Firm Dynamics and Local Economic Shocks: Evidence from the Shale Oil and Gas Boom*

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JEL Codes: L26, M13, E24, R23, Q33, Q35

July 12, 2018

Abstract

Empirical evidence and models of firm dynamics ascribe an important job creation role to new businesses and a particular sensitivity of young firms to economic shocks. Studying the role of entrepreneurs and new businesses in the economy's response to economic shocks is difficult due to the complicated causal connections between economic growth and firm entry. The recent revolution in shale oil and gas extraction—which created rapid, large gains in economic activity in areas possessing certain geological characteristics—presents a unique opportunity to study the response of firms—both new and existing—to an expansion of economic conditions. Using a diff-in-diff research design, we show that establishment entry accounts for most of the employment growth in shale regions. New firms and new establishments of existing firms account for about a quarter and three quarters of the increased annual aggregate growth rates, respectively, relative to plausible counterfactuals; cumulatively, establishments that opened after the shale boom began account for three quarters of total net employment gains from 2007 to 2014, and new firms comprise the majority of the cumulative growth from new establishments. These results have important implications for theories of firm dynamics.

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1 Introduction

Entrepreneurs and new businesses play a critical role in aggregate job creation and productivity growth. Moreover, a growing theoretical and empirical literature suggests that new business formation is key to how economies respond to economic shocks. The precise causal role of new businesses is difficult to study, however, due to paucity of plausibly exogenous variation in economic activity (i.e., economic shocks that are exogenous to new business formation). Better knowledge of the margins of adjustment to economic shocks—including the relative roles of new and existing firms—can improve our approach to models of firm dynamics and inform policymakers about determinants of vibrant economies. As an economy responds to a positive aggregate shock, how much growth is provided by new firms and greenfield establishments?

The shale oil and gas revolution provides a unique opportunity to investigate this important question in firm dynamics. After many years of declining crude oil production in the United States, recent technological developments have made the extraction of previously inaccessible energy resources feasible in regions with certain preexisting geological characteristics. Specifically, the advent of horizontal drilling and hydraulic fracturing techniques has enabled the exploration and production of oil and gas from "shale" geological formations and led to significant new drilling activity over the past decade. Because of the nature of these geological formations, an economic "boom" was created in clearly specified local areas where these previously inaccessible resources could now be profitably extracted. Indeed, many of these areas had no signifiant oil and gas activity before these discoveries were made. In this paper, we examine the effect of shale oil and gas development on business dynamics in seven U.S. regions that have the geological formations necessary for shale oil and/or gas extraction; these areas are *Bakken*, *Eagle Ford*, *Haynesville*, *Marcellus*, *Niobrara*, *Permian*, and *Utica*.[1]

Due to the richness of data available through the Census Bureau's Longitudinal Business Database (LBD), we can study the effects of the shale boom not only on overall employment but, more specifically, on particular margins of business adjustment including job creation by both new firms and new establishments of existing firms (the latter are often referred to as "greenfield establishments," a convention we adopt hereafter). Moreover, we can explore the rich regional and industrial heterogeneity that underlies the aggregate effects as growth in the oil and gas sectors is transmitted to other types of businesses. In addition to con-

[1] These areas are defined by EIA (2017); see Figure 3.

tributing compelling empirical results to the firm dynamics and entrepreneurship literature, our research adds to a growing literature documenting the economic effects of the shale boom on a number of variables, such as labor and housing markets; to our knowledge, ours is the first paper specifically to examine new employer business activity.

Using a difference-in-differences framework, we find that new business establishments played a disproportionate role in the overall employment growth of shale areas relative to plausible counterfactuals. Greenfield establishments of existing firms are more important than new firms at an annual frequency, accounting for the majority of the increase in annual aggregate employment growth, but new firms also account disproportionately for increased annual growth. Consistent with existing literature on early lifecycle dynamics of firms, the strong contribution of new firms continues during their first few years of existence such that the overall role of entry for cumulative aggregate growth is enhanced: Relative to a plausible counterfactual, seven years after the onset of the oil and gas boom new firms account for almost half of total cumulative jobs created. More broadly, the results highlight the importance of entrepreneurship and the extensive margin of the firm distribution for studying economic fluctuations—emphasizing the relevance of firm heterogeneity and dynamics—while also highlighting the distinction between new firms and greenfield establishments, a distinction that is frequently glossed over in formal treatments.

Sectoral and regional analyses reveal further insights into firm dynamics. Total employment responds strongly both in and out of the oil and gas sector. In the oil and gas mining sector greenfields account for more than one third of the overall employment growth response, while outside of the oil and gas mining sector—in industries that may be thought of as responding endogenously to the oil and gas shock—greenfields comprise more than three quarters of the overall employment response while existing establishments make no measurable contribution. That is, outside the oil and gas mining sector the response of employment growth is entirely accounted for by new firms and greenfield establishments, and we find that the role of new firms is even stronger when the oil and gas shock is scaled by measures of extraction activity (i.e., rig counts and revenue).

We show that shale regions differ widely in terms of these patterns. New and young firms account for about half of the response of employment growth in Bakken, Eagle Ford, and Permian Basin along with sizable contributions from greenfield establishments; these are regions that saw large overall employment gains. Other regions saw smaller or sometimes negative effects on overall employment growth, with correspondingly small gains in new firm and establishment activity. The quantitatively similar role of new firms documented in the regions for which overall effects were large and positive is reassuring and suggests our results may be useful and important for guiding parameterization decisions in formal studies of firm dynamics.

2 Theory and Relevant Literature

2.1 The Role of New Businesses in Employment Growth

Models of representative firms—often characterized by perfect competition and constant returns to scale production—give rise to intuition in which economic shocks are accommodated entirely by homogenous existing firms that scale up or down as necessary. In contrast, models of firm heterogeneity allow for a more realistic, nondegenerate firm distribution based typically on revenue function curvature arising from imperfect competition and/or decreasing returns to scale production technology.[2] Moreover, models with entry and exit typically use some version of a free entry condition that links the value of even incumbent firms to entry costs. In such an environment, existing firms do not grow enough to fully accomodate aggregate shocks, so the resulting increase in aggregate production depends on growth in the number of firms, including through increased entry.[3] In other words, richer models faciliate a role for entrepreneurs in macroeconomics.

We first describe a simple model sketch to illustrate the basic mechanisms present in standard models (below and in the appendix, we cite and descibe more realistic generalizations of the model that deliver similar intuition). Consider a model in the class of Hopenhayn (1992); in particular, we describe a simplified version of Clementi and Palazzo (2016) in which potential entrants are ex ante homogenous and labor is the only factor of production. Incumbent firms differ in productivity, given by z where z follows an AR(1) process with idiosyncratic shocks each period (we omit firm subscripts for simplicity). The productivity term z may refer to technical efficiency, entrepreneurial ability, or, in a broader sense, a firm-specific demand shock. Incumbents produce output with technology given by $y = Azn^{\alpha}$, where A is an aggregate productivity factor (the capitalization indicates an aggregate variable), n is labor, and $\alpha < 1$. In this setup the firm's revenue function derives curvature from α, which generates decreasing returns to scale in production; however, the key insights developed here

[2]Other options for generating a firm distribution include static distortions, matching frictions, factor adjustment costs, and heterogeneity of factor prices.

[3]Karahan et al. (2018) make this point eloquently in a balanced growth perspective, showing that under certain assumptions the bulk of labor demand adjustment is accommodated on the entry margin.

would also hold if revenue curvature were generated by imperfect competition. Intuitively, revenue function curvature may arise from span of control issues (e.g., the difficulty of increasing the responsibilities of managers with finite time or scope for action), firm-specific demand curves, geographic limitations, or other factors.

The firm's profit function solves $\pi(z; A, w) = \max_n Azn^\alpha - wn$. The firm's value function—a simple object in this parsimonious model with no durable factors of production—is given by

$$V(z; A, w) = \pi(z; A, w) + \beta \mathbb{E}_{c_f} \max\{0, \mathbb{E}_{z'|z} V(z'; A, w) - c_f\}, \tag{1}$$

where c_f is a stochastic fixed operating cost and the next-period maximization drives the firm's exit decision. Given wage w, the firm's first-order condition for labor is:

$$n(z; A, w) = \left(\frac{w}{\alpha A z}\right)^{\frac{1}{\alpha-1}}. \tag{2}$$

Suppose A increases by x percent. Our interest is in the growth of firm-level employment in a comparative statics view:

$$g = \frac{n(z; (1+x)A, w) - n(z; A, w)}{n(z; A, w)} \tag{3}$$

where we hold the wage constant (i.e., partial equilibrium). In this simple environment it is straightfoward to show that

$$g = (1+x)^{\frac{1}{1-\alpha}} - 1, \tag{4}$$

that is, the firm's employment growth response is a function only of x and α. Importantly for our study, the absolute value of the growth rate is increasing in α or, equivalently, decreasing in the curvature of the revenue function. Revenue function curvature dampens the response of incumbents to shocks.[4] Equivalently, revenue function curvature compresses the distribution of labor demand across firms of different productivity realizations. This implies that aggregate shocks affect the number of firms, not just the size of preexisting firms.

We next consider entry, which is governed by the free entry condition:

$$c_e = \mathbb{E}_{z'} V(z'; A, w), \tag{5}$$

[4] Decker et al. (2018) find that this result holds more generally in a more fully specified and calibrated model with labor adjustment costs.

where c_e is the entry cost. In this simple setup, potential entrants—which are ex ante homogenous—form businesses until the value of the firm (in unconditional expectation) is equal to the entry cost. This free entry condition is extremely powerful as it pins down the average value of incumbent firms. Aggregate shocks (i.e., changes in A) have no effect on the value of the average incumbent; the wage must adjust to aggregate shocks such that the average incumbent firm's value is unchanged. Moreover, revenue curvature implies that differences across firms are limited, restraining the potential for deviation from the behavior of the average firm. We descibe more details about this model in the appendix.

We next consider an experiment using our simple model. We solve the model for a baseline stationary state and for a high-productivity stationary state in which aggregate TFP is higher than the baseline. We then compute the transition from the baseline to the high-productivity scenario: the economy begins in the baseline steady state at time $t = 0$. During time $t = 1$, agents learn that aggregate TFP will rise in the following period. We then study the evolution of the economy during subsequent periods. Key results are described on Figure 1, where each quantity is reported relative to its value in the initial state. The solid blue line shows the path of aggregate TFP. The black dotted line shows the number of firms in the economy; consistent with the intuition described above, the economy adjusts to the improvement in aggregate conditions through an increase in the number of firms (rather than only existing firms growing). The red dashed line shows that this increase in the firm count is faciliated by a sharp rise in firm entry, and the green dot-dashed line shows that this rise in entry also raises the share of overall employment that is accounted for by new entrants. In this model setup, these general qualitative results are highly robust to changes in parameterization, such as variation in the labor supply elasticity, revenue function curvature, or the entry cost.

While the model sketch above is extremely stylized, the basic intuition can hold in richer, more realistic settings. An important example is Clementi and Palazzo (2016), which explores an enhanced firm dynamics model calibrated to establishment dynamics data and consisting of capital (and capital adjustment costs), a richer distribution of recent entrants, and explicit business cycle dynamics. In their general equilibrium formulation, potential entrants receive advance signals about their productivity and enter when the expected discounted profits from doing so exceed entry costs. Incumbent firms face decreasing returns to scale. Positive aggregate shocks (whether demand or technology) induce significant entry activity for the reasons sketched above.

However, there are limits to this line of reasoning. As we discuss in the appendix, while the rise in the number of firms in response to the aggregate shock is a quite general result (arising in part from revenue function curvature), the role of *new entrants* in facilitating the rise in the firm count is actually model dependent. When we generalize our model to allow ex ante heterogeneity of entrants (i.e., potential entrants receive a signal about their quality), the strong responsiveness of the entry rate to the positive aggregate shock becomes dependent on calibration; there are choices of the labor supply elasticity, revenue curvature parameter, and operating costs for which the rise in the number of firms is faciliated by a drop in exit without a surge in entry. The model and calibration dependence of this popular result is one motivation for our empirical study.[5]

Importantly for our purposes, in the more fully specified model of Clementi and Palazzo (2016) (not our simplified version) not only do aggregate shocks boost the share of activity accounted for by entrants, but also surviving young firms grow quickly on average such that each cohort of entrants has persistent effects on aggregate employment in early years.[6] The reason for the rapid growth of young businesses is that many young businesses have high marginal products due to the cost of obtaining and adjusting their capital stock. Our paper can be thought of, in part, as a simple empirical study of models like Clementi and Palazzo (2016), but our contribution has other dimensions since in reality the prevalence of high marginal products among recent entrants is likely limited to young *firms*, while young *establishments* of existing firms are more likely to enter fully capitalized. One contribution of our paper is to demonstrate the differing dynamics of new firms and greenfield establishments in response to economic shocks, showing that the choice to calibrate firm dynamics models to establishment data is not benign.[7]

Broadly speaking, the theoretical insight of our model and others like Clementi and Palazzo (2016) that potential entrants and young firms respond disproportionately to shocks is consistent with a large empirical literature finding that new entrants play a disproportionate role in job creation. Decker et al. (2014) note that new entrants account for nearly one fifth of gross job creation annually in the U.S. despite accounting for less than 10 percent of firms and less than 5 percent of employment. Haltiwanger et al. (2013) show that the job creation benefits often attributed to small businesses are more accurately attributed to new businesses, inspiring our focus on new firm activity. These insights hold over the business

[5]In future drafts we will explore this calibration dependence in more detail and more directly tie our empirical results to calibration choices.

[6]This is broadly consistent with Decker et al. (2014), who show that, despite high failure rates of young firms, typical firm cohorts retain 80 percent of their initial employment impact after five years.

