The Local Economic and Welfare Consequences of Hydraulic Fracturing

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Abstract

Exploiting geological variation and timing in the initiation of hydraulic fracturing, we find that fracing leads to sharp increases in oil and gas recovery and improvements in a wide set of economic indicators. There is also evidence of deterioration in local amenities, which may include increases in crime, noise, traffic and declines in health. Using a Rosen-Roback-style spatial equilibrium model to infer the net welfare impacts, we estimate that willingness-to-pay (WTP) for allowing fracing equals about $2,400 per household annually (5.2% of household income), although WTP is heterogeneous, ranging from more than $10,000 to roughly zero across ten shale regions.

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1 Introduction

The discovery of hydraulic fracturing is considered the most important change in the energy sector since the commercialization of nuclear energy in the 1950s. Fracing,[1] as it is known colloquially, has allowed for the recovery of vast quantities of oil and natural gas from shale deposits that were previously believed to be commercially inaccessible. The result has been sharp increases in US production of oil and natural gas to levels unimaginable even a decade ago, substantial reductions in energy prices that have greatly aided consumers both domestically and abroad, and fundamentally altered global geopolitics that are likely to benefit the United States (e.g., reducing the power of OPEC and Russia). Further, there are extensive shale deposits of both natural gas and oil around the world that greatly increase the potential supply of inexpensive fossil fuels. These deposits offer immediate economic benefits in terms of lower energy prices but also pose a challenge for reducing the rate of climate change.

Ultimately, access to these energy resources rests on the willingness of local communities to allow fracing within their jurisdictions. Drilling brings royalty payments and economic activity, but there are substantial concerns about potential impacts on the quality of life, including pollution, traffic congestion, and crime.[2] There has been substantial heterogeneity in communities' reactions with Pennsylvania, Texas, and North Dakota embracing fracing, while other localities, like New York, Vermont, and some countries such as Germany and France, have banned it. In making these decisions about allowing fracing, policymakers and their communities have not had systematic evidence on its benefits or costs.

This paper's aim is to develop a measure of the net welfare consequences of fracing on local communities that accounts for both its benefits and costs. This task requires developing a counterfactual for what would have happened in fracing communities in the absence of fracing and a theoretically grounded measure of welfare. With respect to the empirical challenge, the task is complicated by the fact that fracing communities are not randomly assigned. Empirically these communities differ from other parts of the US both in levels and trends of economic variables. Consequently, we develop an identification strategy that is based on geological variation within shale formations and local variation in the initiation of fracing. Specifically, we exploit Rystad Energy's index of fracing suitability. Rystad is an international oil and gas consulting company and their index is based on several factors, including thickness, depth, and thermal maturity of the shale deposit. Thus, our identification strategy focuses on counties in the same shale play or formation. The second source of variation is the difference in fracing's initiation timing across shale plays; these differences are also due to geological variation, among other factors. Together, these two sources of variation are

[1] Hydraulic fracturing has been abbreviated in a number of ways, including "fracing," "fracking," "frac'ing," and "fraccing." We use "fracing" throughout the paper.

[2] The Environmental Protection Agency (EPA) has devoted an entire website to the issues surrounding fracing. http://www2.epa.gov/hydraulicfracturing.

the basis for a difference-in-differences-style identification strategy, comparing the change in local economic outcomes in areas with high geological potential for fracing to areas with lower geological potential for fracing within the same shale formation.

Our estimates of the welfare consequences are based on a Rosen-Roback-style model of locational equilibrium. Building on the work by by Moretti (2011) and Hornbeck and Moretti (2015), who add moving costs and elastic housing supply to Roback's (1982) canonical model, we allow fracing to shift both local productivity and local amenities. We derive an expression for willingness-to-pay (WTP) for fracing that is equal to the product of a locality's total population and the change in real income (i.e., accounting for changes in income and local prices, measured by housing prices) and the WTP for amenity changes. We also derive an expression for WTP for amenity changes. Importantly, these expressions are functions of the reduced form estimates delivered by the paper's identification strategy.

There are three primary findings. First, counties with high-fracing potential experience a natural resources boom. They produce roughly an additional \$400 million of oil and natural gas annually three years after the discovery of successful fracing techniques, relative to other counties in the same shale play. Further, they experience marked increases in economic activity with gains in total income (4.4 - 6.9 percent), employment (3.6 - 5.4 percent), and salaries (7.6 - 13.0 percent). There are also increases in housing prices (5.7%) and rental rates (2.7%). Additionally, local governments see substantial gains in revenues (15.5 percent) that are larger than the average increases in expenditures (12.9 percent).

Second, there is evidence of deterioration in the non-economic quality of life or total amenities. One advantage of the model is that it allows for an estimate of the WTP for the total change in amenities, even when the full vector of amenities is unobservable. Using the model's results, we estimate that annual willingness-to-pay (WTP) for fracing-induced changes in local amenities is roughly equal to -\$1,400 per household annually or -3.1 percent of mean annual household income. Direct empirical estimates of local amenities are more difficult given limited data on local amenities. However, we find some, albeit noisy, evidence of higher violent crime rates, despite a 20 percent increase in public safety expenditures.

Third, we use the model to develop a measure of the net change in welfare among households that lived in these communities prior to fracing's initiation that accounts for the economic benefits *and* costs of declining amenities. We estimate that across all US shale plays, WTP for allowing fracing equals about \$2,400 per household annually or about 5.2 percent of mean household income. Importantly, we uncover substantial heterogeneity in WTP across shale plays. The largest estimates come from the Bakken's (primarily in North Dakota and Montana) annual WTP of \$11,600 and the Woodford-Arkoma's (Oklahoma) \$4,500, although there are also large net gains in the Fayetteville (in Arkansas and Oklahoma) and the Marcellus (largely in Pennsylvania, West Virginia, and Ohio) plays. The estimates of WTP are roughly zero and statistically insignificant for several of the plays.

This paper makes several contributions. First, the focus on net welfare consequences provides a broad picture of fracing's overall impacts.[3] Previous work has largely focused on either estimating the local labor market benefits of fracing or the environmental and social costs, and we bridge the gap between these two literatures by using an equilibrium model of local decisions to estimate the value of both the benefits and costs to local communities. Of course, these estimates are only as good as the information on impacts of fracing that households have at their disposal; and as new information emerges about potential health consequences (e.g.,) and other impacts, this information may change.[4]

Second, the examination of 9 different shale plays provides a more comprehensive measure of the impacts of fracing across the United States,[5] building on important previous work that has focused largely on single shale plays, especially the Marcellus in Pennsylvania (Gopalakrishnan and Klaiber (2013);Muehlenbachs et al. (2014a)). Third, the paper demonstrates that areas of the country with abundant opportunities for fracing differ from the rest of the country in important ways. As a solution to this identification problem, this paper offers a new and credible identification strategy based on the geological characteristics of shale deposits and the timing when new technologies became available. Fourth, we have collected data on a wide set of outcomes, ranging from measures of local economic activity to crime to housing market outcomes, which together with the locational equilibrium model that we set out provides a fuller picture of fracing's impacts than has been available previously. In this respect, it expands our understanding of resource booms (see, e.g., Wynveen (2011)).[6] In the most closely related work, Jacobsen (2016) also finds that fracing has benefited local communities economically as measured by wages and housing rental rates.

Our estimates are likely to be relevant for communities making decisions about whether to allow fracing. There are vast shale deposits around the globe that have not yet been accessed due to a mix of legal, institutional, technical and and economic reasons. As some of these barriers are removed more jurisdictions will be confronted with decisions about whether to allow fracing.[7]

The paper proceeds as follows. Section 2 outlines our conceptual framework. Section 3 discusses hydraulic fracturing and how it differs from conventional oil and natural gas recovery. Section 4 discusses the data used in the analysis, while section 5 describes our identification strategy. Section

[3]Due to the use of county-level information on housing prices, this paper is not able to provide a detailed assessment of the distributional consequences of fracing on the housing market. In an important paper, Muehlenbachs et al. (2014a) find that in a sample of roughly 1000 Marcellus region houses, proximity to a fracing site reduces prices by 20 percent for houses that rely on well water, relative to those that utilize piped water. Nor does our paper deal with the more global issue of how fracing affects global greenhouse gas emissions and geopolitics.

[4]The EPA released a preliminary report on a wide-ranging study on the health and environmental risks of fracing (Environmental Protection Agency, Office of Research and Development (2015)). Regulations also continue to evolve.

[5]We restrict the sample to 9 plays to ensure enough post-fracing data to identify the effects.

[6]Our work does not shed light on the potential for the "Dutch disease" (see, e.g., Allcott and Keniston (2014) and Fetzer (2015) for recent work on this topic) or our understanding of how these effects propagate (see, e.g., Feyrer et al. (2015)).

[7]See Covert et al. (2016) for a discussion of these issues and `http://www.eia.gov/todayinenergy/detail.cfm?id=14431` for a map of world resources.

6 provides preliminary evidence, our econometric estimates, and evidence about the robustness of those results. Section 7 presents evidence of local welfare implications of our estimates. Finally, Section 8 concludes.

2 Conceptual Framework

This section extends a stylized model that builds upon the canonical Roback (1982) model, following Chay and Greenstone (2005); Greenstone et al. (2010); and Kline and Moretti (2015)). The model is a slightly modified version of Moretti (2011) and Hornbeck and Moretti (2015), who incorporate the possibility of moving costs and elastic housing supply into a Roback (1982) style model. The only difference between the model we present here and Hornbeck and Moretti (2015) is that they are focused on the effects of a pure productivity shock, whereas we allow the introduction of fracing to shift both local productivity and amenities. The ultimate aim is to develop expressions for WTP even though all amenity changes are not observed.

We assume that household i in location j at time t obtains utility from the consumption of a numéraire good sold on a global market, C_{ijt} (with price normalized to 1), housing, H_{ijt}, location amenities, A_{jt}, and idiosyncratic place-based preferences and moving costs, μ_{ijt}. Assuming Cobb-Douglas utility yields:

$$u_{ijt} = \quad C_{ijt}^{1-\beta} H_{ijt}^{\beta} A_{jt}^{\alpha} \mu_{ijt}^{s}, \tag{2.1}$$

where β is the share of household income spent on housing, the exponent s measures the size of moving costs or variance of idiosyncratic preferences; in the canonical Roback model, these idiosyncratic preferences and moving costs do not exist which is equivalent to assuming $s = 0$. Additionally, α measures the utility of amenities. Each consumer in location j at time t earns wage and salary income, w_{jt}, and pays r_{jt} in rent.[8] Solving for the consumer's problem and taking logs yields the indirect utility function:

$$v_{ijt} = \quad \ln w_{jt} - \beta \ln r_{jt} + \alpha \ln A_{jt} + s \times \epsilon_{ijt}, \tag{2.2}$$

where $\epsilon_{ijt} = \ln \mu_{ijt}$. A key feature of the model is that housing supply is elastic, where inverse housing supply (i.e. X_{jt}) is given by:

$$\ln r_{jt} = \gamma_j + \kappa_j \ln X_{jt}. \tag{2.3}$$

[8] We abstract away from differences in housing rents and housing prices. In the simplest model with competitive housing markets, the housing price will equal $\frac{1}{1-\rho}\bar{r}$, where ρ is the discount rate and $\bar{r}$ is the rental price. Therefore a permanent and immediate change in $\bar{r}$ will shift rents and house prices by the same percentage. We also assume that non-labor market income, such as interest and dividend income from lease payments, does not depend on individual location decisions and we abstract away from income effects of non-labor market income on the share of income spent on housing.

For intuition on how prices allocate individuals across locations, consider the case where there are only two locations, a and b. Assuming that μ_{ijt} are independently drawn every period so that future shocks do not affect current decisions, the household's problem simplifies to choosing the location that maximizes current period utility. Consequently, a household chooses to live in location a in period t if and only if $u_{iat} - u_{ibt} > 0$. Defining $\tilde{x} = x_a - x_b$ and using our expression for indirect utility in Equation 2.2, we can write the household's decision rule as:

$$\widetilde{\ln w_t} - \beta\widetilde{\ln r_t} + \alpha\widetilde{\ln A_t} + s \times \widetilde{\epsilon}_{it} > 0.$$

If $\frac{\mu_{ibt}}{\mu_{iat}} \sim U[0,2]$, then $s \times \widetilde{\epsilon}_{it}$ is distributed exponentially with the shape parameter equal to $\frac{1}{s}$, and we can express the share of households who choose to live in location a in time t as:

$$\frac{N_{at}}{N} = \quad \exp\left[\frac{\widetilde{\ln w_t} - \beta\widetilde{\ln r_t} + \alpha\widetilde{\ln A_t} - s\ln 2}{s}\right].$$

Taking logs yields a linear expression for the log share of households who choose to live in location a:

$$\ln\frac{N_{at}}{N} = \frac{\widetilde{\ln w_t} - \beta\widetilde{\ln r_t} + \alpha\widetilde{\ln A_t} - s\ln 2}{s}. \tag{2.4}$$

Differentiation of Equation 2.4 and re-arrangement yields an expression for household willingness-to-pay for the amenity changes caused by fracing:

$$\Delta\text{WTP for Amenities} = \quad \alpha\Delta\ln A_{at} = \quad s\Delta\ln N_{at} - (\Delta\ln w_{at} - \beta\Delta\ln r_{at}) \tag{2.5}$$

Equation (2.5) is of tremendous practical value, because it provides an expression for the full set of amenity changes,[9] even though a data set with the complete vector of amenities and information on willingness-to-pay for these amenities is unlikely to ever be available. Specifically, this expression says that the WTP for the change in amenities, expressed as a percentage of income, is equal to the difference between the percentage change in population, adjusted for the magnitude of moving costs, and the percentage change in real wages. In the subsequent empirical analysis, we will estimate the effect of fracing on housing prices and rents ($\Delta\ln r_t$) that are assumed to be an index for locally produced goods[10], household wage and salary income ($\Delta\ln w_t$), and population ($\Delta\ln N_t$) respectively. We go to the previous literature to obtain estimates of the values of the standard-deviation

[9] A_{at} is the full vector of a location's amenities and α measures the willingness to pay for log-changes in those amenities.

[10] If fracing shifted rents in a place permanently, competitive housing markets would imply that the percentage change in rents and housing prices should be the same. However, the shift in rents may not be permanent because owning a home can involve lease payments that renters do not receive, and renter and owner-occupied homes may not be perfect substitutes; for these reasons, the percentage change in rents and owner-occupied homes are likely to differ.

of idiosyncratic location preferences or moving costs, s, and the share of household income spent on housing, β, calibrated from Albouy (2008), Diamond (2016), and Suarez Serrato and Zidar (2016). The bottom line is that by combining the paper's empirical estimates with estimates of moving costs and the share of income devoted to housing, it is possible to derive an implementable expression for the willingness-to-pay for the change in amenities in location a. The intuition behind this approach comes from the fact that, in spatial equilibrium, the marginal resident must be indifferent to relocating, which means that local housing prices will respond to changes in local wages. The strength of this response will depend on both the elasticity of local housing supply and moving costs.

