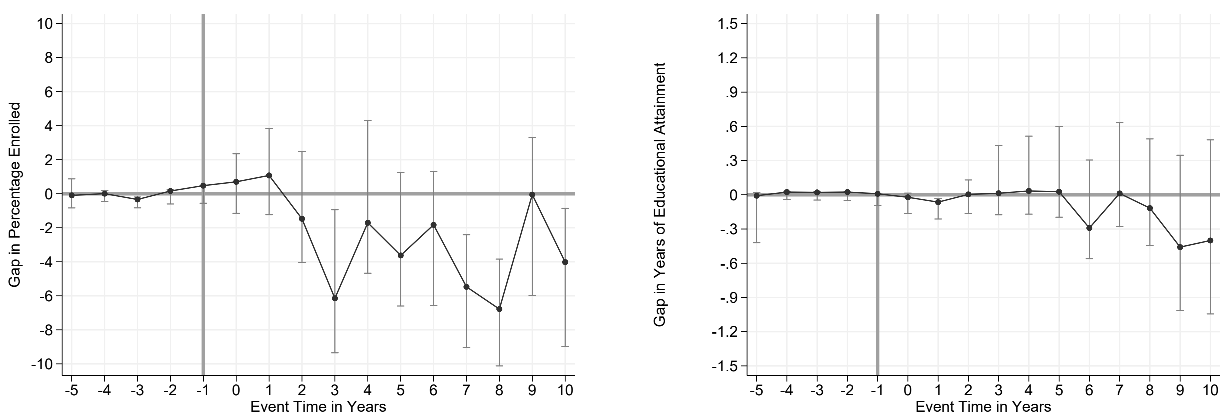

*Notes*: Panel (a) shows trends in the proportion of long-term resident men aged 16 to 19 at the start of a boom enrolled in college, as well as their educational attainment, in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects, $\bar{\alpha}_l$ from equation (12), of fracking on the proportion of these men enrolled in college, measured in percentage points, as well as on their educational attainment, measured in years of completed schooling. For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).

Figure 30: College Enrollment Rates and Educational Attainment of Long-Term Resident Females Aged 16 to 19 at the Start of a Boom

(a) Trends




(b) Gap Between Boom Counties and their Synthetic Control




*Notes*: Panel (a) shows trends in the proportion of long-term resident women aged 16 to 19 at the start of a boom enrolled in college, as well as their educational attainment, in boom counties and their synthetic controls. Panel (b) shows average lead and lag specific effects, $\bar{\alpha}_l$ from equation (12), of fracking on the proportion of these women enrolled in college, measured in percentage points, as well as on their educational attainment, measured in years of completed schooling. For each lead and lag specific effect, the 95 percent confidence intervals are also shown, and are estimated using equation (14) following the steps outlined in section 5.3. Data source: 2005-2017 American Community Survey (ACS).