[7]Clementi and Palazzo (2016) is just one of several recent modeling exercises based on an establishment concept; other recent examples include Moreira (2017) and Lee and Mukoyama (2015).

cycle as well; for example, Fort et al. (2013), Pugsley and Sahin (2015), and Sedlacek and Sterk (2017) show that young firms are more cyclically sensitive than older firms. Bernstein et al. (2018) find that new and young firms also respond strongly to commodity price shocks in Brazilian data (and, interestingly, these new firms are disproportionately formed by young entrepreneurs).

A paper closely related to our question is Adelino et al. (2017), who study local economic shocks and find that new firms disproportionately account for the response of both net and gross employment. The authors seek identification from a Bartik-style instrument that generates local variation in manufacturing activity driven by nationwide dynamics. Our approach is similar to theirs in that we focus on local shocks to generate insights about firm dynamics. Our approach differs from theirs in several ways. First, Adelino et al. (2017) focuses on the U.S. broadly, while we limit our focus to the shale areas (and counterfactual counties). Second, Adelino et al. (2017) focuses on shocks originating from the manufacturing sector, while our identifying shock is to the oil and gas extraction sector. Finally, instead of the Bartik approach we specifically identify off of the interaction of shale extraction technology and preexisting geological formations, allowing for a diff-in-diff causal interpretation. Our results are broadly supportive of—and, given the limits of Bartik designs (Goldsmith-Pinkham et al. (2018)), complementary to—the Adelino et al. (2017) conclusions in terms of the importance role of new firms, though we add a focus on greenfield establishments of existing firms.

New firms have often been treated synonymously with "entrepreneurship" in much relevant literature, largely due to the importance of business age for key job creation and productivity results (Decker et al. (2014), Haltiwanger et al. (2013)). Other concepts of entrepreneurship have been studied in relation to energy booms, however. Gilje and Taillard (2016) examine investment by public and private firms in the natural gas industry and find that publicly traded firms are more responsive to changes in investment opportunities than private firms, a finding that may be thought of as contrary to the view that new firms are key but may be supportive of our findings on greenfield establishments. Tsvetkova and Partridge (2017) document declining self-employment (i.e., including nonemployer self-employment) in energy boom towns in 2001–2013 using American Community Study (ACS) data, consistent with previous evidence that resource sector booms may crowd out entrepreneurial activity (Davis and Haltiwanger, 2001; Glaeser et al., 2015; Betz et al., 2015). Our data cover employer businesses, so nonemployer self-employment is outside the scope of our study. We therefore view our work as complementary to Tsvetkova and Partridge (2017) as we add the employer-business side of entrepreneurship, which likely has a stronger association with later economic growth but has somewhat different interpretations in terms of the entrepreneurial occupational choice.[8] In this respect, we add employer entrepreneurship to the list of economic outcomes that have been studied in relation to resource booms, a literature that we review next.

2.2 Economic Effects of Oil and Gas Booms

Modern crude oil production began in 1859 with Drake Well, five miles south of Titusville, Pennsylvania, and was followed by a period of rapid growth and expansion in the oil industry (Yergin, 1999). As people from all income ranges around the country began "pushing back the night" for the first time with inexpensive fuel that could be used for lighting homes, oil became an almost instant necessity. So began the age of oil that quickly spread throughout the world.

For almost a century the U.S. experienced consistent increases in oil production. But in 1970, this age of increasing domestic production reached its end and for the first time in U.S. history production began a period of decline that continued for the next four decades. However, over the last decade, the oil landscape has changed both suddenly and dramatically as illustrated in Figure 2. By 2007, after a long period of declining U.S. production, a technological breakthrough allowed "shale" oil and gas extraction to become economically viable for the first time in history; the "shale boom" was underway.[9]

Shale oil and gas refers to oil and natural gas trapped in shale formations thousands of feet below the earth's surface. Geologists have been aware of these resources for decades, but extracting them economically has been challenging for a number of reasons. First, these formations are typically deeper than other formations. In fact, many conventional reservoirs are the result of oil and gas that have naturally migrated up from shale formations and trapped in pools of hydrocarbons that are closer to the surface. Second, the nature of the reservoirs themselves make extraction more difficult. The reservoirs are commonly referred to as "tight"[10] due to the fact that the hydrocarbons are trapped tightly compared to a

[8] Poschke (2018) provides a model with a clear distinction between employer businesses and nonemployer ("own account") self-employment, using cross-country evidence to argue that nonemployer self-employment is best thought of as an occupational choice in response to weak labor markets. It would therefore be unsurprising to find that nonemployers and employers respond differently to shocks.

[9] For the main empirical specifications in this research, the shale boom will begin in 2007 consistent with the time that EIA began tracking shale production (EIA, 2017). We will consider the specific timing of the treatment in an alternative specification.

[10] The term "LTOs" or "light tight oils" is commonly used to refer to oil from shale formations.

conventional reservoir. Due to the innate nature of the geology, when a well is drilled into a shale formation, the area around the well bore quickly dries up as the hydrocarbons are not able to easily flow.

George Mitchell with Mitchell Energy[11] is credited for successfully drilling the first shale wells in the Barnett shale formation outside of the Dallas area in Texas using a combination of horizontal drilling and hydraulic fracturing (informally referred to "fracking"). First, shale wells are drilled horizontally to cover a large amount of surface area through the reservoir. Then, hydraulic fracturing—pumping a mix of water and sand into the well at high pressure—opened up the rock allowing the hydrocarbons to flow to the surface. Before this technological advancement and the productivity improvements that followed, there were vast amounts of hydrocarbons in known formations that geologists and engineers simply were not able to extract due to the technical reasons cited above.

The advent of horizontal drilling and hydraulic fracturing fundamentally transformed the oil and gas industry such that both oil and natural gas production are currently at record levels. In addition to the innovations that first made shale production economical, subsequent innovations have generated dramatic gains in output and, therefore, magnified the economic consequences of the shale boom (see Decker et al. (2016a)). Some innovations mitigate the considerable costs of assembling and disassembling drilling rigs, which can take multiple days and require dozens of heavy trucks; these include pad drilling (in which a rig drills multiple wells from a single spot) and "walking rigs" (which complete one well then transport themselves a few dozen feet to drill the next well). Other innovations increased output by boosting the productive capacity of wells, such as increases in well length, changes in the mix of water versus sand and other proppants in the fracking process, and recompletions (re-fracking of existing wells). Still others improved productivity by improving well site selection and design, such as improvements in the computing tasks associated with exploration. The result of these various innovations is that shale production has become economical under a wide range of oil market circumstances, including far lower world market prices than was the case two decades ago. It is the interaction of these technological improvements with the preexisting geological characteristics of the shale regions that we use to identify economic booms and the specific role of entry.

Unsurprisingly, a growing body of work quantifies the economic effects of localized natural resource based booms. While this literature began before the specific shale oil and gas booms

[11] Mitchell Energy was later acquired by Devon Energy, a firm that is to this day actively producing from shale formations.

of this past decade (Black et al., 2005; Allcott and Keniston, 2014), this new era of shale has created a significant resurgence in this literature in part because of the clean empirical identification afforded by the nature of the shock.

Most recently, Feyrer et al. (2017) finds that the shale boom specifically created significant economic shocks to local labor markets. Every million dollars of oil and gas extracted is estimated to generate \$243,000 in wages, \$117,000 in royalty payments, and 2.49 jobs within a 100 mile radius. In total, the authors estimate that the shale boom was associated with 725,000 jobs in aggregate and a 0.5 percent decrease in the unemployment rate during the Great Recession. Marchand (2012) similarly finds both direct and indirect impacts of the shale boom on employment; for every 10 jobs created in the energy sector, 3 construction, 4.5 retail, and 2 services jobs are created. Agerton et al. (2016) find that one additional rig results in the creation of 31 jobs immediately and 315 jobs in the long-run. Other studies corroborate the positive impact of the shale boom on local labor markets (Weber, 2012; Marchand and Weber, forthcoming; Komarek, 2016; Bartik et al., 2017; Upton and Yu, 2017).[12] While positive effects associated with the economic activity spurred by drilling and production have been documented extensively, negative effects might also be observed, specifically in the manufacturing sector (Cosgrove et al., 2015; Freeman, 2009).

In addition, an emerging literature considers the potential implications of resource booms on a number of other local outcomes. Bartik et al. (2017) finds local governments experience revenue increases that are greater than expenditure increases. Marchand and Weber (2015) focuses specifically on Texas and finds that some of these increases in revenues were spent on local school districts, in particular on investment in fixed assets (e.g. new school buildings). Fedaseyeu et al. (2015) presents evidence that these resource booms can also affect voter behavior, specifically increasing support for conservative policies and Republican political candidates. Cosgrove et al. (2015) and Bartik et al. (2017) find evidence of growth in the local population likely due to temporary migration of workers to these areas.

Another strand of literature has focused on the impact on local housing markets. Overall, housing values increase (Bartik et al., 2017), but the impact to properties is asymmetric in that homes directly impacted by drilling decline in value (Muehlenbachs et al., 2015). Additionally, local housing markets are positively affected by the shale boom through reduction in mortgage default (McCollum and Upton, 2016).

[12] It should be noted that due to the oil and natural gas price declines of 2014, there is an emerging literature on the "bust" side of the cycle that will likely grow in upcoming years. For instance, Brown (2015) finds that elimination of each active rig eliminates 28 jobs in the first month and this increases to 171 jobs eliminated in the long-run.

Finally, there has been interest in how shale booms affect local financial conditions. Gilje (forthcoming) treats the shale boom as a catalyst to an exogenous increase in local bank deposits and local credit supply and finds that counties with large shale booms also experience a large increase in new business establishments that are reliant on external bank financing. This effect is particularly strong in counties that are dominated by small local banks. Similarly, Gilje et al. (2016) exploit the shale boom to show that bank branch networks continue to play an important role in financial integration by demonstrating that banks with branch exposure to shale booms also increase mortgage lending in non-boom counties (see also Plosser (2015)). Related, Brown (2017) finds evidence that local residents increase both expenditures (that can account for some of the more general economic effects) and consumer debt. Specifically, each well drilled as result of shale boom associated with an increase in consumer debt of $6,750.

Our work adds to this growing body of literature in that we are the first study to investigate the margins by which the business sector adjusted to the shale boom, directly tying the event to broader questions in firm dynamics and macroeconomics. We find that establishment entry accounts for most of the employment growth in shale regions and that new firms and new establishments of existing firms account for about a quarter and three quarters of the increased growth rates, respectively.

3 Data, Variables, and Summary Statistics

3.1 Data

We use the Census Bureau's Longitudinal Business Database (LDB), which consists of longitudinal establishment-level microdata covering almost all private non-farm businesses in the U.S.[13] The LBD provides annual data on establishment location and detailed NAICS industry as well as annual employment counts (corresponding to the pay period including March 12). LBD information is based on IRS and Social Security Administration records and is administrative in nature, so the data are not subject to sampling error (but may be subject to various forms of non-sampling error). Importantly for our purposes, the LBD provides firm identifiers that allow us to link establishments together as firms and to track

[13]The LBD is constructed from the Census Bureau's Business Register, which is also the source of the public-use County Business Patterns (CBP) and Statistics of U.S. Businesses (SUSB) datasets (see DeSalvo et al. (2016) for details on the construction of the Business Register). Our LBD dataset has the same industry scope as CBP, covering almost all private non-farm industries. Notable exceptions include rail transportation and private households.

firm age.[14] Jarmin and Miranda (2002) provide more detail on the LBD.

Consistent with much of the literature (e.g., Haltiwanger et al. (2013)), we define an establishment birth as the first year in which an establishment has positive employment, and we determine firm age as follows: when a firm identifier first appears in the data, it is assigned the age of its oldest establishment; thereafter, the firm ages naturally each year.[15] For our purposes it is not necessary to assign an industry code to firms; all industry categories are based on establishment industry (and, as such, industry characteristics of "new firms" actually reflect the industry characteristics of establishments of new firms in a given county).

3.2 Control and Treated Areas

EIA (2017) provides a list of counties that are located within each shale play. We classify counties that are located within the *Bakken*, *Eagle Ford*, *Haynesville*, *Marcellus*, *Niobrara*, *Permian*, and *Utica* plays as treated areas. Figure 3 shows a map of where these shale plays are located.

We conduct our main exercises on all counties in all shale areas combined; in other exercises we also study each play individually (with its own counterfactual group). For each of these groupings, we first construct a control group of counties through propensity score matching. The variables on which we match are total county employment, the share of firms in the county that are new, the share of employment in the county that is at new firms, the share of establishments in the county that are new establishments of existing firms, the share of employment in the county that is at such establishments, and the share of employment in the county that is at oil and gas establishments (NAICS 211, 213, 324, and 325) and manufacturing establishments (NAICS 31-33); we match based on county averages for 2000-2006. In this way, we construct a control group that is similar to the treatment group in terms of new firm activity, greenfield establishment activity, and activity of the oil and gas and manufacturing industries in the pre-shale time period. In other words, for each treatment county we find a corresponding "control" county that has similar patterns of firm

[14] An establishment is defined as a specific business location. A firm is a group of establishments under common majority ownership.

[15] The establishment-level longitudinal linkages in the LBD are generally considered to be of high integrity. Unfortunately, the longitudinal linkages of the LBD's firm identifiers are less reliable and are therefore a source of measurement error. Nevertheless, we follow much recent literature in proceeding with firm age concepts that rely on the LBD firm identifier; these concepts are made more robust by the popular method, which we adopt, of assigning firm age based on establishment age at the firm's first appearance. A particular benefit of the LBD firm identifier is that, unlike several other prominent data sources, the LBD firm corresponds to an ownership concept (rather than arbitrary tax identifiers).

dynamics *ex ante*. We construct a control group for the all-plays treatment group, then we create separate control groups for each play individually (i.e., for regressions that include only a specific play, the control group is redrawn).

To reduce the risk of our results being contaminated by spillover effects, counties that are in states with shale activity but that themselves do not contain oil and/or gas activity were removed from the list of potential control counties. In addition, states that directly border counties with shale activity were removed from the potential control group.[16] We will show that results are robust to placebo tests and alternative control groups.