Additionally, it is possible to develop an expression for the change in welfare for all the people who either reside or own property in location a before the change in amenities and local productivity occurred.[11] This is the population that has the greatest influence on whether fracing should be allowed in a community. In particular, let $\bar{W}_a$ be average baseline household wage and salary income, $\bar{Y}_a$ be the average household rental, dividend and interest income, and $\bar{R}_a$ be average baseline rent. Then, the welfare change in dollars for an individual renter is $\bar{W}_a(\Delta \ln w_{at} + \alpha\Delta \ln A_{at} - \beta\Delta \ln r_{at})$, the welfare change for a landowner (who may or may not reside in location a) who owns one housing unit is $\bar{R}_a \times \Delta \ln r_{at} + \bar{Y}_a^{\text{owner}} \times \Delta \ln y_{at}^{\text{owner}}$[12], and WTP for all individuals that either reside or own property in location a before fracing is the sum of these two terms:

$$\text{WTP for Allowing Fracing} = \Delta V_{at} \approx N_{at} \times \left(\bar{W}_a \Delta \ln w_{at} + \bar{Y}_a \times \Delta \ln y_{at} + \bar{W}_a \alpha \Delta \ln A_{at} \right) \quad (2.6)$$

Therefore the total change in local welfare is equal to total population in place a, times the change in income per household (including both the change in wage and interest and dividend income per household) and the change in the WTP for amenities per household. The change in rents has dropped out, because renters' loss (gain) from the increase (decrease) in rents is exactly counterbalanced by the gain (loss) for property owners from the same increase (decrease) in rents.[13] An appeal of this expression for WTP is that it is more realistic than the workhorse expression from the canonical Roback (1982) model (which is simply equal to the change in property values), because it does not make the unrealistic assumption that housing is supplied perfectly inelastically, and it reflects the fact that households face moving costs.

Nevertheless, this model is still stylized and there are three caveats worth highlighting. First, the model assumes that workers are homogenous, and relaxing this assumption would lead to additional welfare consequences. Renters with skills that are not well-suited for fracing-related employment

[11] This calculation ignores the change in welfare for in-migrants, as well as any profits received by oil and gas firms in excess of lease payments to local residents. It also assumes that the average change in household income is attained by original residents, and is not due to high earnings by immigrants. Finally, the expression omits profits of landowners who develop new housing units or rent previously vacant housing units. However, we believe it is the correct expression for WTP for allowing fracing in a community.

[12] Where $\bar{Y}^{\text{owner}}$ is the average interest and dividend income for home-owners.

[13] It is perhaps most straightforward to see this point in the case where all homes are owner occupied.

(e.g., the elderly) are especially vulnerable; this group could experience declines in utility due to continued residence in a jurisdiction that allows fracing and they could face moving costs that, in principle, could lock them into their current locations. Additionally, some homeowners may not own the mineral rights to their homes, meaning that they will not benefit from lease payments even if there is drilling on or near their property. While these benefits obviously accrue to someone, our estimates of fracing on the change in housing prices will not capture these benefits. Second, the model assumes that households have knowledge of and rational expectations about fracing's impact on all present and future changes in household income and amenities. If households are misinformed or uninformed about current or future changes, then the true welfare impacts of fracing will be more complicated. Of course, as new information about fracing's impacts (e.g., health effects as in Currie et al. (2017)) emerges, then households will update their willingness-to-pay for local amenities. Finally, it must be emphasized that this model provides expressions solely for *local* welfare changes. The model is silent on the many potential regional, national, or global effects of fracing, including reductions in petroleum, natural gas, or electricity prices, effects on global warming, adoption of renewable technologies, and changes in geopolitics resulting from America's growing role as a fossil fuel producer. The model also assumes that fracing affected areas are small enough relative to the US labor market that we can abstract from general equilibrium effects on overall wages in the US.

3 A Primer on Hydraulic Fracturing and a New Research Design

This section provides a brief primer on hydraulic fracturing. It also describes how geological variation in the suitability of shale for drilling within shale plays and variation in the timing of the spread of fracturing techniques across US shale formations provide the basis for our research design. The appendix provides more details.

3.1 A Primer on Hydraulic Fracturing

3.1.1 A Layman's Description of Conventional and Hydraulic Fracturing Drilling

The traditional approach to gas and oil recovery involves drilling into the earth in search of a "pool." The oil and gas migrates to "pools" in permeable reservoir rocks such as limestone from deeper source rocks (such as shale) where the hydrocarbons were formed. The hydrocarbons migrate until they reach a impermeable "cap" or "seal" rock which traps them. When the drill reaches the layer of the pool (typically 1,000 - 5,000 feet below the surface for an on-shore well), the drill bit is removed, and casing-pipe is placed into the hole. Finally, the casing is perforated toward the bottom of the casing so that the deposits, being under pressure, will flow up through the pipe on their own. Alternatively, they may be pumped. For unconventional wells, drilling often continues to lower depths—sometimes exceeding 10,000 feet. Once the drill bit nears the shale formation, the bit begins to turn sideways and drilling often continues in a horizontal fashion for more than 10,000 feet. This portion of the well is then cased and then perforated. However, the deposits do not flow because they are trapped in small pockets within the shale formation and the surrounding rock is not sufficiently permeable to allow the hydrocarbons to flow to the well-head. To break the pockets, a mixture of water, sand, and chemicals is pumped into the well under high pressure. Once the shale is fractured, the hydrocarbons can escape up through the piping to the surface.

There are noteworthy differences in the economics of conventional and unconventional drilling. A typical conventional well requires an investment of roughly $1 to 3 million to determine whether the resources below the ground can be recovered. Fracing is more expensive with an investment cost of approximately $5 to 8 million per well.[14] However, fracing has been dubbed farming for the relative certainty of producing hydrocarbons. Although national data on the number of wells that are fraced are unavailable, we can gain a sense for the emergence of fracing from the share of new wells that are drilled horizontally over shale formations; this share increased from 0.7 percent in 2000 to 25 percent in 2011 (Data purchased from Drilling Info, Inc (2012)). In part because of this rapid increase in fracing, the fraction of successful exploratory wells in the US has risen from 41 percent in 2000 to 62 percent in 2010 (EIA, 2014).[15]

3.1.2 Shale Terminology

Throughout the paper, we refer to shale basins and shale plays. A basin is a geological concept that refers to a region where geological forces have caused the rock layers to form a rough bowl shape, with the center then filled in by layers of sediment. If one of the layers is a shale layer, the basin can be referred to as a "shale" basin. A shale play is part of a shale basin where oil and gas producing firms have targeted a specific formation that exhibits similar geological and drilling characteristics. The definition of a shale play often depends on where drilling has occurred or may occur. For example, a widely used 2011 Energy Information Administration map[16] defined shale plays by drawing a line around the parts of shale formations with the highest density of wells. Additionally,a shale play usually refers to one formation (for example, the Marcellus shale), while shale basins often contain several different shale formations. For example, the Appalachian Basin contains both the Marcellus shale and the Utica shale, which overlap for much of their extent but at different depths.

3.1.3 Local Impacts of Hydraulic Fracturing Activity

This paper builds on previous work that has striven to measure the economic benefits of fracing to local communities in terms of hydrocarbon production, employment, income, net migration, etc. (see Feyrer et al. (2015), Fetzer (2015), **?**, Muehlenbachs et al. (2014a), Jacobsen (2016), Newell and Raimi (2015), Weber (2012), Weinstein (2014) as examples). However, these benefits may come with substantial costs in terms of water and air pollution, traffic, crime, and damage to otherwise largely unperturbed physical environments (see e.g. Environmental Protection Agency, Office of Research and Development (2015), Phillips (2014), Ground Water Protection Council and ALL Consulting (2009), National Energy Technology Labratory (2013), Rubinstein and Mahani (2015)). We attempt

[14] `https://blogs.siemens.com/measuringsuccess/stories/688/`.

[15] Advances in 3D-imaging have also reduced dry holes for conventional wells.

[16] See `http://www.eia.gov/analysis/studies/usshalegas/` We, as well as much of the growing economics literature on fracing, use this map to define the boundaries of shale plays.

to measure as many of these local impacts as possible, but ultimately, they cannot all be measured and even if they could, their net impact on social welfare is unknowable. Our conceptual framework offers a way out of this conundrum by allowing us to develop estimates of the WTP for the total change in amenities and the net welfare impacts of allowing fracing in the community. This approach allows us to bridge the gap between the literatures studying the benefits of fracing and the literature studying the costs of fracing, providing the first picture of the net impacts on local communities.

3.2 A New Research Design

This paper's empirical analysis aims to determine the consequences of fracing for a local community. The empirical challenge is to identify a valid counterfactual. The difficulty is that places with fracing may differ from those without for reasons that also affect key outcomes. Places that have a more extensive history of oil and gas development, a lower value of land, or different local economic shocks may be more likely to experience fracing, other things being equal.

The growing fracing literature offers a variety of identification strategies. Perhaps, the most widely used is to compare areas over shale formations to areas without shale formations beneath them (see e.g., Cascio and Narayan (2015); Fetzer (2015); Maniloff and Mastromonaco (2014); Weber (2012); Weinstein (2014)). As we demonstrate below, however, these places differ on many dimensions in both levels and trends. Others have taken advantage of a border discontinuity design, based on comparing border areas in Pennsylvania where fracing has been embraced versus New York where it has been banned (Boslett et al. (2015)). This design is appealing for reasons of internal validity. However, as we show below, there is considerable heterogeneity in the effects of fracing across shale plays, so it is useful to develop an identification strategy that can be applied to multiple plays.

Our identification strategy is based on differences in geology within shale plays and the rate at which the basic principles of hydraulic fracturing were successfully applied across US shale formations. The remainder of this subsection describes these two sources of variation.

3.2.1 Cross-Sectional Variation in Prospectivity within Shale Plays

There is significant variation in the potential productivity of different locations within a shale play. Geological features of the shale formation affect the total quantity and type of hydrocarbons contained within a shale formation, the amenability of the shale to fracing techniques, and the costs of drilling and completing the well. Among others, these features include the depth and thickness of the shale formation, as well as the thermal maturity, porosity, permeability, clay content, and total organic content of the local shale rock (Zagorski et al. (2012), Budzik (2013), Covert (2014), McCarthy et al. (2011)). Rystad Energy is an oil and gas consulting firm that has created a "prospectivity" index of the potential productivity of different portions of shale plays based on a non-linear function of the different geological inputs. We purchased Rystad's NASMaps product which includes GIS shapefiles of Rystad's Prospectivity estimates for each North American shale play (Rystad Energy (2014)). Figure 2 maps the Rystad Prospectivity estimates for the major US shale plays. The geological variables included and the functional forms used to transform them into prospectivity scores differ for each shale, so scores cannot be compared across shale plays.

We aggregated the Rystad prospectivity measure to the county level by computing the mean and maximum Rystad score within each county. We then divide the counties in each shale play into Rystad score quartiles. Our preferred measure of potential fracing exposure is based on the maximum prospectivity score within each county. This decision is motivated by the observation that the quality of a county's best resources may more strongly impact hydrocarbon production than the average quality. We also explore the sensitivity of the results to alternative measures of fracing exposure. Figure 3 shows a map of the county assignments. The appendix illustrates in greater detail how the Rystad prospectivity measure was used to divide counties into the top quartile and the bottom three quartiles.

3.2.2 Temporal and Cross-sectional Variation in the Discovery of Successful Fracing Techniques

While geological features of the shale deposits provide cross-sectional variation, the paper's research design also exploits temporal variation in the initiation of fracing across shale plays. This time variation comes both from heterogeneity in the shale formations' geology and potential for oil and gas recovery that led to differences in the time elapsed before drilling and exploration firms devised successful fracing techniques in each play, as well as local and national economic factors influencing oil and gas development. We determined the first date that the fracing potential of each of the 14 shale plays in the US became public knowledge. When possible, these dates correspond to investor calls and production announcements when firms first began drilling operations involving fracing in an area or released information on their wells' productivity. The appendix provides more details on the development of the dates and the implications for identification.

Table 1 summarizes the temporal variation in the initiation of fracing across shale plays, as well as the distribution of top-quartile counties within each play. The Barnett was the first play where modern hydraulic fracturing in shale plays combined with horizontal wells found success. This success started becoming public in late 2000 and early 2001. Fracing was initiated in 10 of the 14 plays by the end of 2009. In total, there are 95 top-quartile counties and 310 counties outside of the top quartile in these 14 plays.Figure 1 shows that horizontal wells - a proxy for fraced wells - are accounting for an increasing fraction of U.S. energy output.

3.3 Potential Spillovers and Alternative Identification Strategies

Fracing opportunities in top quartile counties might have spillovers on other counties, especially other counties in the same shale play for at least two reasons. First, counties in physical proximity to top quartile counties may experience an increase in fossil fuel recovery within their own boundaries. Second, the increased economic activity in top-quartile counties can directly benefit nearby counties. In the presence of positive spillovers, the paper's identification strategy would underestimate the impacts on top-quartile counties because it relies on comparisons of top-quartile counties to neighboring counties in the same shale play. Further, the identification strategy is not designed to produce estimates of the full impacts of fracing because it doesn't measure the impacts on non top-quartile counties.

An alternative identification strategy would involve using propensity score matching to match all counties within shale plays to counties outside shale plays (Imbens and Rubin (2015)). However, our exploration of this strategy showed that it is extremely difficult to balance covariates between the shale play counties and their matched comparisons. In light of the potential for confounding, we restrict reporting on the results from this approach to an abbreviated discussion in the appendix. See Appendix Tables 14 to 19, which parallel tables 3 to 8 in the main text.

4 Data Sources and Summary Statistics

Clearly, it would be impossible to estimate the effects of fracing on every potential outcome; however, we collected data on a large set of outcomes and will use these results to estimate the net welfare effects of fracing. This section briefly describes the data sources, with more details provided in the Data Appendix, and provides some evidence on the validity of the research design.

4.1 Data Sources

4.1.1 Fracing Data

Shapefiles of the locations of shale plays and basins, as well as historic oil and gas prices, come from the Energy Information Agency (EIA).[17] Oil and gas production data for 1992 through 2011 were purchased from Drilling Info, Inc (2012). The research design depends on the prospectivity estimates from Rystad Energy's NASMaps product purchased from Rystad Energy (Rystad Energy (2014)).

4.1.2 Economic Outcomes

Data on county-level economic outcomes come from several sources. The Bureau of Economic Analysis' Regional Economic and Information Systems (REIS) data on total employment and total annual earnings by type (US Bureau of Economic Analysis (BEA) (2014)) are complemented by the Quarterly Census of Employment and Wages' (QCEW) data on wages by industry (Bureau of Labor Statistics, US Department of Labor (2014)).

Housing price data for 2009 through 2013 come from the American Community Survey (ACS), while housing price data for previous decades (2000 and 1990), as well as data on the total number of housing units, come from the decennial Census.[18] In some of our specifications, we also draw on economic data from the decennial Census and 2009 - 2013 pooled ACS, including employment, per capita income, population, and population broken down by age and sex.[19] The 2009 - 2013 ACS data

[17] For oil prices we use the Cushing, OK, spot price for West Texas Intermediate (Energy Information Agency (2011)) and for natural gas we use the city-gate price. Shapefiles for the boundaries of shale plays and basins come from the EIAs Maps: Exploration, Resources, Reserves, and Production site (Energy Information Agency (2011)).

[18] Alternatives to Census data on housing outcomes do exist, such as Zillow or RealtyTrac data. However, for many of the counties affected by fracing, these data are either missing or interpolated. In addition, these data do not have information on rental markets.

[19] All Census and ACS data were retrieved from the National Historical Geographical Information System (Minnesota Population Center (2011)).

need to be pooled to precisely estimate average county outcomes, so, for a given county, these data are treated as a single year's observation.[20] Housing permit data come from the Census Bureau's New Residential Construction data-series (US Census Bureau (2014a)). Monetary variables are inflation adjusted using the Consumer Price Index (CPI) produced by the BLS (Bureau of Labor Statistics, U.S Department of Labor (2015)). Migration data come from the Internal Revenue Service's county-county migration dataset, released as part of the Statistics on Income (Internal Revenue Service (2015)).

4.1.3 Crime Data

Crime data come from the Federal Bureau of Investigation (2015) Uniform Crime Reporting program (UCR). Individual police agencies (e.g. City of Cambridge Police, MIT Police, etc.) report "index crimes" to the FBI, including murder, rape, aggravated assault, robbery, burglary, larceny, and motor-vehicle theft. Reporting is not mandatory,[21] and consequently not all agencies report all index crimes in all years. In order to define a consistent series we use agencies that report[22] index crimes in most years[23] from 1992 through 2013. To ensure that the consistently reporting agencies are representative of the county as a whole, we only include counties in which sample agencies account for at least 20 percent of the total crimes in the county between 2011 and 2013.[24] Following the FBI, we sometimes group crimes into the categories of violent crimes and property crimes. Violent crimes include murder, rape, aggravated assault, and robbery, while property crimes include burglary, larceny, and motor-vehicle theft.

4.1.4 Public Finance

Data on local government spending and revenues come from the Censusof Governments conducted every 5 years (years ending in 2 and 7) by the US Census Bureau (US Census Bureau (2014b)). We aggregate direct expenditures and revenues to the county level by summing the values for all local governments within the county. These outcomes are inflation adjusted using the same CPI as above. We supplement these data using school district-level enrollment data from the Common Core (National Center for Education Statistics (2015)), which allow us to create measures of spending per pupil. Specifically, for all counties in which every school district reports enrollment data in 1997,

[20] The Census Bureau suppresses data for many counties in the 1-year and 3-year ACS releases. Data from very few counties are suppressed in the 5-year ACS estimates.

[21] Some federal grants are conditioned on reporting UCR data, so there is an incentive to report.

[22] Some agencies report crime for only a few months in some years, while others report 0 crime in some years despite covering a large population and reporting high levels of crime in other years, while still others report some crime types but not others. We discuss how we handle these and other misreporting or insufficient reporting in the appendix.

[23] We interpolate each crime type for an agency in year t if the agency reports the given crime type in year $t+1$ and $t-1$ and the crime type is missing for the agency for no more than three years from 1990 to 2013. The consistent sample is then agencies for which we have either a reported or an interpolated crime value for each crime type in every year from 1992 to 2013.

[24] Unfortunately, a few counties do not have any agencies that report crimes in most years, and consequently our sample size is smaller for crime than our other outcome variables, containing 56 Rystad top-quartile counties and 340 total counties, compared to 65 Rystad top-quartile counties and 405 total counties in the full sample.

2002, and 2012[25] we total county-level primary and secondary enrollment and divide elementary and secondary direct expenditures from the Census of Governments by this enrollment number to compute spending per pupil.

4.2 Summary Statistics

Column (1) of Table 2 reports the county-level means of key variables. Panel A reports the values in 2000, before the widespread adoption of fracing, while Panel B reports on the change between 2000 and 1990. The entries in the first column are intended to provide a sense of the economic magnitude of the differences in means between pairs of counties that are reported in the remaining columns. These comparisons provide an opportunity to gauge the credibility of the paper's quasi-experimental research design, as well as alternative potential designs. Because the crime data have many more missing observations than the data for the other variables, we perform this exercise separately for the crime and non-crime variables. We first discuss the non-crime variables and then the crime variables.

Column (2) compares counties over shale basins with other U.S. counties and shows that there are important differences between these two sets of counties. Counties within a shale basin had worse economic outcomes in 2000; for example, per capita income in 2000 is almost 30 percent (0.279 natural log points) lower in shale basin counties. Indeed, 9 of the 10 reported variables are statistically (and economically) different between the two sets of counties. Panel B reveals that shale basin counties were growing more slowly than the rest of the country from 1990 to 2000; again, 9 of the 10 variables are statistically different across the two sets of counties. Overall, the results in column (2) suggest the need for an alternative to a difference-in-difference specification that is based on comparing shale basin counties with the rest of the United States.

Column (3) explores the validity of comparing counties in shale plays with counties in the same shale basin but not necessarily in the same shale play. The entries report the results from regressions of the variable in the row against an indicator for whether the county is in a shale play, an indicator for whether a county is in a shale play interacted for an indicator for whether the shale play is in the balanced sample of shale plays, and basin fixed effects on the subset of counties in shale basins. The coefficient and standard error associated with the shale play indicator are reported in the table and are based on the balanced sample of counties. The differences in income levels and income changes are even larger than in column (2), and across the 10 variables there are again statistically and economically large differences between these sets of counties. The entries suggest that this comparison is also unlikely to be a good basis for a credible quasi-experiment.

In contrast, the entries in column (4) support the validity of this paper's identification strategy. The entries report the results from regressions of the variable in the row against an indicator for whether the county has landmass with a top-quartile Rystad prospectivity score, this Rystad top

[25] We don't use 2007 data because we estimate long-difference models of the change in public finance outcomes between 2002 and 2012. We include 1997 data because, in Appendix Table 12, we also report the robustness of our results to estimating long-difference models of the change between 1997 and 2012.

quartile indicator interacted with an indictor for whether the shale play that lays under the county is in the balanced sample of shale plays, and play fixed effects on the subset of counties in plays. The coefficient and standard error associated with the top-quartile indicator are reported in the table and are based on the balanced sample of counties. A comparison of pre-treatment levels and trends finds little evidence of differences between counties within a shale play that have a top quartile Rystad prospectivity measure and other counties in the same play. The null of equality between the reported variables cannot be rejected in either levels or trends.[26]

The last two columns compare top-quartile counties and non-top quartile counties to their propensity-score matched counterparts. Column (5) shows that the propensity-score technique performs well for top-quartile counties. Column (6) shows however, that it is more difficult to find matches for counties in quartiles 1 through 3; all variables but hydrocarbon production are statistically different across the two groups.

Turning to the crime variables and pre-trends in Panels A2 and B2, column (2) shows that there are small differences in levels of crime rates, but larger differences in trends, in counties within shale basins compared to the rest of the US. In particular, counties within shale basins had rising property and violent crime between 1992 and 2000 relative to counties outside shale basins. Column (3) shows that comparing counties within shale plays to other counties within the same shale basin increases the magnitude of the difference in crime levels in Panel A2 markedly, but actually leaves the magnitude of the differences in crime trends unchanged. Column (4) shows that when comparing Rystad top-quartile counties to other counties within the same shale play, we cannot reject the joint null of similar property and violent crime trends between top-quartile and other shale play counties in either levels or trends. The estimated difference in levels for property crime is statistically significant. However, the standard errors for both trend variables are extremely large, meaning that we cannot rule out quite large pre-trends in crime in top-quartile counties. Consequently, our crime results must be interpreted cautiously.

Although the column (4) results generally confirm the similarity of the top-quartile Rystad measure counties and other counties in the same shale play, all reported specifications will control for all permanent differences between them. Further, we will also report on some specifications that adjust for county-specific time trends. The next section discusses the estimation details.

Finally, we turn to the propensity-score matching comparisons in Columns (5) and (6). Each of the shale play county groups exhibit statistically significantly lower crime rates compared to their propensity-score matched counterparts. These findings suggest that the propensity-score-matching procedure is not successful in generating an adequate match for counties exposed to fracing, or for

[26]One of the few variables that remains different in levels across all columns is total hydrocarbon production. We believe this is because some locations with high potential for fracing also had high potential for earlier, conventional production. Reassuringly, these differences are dramatically reduced when we look at trends in hydrocarbon production, which are not economically or statistically significantly different between top quartile and other counties within shale plays.

the control group of counties that are less likely to be exposed.

5 Empirical Strategy

This section describes the paper's approach to implementing the research design based on variation in geology within shale plays and timing in when fracing techniques were adapted to individual plays. Depending on whether the economic variable of interest is measured annually or decennially, we estimate difference-in-differences or long-difference specifications.

5.1 Estimation: Time-Series Difference-in-Differences

When annual data are available, we estimate the following equation for outcome variable y_{cpt}, where the subscripts refer to county (c), shale play (p), and year (t):

$$\begin{aligned} y_{cpt} = \quad & \mu_{pt} + \gamma_c \\ & + \delta\left(1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c\right) + \epsilon_{cpt}. \end{aligned} \tag{5.1}$$

The specification includes year-by-play, μ_{pt}, and county fixed effects, γ_c. The two key covariates are: 1) $1[\text{Post Fracing}]_{pt}$, which is an indicator that equals 1 in the year that fracing is initiated in shale play p and remains 1 for all subsequent years. This variable equals one for all counties that intersect a shale play after its first-frac date. 2) $1[\text{Rystad Top Quartile}]_c$ is an indicator for whether the maximum prospectivity value within county c is in the top quartile for counties in shale play p. The model is fit on the sample of counties that intersect at least one of the 14 US shale plays listed in Table 1.

The parameter of interest, δ, is a difference-in-differences estimator of the effect of fracing. It measures the change in the difference in y_{cpt} between high and low Rystad prospectivity counties within shale plays, after fracing was initiated, relative to before its initiation. Two limitations to this approach are that δ could confound any treatment effect with differential pre-trends in the Rystad top-quartile counties[27] and that it assumes that fracing only affects the level of economic activity, rather than the growth rate. With respect to the latter issue, the possibility of adjustment costs, as well as capital and labor frictions, means that the effect of fracing on economic and other outcomes may evolve over time in ways that a pure mean shift model fails to capture.

Hence, we also estimate a richer specification that directly confronts these two potential short-

[27] Although we are not able to reject the joint null hypothesis there are no overall differences in pre-trends between Rystad top-quartile and other counties for all of our outcome variables, a few important outcomes, such as income and employment, exhibit economically large pre-trends. Allowing for differential pre-trends reduces concerns that these pre-trends in income and employment are biasing our results.

comings of equation (5.1):

$$y_{cpt} = \mu_{pt} + \gamma_c + \beta_1(\tau_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) + \delta_0(1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) + \delta_1(\tau_{pt} \cdot 1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) + \epsilon_{cpt}. \quad (5.2)$$

This model allows for differential pre-trends in event time for Rystad top-quartile counties, which are captured by the parameter β_1. Moreover, it allows for a trend break in outcomes, δ_1, as well as a mean shift, δ_0. Thus, the estimated effect of fracing τ years after the start of fracing is then $\delta_0 + \delta_1 \times \tau$. Finally, we will also report on models where we include trends in the calendar year t that are allowed to vary at the county level.[28]

To account for possible heteroskedasticity, we weight the equations for county-level outcomes with the square root of the sample size used to compute the value (e.g., the total number of owner occupied housing units for the county-level mean housing price).[29] The reported standard errors are clustered at the county level to allow for arbitrary serial correlation in residuals from the same county. Robustness Tables 4 and A8 report Conley standard errors in brackets under the first row, which allow for spatial correlation in the error terms between nearby counties. We discuss these results in more detail in Section 6.4.

There are differences in the number of pre- and post-fracing years across shale plays, including some that have none or very few post-fracing years. To avoid introducing compositional bias in the estimation of the treatment effects, we focus estimation on a balanced sample throughout the analysis; this sample is restricted to county-year observations with corresponding event years that range from -11 through 3, 4, or 5 (depending on the data source), from the 9 shale plays with first-frac dates in 2008 or earlier. The subsequent analysis reports both treatment effects that are estimated using all available data and treatment effects estimated using the balanced sample. In the former sample, the years outside the balanced sample contribute to the identification of the county fixed effects.[30] Among these 9 shale plays, there are a total of 65 top-quartile counties and 310 counties

[28] The variable $\tau_{pt} \cdot 1[\text{Rystad Top Quartile}]_c$ is collinear with the county-specific time trends, so that variable is dropped in these specifications.

[29] The variables for which we implement this weighted least squares approach are: mean housing prices, median housing prices, mean rents, median rents, mean mobile home rental price, mean mobile home value, salary income per worker, income-per-capita, median household income, employment-to-population ratio, unemployment rate, sex by age population shares, manufacturing employment share, and mining employment share.

[30] The unbalanced sample is comprised of observations from shale plays with first-frac dates after 2008 and observations from shale plays with first-frac dates before 2009, for the years corresponding to less than -11 or -10 years or greater than 3, 4, or 5 years (depending on the data source) in event time. In practice, the models are estimated on the full sample so, for example, the specification corresponding to equation (5.2) takes the following form to ensure

outside the top quartile.[31] We report estimates of fracing's impact on outcomes evaluated 3, 4, or 5 years (depending on the data source) after fracing's initiation from this balanced sample.

5.2 Estimation: Long-Differences

For a number of outcomes, such as housing values, population, and demographic variables, well-measured county-year level data are not available nationally. For these outcomes, we turn to the Decennial Census and the American Community Survey (ACS) to estimate long-difference models using the pooled 2009 - 2013 ACS as the post-period and 2000 decennial census as the pre-period.[32] The long difference specification may be especially appealing in the case of housing prices: as discussed in Section 3.2.2, asset prices very quickly reflect information about the future, so with annual housing data, assigning a first fracing date after information about fracing potential was known would lead to an understatement of the effect on housing prices. Consequently, a long-difference specification, where the first year of the period is before fracing information is available anywhere in the country and the last year is after the estimated first fracing date for the shale play where fracing arrived last, is appealing. The estimating equation is derived by first differencing equation (5.2), which gives:

$$y_{cp,2013/09} - y_{cp,2000} = \gamma_p + \delta(1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) + \epsilon_{cpt}. \tag{5.4}$$

The parameter δ is a difference-in-differences mean shift estimate of the effect of fracing and maps directly to δ in equation (5.2).

Note that the long-difference approach is unable to adjust the estimates for differences in pre-existing trends in outcomes between the top-quartile and other counties within a play. .[33]

5.3 A note on prospectivity as a potential instrument

The approaches discussed above are reduced form and an alternative empirical approach would be to use the Rystad prospectivity score as an instrumental variable. However, we think that our

that the treatment effects are identified from the balanced sample only:

$$\begin{aligned} y_{cpt} = \quad & \mu_{pt} + \gamma_c + \beta_1 \tau \cdot 1[\text{Rystad Top Quartile}]_c \\ & + \beta_2(1[\text{Unbalanced Sample}]_{ct} \cdot \tau \cdot 1[\text{Rystad Top Quartile}]_c) \\ & + \delta_0(1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) \\ & + \delta_1(\tau \cdot 1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) \\ & + \delta_2(1[\text{Unbalanced Sample}]_{ct} \cdot 1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) \\ & + \delta_3(1[\text{Unbalanced Sample}]_{ct} \cdot \tau \cdot 1[\text{Post Fracing}]_{pt} \cdot 1[\text{Rystad Top Quartile}]_c) \\ & + \epsilon_{cpt}. \end{aligned} \tag{5.3}$$

The reported estimate of the treatment effects is then based on δ_0 and δ_1.

[31] For outcomes with annual data, we restrict the sample to counties with non-missing data in all years since 1990 (1992 for the drilling variables). For some variables, this reduces the sample size slightly.

[32] For long-difference results using the Census of Governments or the Census of Agriculture, the post-year is 2012 and the pre-year is 2002.