3.3 Variables

We consider several outcome variables. In initial background exercises, we study the effect of the shale boom on overall county employment levels (in logs). Our main outcome of interest, however, is annual employment growth. Consider the following growth rate concept:

$$g_{ct} = \frac{emp_{ct} - emp_{ct-1}}{0.5(emp_{ct} + emp_{ct-1})} \tag{6}$$

where c indexes counties, t indexes years, and emp_{ct} is total employment for county c in year t. The growth rate g_{ct} is commonly referred to as the DHS growth rate after Davis et al. (1996); this growth rate concept has the desirable property of facilitating the inclusion of entry and exit. Now consider a related growth rate, commonly referred to as a growth component:

$$g^j_{ct} = \frac{emp^j_{ct} - emp^j_{ct-1}}{0.5(emp_{ct} + emp_{ct-1})} \tag{7}$$

where j indicates a grouping based on firm or establishment ages (and lack of superscript indicates inclusion of all groups). In the case of firms, $j \in J = \{\text{age 0}, \text{age 1-4}, \text{age 5+}\}$, where we define the categories as "new," "young," and "mature." In the case of establishments, $j \in J = \{\text{new firm}, \text{greenfield estab}, \text{incumbent estab}\}$. Defined in either way, it is straightforward to show that:

$$\sum_{j \in J} g^j_{ct} = g_{ct} \tag{8}$$

[16] After applying these criteria, the potential control group comes from firms located in counties in the following 29 states: AL, AZ, CA, CT, DE, FL, GA, HI, ID, IL, IN, IA, ME, MI, MN, MS, MO, NV, NH, NJ, NC, OK, OR, RI, SC, TN, VT, WA, WI. These criteria follow McCollum and Upton (2016).

Hence, each g_{ct}^j is a growth "component" such that the components sum to the overall growth rate. This follows the approach of Adelino et al. (2017) and allows for ease of coefficient interpretation; moreover, for any group, g_{ct}^j / g_{ct} gives the share of aggregate (county) employment growth accounted for by group j.

The main outcomes of interest, then, are the share of annual employment growth accounted for by new firms, "young" firms (those with age 1-4), mature firms, greenfield establishments (of existing firms), and incumbent establishments of existing firms. The use of these growth components as dependent variables in our linear regression framework ensures that regression coefficients are additive in the way described above. Importantly, for the firm-based growth components we focus on "organic" growth as in Haltiwanger et al. (2013) and subsequent literature, in which the lagged employment term emp_{ct-1}^j is comprised of the lagged employment of all establishments in county c that belong to firms in group j in year t. This approach allows us to abstract from growth driven by merger and acquisition activity. In practice this means that the growth of an establishment that changes firm owners between years $t-1$ and t is assigned to the firm that owns the establishment as of time t.

Our sector definitions are as follows. We define the oil and gas sector as NAICS 211, 213, 324, and 325; this encompasses drilling and support, extraction, and manufacturers of petroleum products (including refining and petrochemicals).[17] We often report oil and gas results separately for mining (211 and 213) and refining and petrochemicals (324 and 325). More broadly, we include NAICS sectors mining (NAICS 21), construction (23), manufacturing (31-33), retail trade (44-45), transportation and warehousing (48-49), professional, scientific, and technical services (54), and other services (81). We define utilities and waste management as NAICS 22 and 562 combined; we also combine NAICS 61 and 62 to create education and health services, and we combine NAICS 71 and 72 to create leisure and hospitality. These sector definitions are not exhaustive but leave out a handful of small sectors, which we include in aggregate analysis but do not individually break out in sector-based exercises.

The changes in key variables in the treatment and control groups are presented in Table 1.[18] There are a few notable items. First, total employment in the shale counties (i.e. treatment group) increased only modestly (by about 3 percent) between the pre-shale and post-shale time periods, while control counties actually experienced a 4 percent decline in

[17] Some of these industries include plants providing services or making products of relevance to other substances such as coal; focusing more narrowly could result in challenges to Census Bureau confidentiality policies.

[18] Additional details on summary statistics can be found in Appendix Table A2.

employment. This is unsurprising given the fact that the United States was in the midst of the Great Recession around the time of the shale boom.

But also notably, the number of new firms as a share of all firms, new firm employment as a share of total employment, and young firm employment as a share of total employment declined substantially in both shale and non-shale areas. New firm shares declined by more than 21 percent in shale counties and more than 28 percent in non shale counties. Thus, while the relative new firm share in shale counties compared to non-shale counties increased, both groups experienced significant declines. A similar pattern is observed for new firm employment as a share of total employment; new firm employment shares declined by 27 percent and 32 percent in shale and non-shale counties, respectively. But shale areas experienced a 5 percentage point slower decline than non-shale counties. Young firm employment shares (firms age 1-4) also declined faster in non-shale counties. It is not surprising that new and young firm activity declined over this time period given the particular sensitivity of young firms to the business cycle documented in the literature described above; this fact highlights the importance of studying the shale boom with a carefully designed empirical strategy.

For the U.S. as a whole, Business Dynamics Statistics data (the aggregated public-use version of the LBD) indicate that young firms comprised 10.2 percent of firms during the 2000-2006 period and 8.5 percent of firms during the 2007-2014 period. This is somewhat higher than the firm shares in our treatment and control group counties; however, young firm employment for the U.S. as a whole was about 2.8 percent of total employment during 2000-2006 and 2.2 percent of total employment during 2007-2014, somewhat less than the share in our treatment and control counties. The interesting implication is that the new firms in our treatment and control counties are fewer in number but larger than the new firms in the U.S. generally. This may reflect interesting selection associated with the broadly rural nature of the shale counties.

Next, Table 1 shows establishment and employment shares of greenfield establishments (i.e., new establishments of existing firms). Note that existing firms need not have existed in the county of interest beforehand; they could have activity anywhere in the U.S. Thus, many of these firms may have existed in other parts of the country and opened up a new establishment in the shale county. In shale counties, greenfield establishments as a share of all establishments and as a share of total employment increased by 7.5 percent and 3.6 percent, respectively. In control counties greenfield establishments as a share of all establishments was also up, but by a more modest 2.6 percent, while employment shares of greenfield establishments was actually down by more than 26 percent in control counties. Thus, from these basic summary statistics, it appears that employment growth from new establishments of existing firms was particularly important during the shale boom and might potentially account for the lion's share of the employment growth.

Finally, we see that both oil and gas and manufacturing employment in shale regions outpaced control areas. In shale areas, oil and gas employment as a share of total employment grew by more than 26 percent points, while manufacturing employment declined by about 21 percent. In control areas, we see similar results in terms of direction for these respective industries, but magnitudes are larger in shale areas.

4 Empirical Strategy

4.1 Difference in Differences

Equation (9) illustrates the commonly used difference-in-differences (DD) style estimation strategy for estimating the effect of shale oil and gas on economic outcomes.

$$y_{ct} = \alpha + \delta(S_{Shale_c} \times Shale_t) + \tau_c + \gamma_t + \varepsilon_{ct} \tag{9}$$

where y_{ct} is the outcome of interest (log total county employment or one of the growth components described by equations 6 and 7 above) for county c in year t; that is, we will study $y_{ct} \in \{ln(emp_{ct}+1), g_{ct}, g_{ct}^j \forall j\}$. S_{Shale_c} is an indicator variable corresponding to counties with shale oil and/or gas activity (i.e., the treatment group) and is zero for non-shale counties. τ_c and γ_t are fixed effects for county and year, respectively. $Shale_t$ is an indicator variable that indicates the years during which shale activity occurred. All of the shale plays, and therefore the counties that EIA defines to have shale activity, saw increases in drilling starting around 2007, and this drilling activity continued until the end of 2014.[19] The coefficient δ gives the estimated causal effect of the shale boom on shale counties, controlling for aggregate temporal shocks as well as time-invariant differences across counties that remain after the propensity score matching process. For each model, we estimate standard errors clustered at the county level.[20] We do find evidence of common pre-treatment trends in our treatment

[19] Of course, the exact start time of the boom varies across shale plays. In the initial specification, we include 2007 as the start date for the shale boom, but we also present the year-specific estimated treatment effects by shale play. While LBD data are available through 2015, we end the analysis at the end of 2014 because in 2015 global oil prices dropped significantly, and therefore the "bust" plausibly began some time during 2015. Therefore, 2007 to 2014 is the best general time period that can be considered the "boom" or "treatment" time period.

[20] Our results are broadly robust to clustering by county and year.

and control counties, though we defer exploration of this important issue to our discussion of cumulative effects in section 5.3.

The first results we present focus, for background purposes, on the effect of the shale boom on the natural log of total county employment; this provides context for our later exercises by firm age and allows for easier comparability with other studies. After discussion of those results, we describe results for the growth components described above. These comprise the main results of the paper.

4.2 Scaling Treatment Effects

In addition to presenting baseline difference in differences estimates on the net effect of employment and employment growth rates, we index results to both rig counts and estimated value of oil and gas production (based on play-level EIA data), as there are two direct channels through which an oil and gas boom can stimulate the economy. First, economic activity is stimulated because local landowners receive bonus and royalty payments for oil and gas production that occurs beneath their land. A bonus payment is given to the landowner at the time a lease is signed as a lump sum payment, then once production begins landowners receive royalty payments that are some share of the value of the oil and gas produced.[21] These royalty payments might only continue for a short time if the well is relatively unsuccessful, or can continue for years, and even decades, as the well continues along its long tail of production. Thus, local residents receiving payments can stimulate the economy through local spending.

The second channel through which oil and gas operations can stimulate a local economy is through the drilling activity itself. In the case of shale plays, the operator typically contracts out a service company to both drill the well and complete the hydraulic fracturing needed to stimulate the well to begin production. The scope of activities required as indirect inputs to drilling is surprisingly large, affecting industries ranging from trucking to lodging. These workers will earn income directly, operators and service companies might sub-contract other companies for services (creating indirect effects), and workers from both direct and indirect employment will spend money in the local economy creating induced effects.

Thus, in auxiliary regressions we scale the size of the shock to these two benchmarks, value of production and drilling rigs in operation. Value of production is associated with the

[21] Note that most shale wells are horizontally drilled, running under potentially multiple landowners' land. Most landowners receive a bonus and royalty payment even if there is no actual drilling activity physically on their land. The landowner for which the actual well is drilled also typically receives a "rental" payment that is the value of renting that land to the company for production.

revenue of local oil operators and the royalty payments accruing to local landowners, while rig counts measure the economic activity associated with the drilling. For these exercises we estimate the following regression:

$$y_{ct} = \alpha + \delta(S_{Shale_c} \times Shale_t) \times R_{ct} + \tau_c + \gamma_t + \varepsilon_{ct}, \tag{10}$$

where R_{ct} is either revenue or rigs associated with county c in year t (but note that revenue is measured at the play level so is common for all counties in a play), and other variables are defined as in equation (9). Equation (10) is identical to equation (9) aside from the inclusion of R_{ct}; hence, the δ recovered from estimating (10) is a version of the standard diff-in-diff estimator that is scaled by activity (revenue or rigs) and is informed by variation in activity across plays and over time (whereas the simple diff-in-diff estimator inherently averages the treatment effect across plays and over time). Note, though, that the exercises in which we employ these variables are not intended to separate these two effects from one another, nor are they intended to describe the channel through which these effects occur. Instead, these are meant to benchmark the effects of shale activity such that our results can be used to (a) exploit variation in the size of the shock between plays and over time and (b) provide generalized point estimates that can be scaled appropriately to be used in other contexts, potentially including calibration exercises.

4.3 Cumulative Effects

Following our main results, we estimate regressions that will shed light on the roles of various types of businesses in the *cumulative* employment change at the county level. To do this, we construct the following outcome variable:

$$e_{ct} = \frac{emp_{ct}}{emp_{c2006}} \tag{11}$$

where e_{ct} is employment in county c in year t relative to employment in county c in the year 2006. We again create a group-specific version of this variable:

$$e^k_{ct} = \frac{emp^k_{ct}}{emp_{c2006}} \tag{12}$$

where k is defined somewhat differently from the j-indexed groups described above. In particular, we focus on three k groupings: (1) establishments that entered in year 2006 or before; (2) establishments that entered after 2006 belonging to firms that existed as of 2006 or before; and (3) establishments that entered after 2006 belonging to firms that entered after 2006. For any year t, e^1_{ct} gives county c employment of establishments that were incumbents as of year 2007; e^2_{ct} gives county c employment of establishments born after 2006 to firms that were incumbents as of year 2007; and e^3_{ct} gives county c employment of establishments born after 2006 to firms born after 2006 (and these firms could have been born in any county in the U.S.). In each case, employment is expressed relative to year-2006 total county employment; therefore, the following convenient condition holds:

$$\sum_{k\in\{1,2,3\}} e^k_{ct} = e_{ct} \tag{13}$$

Moreover, note that $e^2_{ct} = e^3_{ct} = 0 \ \forall t \leq 2006$ by construction. We choose the year 2006 consistent with our assumption above that the shale boom began in 2007; of course the true timing is subject to some debate, but 2007 proves to be a reasonable turning point in the data and is consistent with the date that EIA begins tracking shale production data (EIA, 2017). The general purpose of this set of dependent variables is to study, for any given year after 2007, how much of the total employment growth in the typical county is accounted for by establishments that existed prior to the boom, establishments born after the boom to firms that existed before it began, and firms born after the boom. This provides an alternative view of the role of the business entry margin in driving aggregate employment that does not depend on single-year growth rates and allows time for early lifecycle dynamics to play out.