[33] The initiation of fracing will affect the quality of the housing stock, in addition to the price of land, so specifications for prices and rents adjust for housing characteristics of both rental and owner-occupied housing units. Appendix Section E.3 describes the housing characteristics we use in more detail.

reduced form approach provides more economically interpretable and policy relevant estimates for two reasons. First, policymakers likely don't have detailed information regarding the exact quantity of future oil and gas production when they decide whether or not to allow fracing. Instead, they are likely to be aware that their county has substantial fracing potential. Consequently, our reduced form estimates of what the average amenity and welfare impacts are in high-fracing areas answer the policy relevant question. Second, the theoretically correct endogenous variable for the key housing price regressions is the present value of *expected* hydrocarbon production from fracing because these market are forward looking, but this variable cannot be observed. Consequently, estimates of WTP for amenity changes or for allowing fracing that rely on current production as the endogenous variable would be difficult to interpret. Further, it is difficult to develop meaningful estimates about future production since fracing remains a new technology and recovery rates are changing rapidly (see, for example, Covert (2015)). For these two reasons, we instead choose to focus on the reduced-form relationships between outcomes and our "instrument": The interaction of an indicator for whether the county is in the top-quartile of prospectivity within the shale play with a variable capturing when fracing techniques were adapted to that individual play. Nevertheless, despite these concerns about the interpretation of the IV estimates, for reference we have included 2SLS estimates of the effects of fracing where the value of current year hydrocarbon production is the endogenous variable in Appendix Section F.2 (see Appendix Table 21).

6 Results

6.1 Oil and Natural Gas Production Effects

We begin our empirical analysis with an event study-style versions of equation (5.1), where the indicator variable, $1[\text{Post Fracing}]_{pt}$, is replaced by a vector of event year indicators, τ_{pt}. Event years are defined as the calendar year (e.g., 2006) minus the first-frac year in the relevant shale play. We plot the coefficients associated with the interaction of this vector and $1[\text{Rystad Top Quartile}]_c$; these coefficients measure the difference in outcomes between top-quartile and other counties within a play, by event years. These figures provide an opportunity to visually assess whether differential pre-trends pose a challenge to causal inference and examine the evolution of the treatment effect over time.

Figure 4 shows the evolution of the total value of hydrocarbon production, measured in millions of dollars. There is little evidence of a trend in hydrocarbon production in advance of the successful application of fracing techniques in the top-quartile counties, relative to the other counties. Additionally, the figure makes clear that following the initiation of fracing, the average top-quartile Rystad county experiences a significant gain in the value of hydrocarbon production, increasing by more than \$400 million from year $\tau = -1$ to year $\tau = 3$.

Table 3 summarizes the findings from Figure 4 more parsimoniously. It reports the results from three alternative specifications, each building upon the previous specification. The column (1) specification includes county and year-by-play fixed effects and reports the mean increase in oil and gas production in the post-fracing years. Column (2) allows for differential pre-fracing event time trends in top-quartile counties and then includes a term to test whether these potentially differential top-quartile trends change after fracing is initiated. Column (3) uses the balanced sample of counties described above and replaces the top-quartile, pre-fracing event time trend variable with county-specific calendar time trends. The bottom of the table reports the estimated treatment effect from each of these models three years after fracing begins.

It is apparent that the initiation of fracing led to substantial increases in hydrocarbon production in top-quartile Rystad counties. The column (1) estimate that does not allow for a trend break suggests that fracing increases the value of production by about \$242 million per year in top-quartile counties. Columns (2) and (3) confirm the visual impression that the change in hydrocarbon production is better characterized by a specification that allows for a trend break, rather than only a mean shift; these specifications suggest that hydrocarbon production was about \$410 million higher in each county three years after the initiation of fracing in top-quartile counties. To put this estimated effect into some context, the median population in top-quartile counties prior to fracing activity is about 22,000, indicating an increase of hydrocarbon production of roughly \$19,000 per capita.

6.2 Labor Market and Amenity Effects

Figures 5 and H.4 are event study plots of county-level natural log of total employment and total income for Rystad top-quartile counties, respectively, after adjustment for county and play-by-year fixed effects. Both total employment and total income increase substantially in top-quartile counties following fracing's initiation. Since there are positive pre-trends for both outcomes, these graphs suggest that specifications that allow for differential pre-trends and a trend break after the initiation of fracing will produce the most reliable estimates.

Table 4 reports the results of estimating the same three specifications used in Table 3 for a series of measures of local economic activity and population flows. For reasons of brevity, the table only reports the estimated treatment effect 4 years after the initiation of fracing, rather than the fuller set of individual regression parameters reported in Table 3. Panels A and B are derived from the REIS data file and report on total employment, total income, and income subcategories, while Panel C uses the Internal Revenue Service (IRS) county-county migration flows data.[34]

Panels A and B indicate that Rystad top-quartile counties experience sharp improvements in economic activity after the initiation of fracing, relative to other counties in the same play. In the preferred specifications presented in columns (2) and (3), the estimates indicate increases in employment of about 4.9 - 5.4 percent. The income results reveal gains of 4.4 - 6.9 percent that are driven by increases in wages/salaries and rents/dividends (this includes royalty payments from natural resource extraction). The migration results in Panel C are not stable across specification but suggest modest increases in net migration.

[34] The IRS data track county-to-county migration flows using the addresses of income tax filers.

Table 5 reports on tests of the robustness of these results by fitting the long difference-in-differences specification with data from the 2009-2013 American Community Survey and 2000 Census of Population and Housing. This specification is most comparable to the column (1) specification in Table 4, because it is not possible to adjust for differential pre-trends with just two years of data per county. Panels A and B suggest a 4.8 percent increase in employment, 2.6 percentage point gain in the employment to population ratio, 0.6 percentage point decline in the unemployment rate, and 5.8 percent rise in mean household income.[35] Finally, Panel C indicates that there was 2.7 percent increase in population although this is only statistically significant at the 10 percent level.

We next turn to the QCEW data to obtain a more nuanced picture of the changes in the local labor market. Figure 6 plots the implied treatment effect four years after fracing begins in Rystad top-quartile counties, along with 95-percent confidence intervals. Across all industries, the estimates indicate that employment increases by an average of roughly 10 percent. This is larger than the 4 - 5 percent increase in employment in Tables 4 and 5, but the QCEW assigns employment to a county based on the place of work, not the place of residence as is the case for the data files used in Tables 4 and 5.[36] Natural resources and mining is the industry with the largest increase in employment, more than 40 percent. There are also statistically significant increases in employment in construction and transportation. No industry has a statistically significant decline in employment.[37]

Hydraulic fracturing is also likely to lead to changes in the composition of the workforce and population, because many of the jobs associated with fracing are held by men in their 20s and 30s. Appendix Table 3 explores how the demographics changes. While many of the estimates are imprecise, we find some evidence of an increase in the share of prime-age males and a decrease in the non-working aged population (both young and old), as well as an increase in the share of people with college degrees, perhaps underscoring the sophistication of these drilling operations.

There is a close connection between the labor market and criminal activity and there have been several media reports suggesting that fracing is associated with increases in crime rates that may be associated with an influx in young men (for example, see Edlund et al. (2013)).[38] Appendix Figure H.5 shows the event-study plot for log violent crime. The estimates are imprecise and difficult to take strong conclusions from. Panels A, B, and C of Table 6 report the results of the same three specifications used in Tables 3 and 4 for total-crime per hundred-thousand residents, violent crime per

[35] The estimate for median household income is an increase of 6.0 percent with a standard error of 1.2 percent.

[36] Furthermore, we use QCEW data through 2013, whereas we only use REIS data through 2012, which one might also expect to decrease the estimated employment effect using REIS data if the effect of fracing on employment is increasing over time.

[37] Despite the large estimated increase in wage and salary income in Table 4, which might make manufacturing firms less competitive in fracing counties, the estimated change in manufacturing employment is very small. There are a few possible explanations. One is that, given capital adjustments costs and other frictions, any effect on manufacturing may appear only a number of years after fracing starts. Alternatively, lower natural gas prices may help keep local manufacturers competitive despite the rise in wages. Fetzer (2015) proposes this channel and finds evidence consistent with lower natural gas prices being an important mechanism keeping manufacturing in fracing counties.

[38] http://geology.com/articles/oil-fields-from-space/.

hundred-thousand residents, and property crime per hundred-thousand respectively. In the simplest model, without controls for differential pre-trends in top-quartile counties, the estimated effect on all kinds of crime per-capita is positive, and significant for violent crime. However, once controls for pre-trends are added, the estimates become less precise and the sign actually turns negative. This lack of precision and sensitivity to specification makes it difficult to come to firm conclusions regarding the effects of fracing on crime.[39]

We also attempted to ask whether air quality in top-quartile counties was affected by fracing-related activity. Unfortunately, the EPA air pollution monitoring network is sparse in the countries covered by shale plays and it was not possible to develop reliable estimates. Even when using the air quality measure with the broadest coverage,[40] only 13 of 65 top quartile counties and 66 of 370 shale play counties have non-missing data in all years between 2000 to 2011.

6.3 Local Public Finance

The influx of hydraulic fracturing may also lead to changes in the composition and levels of local government's public finances, specifically revenues and expenditures, in ways that affect public well-being. Table 7 reports the estimated treatment effects for local government expenditures and revenues, based on the fitting of equation 5.2. The estimates suggest that fracing is largely budget neutral; county-wide local government expenditures increase by 12.9 percent, while revenues increase by 15.5 percent. The specific sources of the increases in expenditures and revenues follow intuitive patterns. We estimate that public safety expenditures increase by about 20 percent, infrastructure and utility expenditures went up by roughly 24 percent, and welfare and hospital expenditures increased by about 24 percent, too (although this increase is not statistically significant by conventional criteria). Interestingly, we only find a small, and noisily estimated, 2.5 percent increase in education expenditures. Panel D, which reports the change in log elementary and secondary education per pupil, shows that spending per pupil is virtually unchanged. The increase in total revenues is largely a result of increases in property tax revenues of 13 percent and other revenues of 26 percent. Panel C reveals that the overall financial position (i.e., debt minus cash and securities as a percentage of annual revenue) of local governments in top-quartile counties is essentially unchanged. This is consistent with recent case-study evidence from Newell and Raimi (2015), although they find important heterogeneity across municipalities which we also explore further below.[41]

Overall, the Table 7 results indicate that fracing leads to important changes in the character of

[39] Note that, although the effects of fracing on *crime-rates* is unclear, the estimated effects of fracing on the total level of crime are more consistent: in results available upon request, fracing is estimated to increase the total level of all types of crime in all specifications.

[40] Average Total Suspended Particulate Matter (TSP), imputed using PM10 or PM2.5 when TSP is not available.

[41] Appendix Table 12 reports long difference results using 1997 as the base-year instead of 2002 (our first-fracing date for the Barnett is in late 2001, so in theory the 2002 local public finance outcomes could already have incorporated some of the effect of fracing). The results for local government spending and revenues are qualitatively unchanged when using 1997 as the pre-year instead of 2002. Appendix Table 11 reports on the impacts of fracing on local government employment and payroll.

local governments. Most obviously, these governments grow in size as the local economies grow. On the spending side, many of the new public resources are devoted to infrastructure investments with much of this spending likely aimed at accommodating and/or supporting the new economic activity. The increase in expenditures on public safety is telling and underscores that a full accounting of the impact on crime must include this additional effort to prevent crime.

6.4 Robustness

We gauge the robustness of the results to alternative definitions of fracing exposure and alternative approaches to controlling for local economic shocks. Panels A and B of Appendix Table 4 and Panel B of Appendix Table 8 report on these exercises for hydrocarbon production, employment, and income, respectively. Column (1) reports the results from fitting specifications that were used in column (2) of Tables 3 and 4. Column (2) adds state-by-year fixed effects to the column (1) specification. Column (3) returns to the specification in column (1), but here the balanced sample is defined to include shale plays that have at least two years of post data for all outcome variables (rather than three years) although the treatment effect is still reported at $\tau = 3$. In practice, this allows the Eagle Ford shale play to contribute to the reported treatment effects. All three columns use the same sample used throughout the paper.

The entries in the rows of each Panel report on alternative definitions of counties that are highly amenable to fracing. The first row repeats the definition that we have utilized throughout the paper. That is, a county must have some land area with a Rystad prospectivity score that is in the top quartile for its shale play. For the entries in this row, we report standard errors clustered at the county-level (in parentheses) as is done throughout the rest of the paper and standard errors that allow for spatial correlation (in square brackets) in the error terms (Conley (1999)).[42] The next two rows alter the definition so that it is based on land area with a Rystad score in the top tercile and quartile, respectively. Rows 4-6 base the definition on the mean value of the Rystad prospectivity score across all of a county's land area, using the top quartile, tercile, and octile, respectively. Figure 7 then graphically reports results from Appendix Tables 4 and 8, showing how our estimates vary with different measures of fracing exposure for our four key outcomes variables: hydrocarbon production, housing-values, total wage and salary income, and employment.

Panel A of Appendix Table 4 suggest that the conclusions about the effect of fracing on hydrocarbon production are qualitatively unchanged by these alternative approaches. It is reassuring that the estimated effect is increasing in the stringency of the indicator definition for fracing amenability in the cases of both the maximum- and mean-based definitions. Further, the estimates are larger for the maximum-based definition. The Conley standard errors tend to be larger than conventional ones, but their use does not appreciably affect the statistical significance of the results. Additionally,

[42] To implement Conley standard errors, we use code from Hsiang (2010). We compute the centroids of counties using GIS software and allowfor spatial correlation between counties whose centroids fall within 200 km of a given county. Nearby counties are uniformly weighted until the cutoff distance is reached. These standard errors also allow for serial correlation in the error terms of a given county.

the estimates are essentially unchanged by replacing the play-year fixed effects with the state by year ones. Finally, it is noteworthy that the estimated effects in column (3) are modestly larger, reflecting the Eagle Ford's boom in petroleum production since 2009.

The results in Panel B of Appendix Table 8 broadly support the conclusions from the preferred results in Table 4. They are qualitatively unchanged by the use of state by year fixed effects or allowing the Eagle Ford to influence the estimated treatment effect. When the maximum Rystad prospectivity score is used, fracing is estimated to increase total income by 6 - 9 percent and the effect is statistically significant in 7 of the 9 specifications. When the mean Rystad prospectivity score is used, the estimated effects tend to be smaller and statistically insignificant, although the 95 percent confidence intervals overlap the analogous intervals associated with the maximum based variables.[43] Panel B of Appendix Table 8 reveals that the employment-based results have the same pattern in that the estimated effects tend to be larger with the maximum-based definitions of a county's suitability for fracing. The broader lesson here seems to be that even within shale plays, the economic benefits of fracing are concentrated in the subset of counties that are most suitable for drilling, although the imprecision of the estimates makes definitive conclusions unwarranted.[44]

An issue that is related to the question of the robustness of the estimated treatment effects is the degree of spillovers between top-quartile counties and other counties in the same play. The full local effects of fracing include these spillovers, which may involve individuals living in a non-top-quartile county but working in one and the resulting knock-on effects in their home county. If there are fixed local costs of drilling, neighboring counties might also experience increases in hydrocarbon production; for example, it is costly to move rigs and other infrastructure long distances. We investigate these possibilities in section 7.2.

6.5 Housing Price and Quantity Estimates

A central component of the welfare calculation is the effect on the housing market. Table 8 provides details on the results of these regressions. Panel A reports on the impact of fracing's initiation in Rystad top-quartile counties from the estimation of the long difference-in-differences specification outlined in equation (5.4). The estimates indicate that median and mean housing values for owner-occupied homes increased by 5.7 percent due to fracing. Further, the median price of mobile homes increased by almost 8 percent. Panel B indicates that rental prices for renter-occupied units increased by 2 to 3 percent.[45]

Panel C of Appendix Table 4 explores the robustness of the estimated effect on log median housing values. The estimates are generally unchanged by the use of alternative Rystad measures

[43] Panel A of Appendix Table 8 reports estimates from the same specifications for total wage and salary income and also suggests that the results for this outcome are robust.