To study these outcomes, we generalize our difference in difference strategy as follows:

$$e^k_{ct} = \alpha + \delta^k_t \times S_{Shale_c} + \gamma^k_t + \varepsilon^k_{ct} \tag{14}$$

where δ^k_t is the year-specific estimated treatment effect for firms in a given group k, and we abuse notation slightly to include the overall group of all establishments as one of our k groups. Note that we omit county fixed effects in this specification since they are a linear combination of included variables; inability to control for county effects is not ideal but the size of the problem is limited by the fact that our control counties are chosen to be similar to our treatment counties in the pre-2007 period, and employment is scaled by 2006 county employment. The difference of means generated by δ^k_t compares shale counties to control counties in any given year, controlling for aggregate shocks affecting all counties. Conveniently, the set of estimated δ^k_t for each of the establishment groups $k \in \{1, 2, 3\}$ described above will sum to the δ_t associated with overall cumulative employment growth (relative to 2006) so that, again, we can easily calculate the share of aggregate employment growth accounted for by different types of establishments.[22] This set of specifications is useful not only because it facilitates the study of cumulative employment effects but also because it allows us easily to inspect the assumption implicit in our difference in differences framework: common pre-shock trends.

5 Results

5.1 Total Employment

Table 2 reports background results that simply show the effect of the shale boom on log total employment, for all industries combined, across shale plays. We present the average treatment effect (corresponding to δ in equation 9) alongside treatment effects scaled by rig counts and production revenue (corresponding to δ in equation 10).

Specifically, we find that the shale boom is associated with a 7.2 percent increase in total employment relative to the control group; note that this is an average quantity comparing all years after the boom to all years before. This effect varies in size and significance across shale plays, with the shale boom in the Eagle Ford region estimated to have the largest effect on employment, a 22.6 percent increase. Our results for value of production and rig count are consistent with the difference in difference results; a hundred-million-dollar increase in oil and gas production in a given year leads to a 16 percent increase in employment. Similarly, for every additional hundred rigs, we estimate that there is a 4.7 percent increase in total employment. Year and county fixed effects are included in all regressions but their estimates are not reported. Of the 24 estimated treatment effects, all are positive (in the expected direction) with fourteen being statistically significant at p=.05. Thus, we find evidence of employment increases across shale plays, and these estimated treatment effects are robust to scaling by both value of production and rig counts.

We next examine the impact of the shale boom on employment across industries (but including all plays combined). These results are presented in Table 3. We first study the oil and gas mining sector, which we define as NAICS 211 and 213.[23] Oil and gas mining activity

[22] In these exercises, we make no attempt to ensure that growth is "organic" since it is not clear how to interpret organic growth in this context. As such, however, the employment share of post-2006 new firms in any given year can, in principle, include employment of establishments that are older but were acquired by those new firms during the post-2007 period.

[23] These industries are oil and gas extraction and support activities for mining (which includes the drilling of oil and gas wells)

rose more than 50 percent with the shale boom; downstream refining and petrochemicals (NAICS 324 and 325) see a small, statistically insignificant effect. Even using the value of production measure yields only a weakly significant effect in oil and gas manufacturing. This finding reflects the fact that while significant downstream investments occurred in response to the shale boom, much of this investment was in areas with historical presence of these industries, not necessarily in new areas where extraction is now occurring (Coombs et al., 2017), therefore spurring significant investment in transportation infrastructure (Agerton and Upton, 2017).

Also presented in Table 3, we find that employment outside of the oil and gas mining sector increased by 5.7 percent, with effects differing significantly across industries. For instance, the construction and transportation industries experienced 20 percent and 12 percent increases in employment, respectively, while retail trade and professional services experienced 4.2 percent and 2 percent increases, respectively (with the latter being statistically insignificant).

Consistent with Table 2, we again find these results are robust across the three scalings of treatment effects. Specifically, we estimate that one hundred million dollars of production and one hundred rigs in operation are associated with a 49.8 percent and 15.4 percent increase in oil and gas mining employment, respectively, and a 13.7 percent and 4 percent employment increase in industries outside of oil and gas mining.

5.2 Employment Growth Rates

We now explore our main results relating the shale boom to *annual* employment growth rates and components as described in section 3.3. Table 4 reports results corresponding to equation (9) where the dependent variable is growth components by firm or establishment type (expressed in percentage points). First, note that the "Total" column, in which the dependent variable is the growth rate of aggregate (county) employment, is equal to the sum of columns 1, 2, and 4 or, alternatively, the sum of columns 1, 5, and 6. Column 3, which reports the growth component for all firms age less than 5, is equal to the sum of columns 1 and 2.

Column 7 of Table 4 indicates that the shale boom is associated with a 0.9 percentage point increase in annual employment growth rates at the county level. This is a strong effect but is not surprising in light of the results for log employment just described, which found a 7 percent increase in the average employment *level*. Column 5 shows that greenfield establishments (new establishments of existing firms) account for 0.7 percentage point of the overall increase; that is, greenfield establishments account for about three quarters of the increase in net employment growth rates. Incumbent establishments do not appear to make a net growth contribution. The estimate for new firms, reported in column 1, is not statistically significant (t statistic 1.5), but since it is large and since scaling the effect by revenue or rigs makes it significant, we argue that it is worth interpreting. Taken at face value, column 1 suggests that new firms account for about one quarter of the overall growth effect. The role of entrants is more starkly demonstrated by column 3, which shows that firms with age less than five account for a statistically significant 0.4 percentage point or 40 percent of the total net growth effect. Mature firms (column 4) make a significant contribution as well, though column 5 suggests that this effect is primarily through greenfield establishments rather than growth of existing establishments.

The evidence points to a large role for new and young firms. On the one hand, it is important not to understate the role of incumbent firms. By no means do young firms account for the majority of the employment growth response. However, the contribution of new firms and young firms generally is significantly disproportionate relative to their typical share of activity levels (about 10 percent of employment). Moreover, when scaled by activity (corresponding to equation 10) we find that the role of new and young firms is even larger, accounting for nearly half of the overall growth effect for both revenue and rigs. Our results are not as dramatic as those found by Adelino et al. (2017), who find that firms age less than two account for 90 percent of the local employment growth response to local demand shocks, but our results are striking nonetheless.

Among incumbent firms, employment growth is facilitated by greenfield establishment formation. In part this may reflect firms based outside the shale areas newly entering the shale area by creating new establishments. More broadly a comparison of the greenfield establishment coefficient with the new firm coefficient highlights the importance of carefully distinguishing between the two when studying firm dynamics. Not only are the effects quantitatively different, but also they reflect fundamentally different economic mechanisms. An incumbent firm, whether starting in or out of a shale play, opens new establishments using the resources of the firm, including supplier relationships, credit access, name recognition and customer base, and workforce. These establishments can enter larger with more upfront job creation than new firms that face particular barriers to credit access, labor market search and matching, upfront investment costs, and supplier and customer acquisition. As such, it is not surprising to see a stronger employment role for greenfield establishments, and the disproportionate role for new firms is all the more striking. We return to this topic in our discussion of cumulative employment gains.

In the appendix, results by firm age disaggregated by oil and gas mining versus industries outside oil and gas mining are presented in Table A3. The total growth rate effects are much stronger in oil and gas mining than in the rest of the economy, consistent with our estimates of employment level effects above. Interestingly, though, new firms account for a similar share (about one quarter) of overall employment growth both within and outside of oil and gas mining. Among incumbent firms, greenfield establishments are far less important in oil and gas mining, where they account for about one third of the overall effect, than outside of oil and gas mining, where they account for more than three quarters of the overall effect. Within-establishment growth of incumbent firms is important in oil and gas mining, accounting for about 40 percent of the overall effect, while this kind of growth is negligible outside of that sector. The oil and gas sector appears uniquely to rely on organic, within-establishment growth to accommodate rising production.

5.3 Cumulative Employment Growth

Table 5 reports effects on cumulative employment, by year and relative to county-level employment in 2006, as described in section 4.3 and equation (14). The results on Table 5 are graphically reported on Figure 4 (where we combine all establishment types and omit standard errors for simplicity); note also that for any given year, the coefficients in columns 1, 2, and 3 sum to column 4. It is important to recall that these specifications include year fixed effects such that coefficients indicate employment relative to control group counties; roughly speaking this is still a difference in differences approach where we compare treatment county employment relative to 2006 to control county employment relative to 2006.[24] The results can be interpreted as the change in the ratio of group employment in a given year relative to total county employment in the base year, 2006, one year before the boom began.

First consider column 4 of Table 5, which reports overall employment relative to 2006. Prior to 2007, total employment is flat and close to zero (and not statistically significant), lending support to the assumption underlying our main difference-in-differences result that treatment and control counties have similar pre-treatment trends. After 2006, total employment rises monotonically, becoming statistically significant in 2009. By 2014, total employment in treatment counties has risen 17 percent since 2006 (and relative to controls).

[24] The specifications cannot include county fixed effects due to multicollinearity; given our control group creation approach this is not an overwhelming concern, and as we note below the coefficients for 2000-2006 reassure us that our treatment and control counties are reasonable counterfactuals.

In column 1 we present results for establishments that were born prior to 2007 (that is, these establishments were incumbents when the shale boom began). We find a positive and significant effect of the shale boom for these establishments from 2009 onwards. For example, in the year 2009, we find that employment among these pre-2007 establishment cohorts has risen 2.0 percent relative to total employment in 2006. This effect peaks at 5.5 percent in 2013 before attenuating slightly to 4.5 percent in 2014. If we divide the 2014 coefficient in column 1 by the 2014 coefficient in column 4, we find that these pre-2007 establishment cohorts account for about one quarter of the total post-2006 rise in employment in shale areas (relative to control counties). The remaining three quarters of the rise is therefore attributable to establishments born after 2006.

In column 2 we present results on the changes to employment at greenfield establishments opened in 2007 or later by firms that existed prior to 2007. Again, we see positive and significant results beginning in 2009 (an increase of 1.4 percent of 2006 total employment) that strengthen annually to the end of the sample in 2014 (5.4 percent relative increase). This net job creation among new establishments of preexisting firms accounts for just under one third of the cumulative gain in total employment as of 2014.

In column 3 we examine the effect of the shale boom on employment in new firms that were started in 2007 or later. Roughly speaking, these are firms that were created after the shale boom began. In these results, we do not see a positive treatment effect until 2011, consistent with the fact that new firms tend to start small, but by 2014 this group has a larger relative increase in employment (7.0 percent) than either of the other two groups. This net job creation among post-2006 firms accounts for more than 40 percent of total shale area employment growth relative to the counterfactual. The results for each of the four groups are presented graphically in Figure 4.

As noted above, new establishments (either born to preexisting firms or new firms) account for about three quarters of the total employment gain. One other important implication arises from these results: while employment among new firms does not become significant until two years after employment at greenfield establishments of older firms, new firm employment surpasses greenfield employment two years later. This is our most striking finding about the difference between new firms and greenfield establishments: new firms start smaller but grow rapidly, consistent with a theory in which greenfield establishments, born with the advantage of existing firm ownership, begin their lifecycle better capitalized or with a stronger customer base than do young firms. New cohorts of young firms grow rapidly, however, likely as a result of a few extremely fast growers as documented by Decker et al. (2014). An important implication for theory is that modelers should not conflate firms and establishments.

It is important to note that our results do not imply that mature incumbent firms contribute little to aggregate growth. We are examining *net* employment growth. Employment growth rates are widely dispersed, even among mature firms (see Decker et al. (2016b)). Our result of low net job growth among mature businesses hides considerable heterogeneity. However, the notion that older firms have low net growth *as a group* is consistent with other evidence, including the typical aggregate growth contributions observable in the Business Dynamics Statistics.

We graphically report these year-specific effects seperately for each shale play in the appendix in Figure A4 (we omit Niobrara, whose results are mostly noise). The results do vary notably by play; Bakken, Eagle Ford, and Permian Basin look similar to the overall results described above. The gas-heavy plays—Haynesville, Marcellus, and Utica—show small overall employment effects (note the values of the Y axes) and a less-consistent story about firm and establishment entry. Preexisting trend differences between treatment and control groups are sometimes evident in these areas as well, though the differences are rarely stastically significant. In short, however, the cumulative results suggest that areas in which the shale boom generated large economic expansions saw an important role for entry, with new firms ultimately accounting for the largest share of activity gains.

5.4 Robustness Tests

5.4.1 Alternative Control Groups

Our main results—and the causal interpretation thereof—depend heavily on our propensity-matched control group. We first test the sensitivity of our results to alternative control groups by randomly choosing 20 control groups (rather than relying on our propensity score matching algorithm). The counties in these groups are drawn from the U.S. broadly, with the exception of counties close to our treatment counties (as noted above). We estimate our employment growth (by firm age) regressions with each control group; Table 6 shows the minimum, mean, and maximum coefficients obtained from these 20 random control groups along with the propensity score match control group estimated treatment effects (i.e., repeated from Table 4). Results for each individual random control group can be found in Appendix Table A5.[25]

[25]Results using the value of production and rig count scaled estimated treatment effects with random control groups can also be found in Appendix Tables Table A6 and Table A7.

The random control group exercises are generally supportive of our main results while pointing to the importance of our propensity score approach for generating causal inference. Column 7 of Table 6 reports coefficients for overall employment growth. Our propensity score match group generates smaller estimates than any of our random control groups, suggesting that our propensity score approach controls for some sources of selection. The coefficients for specific establishment groups tell a similar story. The average portion of employment growth rates accounted for by new firms and young firms among random control group estimates is close to, though slightly larger than, our main estimate. New establishments of existing firms account for a larger share of employment growth in the random control groups than in our propensity score method. Broadly speaking, though, the random control group exercises support our main results and do not raise any concerns about our research design.

5.4.2 Placebo Tests

We also perform two placebo tests. First, we perform a placebo test for employment by shale play, following the model we estimated in Table 2. To perform our placebo tests, we randomly assign observations to the control and treatment groups in two ways. First, we estimate our model only using the treated observations (i.e., counties in shale plays) but randomly assigning the observations to be "treatment" or "control". Second, we repeat this exercise using only the control observations (i.e., counties included in our propensity matched control group). Results of placebo tests for employment by shale play are presented in Table 7. Only one of the 16 estimates presented in this table is significant at the 10 percent level.[26]

We next repeat this exercise for employment by firm age using the same model that we used in Table 4. We follow the same method for estimating the treatment effect by randomly assigning observations to arbitrary "treatment" and "control" groups as described in the previous paragraph. Results of placebo tests for employment by firm age are also presented in Table 7. Of the fourteen coefficients presented, just one is significant at p=.05. Broadly speaking, our placebo tests are supportive of our identification strategy.

[26] We do not perform placebo tests using the revenue or rig count variables since these variables are common within plays and are uniformly zero in our matched control groups.

6 Conclusion

The U.S. shale boom has given rise to a large literature studying the economic effects of natural resource shocks. We add to this literature by studying the effects of the shale boom on new firms and establishments, adding entrepreneurship and business creation to the list of economic outcomes that are stimulated by natural resource production (i.e., natural resource booms do not appear to only benefit existing business establishments). But our results also have significant implications for the study of macroeconomics. In particular, a large literature in firm dynamics focuses on the role of new business creation in the response of the aggregate economy to broad economic shocks. We show that the growth of aggregate employment in response to the shale boom is, on net, entirely accounted for by new firms and new establishments of existing firms. This finding lends strong support to models of firm dynamics in which, under standard assumptions, the entry margin accounts for a large share of aggregate adjustment. Further, though, our results point to important differences between new firms and new establishments of existing firms ("greenfield" establishments). New firms appear to start small but, as a cohort, grow rapidly. New establishments of incumbent firms appear to start out larger, with a more gradual growth trajectory.

These differences between firms and establishments have important implications for theories of firm dynamics. New firms are likely more constrained than greenfield establishments in terms of initial investment costs and the challenges associated with building a workforce, establishing supplier relationships, and building a customer base (Moreira (2017), Foster et al. (2016)). As such, while greenfield establishments are significantly more important than new firms when accounting for increased annual employment growth, over several years the importance of firms born after the boom increases such that new firms ultimately play a larger role than greenfield establishments. These results shed additional light on the dynamics of young businesses and their importance for aggregate adjustment, presenting important facts with which models of firm dynamics must grapple.

7 Tables and Figures

Figure 1: Model dynamics after aggregate productivity increase

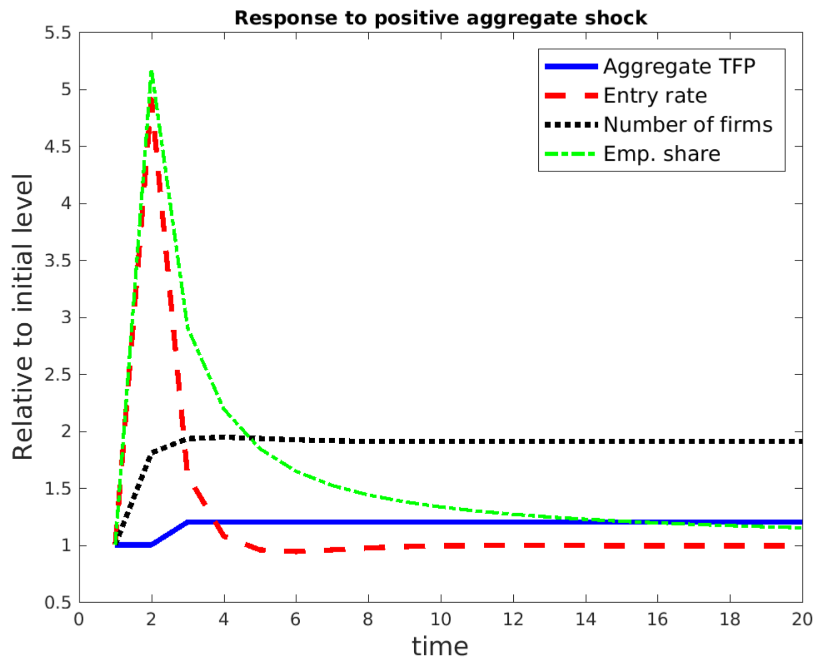


Figure 2: Historical U.S. Crude Production

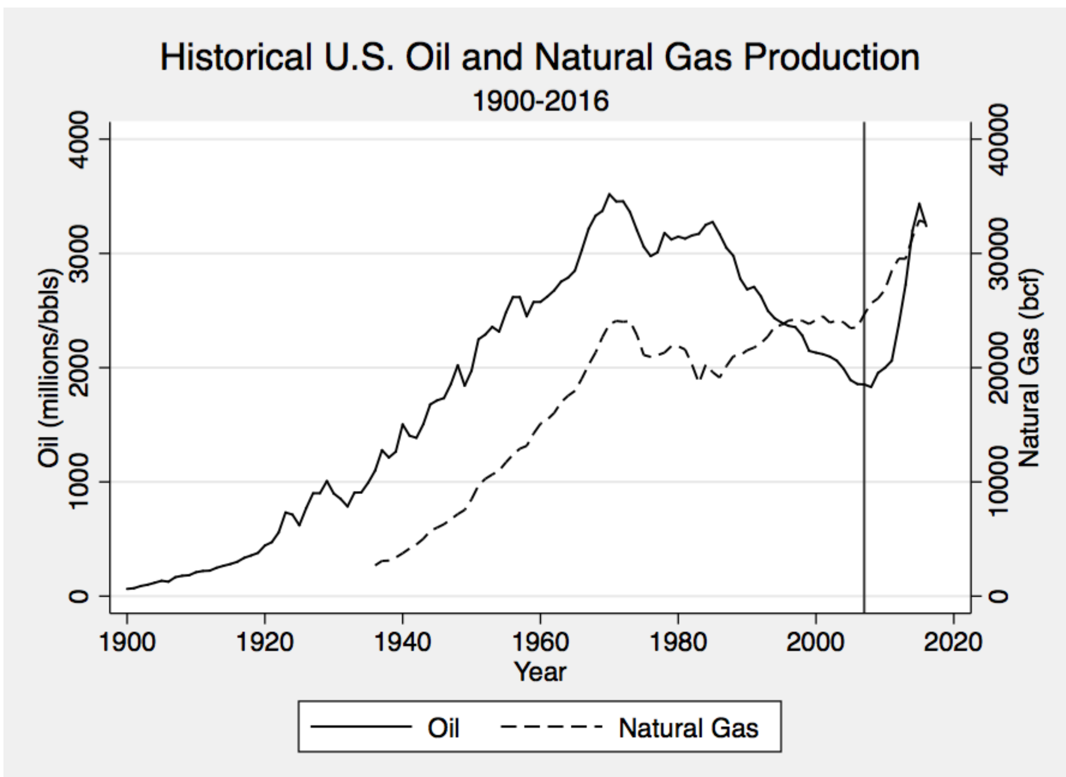
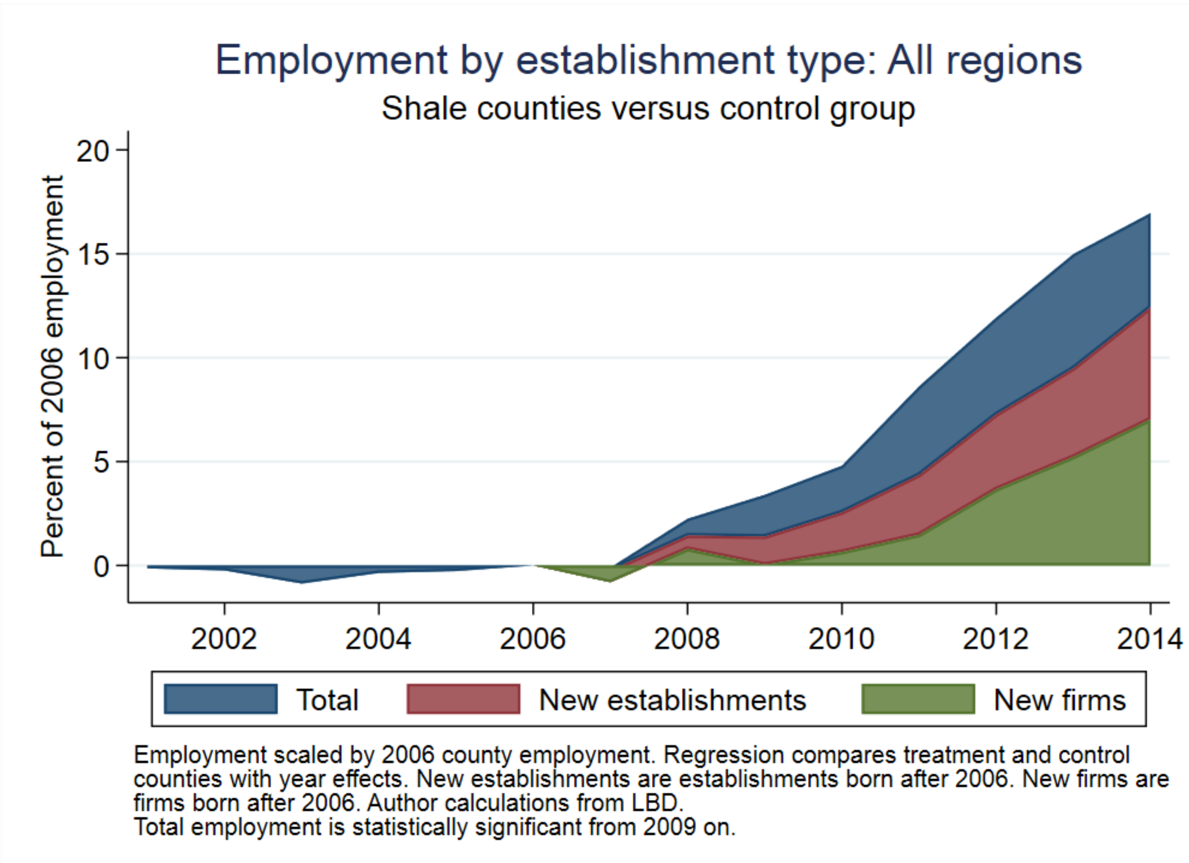


Figure 3: U.S. Shale Plays

Figure 4: Employment treatment effects by year



Coefficients corresponding to regressions reported on Table 5. Yearly regression coefficients from regression comparing treatment and control counties with aggregate year effects. New establishments are establishments born after 2006. New firms are firms born after 2006. Author calculations from the Longitudinal Business Database.

Table 1: Summary Statistics: Baseline Sample

	Treatment Group			Control Group			
	Pre 2007	Post 2007	Percent Change	Pre 2007	Post 2007	Percent Change	%ΔTreatment - %ΔControl
Total Employment	21,100	21,700	2.76%	18,300	17,600	-3.98%	6.74%
New Firm Share of Firms	6.7%	5.5%	-21.82%	6.7%	5.2%	-28.85%	7.03%
New Firm Share of Employment	3.3%	2.6%	-26.92%	3.3%	2.5%	-32.00%	5.08%
Young Firm Share of Employment	10.8%	9.0%	-20.00%	10.9%	8.4%	-29.76%	9.76%
Greenfield Share of Establishments	3.7%	4.0%	7.50%	3.7%	3.8%	2.63%	4.87%
Greenfield Share of Employment	2.7%	2.8%	3.57%	2.9%	2.3%	-26.09%	29.66%
Oil and Gas Share of Employment	4.7%	6.4%	26.56%	2.6%	3.0%	13.33%	13.23%
Manufacturing Share of Employment	13.40%	11.10%	-20.72%	13.8%	12.2%	-13.11%	7.61%

Averages of annual data for treatment and control groups. Pre-2007 period is 2000-2006. Post-2007 period is 2007-2014. Refer to Appendix Table A2 for more detailed summary statistics. Total employment in counts. "New Firm Share of Firms" is the total number of new firms as a share of total firms in the county. "New Firm Share of Employment" is employment associated with new firms as a share of total county employment. "Young Firm Share of Employment" is employment associated with young firms (age 1 to 4) as a share of total employment. "Greenfield Share of Establishments" is the share of establishments that were opened by existing firms within that year. "Greenfield Share of Employment" is the share of employment associated with new establishments of existing firms. "Oil and Gas Share of Employment" is the share of total employment in the oil and gas industry (NAICS 211, 213, 324, and 325) and "Manufacturing Share of Employment" is the share of total employment in the manufacturing industry (NAICS 31-33).

Table 2: Impact of Shale on Employment by Play - All Industries

	(1) All	(2) Bakken	(3) Eagle Ford	(4) Haynesville	(5) Marcellus	(6) Niobrara	(7) Permian	(8) Utica
Treatment Effect	0.072***	0.216***	0.226***	0.073	0.039**	0.039	0.089**	0.056
	(0.014)	(0.074)	(0.056)	(0.059)	(0.017)	(0.044)	(0.044)	(0.034)
Observations	8,550	600	690	750	3,180	1,110	1,620	600
Value of Prod. (100 millions)	0.16***	0.58***	0.34***	0.21	0.11**	0.11	0.09**	1.54
	(0.03)	(.016)	(0.09)	(0.17)	(0.06)	(0.12)	(0.04)	(1.11)
Observations	8,550	600	690	750	3,180	1,110	1,620	600
Rig count (hundreds)	0.047***	0.221***	0.146***	0.031	0.05***	0.029	0.026**	0.152
	(0.009)	(0.062)	(0.039)	(0.027)	(0.019)	(0.046)	(0.013)	(0.136)
Observations	8,550	600	690	750	3,180	1,110	1,620	600

Dependent variable natural log of total employment in all regressions. County clustered standard errors shown. Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS.