[44] The number of top-quartile counties with the maximum- and mean-based definitions are 65 and 75, respectively. The analogous numbers of counties for the octile variables are 32 and 39, and 88 and 102 for the tercile ones.

[45] Appendix Table 9 demonstrates that the housing price results are robust to including vacant homes and rentals in the calculation of mean home values and mean rents.

(e.g., quartile versus octile and maximum versus mean). The models that add state-by-year fixed effects in column (2) tend to produce smaller point estimates, although the 95 percent confidence intervals of these estimates overlap with those in column (1).[46] In total, 17 of the 18 estimates fall in a range of roughly 2 percent to 6 percent. Allowing for spatial correlation, which is done in brackets below row 1, roughly doubles the standard errors, but the estimates in columns (1) and (3) still remain significant at a 95 percent level. Overall, we conclude that the initiation of fracing led to meaningful increases in housing prices in counties especially amenable to fracing, relative to other counties in the same shale play.

These estimated effects on county-level housing prices are large, relative to the magnitude of the effects of other substantive local changes on housing prices that have been documented in the previous literature. It is instructive that there is an extensive literature documenting the capitalization of various amenities into local housing prices and that 5.7 percent is a large county-level effect.[47] For example, Chay and Greenstone (2005) find that the dramatic air quality improvements induced by the implementation of the Clean Air Act increased housing prices by just 2.5 percent in counties that faced strict regulation. Further, Cellini et al. (2010) find that school facility investments lead to 4.2-8.6 percent increases in house prices but over the smaller geographic unit of school districts. While Currie et al. (2015) find that the opening of an industrial plant leads to 11 percent declines in housing prices, this effect is limited to houses within 0.5 miles of the plant.

Returning to Table 8, Panel C examines the impact on housing supply and land use. Contrary to the conventional wisdom, the data do not reveal a substantial increase in the number of housing units or even mobile homes. The point estimate for acres of agricultural land is large and negative, but not statistically significant.[48] It is noteworthy, however, that the vacancy rate for housing units declined by 1.0 percentage point.[49].

[46]Although adding state fixed effects tends to reduce the estimated effect of fracing on housing prices, Appendix Table 7 shows that adding state fixed effects does not dramatically influence many of the point estimates in the individual plays. The most notable change is that the estimate of the impact of fracing on housing prices for the Marcellus is reduced from roughly 9 percent to about 6 percent.

[47]The 5.7 percent average effect obscures important within-county variation in housing price changes, and indeed this is an important finding in Muehlenbachs et al. (2014b).

[48]As for local public finance, the Census of Agriculture is reported in every year ending in 7 or 2. Consequently, it is unclear whether 2002 or 1997 is the best base year for the Barnett play because our first-frac date for the Barnett is in late 2001. In Appendix Table 13 we report specifications where we replace 2002 with 1997 as the base year. The point estimate for the effect of fracing on agricultural land quantities becomes 0.067 and is, again, imprecisely estimated. The sensitivity of the agricultural land results suggest that they must be interpreted with caution.

[49]A shortcoming of the housing supply data is that the end of period data is an average calculated from 2009-2013, and this includes several years when fracing was only in its early stages in some shale plays. Hence, we also examined the initiation of fracing on the number of housing unit construction permits issued. Appendix Figure H.6 is an event study graph which suggests that there was an increase in permits with the introduction of fracing but that this increase does not become apparent until three years after fracing was initiated. (Panel C of Appendix Table 2 shows the same findings in a regression framework)

6.6 Heterogeneity Across Shale Plays

The empirical design also allows us to estimate play-specific effects from fracing. We report on the 9 shale plays included in the pooled results. Additionally, we also include the Eagle Ford shale play although fracing began there in 2009 which is beyond the cutoff for our pooled results; however, the Eagle Ford, located in the southern part of Texas, has attracted a lot of attention.

The 10 event study plots for hydrocarbon production (Figure H.7) suggest that in 9 of the shale plays, hydrocarbon production in top-quartile counties prior to fracing was largely flat and then took off after the commencement of fracing. The lone exception is the Woodford Anadarko play, which for largely idiosyncratic reasons experienced an increase in production in advance of fracing and decline afterwards.[50]

Table 9 reports the econometric results across the ten shale plays. Here, we focus on three outcomes: hydrocarbon production, wage and salary income, and housing prices.[51] Column (1) reproduces the overall estimate for the relevant outcome from previous tables. The play-specific estimates are in columns (2) through (10) and the Eagle Ford estimates are in column (12). Column (11) reports the F-statistic and associated p-value from a test that the 9 shale estimates in columns (2) through (10) are equal. The Eagle Ford is not included in the F-test or in the overall estimates for Column (1).

As suggested by the event study graphs, we estimate large increases in hydrocarbon production in 9 of the 10 plays; the estimates are statistically significant in 6 of them. Similarly, we estimate sizable increases in income per household in 7 of 10 plays, 4 of which are statistically significant. In contrast, the gains in housing prices appear to be concentrated in two of the 10 plays. Specifically, the house price gains in the Bakken and Marcellus shale plays—the two shale plays that have generally received the most media attention—are 23 percent and 9 percent, respectively. It is noteworthy that we can reject the null of equal effects for all three outcome variables. With only 10 observations, it is difficult to make precise statements about the sources of the observed heterogeneity.

6.7 Quantitative Comparison to the literature

Before turning to the welfare analysis, it is important to place these reduced-form results in the context of the larger literature. We note from the outset though that the meaning of these

[50] Two factors explain the patterns in the Woodford Anadarko. First, there is only one top-quartile county in the Anadarko play. Therefore, we are essentially measuring how this county compares to the rest of the play. Consequently, even if top-quartile counties are expected to have much more fracing than others, with only one draw there is a non-trivial probability that the top-quartile county will not have higher hydrocarbon production. Second, the Anadarko play had considerable conventional drilling activity prior to hydraulic fracturing. Therefore, our estimation conflates the decline in conventional production and the increase in fracing, possibly beginning as a response to the reduction in conventional production. See, for example, http://www.ogj.com/articles/print/volume-93/issue-10/in-this-issue/exploration/partial-us-oil-gas-resource-volumes-termed-39astonishing39.html.

[51] Given the substantial heterogeneity suggested by these results, it is also interesting to explore whether this heterogeneity extends to other outcomes. Appendix Table 5 reports play-specific results for a broad set of additional hydrocarbon, labor market, quality of life, and housing variables. The results also show substantial heterogeneity on these dimensions, and like our other results, suggest that the effects of fracing on the Bakken have been much larger than the effects on other plays.

comparisons is limited by the fact that this paper relies on a new research design and we believe it is the most comprehensive in terms of coverage of shale plays and outcome variables. Nevertheless, there are some striking similarities and dissimilarities with previous work. We specifically focus on the three papers that estimate the most similar parameters, Boslett et al. (2015), Feyrer et al. (2015), and Jacobsen (2016), and discuss how they compare to our estimates. Feyrer et al. (2015) are interested in estimating the geographic extent of the labor market impacts of fracing. They instrument for local oil and gas production using predicted values from a model of county-level oil and gas production. They find that a one-million dollar increase in oil and gas production per capita increases earnings-per-capita in exposed counties by $78,751 per capita, or 2.2% per ten-thousand dollars in oil and gas production per capita. In our IV estimates report in Appendix Table 21, we find that being a ten-thousand dollar increase in oil and gas production per capita increases earnings-per-capita by a similar 3.1% percent.

Boslett et al. (2015) exploit variation in exposure to fracing from New York's 2008 moratorium on fracing in New York state. They use house transaction data from five counties along the New York and Pennsylvania border, near the area of Northeast Pennsylvania and Southern New York that has high-fracing potential. They find that housing prices rise 10.1% more in Pennsylvania counties where fracing is allowed relative to New York counties where it is not allowed. As before, these results are broadly consistent with our finding that fracing increased housing prices in exposed counties, but the magnitude differs somewhat (we find a 5.7% effect on housing values).

To our knowledge, Jacobsen (2016) is the only other paper in the literature to explore both the labor and the housing market impacts of fracing. Defining areas exposed to fracing based on the ex-post change in oil and gas production, Jacobsen (2016) finds that non-metropolitan areas more exposed to fracing, wage and salary income per-capita rise 13.8%, population rises 3.9%, home-values rise 9.9%, and rents rise 3.4%. These patterns are qualitatively similar, but all of the estimates are 50-100% greater in magnitude than the corresponding difference in differences estimates in this paper that rely on geological and time variation.

The estimates in all three of these papers are qualitatively similar to those in this paper: the papers consistently find that fracing increases housing values 5 to 12%, increases wage and salary income 7 to 15%, and increases population 2 to 4%. However, in every case, although the order of magnitudes is the same, the exact quantitative values differ non-trivially. There are three possible explanations for these differences. First, the Boslett et al. (2015) and Jacobsen (2016) use different samples, with Boslett et al. (2015) using only a sample from five counties in New York and Jacobsen (2016) using only smaller, non-metropolitan areas. If there are heterogeneous treatment effects, then fracing may have different effects in non-metropolitan areas or New York and Pennsylvania than other regions. Indeed, our estimate of the effect offracing on housing prices for the Marcellus Shale, which covers New York and Pennsylvania, in Table 9 is 8.9% is much closer to the estimate in Boslett et al. (2015). The larger estimated effects of fracing on local labor market outcomes found in Jacobsen

(2016) could be driven by larger effects of fracing in smaller labor markets. Even in the case of Feyrer et al. (2015), which is also national in scope, their empirical strategy relies on different sources of variation than ours, which can also result in different estimated effects of fracing. Second, in the case of reduced form studies like Jacobsen (2016) or Boslett et al. (2015), the implicit first-stage effect on oil and gas production may be different. Finally, although all three papers use difference-in-difference style strategies as in this paper, the underlying source of variation in exposure to fracing is different in each of these papers and readers will naturally make their own judgments about the credibility of the various research designs.

7 Interpretation and Local Welfare Consequences of Fracing

What are the net local welfare consequences of fracing? To this point, the paper has reported on a wide range of outcomes with some indicating that, on average, Rystad top-quartile counties have benefited from the initiation of fracing, while others reveal less positive impacts. Guided by the conceptual framework outlined in Section 2, this section develops measures of willingness to pay for the change in local amenities and for the net local welfare consequences of the initiation of fracing, using the estimated changes in housing prices and rents, income, and population from the previous Section.

7.1 Local Welfare Estimates

While there is little question that fracing increases local productivity, a central question in the debate about fracing is the magnitude of its negative aspects or its net impact on local amenities, and how large these negative aspects are relative to the increases in local income. With some assumptions, it is possible to develop a back-of-the-envelope estimate of the total local welfare change caused by fracing, as well as the willingness-to-pay for the change in amenities. We use the local labor market model in developed in Section 2 above. As we noted above, the intuition behind this approach comes from the fact that, in spatial equilibrium, the marginal resident must be indifferent to relocating, which means that local housing prices will respond to changes in local wages. The strength of this response will depend on both the elasticity of local housing supply and moving costs. Using estimates from the literature on the relationship between pure productivity shocks and house prices, we can then back out the change in local amenities and use these estimates to infer the total change in local welfare.

Specifically from Equation 2.5, WTP for the change in amenities can be expressed as:

$$\alpha\widehat{\Delta \ln A_{at}} = \quad s\widehat{\Delta \ln N_{at}} - (\widehat{\Delta \ln w_{at}} - \beta\widehat{\Delta \ln r_{at}}), \tag{7.1}$$

where $\Delta \ln N$ is the change in local population and s is the standard deviation of idiosyncratic location preferences or moving costs and the term in parentheses is the change in real income, which is measured as the difference between the change in wage and salary income per household, $\Delta \ln w$, and the product of the share of locally produced goods in the consumption basket, β, and the change in housing prices or rents (a proxy for a price index for local goods), $\Delta \ln r$.[52] Thus, WTP for the change in amenities, expressed as a percentage of income, is equal to the difference between the change in population, adjusted for the magnitude of moving costs, and the change in real wages.

To gain further intuition about the expression of WTP for amenity changes, consider the case where WTP for amenities is zero: In this case, the change in real income is equal to the adjusted change in population. Alternatively, when the population change is larger than the change in real income normalized by s, i.e., $\frac{\widehat{\Delta \ln w_{at}} - \beta \widehat{\Delta \ln r_{at}}}{s}$, then amenities must have risen (fallen); that is, at the margin, people are exchanging reductions in real incomes for higher amenity levels. Finally, higher values of moving costs/locational preference (i.e., s) mean that location decisions are less responsive to changes in real wages.

Table 10 reports empirical estimates of the annual WTP for the change in amenities. With these estimates in hand, it is straightforward to develop an estimate for the WTP for allowing fracing (i.e., the net welfare change for original residents) by using 2.6, which also incorporates income from lease payments received by households, and the previous section's empirical estimates; Table 10 reports this too. The entries in Panel A report the mean annual WTP for the change in amenities and for allowing fracing per household for households originally living or owning land in top-quartile counties. The entries in Panel B report aggregate the present value of the WTP measures for original households in all 65 top-quartile counties with a 5% discount rate when it is assumed that fracing is allowed permanently and the estimated annual changes in amenities, income, housing costs, etc are assumed to be constant and to last forever. Columns (1) - (2) use the increase in rental prices (2.9%) as the measure of the change in housing costs and columns (3) - (4) use the increase in housing prices (5.7

All estimates in the Table assume that $\beta = 0.65$, the share of household wage and salary income spent on locally produced goods, following Albouy (2008) and $s = 0.30$, the standard deviation of idiosyncratic location preferences or moving costs, which is the population-share weighted average of the values for non-college educated and college-educated workers of 0.27 to 0.47 estimated by Diamond (2016).[53] Throughout, we use the estimated 7.5 percent change in mean wage and salary income, a 9.3 percent change in interest and dividend income, and a 2.7 percent change in population (based on the Table 5 results).

There is substantial uncertainty in the true values of s and β. To account for this fact, we

[52] The model discussed above is based on rents. If the housing market is perfectly competitive and the change in rents is constant after the introduction of fracing, then $\Delta \ln p_j = \frac{1}{1-\beta} \Delta \ln r$ and the percentage change in rents and house prices will be identical. In practice, we do not find an identical increase in house prices and rents. This result could be due to several factors, including the fact that homeowners receive oil and gas lease royalty payments while renters do not. Alternatively, the larger increase in house prices could reflect expectations about future growth associated with fracing.

[53] The 65% share of income spent on housing is significantly higher than the 30-40% usually found in the Consumer-Expenditure Survey. This difference is driven by two primary factors. First, as mentioned above, the 65% number incorporates the correlation between local rents and the prices of other locally traded goods, such as retail services, etc.. Second, this 65% is in terms of household wage and salary income rather than total income.

incorporate uncertainty in the values of s and β into the standard errors of our amenity change and welfare estimates. Specifically, we assume that s has standard deviation of .09 (the average of the standard error of the point estimates for college and non-college educated workers in Diamond (2016)), that β has a standard deviation of .1, and that the covariance between these terms and between these parameters and our estimated parameters is 0.