Table 3: Impact of Shale on Employment by Industry- All Plays

	(1) Oil and Gas- Mining	(2) Non Oil and Gas- Mining	(3) Refineries & Petrochemical	(4) Utilities and Waste Mgt	(5) Construction	(6) Manufacturing
NAICS	211, 213		324, 325	22, 562	23	31-33
Treatment Effect	0.504***	0.057***	0.002	0.04	0.2***	0.028
	(0.064)	(0.013)	(0.069)	(0.041)	(0.031)	(0.039)
N	8,550	8,550	8,550	8,550	8,550	8,550
Revenue (hundred millions)	0.488***	0.137***	0.153*	0.16**	0.386***	0.164**
	(0.89)	(0.25)	(0.84)	(0.65)	(0.57)	(0.68)
N	8,550	8,550	8,550	8,550	8,550	8,550
Rig count (hundreds)	0.154***	0.04***	0.034	0.047**	0.127***	0.044**
	(0.028)	(0.008)	(0.027)	(0.021)	(0.018)	(0.021)
N	8,550	8,550	8,550	8,550	8,550	8,550
	(7) Retail Trade	(8) Transport & Warehousing	(9) Prof., science, & tech	(10) Educ. & health	(11) Leisure & Hospitality	(12) Other Services
NAICS	44-45	48-49	54	61-62	71-72	81
Treatment Effect	0.042***	0.123***	0.02	0.019	0.094***	0.032*
	(0.013)	(0.046)	(0.03)	(0.023)	(0.024)	(0.018)
N	8,550	8,550	8,550	8,550	8,550	8,550
Revenue (hundred millions)	0.113***	0.358***	0.069	0.026	0.159***	0.082***
	(0.19)	(0.86)	(0.44)	(0.51)	(0.46)	(0.26)
N	8,550	8,550	8,550	8,550	8,550	8,550
Rig count (hundreds)	0.034***	0.1***	0.015	0.006	0.05***	0.023***
	(0.006)	(0.027)	(0.014)	(0.015)	(0.015)	(0.008)
N	8,550	8,550	8,550	8,550	8,550	8,550

Dependent variable natural log of total employment in all regressions. County clustered standard errors shown. Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS.

Table 4: Impact of Shale on Employment Growth by Establishment Age - All Industries

	(1) New Firms	(2) Young Firms	(3) New & Young Firms (1) + (2)	(4) Mature Firms	(5) Greenfield Estabs	(6) Incumbent Estabs	(7) Total (1) + (2) + (4) (1) + (5) + (6)
Treatment Effect	0.227	0.149	0.376**	0.545*	0.707***	-0.012	0.921**
	(0.149)	(0.135)	(0.150)	(0.305)	(0.193)	(0.346)	(0.376)
Observations	8,550	8,550	8,550	8,550	8,550	8,550	8,550
Revenue (100 millions)	0.97***	0.01	0.98***	1.15**	1.11***	0.05	2.12***
	(0.31)	(0.25)	(0.35)	(0.55)	(0.29)	(0.68)	(0.78)
Observations	8,550	8,550	8,550	8,550	8,550	8,550	8,550
Rig count (hundreds)	0.296***	0.104	0.4***	0.428**	0.227**	0.304	0.828***
	(0.091)	(0.064)	(0.114)	(0.178)	(0.092)	(0.21)	(0.260)
Observations	8,550	8,550	8,550	8,550	8,550	8,550	8,550

Dependent variable growth component in all regressions. County clustered standard errors shown. Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+. Columns 1+2=3, columns 1+2+4=7, and columns 1+5+6=7

Table 5: Impact of Shale on Employment Ratio

	(1) Pre-2007 establishments	(2) New establishments 2007 to pre-2007 firms	(3) New establishments of firms born 2007 and later	(4) Total
Treatment effect 2000	-0.0387	0	0	-0.0387
	(0.0354)			(0.0354)
Treatment effect 2001	-0.0014	0	0	-0.0014
	(0.0241)			(0.0241)
Treatment effect 2002	-0.0024	0	0	-0.0024
	(0.0136)			(0.0136)
Treatment effect 2003	-0.0087	0	0	-0.0087
	(0.0146)			(0.0146)
Treatment effect 2004	-0.0036	0	0	-0.0036
	(0.0136)			(0.0136)
Treatment effect 2005	-0.0027	0	0	-0.0027
	(0.0119)			(0.0119)
Treatment effect 2006	0	0	0	0
Treatment effect 2007	0.0013	0.0058	-0.0081	-0.001
	(0.0069)	(0.0041)	(0.005)	(0.0096)
Treatment effect 2008	0.0081	0.0064	0.008	0.0225
	(0.0076)	(0.0056)	(0.0107)	(0.0154)
Treatment effect 2009	0.0201**	0.0135**	0.0004	0.034***
	(0.0086)	(0.0068)	(0.0035)	(0.0114)
Treatment effect 2010	0.0224**	0.0191**	0.0065	0.048***
	(0.0091)	(0.0085)	(0.0041)	(0.0127)
Treatment effect 2011	0.0427***	0.0288***	0.0148***	0.0862***
	(0.0130)	(0.0098)	(0.0057)	(0.0185)
Treatment effect 2012	0.0465***	0.036***	0.0367***	0.1193***
	(0.0132)	(0.0110)	(0.0107)	(0.0242)
Treatment effect 2013	0.0551***	0.0426***	0.0523***	0.1499***
	(0.0144)	(0.0127)	(0.0140)	(0.0301)***
Treatment effect 2014	0.0454***	0.0539***	0.0704***	0.1696***
	(0.0130)	(0.0141)	(0.0180)	(0.0351)
Observations	8,550	8,550	8,550	8,550

County clustered standard errors shown. Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+. Employment ratio is defined as the ratio of a given group's employment in a given year to the total county employment for that group in the base year of 2006. Pre-treatment period is 2000-2006 and post-treatment period is 2007-2014.

Table 6: Comparison of Estimated Treatment Effects by Firm Age

	(1) New Firms	(2) Young Firms	(3) New & Young Firms (1) + (2)	(4) Mature Firms	(5) Greenfield Estabs	(6) Incumbent Estabs	(7) Total (1) + (2) + (4) (1) + (5) + (6)
Treatment Effect Results							
Propensity Score Match Group	0.227	0.149	0.376**	0.545*	0.707***	-0.012	0.921**
Random Control Group (Min.)	0.14	0.15	0.47	0.57	0.57	0.12	1.19
Random Control Group (Mean)	0.39	0.29	0.63	0.80	0.72	0.38	1.43
Radom Control Group (Max.)	0.47	0.43	0.80	1.14	0.86	0.54	1.74
Revenue Results							
Propensity Score Match Group	0.097***	0.001	0.098***	0.115**	0.111***	0.005	0.212***
Random Control Group (Min.)	0.086	-0.002	0.095	0.091	0.10	-0.015	0.209
Random Control Group (Mean)	0.1025	0.011	0.114	0.118	0.114	0.015	0.232
Random Control Group (Max.)	0.115	0.22	0.127	0.142	0.128	0.033	0.258
Rig Count Results							
Propensity Score Match Group	0.296***	0.104	0.4***	0.428**	0.227**	0.304	0.828***
Random Control Group (Min.)	0.26	0.08	0.41	0.38	0.21	0.25	0.85
Random Control Group (Mean)	0.32	0.13	0.45	0.46	0.25	0.35	0.91
Random Control Group (Max.)	0.36	0.17	0.49	0.55	0.29	0.41	1

Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Data across all industries and shale plays is used. Treatment effect, revenue, and rig count coefficient estimates are from Table 4. Revenue is expressed in hundreds of millions of dollars and rig count is expressed in hundreds of rigs. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+. Columns 1+2=3, columns 1+2+4=7, and columns 1+5+6=7

Table 7: Placebo Tests

	(1) All	(2) Bakken	(3) Eagle Ford	(4) Haynesville	(5) Marcellus	(6) Niobrara	(7) Permian	(8) Utica
Treatment Placebo								
Treatment Effect	-0.008	0.029	0.13	-0.088	0.007	0.007	0.043	-0.039
	(0.023)	(0.115)	(0.092)	(0.062)	(0.02)	(0.051)	(0.07)	(0.047)
Observations	4,275	300	345	375	1,590	555	810	300
Control Placebo								
Treatment Effect	0.001	-0.068	-0.114*	0.15	-0.037	-0.014	0.083	0.025
	(0.016)	(0.099)	(0.060)	(0.102)	(0.028)	(0.073)	(0.055)	(0.051)
Observations	4,275	300	345	375	1,590	555	810	300

	(1) New Firm	(2) Young Firm	(3) New & Young Firm (1) + (2)	(4) Old Firm	(5) New- Existing	(6) Old-Exisiting	(7) Total (1) + (2) + (4) (1) + (5) + (6)
Treatment Placebo							
Treatment Effect	0.089	0.095	0.184	0.131	-0.099	0.325	0.315
	(0.201)	(0.178)	(0.241)	(0.477)	(0.242)	(0.543)	(0.613)
Observations	4,275	4,275	4,275	4,275	4,275	4,275	4,275
Control Placebo							
Treatment Effect	-0.206	-0.223	-0.429**	0.257	-0.383	0.418	-0.172
	(0.219)	(0.202)	(0.178)	(0.38)	(0.302)	(0.429)	(0.439)
Observations	4,275	4,275	4,275	4,275	4,275	4,275	4,275

Dependent variable natural log of total employment in all regressions. County clustered standard errors shown. Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+.

A Appendix

Clementi and Palazzo (2016) construct a fully featured model of firm dynamics for studying the cyclical properties of business entry. Here we describe a moderately simplified version of that model to explore key results. The differences between our model here and that of Clementi and Palazzo (2016) are (a) we omit capital from the model and (b) we study a simple transition path exercise rather than implementing full stochastic aggregate risk and business cycle exercises. We also initially differ by shutting down ex ante heterogeneity of entrants, but we expand our investigation to include ex ante heterogeneity further below. While we do calibrate the model, we take much of our calibration from existing literature and focus primarily on the qualitative results.

Firms face idiosyncratic productivity draws z and an aggregate productivity state A. Idiosyncratic productivity evolves according to $\ln z' = \rho_z \ln z + \sigma_z \varepsilon_z'$ where $\varepsilon_z \sim N(0,1)$; this yields a conditional distribution of z' given by $H(z'|z)$. Firms produce using technology Azn^{α}, where α governs revenue curvature (which we interpret here as decreasing returns to scale); firms discount profits with factor β and face a spot market for labor with wage w and labor supply curve $L_s(w) = w^{\gamma}$ (with $\gamma > 0$). Continuing firms must pay a fixed operating cost c_f; the operating cost is not persistent, and $c_f \sim LN(\mu_c, \sigma_c)$.

In the main text, we consider a version of the model in which potential entrants are homogenous and receive no signal about their quality. Under these assumptions, entry is determined by the free entry condition:

$$c_e = \mathbb{E}_{z'} V(z'; A, w), \tag{15}$$

where c_e is the entry cost and $V(z'; A, w)$ is the value function of an operating firm. The mass of entrants is determined in equalibrium such that the average firm value is pinned down to the entry cost. Upon entry, new entrants receive porductivity draws consistent with the unconditional productivity distribution of incumbent firms.

The timing of the model is as follows. At the beginning of the period, incumbents observe their productivity z then hire labor and produce. Incumbents, following production, draw their operating cost c_f then choose whether to continue or exit; at the same time, the mass of entrants is determined, and entrants pay the entry cost c_e. Then the next period begins.

The incumbents' problem is as follows. First, the incumbent faces a static profit maximization problem yielding the following first-order condition for labor demand:

$$n(z;A,w) = \left(\frac{w}{\alpha A z}\right)^{\frac{1}{\alpha-1}}. \tag{16}$$

This yields a profit function $\pi(z;A,w)$. The value of an incumbent at the beginning of a period is given by:

$$V(z;A,w) = \pi(z;A,w) + \beta \mathbb{E}_{c_f}\left[\max\{0, \mathbb{E}_{z'|z} V(z';A,w) - c_f\}\right] \tag{17}$$

This optimization problem yields an exit rule such that firms choose to exit when the expected value of the firm is negative (where exit provides a payoff of zero, as shown in the internal maximization operator); this results in a threshold rule such that incumbents exit when $z \leq z^*(A,w)$.

The recursive competitive equilibrium is defined as follows. $V(z;A,w), n(z;A,w)$, and the associated exit rule arising from the threshold z^* solve the incumbents' problem, and the mass of entrants M is such that the free entry condition (15) holds with equality; the distribution of new entrants is given by $E(z') = M^* H(z')$. The labor market clears; that is, $w^\gamma = \int n(z;A,w) d\Gamma(z)$, where $\Gamma(z)$ is the measure of producing firms (distributed over z). Finally, the measure of firms evolves according to $\Gamma'(z') = \int \int_{c_f} \int_{z^*}^{\infty} d\Gamma(z) dG(c_f) dH(z'|z) + E(z')$. The latter condition simply illustrates that the new distribution of firms reflects the distribution of incumbents that chose not to exit, appropriately transitioned to updated productivity draws, plus the mass and distribution of new entrants .

We calibrate the model as reported on Table A1 in the column labeled "Model 1"; this calibration mostly follows Clementi and Palazzo (2016) except that we choose μ_c (the operating cost distribution mean) to target an entry rate of 9 percent (that is, entrants account for 9 percent of firms), consistent with Business Dynamics Statistics data from the early 2000s.

We solve the steady state of the model by starting with guesses for the entry mass M and the wage w, solving value functions and policy functions (via value function iteration), iterating to a stationary distribution where $\Gamma' = \Gamma$, checking labor market clearing, revising the wage until the market clears, then revising the entry mass M until the free entry condition holds. We consider two steady states; in the baseline steady state we set $A = 1$, and in the expansion steady state we set $A = 1.2$ (these choices are arbitrary, designed only to illustrate qualitative dynamics). We then study a transition from the baseline to the expansion state.

In period 0, the economy is in the baseline steady state with no expectation for change. In period 1, firms learn that A will transition from 1 to 1.2 effective the beginning of period 2, after which the economy will converge to the steady state associated with $A = 1.2$ and no expectation of change. This exercise is illustrated on Figure 1 and desribed in the main text. In short, the positive aggregate shock (solid blue line) causes a permanent increase in the number of firms (dotted black line); this rise in the firm count is facilitated by a surge in entry (dashed red line), including the employment-weighted entry rate (dot-dashed green line). In unreported exercises, we find that this result (surging entry and employment-weighted entry) is robust to a wide range of parameterizations.

We next generalize the model slightly to allow ex ante heterogeneity among entrants. At any time there exists a mass M_p of potential entrants. Each potential entrant receives a *signal* about their productivity given by $q \sim Pareto(\min(z), \xi)$. The signal q relates to productivity on entry with the conditional distribution $H(z'|q)$; that is, productivity on entry follows $\ln z' = \rho_z \ln q + \sigma_z \varepsilon'_z$. While it is not strictly necessary that the distribution of potential entrants' signals differ from the distribution of incumbents' productivity, doing so makes it possible to match the number and size of entrant firms to the data. While incumbent firms are producing, potential entrants observe their signal q and choose whether to enter for production in the next period. The potential entrants' problem is solved simply by choosing to enter when the free entry condition holds:

$$\beta \mathbb{E}_{z'|q} V(z'; A, w) \geq c_e \tag{18}$$

As is common in models of this class, this free entry condition yields an entry rule such that potential entrants choose to enter if and only if $q \geq q^*(A, w)$, where $q^*(A, w)$ is a threshold value dependent on the aggregate state. This threshold rule differs in important ways from the simpler free entry condition given by (15); in particular, the threshold rule does not hold with equality and, therefore, has less stark implications for the value of existing firms. Additionally, the productivity distribution of new entrants differs from that of continuing incumbents due to the signal distribution; this is necessary for matching the firm size distribution (as noted by Clementi and Palazzo (2016)), but it creates different dynamics for the employment share of entrants. On Table A1, the column "Model 2" reports calibration details for this model generalization.

We conduct the same transition path exercise as above, reported on Figure A1. The solid blue line reports the path of aggregate productivity. The dotted black line shows that, as in the previous experiment, the improvement in aggregate conditions causes a rise in the

Table A1: Calibration details

Parameter	Description	Model 1	Model 2
β	Discount factor	0.96	0.96
α	Returns to scale	0.8	0.8
γ	Labor supply elasticity	2	2
ρ_z	Firm TFP persistence	0.55	0.55
σ_z	Firm TFP dispersion	0.22	0.22
μ_c	Fixed operating cost mean	-6.7	-6.7
σ_c	Fixed operating cost dispersion	0.9	0.9
c_e	Entry cost	e^{μ_c}	$3e^{\mu_c}$
ξ	Entrant signal shape		2.69

number of firms as existing firms do not grow enough to accomodate the shock. The red dashed line shows that, in this calibration, the rise in the number of firms is faciliated in part by a surge in entry. However, unlike the previous experiment, the green dot-dashed line shows that the employment share of entrants does not rise. This is the result of ex ante heterogeneity and quality signals; in this setup, the rise in entry is driven by a decline in the threshold for the productivity signal above which entry is profitable. This induces a selection mechanism in which the positive aggregate shock allows lower-quality entrepreneurs to enter; upon entering, their employment is lower than the minimum productivity of entrants during the initial stationary state.

The exercises from our more general model still support the notion that aggregate shocks are accomodated, at least in part, by a rise in entry. However, even this result is heavily influenced by calibration. For example, Figure A2 reports the same experiment except that the revenue curvature parameter α is reduced to 0.7 (from 0.8); in this experiment, even the unweighted entry rate responds negatively to the shock (note that the number of firms still rises, faciliated by a lower exit rate). Figure A3 shows that the entry rate effect can be reduced by lowering the labor supply elasticity to $\gamma = 1$ (from $\gamma = 2$). In future drafts we will further explore calibration considerations in relation to our empirical results.

Figure A1: Model with quality signals

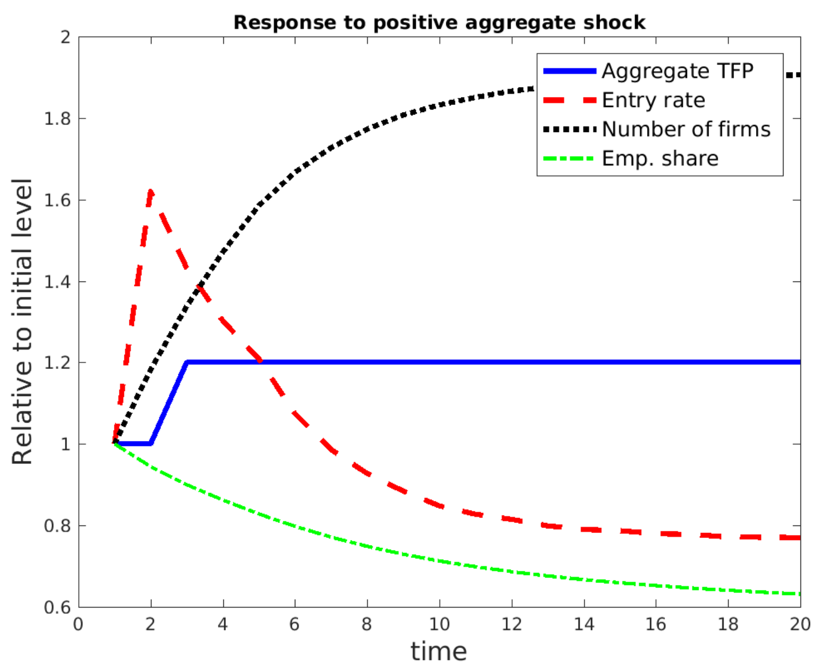


Figure A2: Model with quality signals ($\alpha = 0.7$)

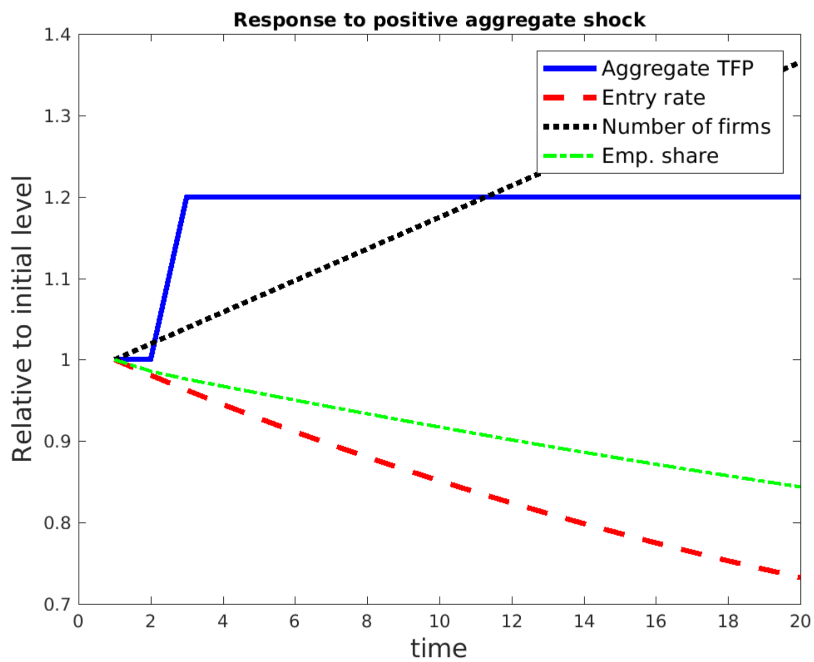


Figure A3: Model with quality signals ($\gamma = 1$)

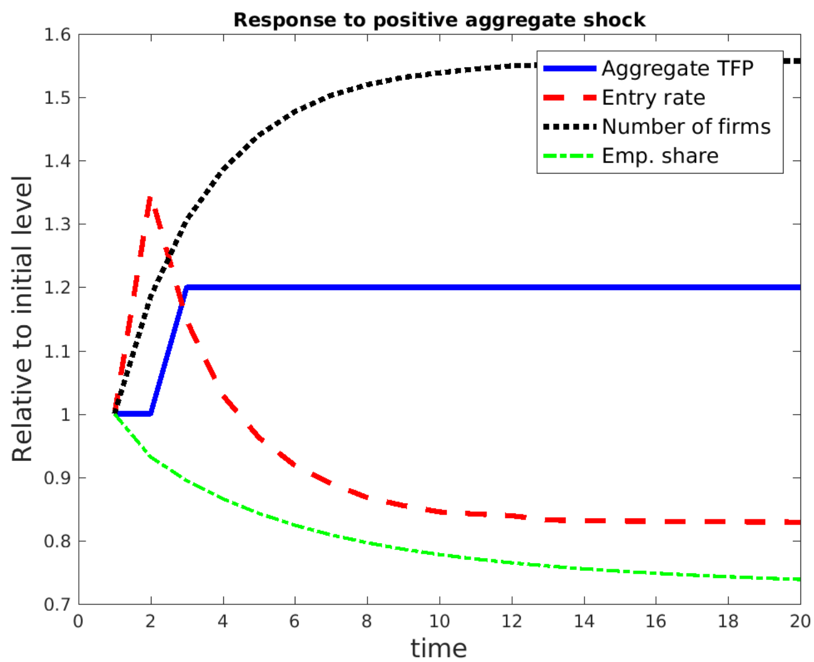


Table A2: Summary Statistics: Baseline Sample

	All			Pre 2007			Post 2007			
	Mean	Std	N	Mean	Std	N	Mean	Std	N	% Change
Treatment Group - Shale Counties										
Total Employment	17,927	55,560	4,275	21,100	55,400	1,995	21,700	55,700	2,280	2.76%
New Firm Share of Firms	6.1%	2.5%	4,275	6.7%	2.3%	1,995	5.5%	2.6%	2,280	-21.82%
New Firm Share of Employment	2.9%	2.7%	4,275	3.3%	2.6%	1,995	2.6%	2.8%	2,280	-26.92%
Young Firm Share of Employment	9.8%	5.1%	4,275	10.8%	5.4%	1,995	9.0%	4.8%	2,280	-20.00%
Existing Firm New Establishment Share of Establishments	3.9%	1.9%	4,275	3.7%	1.8%	1,995	4.0%	1.9%	2,280	7.5%
Existing Firm New Establishment Employment Share	2.8%	3.3%	4,275	2.7%	3.2%	1,995	2.8%	3.4%	2,280	3.57%
Oil and Gas Share of Employment	5.6%	9.8%	4,275	4.7%	9.3%	1,995	6.4%	10.3%	2,280	26.56%
Manufacturing Share of Employment	12.2%	10.7%	4,275	13.4%	11.6%	1,995	11.1%	10.0%	2,280	-20.72%
Control Group - Propensity Score Match Counties										
Total Employment	17,927	44,333	4,275	18,300	47,000	1,995	17,600	42,000	2,280	-3.98%
New Firm Share of Firms	5.9%	2.1%	4,275	6.7%	2.2%	1,995	5.2%	2.0%	2,280	-28.85%
New Firm Share of Employment	2.9%	2.9%	4,275	3.3%	3.2%	1,995	2.5%	2.6%	2,280	-32.00%
Young Firm Share of Employment	9.6%	4.9%	4,275	10.9%	5.2%	1,995	8.4%	4.7%	2,280	-29.76%
Existing Firm New Establishment Share of Establishments	3.8%	1.7%	4,275	3.7%	1.8%	1,995	3.8%	1.7%	2,280	2.63%
Existing Firm New Establishment Employment Share	2.6%	3.4%	4,275	2.9%	3.7%	1,995	2.3%	3.1%	2,280	-26.09%
Oil and Gas Share of Employment	2.8%	6.0%	4,275	2.6%	5.9%	1,995	3.0%	6.1%	2,280	13.33%
Manufacturing Share of Employment	12.9%	10.3%	4,275	13.8%	10.9%	1,995	12.2%	9.8%	2,280	-13.11%

Averages of annual data for treatment and control groups. Pre-2007 period is 2000-2006. Post-2007 period is 2007-2014. Total employment in counts. "New Firm Share of Firms" is the total number of new firms as a share of total firms in existence within the county. "New Firm Share of Employment" is employment associated with new firms as a share of total employment. "Young Firm Share of Employment" is employment associated with young firms (age 1 to 4) as a share of total employment. "Existing Firm New Establishment Share of Establishments" is the share of establishments that were opened by existing firms within that year. "Existing Firm New Establishment Employment Share" is the share of employment associated with new establishments of existing firms. "Oil and Gas Share of Employment" is the share of total employment in the oil and gas industry (NAICS 211, 213, 324, and 325) and "Manufacturing Share of Employment" is the share of total employment in the manufacturing industry (NAICS 31-33).

Table A3: Impact of Shale on Employment Growth by Firm Age - Mining vs. Non-Mining Sectors

	(1) New Firms	(2) Young Firms	(3) New & Young Firms (1) + (2)	(4) Mature Firms	(5) Greenfield Estabs	(6) Incumbent Estabs	(7) Total (1) + (2) + (4) (1) + (5) + (6)
Treatment Effect OGM	2.5	2	4.5**	6.1***	3.8**	4.3*	10.5***
	(1.7)	(1.4)	(2.2)	(2.2)	(1.7)	(2.3)	(3.0)
Observations	5,184	5,184	5,184	5,184	5,184	5,184	5,184
Treatment Effect Non-OGM	0.19	0.12	0.31**	0.44	0.62**	-0.07	0.75**
	(0.15)	(0.15)	(0.16)	(0.29)	(0.19)	(0.34)	(0.36)
Observations	8,550	8,550	8,550	8,550	8,550	8,550	8,550
Revenue (100 millions) OGM	1.6	1.3	2.9	7.2***	5.3***	3.2	10.1***
	(1.7)	(1.6)	(1.9)	(2.4)	(1.6)	(2.4)	(2.8)
Observations	5,184	5,184	5,184	5,184	5,184	5,184	5,184
Revenue (100 millions) Non-OGM	0.91***	0.1	1.02***	0.9*	0.84***	0.16	1.92***
	(0.3)	(0.35)	(0.4)	(0.46)	(0.27)	(0.67)	0.7)
Observations	8,550	8,550	8,550	8,550	8,550	8,550	8,550
Rig Count (hundreds) OGM	0.8	0.7	1.4***	2.7***	1.7***	1.7**	4.2***
	(0.5)	(0.5)	(0.6)	(0.8)	(0.5)	(0.8)	(0.9)
Observations	5,184	5,184	5,184	5,184	5,184	5,184	5,184
Rig Count (hundreds) Non-OGM	0.28***	0.13	0.41***	0.35***	0.16**	0.32	0.76***
	(0.08)	(0.09)	(0.13)	(0.15)	(0.08)	(0.2)	(0.24)
Observations	8,550	8,550	8,550	8,550	8,550	8,550	8,550

County clustered standard errors shown. Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+.