These assumptions can then be used, along with the sampling variation in ΔlnN_{at}, Δlnw_{at}, Δr_{at}, and Δy_{at} to compute the standard error of the estimates of WTP for the amenity change and of WTP for allowing fracing (i.e., welfare). As described in more detail below, the standard errors are relatively small, giving us greater confidence in the estimates. Further, Appendix Table 20 provides a different set of amenity and welfare estimates when alternative reasonable values of s and β, different measures of the ΔlnN_{at}, Δlnw_{at}, and Δr_{at}, and alternative empirical specifications are used; the qualitative patterns hold, suggesting that values of these key parameters do not drive the results. However, it must be kept in mind that the exact magnitudes of the amenity and welfare effects of fracing will depend on the true values of s and β, which are ultimately unknown.

The Table 10 estimates suggest that the initiation of fracing decreases local amenities. Using the preferred assumptions, the estimated annual WTP is -\$1,405 per household when the change in housing prices is used as a proxy for local prices and -\$2,225 with the change in rental rates. The estimated effects on amenities are precisely estimated, with the standard errors allowing us to rule out effects smaller than -\$500 in magnitude. If we assume that the decline in amenities is permanent, then the present value of the decline in local amenities is -\$47 billion with housing prices and -\$74 billion with rental rates.[54] Finally, we note that, in principle, these estimates capture all of the changes in positive and negative amenities, including any changes in truck traffic, criminal activity, noise and air pollution from drilling activity, and household beliefs regarding expected health impacts.

The full WTP for allowing fracing accounts for both the decline in amenities and the greater economic opportunities (i.e., it is the difference between the gross benefits and the gross costs). The estimates in columns (2) and (4) suggest that the net effect is positive meaning that on average the benefits exceed the costs. Specifically, we estimate that WTP for allowing fracing equals about \$1,500 to \$2,400 per household annually (i.e., 3.5 to 5.2 percent of annual income). As is the case with the estimated WTP for amenities, the estimated welfare effects are quite precise, with the estimated standard errors allowing us to rule out positive welfare effects smaller than \$500 per household. If the changes in amenities and economic opportunities are permanent, Panel B suggests that the aggregate increase in welfare is in the neighborhood of \$53 billion to \$80 billion for the top quartile Rystad counties.

It is instructive to compare the welfare gains implied in Table 10 with those that a standard Roback analysis would produce. Specifically, the estimated welfare gain is about \$160 million in the average county or \$10.4 billion among all top quartile counties when the welfare change is equal to

[54]This calculation uses the 2000 Census population for each county.

the change in housing prices as in the canonical Roback model. The reason for this much smaller estimated welfare effect is that when there are zero-moving costs and inelastic housing supply, large changes in income would cause very large rises in rents if amenities were unchanged. The fact that there is only a small rise in rents, despite the rise in wage and salary income, implies that there must have been a large decline in local amenities. The results from this paper's model and the standard Roback model both indicate that the value of the greater economic opportunities outweighs the decline in local amenities, suggesting large and meaningful average net gains for the top quartile counties.

Are these estimates plausible? Recall that our estimate of the impact of the introduction of fracing on local hydrocarbon production is roughly $400 million per year, which, if it represented a permanent change, would have a present discounted value of $8 billion dollars per county with a 5 percent discount rate. There are 65 top-quartile counties, so the estimated national welfare gain of $44 to $64 billion is approximately 10 percent of the increase in hydrocarbon production of $520 billion from these counties. Thus, at least with this basis for comparison, these estimates seem reasonable.

It is worth underscoring that Table 10 has reported average estimates of WTP and it is unlikely that all residents are made better off by allowing fracing. For example, individuals who are not in the labor force will not benefit from the increase in local productivity. Renters who are not in the labor force are likely to fare especially poorly because they will face higher rents and no change in income. Additionally, homeowners who do not own the mineral rights to their property will not benefit from the drilling royalties, but may experience the negative impacts of drilling activity. The extent of the heterogeneity in the impacts of local productivity shocks and of changes in local amenities is a promising area for future research although decisive evidence would likely require more detailed micro data.

It is nevertheless possible to provide some preliminary evidence on heterogeneity in the welfare measures by home-ownership and across shale plays. Columns (5)-(10) of Table 10 explore how the estimates of WTP for allowing fracing differs for individuals who own their own home (and work in the labor market), renters, and absentee landlords. It is striking that the WTP for allowing fracing is two to three times higher among homeowners than it is for renters. Of course, these welfare estimates should be viewed cautiously, because they require even stronger assumptions, including the assumption that renters and owners have identical preferences and abilities to benefit from fracing's labor market effects and that all landlords live outside of fracing exposed areas and are unexposed to the labor market or amenity effects of fracing. Even with these assumptions in mind, these results suggest that the welfare effects of fracing are likely to vary substantially across individuals, even within top quartile counties.

In Table 9, Panel E, we report the estimated change in WTP for amenities and for allowing fracing separately by shale play. The estimates are qualitatively consistent across shale plays, with 8 of 10 shale plays experiencing declines in amenities or quality of life and 6 of 10 experiencing welfare improvements. The largest estimates comes from the Bakken's (primarily in North Dakota and Montana) annual WTP of \$11,600 and the Woodford-Arkoma's (Oklahoma) annual WRP of \$4,500, although there are also large net gains in the Fayetteville (in Arkansas and Oklahoma) and Marcellus (largely in Pennsylvania, West Virginia, and Ohio). Interestingly, the shale plays with negative welfare estimates have values that are small in magnitude and statistically insignificant. Overall, the play-specific estimates are very demanding of the data and hence substantially less precise than the aggregate estimates.

It is natural to wonder about the sources of heterogeneity in the welfare impacts across the plays. Panel A reports the average population in top quartile counties and the share of hydrocarbon production value that comes from oil as we had ex ante assumed that these two variable would be important predictors of WTP to allow fracing. Among the three largest gainers one is dominated by petroleum (Bakken) and the other two (Fayettevile and Marellus) are dominated by natural gas production. Besides observable predictors, it seems plausible that there is heterogeneity across shale plays in moving costs, s and the share of income spent on housing, β, due to differences in proximity to other labor markets, demographic composition, or tastes that influence the welfare estimates. Overall, it is apparent that the question of where fracing offers the largest net benefits cannot be answered decisively with just ten data points.[55]

Two final points are noteworthy. First, these revealed preference estimates of WTP to allow fracing (and for amenity changes) are ultimately determined by households' knowledge. If new information causes households to update their estimates of fracing's environmental and quality of life impacts, then this paper's WTP estimates will necessarily change. Second, this paper's estimates of WTP to allow fracing only reflect local changes in welfare. The global welfare effects of fracing include potentially very important consequences for petroleum, natural gas and electricity prices, local air pollution, global warming, and geopolitics. All of these impacts are outside the scope of this paper; however, none of them become relevant if local communities do not allow fracing within their jurisdictions.

7.2 Spillovers

To the extent that fracing activity in a county has spillover effects on other counties in the same shale play, our identification strategy will underestimate the benefits and costs of fracing. In order to investigate this hypothesis we also explored models using propensity-score matching to select the "control" counties to compare to both counties in the top quartile of the Rystad prospectivity measure, and counties in the lower three quartiles ((Imbens and Rubin (2015)). As discussed above, we were unable to select control counties with covariates that balanced using propensity scores. We do present these propensity score estimates in Appendix Section D.3.1 and Appendix Tables 14

[55] In Appendix Table 6 we report play-specific estimates instead using the change in rents to measure house prices. This table also reports aggregate affects of fracing on welfare by play.

through 19. The estimates do suggest gains in income and employment in the bottom three quartiles, though they are smaller in magnitude then for the top quartile counties. These results suggest that spillovers may in fact mean that our method understates the magnitude of both the benefits and costs of fracing, but the imbalance in covariates means that these results should be interpreted cautiously.

8 Conclusions

This paper has developed a measure of the net welfare consequences of fracing on local communities that accounts for both its benefits and costs. To do so, we utilize a new identification strategy based on geological variation in shale deposits within shale plays and differences in the timing of the initiation of fracing across plays. Further, we set out a Roback-Rosen-style locational equilibrium model and use it to derive an expression for WTP for allowing fracing in a local community that is a function of the parameters that can be estimated with the identification strategy.

There are three primary findings. First, counties with high fracing potential experience a boom in oil and natural gas production. This boom is characterized by sharp increases in a broad set of economic indicators, including gains in total income (4.4 - 6.9 percent), employment (3.6 - 5.4 percent), housing prices (5.7%), and housing rental rates (2.7%). Second, there is evidence of deterioration in the non-economic quality of life or total amenities, including higher violent crime rates. Using the model's results, we estimate that annual willingness-to-pay (WTP) for fracing-induced changes in local amenities is roughly equal to -\$1,400 per household annually or -3.1 percent of mean annual household income. Third, the net welfare effects of allowing fracing appear to be substantial and positive for local communities. Again using an expression derived from the model, we estimate that across all US shale plays, WTP for allowing fracing is about \$2,400 per household annually or about 5.2 percent of mean household income among original households in counties with high fracing potential. Importantly, there is also evidence of substantial heterogeneity in WTP across shale plays.

The discovery of hydraulic fracturing is widely considered the most important change in the energy sector since the commercialization of nuclear energy in the 1950s. To date, almost all of the fracing activity has been confined to North America, yet even so it has upended many features of the global economy, global environment, and international relations. There are substantial shale deposits both in North America and other parts of the world that have not been exploited to date so there is potential for further change. This paper demonstrates that to date local communities that have allowed fracing have benefited on average, although there is evidence of important heterogeneity in the local net benefits. Understanding the sources of this heterogeneity is a first-order question for researchers and policymakers interested in assessing the impacts of allowing fracing in their community.

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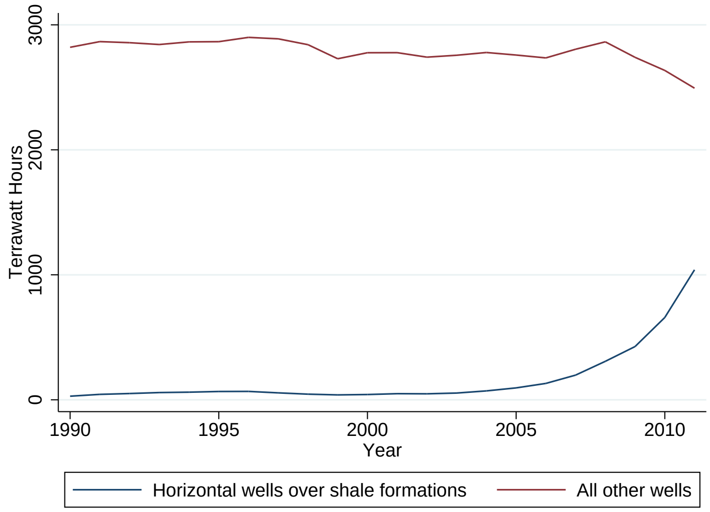
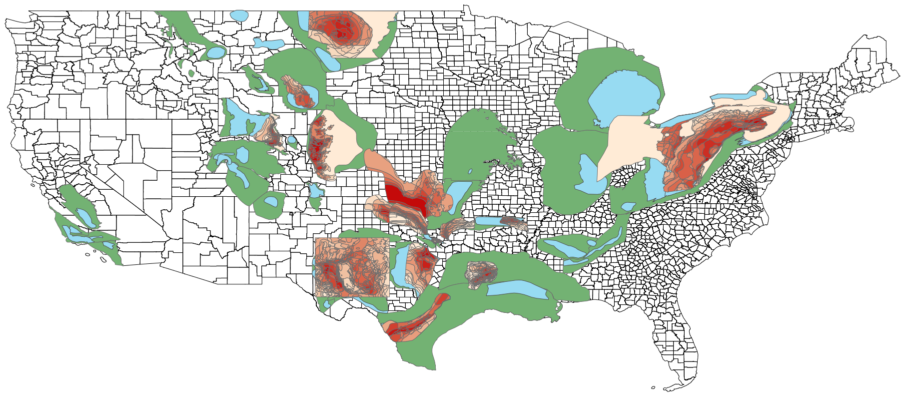
9 Figures

Figure 1: Hydrocarbon production from horizontal wells over shale play



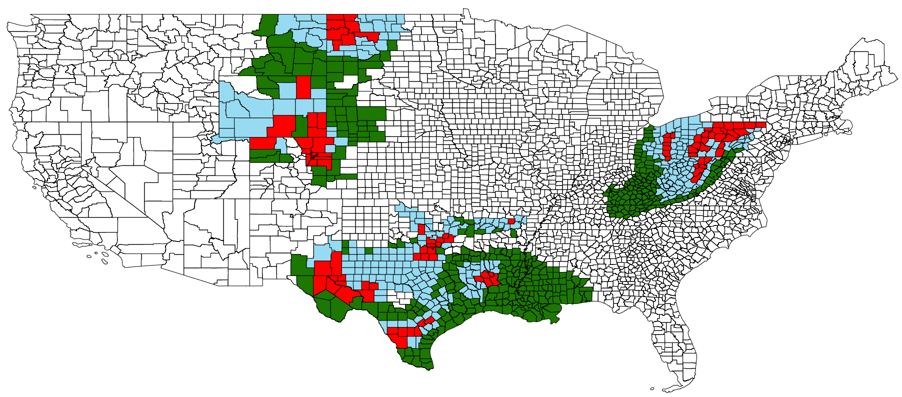
Notes: This figure plots the total energy content of hydrocarbons produced from horizontal wells over shale plays over time. In 1991, there is almost no production from these wells. However, as a results of the technological innovations in using fracing and horizontal drilling into shale formations, these types of wells have grown dramatically as a share of US hydrocarbon production, rising to more than a quarter of all US hydrocarbon production by 2011. The data come from Drilling Info, Inc (2012).

Figure 2: Shale basins, plays, and prospectivity scores



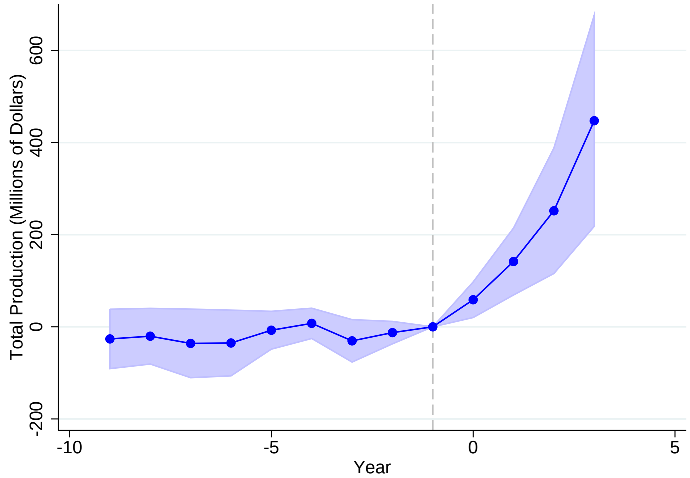
Notes: This figure overlays shale basins, shale plays, and Rystad prspectivity scores over a map of US counties. Shale basins are shown in green, shale plays are shown in blue, and Rystad Prospectivity scores are shown in shades of red, with darker red indicating a higher prospectivity score. Shapefiles for US shale basins and plays comes from the Energy Information Agency (2011), while prospectivity scores were purchased from Rystad Energy (2014).