Table A4: Impact of Shale on Employment by Firm Age - by Shale Play

	(1) New Firms	(2) Young Firms	(3) New & Young Firms (1) + (2)	(4) Mature Firms	(5) Greenfield Estabs	(6) Incumbent Estabs	(7) Total (1) + (2) + (4) (1) + (5) + (6)
ln(**Total Employment**)							
Treatment Effect- Bakken	1.04*	1.52***	2.56***	2.8**	0.69	3.64***	5.36***
	(0.57)	(0.40)	(0.79)	(1.36)	(0.59)	(1.26)	(1.90)
Observations	600	600	600	600	600	600	600
Treatment Effect- Eagle Ford	0.55	1.3**	1.85***	1.81	1.66	1.45	3.66**
	(0.51)	(0.50)	(0.62)	(1.21)	(1.15)	(1.5)	(1.62)
Observations	690	690	690	690	690	690	690
Treatment Effect- Haynesville	0.02	-0.44	-0.43	-0.23	0.6*	-1.27	-0.65
	(0.31)	(0.3)	(0.34)	(0.98)	(0.33)	(1.14)	(1.04)
Observations	750	750	750	750	750	750	750
Treatment Effect- Marcellus	-0.36**	0.22*	-0.14	0.12	0.22	0.11	-0.03
	(0.15)	(0.13)	(0.15)	(0.42)	(0.21)	(0.42)	(0.45)
Observations	3,180	3,180	3,180	3,180	3,180	3,180	3,180
Treatment Effect- Niobrara	-0.91	0.76	-0.15	-0.89	-0.11	-0.02	-1.04
	(0.62)	(0.73)	(0.43)	(1.04)	(0.49)	(1.27)	(1.21)
Observations	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Treatment Effect- Permian	0.78	-0.11	0.67	0.51	0.64	-0.25	1.17
	(0.59)	(0.57)	(0.47)	(0.83)	(0.52)	(1.17)	(1.11)
Observations	1,620	1,620	1,620	1,620	1,620	1,620	1,620
Treatment Effect- Utica	-0.6	0.23	-0.37	-0.93	0.07	-0.76	-1.3*
	(0.42)	(0.38)	(0.31)	(0.72)	(0.43)	(0.76)	(0.70)
Observations	600	600	600	600	600	600	600

County clustered standard errors shown. Treatment time period post 2007. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+.

Table A5: Estimated Treatment Effect for 20 Random Control Groups: Ln(Employment)

Iteration	New Firms	Young Firms	New & Young Firms	Mature Firms	Greenfield Estabs	Incumbent Estabs	Total
1	0.30	0.25	0.55	0.8 0	0.74	0.31	1.35
2	0.29	0.33	0.63	0.74	0.61	0.47	1.37
3	0.31	0.34	0.65	0.63	0.67	0.31	1.28
4	0.39	0.16	0.55	0.89	0.59	0.45	1.43
5	0.25	0.21	0.47	0.80	0.75	0.26	1.27
6	0.42	0.38	0.80	0.80	0.86	0.33	1.60
7	0.26	0.32	0.58	0.76	0.83	0.25	1.34
8	0.44	0.20	0.64	1.03	0.74	0.49	1.67
9	0.39	0.25	0.64	0.71	0.66	0.30	1.35
10	0.34	0.32	0.65	0.86	0.77	0.41	1.51
11	0.39	0.29	0.68	0.57	0.70	0.16	1.25
12	0.47	0.17	0.64	0.77	0.82	0.12	1.41
13	0.41	0.34	0.75	0.95	0.74	0.54	1.70
14	0.24	0.35	0.59	0.87	0.84	0.38	1.46
15	0.29	0.36	0.64	0.76	0.67	0.46	1.41
16	0.33	0.38	0.71	0.87	0.76	0.49	1.58
17	0.36	0.23	0.59	0.61	0.57	0.27	1.20
18	0.29	0.43	0.72	0.76	0.64	0.54	1.48
19	0.45	0.15	0.60	1.14	0.81	0.48	1.74
20	0.14	0.35	0.49	0.70	0.57	0.48	1.19
Mean	0.39	0.29	0.63	0.80	0.72	0.38	1.43
Std. Dev.	0.08	0.08	0.08	0.14	0.09	0.12	0.16
Min	0.14	0.15	0.47	0.57	0.57	0.12	1.19
Max	0.47	0.43	0.80	1.14	0.86	0.54	1.74

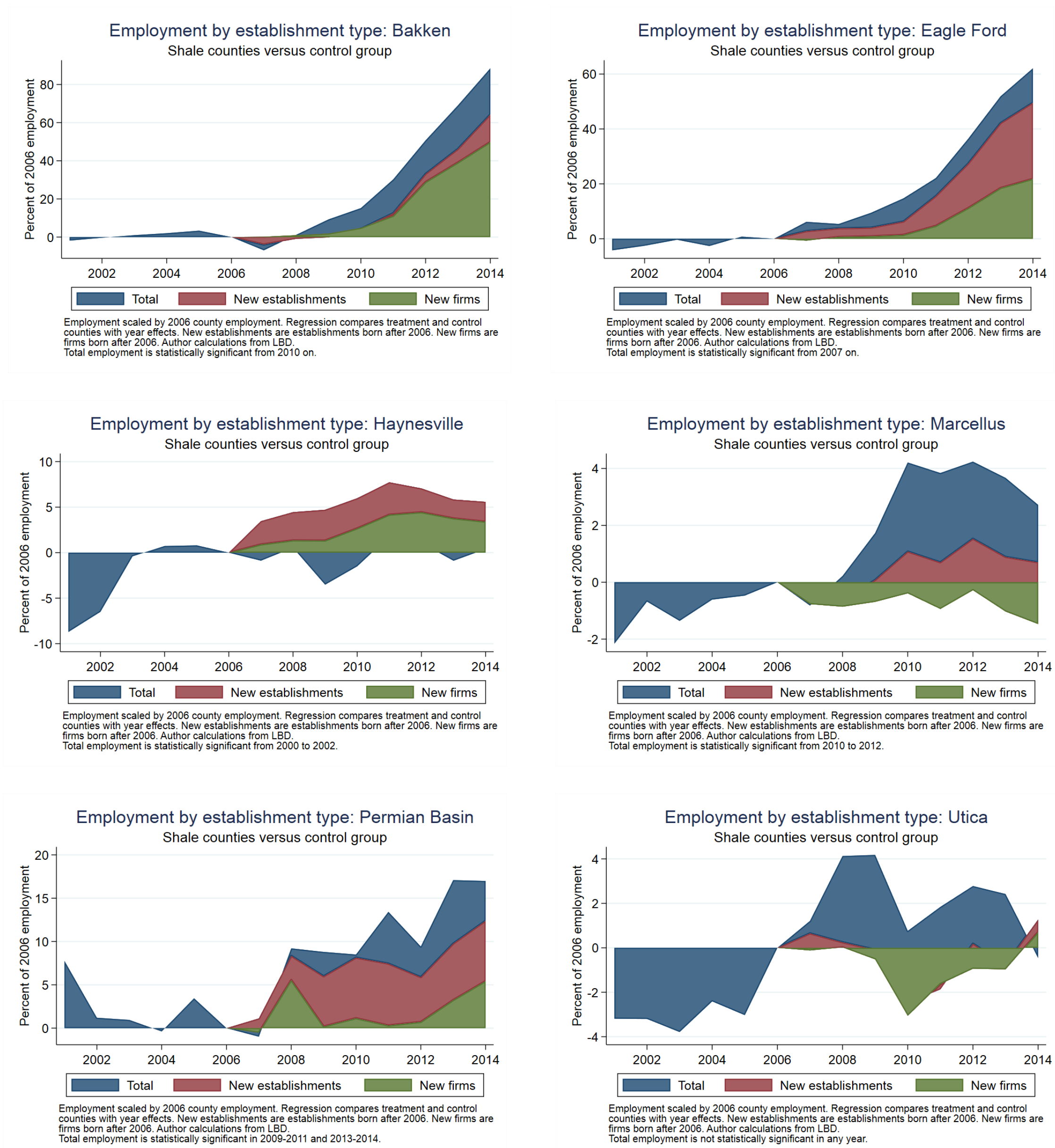
County clustered standard errors estimated, but not shown. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+. Minimum and maximums in absolute values.

Table A6: Estimated impact of revenue for 20 Random Control Groups: Ln(Employment)

Iteration	New Firms	Young Firms	New & Young Firms	Mature Firms	Greenfield Estabs	Incumbent Estabs	Total
1	10.2	0.03	1.05	1.18	1.17	0.04	2.23
2	9.3	0.14	1.07	1.11	1.0	0.25	2.18
3	1.08	0.11	1.19	1.0	1.04	0.06	2.19
4	1.08	-0.02	1.06	1.34	1.07	0.25	2.4
5	0.9	0.04	0.95	1.21	1.19	0.07	2.16
6	1.09	0.18	1.27	1.27	1.28	0.16	2.54
7	0.91	0.15	1.06	1.1	1.22	0.02	2.16
8	1.11	0.07	1.18	1.37	1.22	0.22	2.55
9	1.06	1.0	1.16	1.13	1.1	0.13	2.29
10	1.03	0.15	1.18	1.35	1.24	0.25	2.52
11	1.08	0.11	1.19	0.91	1.1	-0.08	2.1
12	1.15	0.01	1.16	1.02	1.18	-0.15	2.18
13	1.12	0.15	1.27	1.31	1.15	0.31	2.58
14	0.89	0.17	1.06	1.33	1.23	0.26	2.38
15	0.95	0.17	1.11	1.08	1.11	0.13	2.2
16	1.04	0.19	1.23	1.3	1.17	0.33	2.53
17	1.04	0.1	1.14	1.01	1.03	0.08	2.15
18	1.03	0.22	1.25	1.13	1.03	0.32	2.37
19	1.13	-0.02	1.11	1.42	1.2	0.19	2.53
20	0.86	0.15	1.0	1.09	1.02	0.22	2.09
Mean	1.025	0.11	1.135	1.183	1.138	0.153	2.317
Std. Dev.	0.087	0.071	0.089	0.146	0.085	0.132	0.173
Min.	8.6	-0.2	9.5	9.1	10	-1.5	2.09
Max.	1.15	0.22	1.27	1.42	1.28	0.33	2.58

County clustered standard errors estimated, but not shown. Revenue in hundreds millions USD. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+. Minimum and maximums in absolute values.

Figure A4: Employment treatment effects by year



Yearly regression coefficients from regression comparing treatment and control counties with aggregate year effects. New establishments are establishments born after 2006. New firms are firms born after 2006. Author calculations from the Longitudinal Business Database.

Table A7: Estimated impact of rig count for 20 Random Control Groups: Ln(Employment)

Iteration	New Firms	Young Firms	New & Young Firms	Mature Firms	Greenfield Estabs	Incumbent Estabs	Total
1	0.31	0.11	0.43	0.46	0.26	0.32	0.89
2	0.3	0.14	0.44	0.47	0.21	0.4	0.91
3	0.33	0.13	0.45	0.42	0.23	0.32	0.88
4	0.34	0.08	0.42	0.5	0.21	0.37	0.92
5	0.29	0.12	0.41	0.47	0.26	0.32	0.87
6	0.34	0.15	0.49	0.48	0.29	0.35	0.97
7	0.29	0.14	0.43	0.44	0.28	0.3	0.88
8	0.34	0.12	0.46	0.52	0.28	0.36	0.97
9	0.32	0.13	0.45	0.43	0.23	0.34	0.88
10	0.33	0.14	0.46	0.5	0.27	0.37	0.96
11	0.33	0.13	0.47	0.38	0.24	0.28	0.85
12	0.35	0.1	0.45	0.42	0.27	0.25	0.88
13	0.34	0.15	0.49	0.5	0.25	0.41	0.99
14	0.28	0.16	0.44	0.47	0.27	0.36	0.92
15	0.31	0.15	0.46	0.45	0.25	0.35	0.91
16	0.32	0.16	0.48	0.48	0.27	0.37	0.96
17	0.31	0.13	0.44	0.42	0.21	0.35	0.86
18	0.32	0.17	0.49	0.45	0.22	0.4	0.94
19	0.36	0.09	0.45	0.55	0.27	0.37	1
20	0.26	0.16	0.42	0.44	0.22	0.38	0.85
Mean	0.32	0.13	0.45	0.46	0.25	0.35	0.91
Std. Dev.	0.03	0.02	0.02	0.04	0.03	0.04	0.05
Min.	0.26	0.08	0.41	0.38	0.21	0.25	0.85
Max.	0.36	0.17	0.49	0.55	0.29	0.41	1

County clustered standard errors estimated, but not shown. Rig count expressed in hundreds of rigs. Treated areas include all counties with shale oil and/or gas production as defined by EIA Drilling Productivity Reports. Control counties chosen using propensity score match from national sample in non-shale states. Parameters estimated with OLS. New firm age (in years) =0, young =1-4, old = 5+. Minimum and maximums in absolute values.

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