Figure 3: County prospectivity score classifications



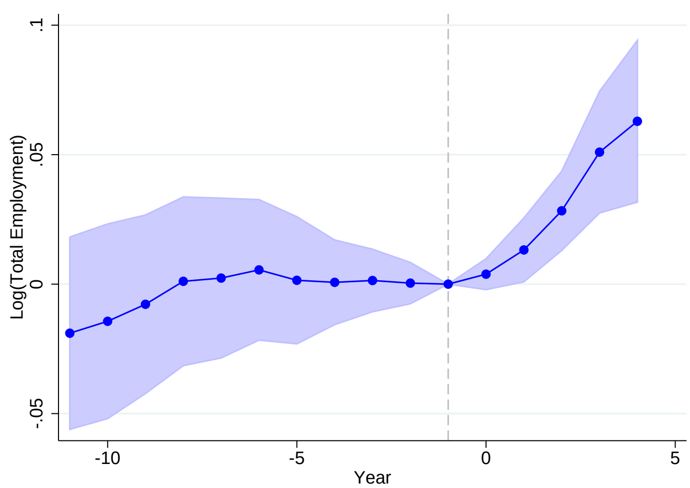
Notes: This figure shows prospectivity score classifications for counties in the contiguous US. Counties in red are in the top quartile of the Rystad prospectivity measure, counties in blue are not in the top quartile of Rystad prospectivity but are within a shale play, and counties in green are not in a shale play, but are in a shale basin.

Figure 4: Event study analysis of county-level value of hydrocarbons



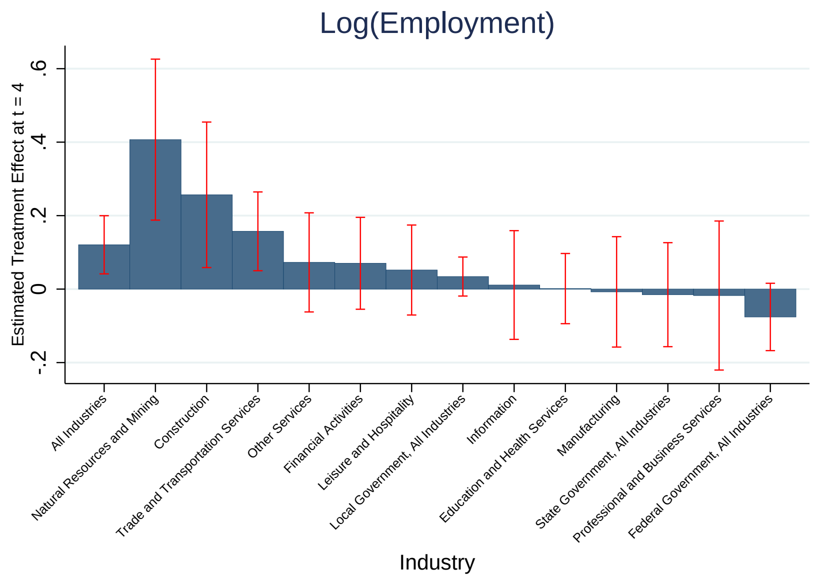
Notes: This figure plots results from an event-study analysis of the difference in the county-level value of hydrocarbon production between high-fracing potential counties and other counties in shale plays before and after fracing began. The reported coefficients come from fitting a modified version of Equation 5.1 where we interact 1[Rystad Top Quartile]$_c$ with a vector of event year indicators, τ_{pt}. Event years are defined as the calendar year minus the first-frac year in the relevant shale play. These coefficients measure the difference in outcomes between top-quartile and other counties within a play, by event years. The model also includes play-year and county fixed effects. All Rystad Top Quartile-event year interactions are interacted with an indicator for being in the unbalanced sample. The reported coefficients correspond to the balanced sample. Consequently, the results in the figure correspond to shale-plays that began fracing in or before 2008 and event-years common to all these shale plays (i.e. event-years observed for all shale plays that began fracing in or before 2008). Data on hydrocarbon production from 1992 to 2011 come from Drilling Info, Inc (2012). The shaded blue region shows 95 percent confidence intervals calculated using standard errors clustered at the county level.

Figure 5: Event study analysis of total employment



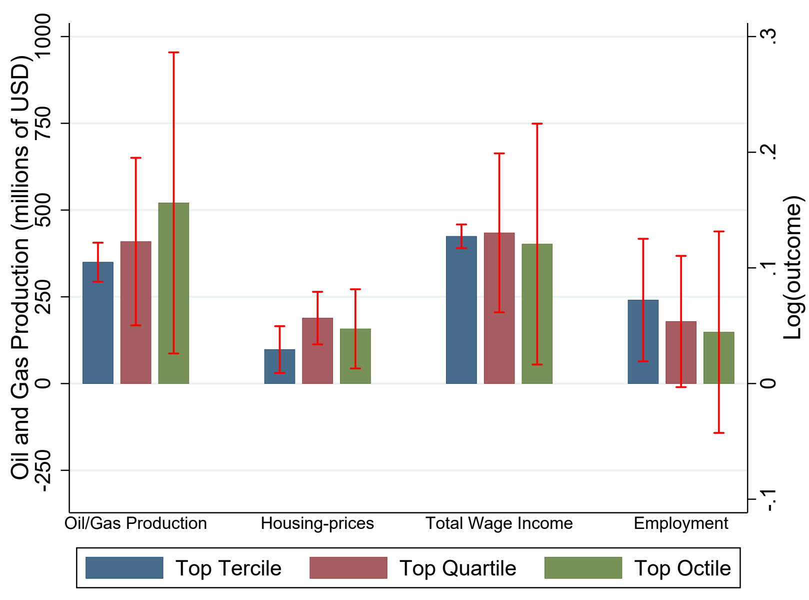
Notes: This figure plots results from an event-study analysis of the difference in log(total employment) between high-fracing potential counties and other counties in shale plays before and after fracing began. The reported coefficients come from fitting a modified version of Equation 5.1 where we interact 1[Rystad Top Quartile]$_c$ with a vector of event year indicators, τ_{pt}. Event years are defined as the calendar year minus the first-frac year in the relevant shale play. These coefficients measure the difference in outcomes between top-quartile and other counties within a play, by event years. The model also includes play-year and county fixed effects. All Rystad Top Quartile-event year interactions are interacted with an indicator for being in the unbalanced sample. The reported coefficients correspond to the balanced sample. Consequently, the results in the figure correspond to shale-plays that began fracing in or before 2008 and event-years common to all these shale plays (i.e. event-years observed for all shale plays that began fracing in or before 2008). Data on county-level total employment from 1990 to 2012 come from the Local Area Personal Income (LAPI) data from the Regional Economic and Information Systems (REIS) data produced by the US Bureau of Economic Analysis (BEA) (2014). Specifically, we use the the variable CA25-10. The shaded blue region shows 95 percent confidence intervals calculated using standard errors clustered at the county level.

Figure 6: Employment effects by industry



Notes: This figure plots estimates of the effect of fracing on employment by industry five years after the start of fracing. Each bar reports results of fitting Equation 5.2 for the given industry, which corresponds to Column (2) in the tables. Equation 5.2 allows for differential pre-trends in event time, as well as a trend break in outcomes and a mean shift for Rystad top-quartile counties. The model also includes play-year and county fixed effects. All Rystad Top Quartile variables are interacted with an indicator for being in the unbalanced sample. The reported estimates correspond to the balanced sample. Data on employment by industry from 1990 to 2013 come from the Quarterly Census of Employment and Wages (QCEW) produced by the Bureau of Labor Statistics, US Department of Labor (2014). Counties are included in the sample if the given employment variable is non-missing in all years from 1990-2013. Red bars report 95 percent confidence intervals calculated using standard errors clustered at the county level.

Figure 7: Estimates by Fracing Exposure Measure



Notes: This figure plots estimates of the effect of fracing using different definitions of fracing exposure: being in the top tercile, quartile or octile of maximum prospectivity within the shale play. Estimates are presented for four outcomes: millions of dollars of oil and gas production, median housing prices for owner occupied housing units, total wagae and salary income, and total employment. The bars for hydrocarbon production, total wage and salary income, and employment report results of fitting Equation 5.2 for the given outcome variable, which corresponds to Column (2) in the tables. Equation 5.2 allows for differential pre-trends in event time, as well as a trend break in outcomes and a mean shift for Rystad top-quartile counties. The model also includes play-year and county fixed effects. The bar for median housing prices reports results of fitting Equation 5.4. All Rystad Top Quartile variables are interacted with an indicator for being in the unbalanced sample. The reported estimates correspond to the balanced sample. Data on hydrocarbon production from 1992 to 2011 come from Drilling Info, Inc (2012). Data on county-level total employment and wage and salary income come from 1990 to 2012 come from the Local Area Personal Income (LAPI) data from the Regional Economic and Information Systems (REIS) data produced by the US Bureau of Economic Analysis (BEA) (2014). Data on median housing prices come from the Decennial Census and the American Community Survey (Ruggles et al. (2015)). Red bars report 95 percent confidence intervals calculated using standard errors clustered at the county level.

10 Tables

Table 1: Treatment and control counties by shale basin

Shale Play (1)	Shale Basin (2)	Play First Frac Year (3)	Top Quartile Counties (4)	Outside Top Quartile Counties (5)
Woodford-Anadarko	Anadarko	2008	1	10
Marcellus	Appalachian	2008	28	95
Utica	Appalachian	2012	7	18
Woodford-Ardmore	Ardmore	2007	4	5
Fayetteville	Arkoma	2005	1	13
Woodford-Arkoma	Arkoma	2006	2	7
Niobrara-Denver	Denver	2010	13	4
Barnett	Forth Worth	2001	5	41
Niobrara-Greater Green River	Greater Green River	2012	2	9
Permian All Plays	Permian	2005	11	34
Niobrara-Powder River	Powder River	2010	1	5
Haynesville	TX-LA-MS Salt	2008	5	21
Eagle Ford	Western Gulf	2009	7	21
Bakken	Williston Basin	2007	8	27
Total			95	310

Notes: This table shows the number of counties by shale play and Rystad prospectivity value. Top Quartile = 1 if the county is in the top-quartile of the Rystad max prospectivity measure within its shale-play and 0 otherwise. Different shale plays have different geological features and were developed at different time periods. Column (3) shows the first year the fracing potential of the shale play became public.

Table 2: Comparison of pre-trends and levels across treatment and control counties

	Mean Value in US	Basin vs. Rest of US	Play vs. Basin	Rystad Top Quartile vs. Play	Rystad Top Quartile vs. Pscore Matched Sample	Quartiles 1-3 vs. Pscore Matched Sample
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Covariate Balance (All Variables measured in 2000 unless noted)						
Panel A1: Non-Crime Variables						
Log(Real Median Home Values)	11.897	-0.402***	-0.071**	0.039	-0.105*	-0.151***
		(0.037)	(0.031)	(0.050)	(0.060)	(0.042)
Log(Real Median Home Rental Prices)	6.621	-0.179***	-0.024	0.055	-0.084	-0.083**
		(0.032)	(0.030)	(0.045)	(0.059)	(0.035)
Log(Total Housing Units)	9.427	-0.159***	0.413***	0.082	-0.211	-0.356***
		(0.055)	(0.087)	(0.143)	(0.169)	(0.109)
Log(Total Employment)	9.532	-0.245***	0.401***	0.057	-0.316*	-0.423***
		(0.060)	(0.104)	(0.161)	(0.178)	(0.117)
Log(Total Income per capita)	13.605	-0.285***	0.411***	0.036	-0.335*	-0.432***
		(0.062)	(0.103)	(0.171)	(0.194)	(0.121)
Share of Population with Bachelor's Degree or more	0.241	-0.041***	0.003	0.042*	-0.003	-0.028**
		(0.010)	(0.016)	(0.025)	(0.026)	(0.013)
Share of Population Ages 18-64	0.619	-0.003	-0.011**	-0.003	-0.003	0.002
		(0.003)	(0.004)	(0.007)	(0.009)	(0.005)
Log(Real Total Government Revenue: 2002 - 1992)	11.513	-0.274***	0.373***	0.050	-0.333*	-0.423***
		(0.059)	(0.101)	(0.159)	(0.177)	(0.114)
Log(Real Total Government Expenditures: 2002 - 1992)	11.516	-0.283***	0.373***	0.063	-0.329*	-0.433***
		(0.060)	(0.102)	(0.162)	(0.180)	(0.115)
Total Value of Hydrocarbon Production: 2000 - 1992	56.238	81.575***	78.569***	108.280*	101.204	-0.968
		(19.983)	(17.700)	(58.527)	(67.921)	(43.346)
F-statistic		25.0	7.8	1.6	3.2	2.9
P-value		0.00	0.00	0.10	0.00	0.00
Counties Exposed	-	715	316	64	64	252
N	2,842	2,842	791	401	1,393	1,608
Panel A2: Crime-Variables						
Property Crimes per 100k residents	3,937	167	-1,480***	-572*	-1,612***	-589**
		(222)	(365)	(334)	(247)	(256)
Violent Crimes per 100k residents	537	-56	-156***	-64	-209***	-89
		(49)	(59)	(81)	(79)	(57)
F-statistic		1.2	5.5	2.6	28.8	1.8
P-value		0.32	0.00	0.05	0.00	0.14
Counties Exposed		523	266	56	56	210
N	2,020	2,020	573	338	875	1,055
Panel B: Pre-Trends (Change 1990 - 2000 unless noted)						
Panel B1: Non-Crime Variables						
Log(real median home values)	0.110	0.020	-0.022	-0.011	0.054***	0.006
		(0.026)	(0.014)	(0.028)	(0.020)	(0.021)
Log(real median home rental prices)	0.012	0.055***	-0.027***	0.003	0.001	0.006
		(0.016)	(0.006)	(0.008)	(0.018)	(0.014)
Log(Total Housing Units)	0.124	-0.036***	-0.054***	0.009	-0.037***	-0.049***
		(0.005)	(0.008)	(0.012)	(0.014)	(0.008)
Log(Total Employment)	0.178	-0.042***	-0.028**	0.028*	-0.021	-0.048***
		(0.007)	(0.012)	(0.016)	(0.019)	(0.013)
Log(Total Income per capita)	0.259	-0.045***	-0.071***	0.036**	-0.021	-0.057***
		(0.007)	(0.013)	(0.018)	(0.021)	(0.014)
Share of Population with Bachelor's Degree or more	0.040	-0.012***	0.002	0.013***	0.009*	-0.006
		(0.003)	(0.003)	(0.005)	(0.005)	(0.004)
Share of Population Ages 18-64	0.001	0.005***	0.000	-0.006	-0.003	0.002
		(0.002)	(0.003)	(0.004)	(0.004)	(0.002)
Log(Real Total Government Revenue: 2002 - 1992)	0.286	-0.064***	-0.112***	0.042	-0.029	-0.070***
		(0.011)	(0.019)	(0.027)	(0.028)	(0.021)
Log(Real Total Government Expenditures: 2002 - 1992)	0.290	-0.029***	-0.124***	0.034	-0.028	-0.062***
		(0.011)	(0.020)	(0.029)	(0.031)	(0.023)
Total Value of Hydrocarbon Production: 2000 - 1992	7.934	6.848*	4.032	28.929	5.004	-25.828
		(4.150)	(7.247)	(18.096)	(23.162)	(19.465)
F-statistic		14.2	9.0	1.4	2.5	4.1
P-value		0.0	0.0	0.2	0.0	0.0
Counties Exposed		715	316	64	64	252
N	2,842	2,842	791	401	1,393	1,608
Panel A2: Crime-Variables (Change 1992 - 2000)						
Property Crimes per 100k residents	-1,365	323*	-365*	125	396*	17
		(177)	(200)	(220)	(207)	(199)
Violent Crimes per 100k residents	-246	56	60	41	93**	4
		(48)	(40)	(51)	(37)	(44)
F-statistic		1.1	3.9	0.2	2.1	0.0
P-value		0.35	0.01	0.88	0.10	1.00
Counties Exposed		523	266	56	56	210
N	2,020	2,020	573	338	875	1,055

Notes: This table shows coefficients from regressions of baseline outcomes (Panel A) and pre-trends (Panel B) on different measures of exposure to Fracing activity. Column (1) shows the mean value for the entire US. Column (2) shows regressions of covariates and pre-trends on an indicator for being in a shale basin. Column (3) shows regressions of covariates and pre-trends on an indicator for being in a shale-play (restricting the sample to counties in a shale basin). Column (4) shows regressions of covariates and pre-trends on an indicator for being in the top quartile of max prospectivity (restricting the sample to counties in a shale basin). Column (5) shows regressions of covariates and pre-trends on an indicator for being in the top quartile of max prospectivity, but the sample is top quartile counties and the corresponding pscore-matched counties for each shale play. Column (6) shows regressions of covariates and pre-trends on an indicator for being in quartiles one through three of max prospectivity, but the sample is the bottom three quartile counties and the corresponding pscore-matched counties for each shale play. All specifications include both the fracing exposure measure and the fracing exposure measure interacted with an indicator for being in the unbalanced sample (defined as having a first-frac date after 2008). The coefficients reported correspond to the balanced sample. Column (3) includes basin fixed effects and Columns (4), (5), and (6) include play fixed effects. Below Panel A we report the joint F-test that all the coefficients are equal to 0 in the covariate regression. Below Panel B we report the joint F-test that all coefficients are equal to 0 in the pre-trends regression. Estimated outcome variables (such real median home values) are weighted by the sample size for the estimate (such as number of owner occupied homes for real median home values). All monetary figures are shown in 2010 USD. Robust standard errors are reported in parentheses in Columns (2)-(4). Columns (5) and (6) cluster standard errors at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 3: Impact of fracing on the value of hydrocarbon production

	(1)	(2)	(3)
Panel A: Total Value of Oil and Gas Production			
1(Fracing Exposure)*1(Post)	242***	36	36
	(68)	(47)	(23)
t*1(Fracing Exposure)		3	
		(6)	
t*1(Fracing Exposure)*1(Post)		124***	125***
		(37)	(38)
Fracing Exposure Effect at tau=3	242***	409***	410***
	(68)	(123)	(115)
Fracing Exposure Group	Top Quartile	Top Quartile	Top Quartile
Control Group	Quartiles 1-3	Quartiles 1-3	Quartiles 1-3
Fracing Exposure Level Shift	Y	Y	Y
Fracing Exposure Trend	N	Y	Y
Fracing Exposure Trend Break	N	Y	Y
County Fixed Effects	Y	Y	Y
County-Specific Trends	N	N	Y
Year-Play Fixed Effects	Y	Y	Y
Restricted to Balanced Sample	N	N	Y

Notes: This table reports regressions of oil/gas production variables on fracing exposure. Fracing exposure is measured using an indicator for whether the county is in the fourth quartile of the Rystad max prospectivity score among counties within the shale play with a non-missing Rystad value. Oil and gas production data come from HPDI well data aggregated to the county level. Column (1) allows for a level shift in Rystad top quartile counties. Columns (2) and (3) allow for pre-trends, a post-fracing level shift, and a post-fracing trend break in Rystad top quartile counties. In Columns (1) and (2), all Rystad top quartile variables are included by themselves, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported coefficients are for the balanced sample. Column (3) adds county-specific trends and restricts the sample to the balanced sample. 1(Post) = 1 if the year is after the first-frac date for the shale, defined as the first year that there is any fracing within the counties shale play. The coefficients and standard errors for Fracing Exposure Effect at tau=3 correspond to the 1(Fracing Exposure)*1(Post) coefficient plus 3 times the t*1(Fracing Exposure)*1(Post) coefficeint. Standard errors clustered at the county level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Sample: Columns (1) and (2) include 8100 county-year observations from 405 total counties, of which 65 Rystad top quartile and 253 outside top quartile counties are in the balanced sample. Column (3) includes 4,134 observations from 318 total counties, of which 65 Rystad top quartile and 253 outside top quartile counties are in the balanced sample.

Table 4: Impact of fracing on employment and aggregate income: time-series specifications

	(1)	(2)	(3)
Panel A: Log(Total Employment)			
Fracing Exposure Effect at tau=4	0.036**	0.054*	0.049***
	(0.016)	(0.029)	(0.019)
Panel B: Income			
Log(Total Income)			
Fracing Exposure Effect at tau=4	0.056***	0.069**	0.044**
	(0.015)	(0.028)	(0.021)
B1. Log(Total Wage/Salary Income): 56 percent of total personal income			
Fracing Exposure Effect at tau=4	0.076***	0.130***	0.089***
	(0.021)	(0.035)	(0.030)
B2. Log(Total Rents/Dividends): 19 percent of total personal income			
Fracing Exposure Effect at tau=4	0.070***	0.080**	0.068**
	(0.019)	(0.038)	(0.028)
B3. Log(Total Transfers): 10 percent of total personal income			
Fracing Exposure Effect at tau=4	0.012	0.001	-0.005
	(0.012)	(0.020)	(0.008)
B4. Log(Total Proprieter's Income): 18 percent of total personal income			
Fracing Exposure Effect at tau=4	0.036	-0.101	-0.041
	(0.040)	(0.064)	(0.069)
Panel C: Migration			
C1. Log(In Migration)			
Fracing Exposure Effect at tau=4	0.044**	0.073*	0.005
	(0.017)	(0.038)	(0.042)
C2. Log(Out Migration)			
Fracing Exposure Effect at tau=4	-0.001	0.007	-0.047
	(0.013)	(0.031)	(0.035)
Fracing Exposure Group	Top Quartile	Top Quartile	Top Quartile
Control Group	Quartiles 1-3	Quartiles 1-3	Quartiles 1-3
Fracing Exposure Level Shift	Y	Y	Y
Fracing Exposure Trend	N	Y	Y
Fracing Exposure Trend Break	N	Y	Y
County Fixed Effects	Y	Y	Y
County-Specific Trends	N	N	Y
Year-Play Fixed Effects	Y	Y	Y
Restricted to Balanced Sample	N	N	Y

Notes: This table reports regressions of aggregate economic outcomes on fracing exposure measured using an indicator for whether the county is in the fourth quartile of the Rystad max prospectivity score among counties within the shale play with a non-missing Rystad value. Employment and income variables in variables in Panels A and B come from the REIS data produced by the BEA. Migration measures in Panel C come from the IRS' county migration data. Column (1) allows for a level shift in fracing exposed counties. Columns (2) and (3) allow for pre-trends, a post-fracing level shift, and a post-fracing trend break in counties exposed to fracing. In Columns (1) and (2), all fracing exposure variables are included by themselves, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported coefficients are for the balanced sample. Column (3) adds county-specific trends and restricts the sample to the balanced sample. The reported estimates and standard errors correspond to the top quartile level shift coefficient + 4 times the top quartile trend break coefficient. Standard errors clustered at the county level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Sample: Includes all counties in any shale play with non-missing data in all years from 1990 to 2012. Panels A, B, B1, B2, and B3, Columns (1) and (2) include 9246 observations from 402 total counties, of which 65 Rystad top quartile counties and 252 outside top quartile counties are in the balanced sample. Panels A, B, B1, B2, and B3, Column (3) include 5,072 observations from 317 total counties, of which 65 Rystad top quartile and 252 outside top quartile counties are in the balanced sample.

Panel B4, Columns (1) and (2) include 8,740 observations from 380 total counties, of which 60 Rystad top quartile and 237 outside top quartile counties are in the balanced sample. Panel B4, Column (3) includes 4,752 observations from 297 total counties, of which 60 Rystad top quartile and 237 outside top quartile counties are in the balanced sample.

Panel C, Columns (1) and (2) include 7,900 observations from 395 total counties, of which 63 Rystad top quartile and 248 outside top quartile counties are in the balanced sample. Panel C, Column (3) includes 4,043 observations from 311 total counties, of which 63 Rystad top quartile and 248 outside top quartile counties are in the balanced sample.

Table 5: Impact of fracing on employment and aggregate income: long-difference specifications

	(1)
Panel A: Employment Outcomes:	
A1. Log(Total Employment)	
	0.048***
	(0.017)
A2. Employment-to-Population Ratio	
	0.026***
	(0.009)
A3. Unemployment Rate	
	-0.006*
	(0.003)
Panel B: Household Income:	
B1. Log(Mean Real Household Income)	
	0.058***
	(0.012)
B2. Log(Mean Real Household Wage and Salary Income)	
	0.075***
	(0.017)
B3. Log(Mean Real Rent and Dividend Income)	
	0.093**
	(0.037)
Panel C: Population:	
C1. Log(Population)	0.027*
	(0.016)
Fracing Exposure Group	Top Quartile
Control Group	Quartiles 1-3
Play Fixed Effects	Y

Notes: This table reports long-difference regressions of the change in county aggregate economic outcomes between 2000 and 2009/2013 on a measure of fracing exposure. Fracing exposure is measured using an indicator for the county being in the fourth quartile of the Rystad max prospectivity score among counties within the shale with a non-missing Rystad value, and the control group are quartiles one through three. The fracing exposure measure is included by itself, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported estimates are for the balanced sample. Robust standard errors are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Sample: Panels A1, B, and C include observations from 404 total counties, of which 65 Rystad top quartile and 253 outside top quartile counties are in the balanced sample.

Panels A2 and A3 include observations from 403 total counties, of which 64 Rystad top quartile and 253 outside top quartile counties are in the balanced sample.

Table 6: Impact of fracing on crime

	(1)	(2)	(3)
Panel A. Total Crime per 100k Residents			
Top Quartile Effect at tau=5	172	-96	-171
	(201)	(138)	(192)
Panel B: Violent Crime per 100k Residents			
Top Quartile Effect at tau=5	56**	29	-4
	(28)	(66)	(75)
Panel C: Property Crime per 100k Residents			
Top Quartile Effect at tau=5	116	-125	-166
	(177)	(123)	(209)
Fracing Exposure Group	Top Quartile	Top Quartile	Top Quartile
Control Group	Quartiles 1-3	Quartiles 1-3	Quartiles 1-3
Fracing Exposure Level Shift	Y	Y	Y
Fracing Exposure Trend	N	Y	Y
Fracing Exposure Trend Break	N	Y	Y
County Fixed Effects	Y	Y	Y
County-Specific Trends	N	N	Y
Year-Play Fixed Effects	Y	Y	Y
Restricted to Balanced Sample	N	N	Y

Notes: This table reports regressions of crime rates on fracing exposure. Fracing exposure is measured using an indicator for being in the Top Quartile of max prospectivity among the counties with Rystad data within the shale play. The fracing exposure variables are included by themselves, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported estimates are for the balanced sample. Crime data come from the FBI Uniform Crime Reporting (UCR) system. Crime reports law enforcement agencies are aggregated to the county level. Data from a law enforcement agency is only included if the agency reports crimes to the FBI UCR system in every year from 1990 to 2013. Columns (2) and (3) allow for pre-trends, a post fracing level shift, and a post fracing trend break in Rystad top quartile counties. In Columns (1) and (2), all Rystad top quartile variables are included by themselves, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported coefficients are for the balanced sample. Column (3) adds county-specific trends and restricts the sample to the balanced sample. The reported estimates and standard errors correspond to the top quartile level shift coefficient + 5 times the top quartile trend break coefficient. Standard errors clustered at the county level are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Sample: Columns (1)-(3) include all counties in any shale play with non-missing data in all years from 1992 to 2013. Columns (1) and (2) include 7480 observations from 340 total counties, of which 56 Rystad top quartile and 210 outside top quartile counties are in the balanced sample. Column (3) includes 3,990 observations from 266 total counties, of which 56 Rystad top quartile and 210 outside top quartile counties are in the balanced sample.

Table 7: Impact of fracing on local government revenues and expenditures

	(1)
Panel A: Log(Total Expenditures): 2012 - 2002	
	0.129***
	(0.034)
A. Log(Direct Expenditures)	
	0.123***
	(0.033)
A1. Direct Expenditures by Type	
A1a. Log(Current Operating Expenditure):	
[84%]	0.107***
	(0.028)
A1b. Log(Capital Outlays):	
[12%]	0.181
	(0.135)
A2. Direct Expenditures by Purpose	
A2a. Log(Education Expenditures):	
[48%]	0.025
	(0.032)
A2b. Log(Public Safety Expenditures):	
[8%]	0.195***
	(0.063)
A2c. Log(Welfare and Hospital Expenditures):	
[10%]	0.240
	(0.154)
A2d. Log(Infrastructure and Utility Expenditures):	
[18%]	0.242***
	(0.071)
A2e. Log(Other Expenditures):	
[16%]	0.122*
	(0.063)
Panel B: Log(Total Revenues): 2012 - 2002	
	0.155***
	(0.032)
B1. Revenues by Type	
B1a. Log(Property Tax Revenues):	
[24%]	0.133***
	(0.042)
B1b. Log(Sales Tax Revenues):	
[4%]	0.594***
	(0.120)
B1c. Log(Other Tax Revenues):	
[2%]	0.038
	(0.155)
B1d. Log(Intergovernmental Revenues):	
[42%]	0.100
	(0.081)
B1e. Log(Charges Revenues):	
[14%]	0.095
	(0.079)
B1f. Log(Other Revenues):	
[14%]	0.261***
	(0.066)
Panel C: Government Balance Sheets	
C. Net Financial Position as Share of Revenues	
	-0.020
	(0.067)
Panel D: Log(Elem/Sec Education Spending per Pupil)	
	0.008
	(0.034)
Fracing Exposure Group	Top Quartile
Control Group	Quartiles 1-3
Play Fixed Effects	Y

Notes: This table shows regressions on the change in government spending and revenues between 2002 and 2012 on fracing exposure measured using an indicator for the county being in the fourth quartile of the Rystad max prospectivity score among counties within the shale with a non-missing Rystad value, and the control group are quartiles one through three. The fracing exposure measure is included by itself, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported estimates are for the balanced sample. Data come from the 2012 and 2002 Census of Governments. Panels A1 and B1 show the share of total government revenues or expenditures represented by the given category in brackets below the category name. Robust standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Sample: Panels A, B, and C, include all counties in any shale play, 405, of which 65 Rystad top quartile and 253 outside top quartile counties are in the balanced sample. Panel D includes all 385 counties in shale plays with non-missing school enrollment data for all districts in 1997, 2002, and 2012, of which 61 Rystad top quartile and 244 outside top-quartile counties are in the balanced sample.

Table 8: Impact of fracing on housing outcomes

	(1)
Panel A: House Values	
A1. Log(Median House Value)	
	0.057***
	(0.018)
A2. Log(Mean Housing Value)	
	0.057***
	(0.018)
A3. Log(Mobile Housing Units: Median Housing Value)	
	0.079**
	(0.037)
Panel B: Rental Prices	
B1. Log(Median Rental Price)	
	0.020*
	(0.010)
B2. Log(Mean Rental Price)	
	0.029***
	(0.011)
Panel C: Housing Quantities	
C1. Log(Total Housing Units)	
	0.011
	(0.012)
C2. Log(Total Mobile Homes)	
	0.022
	(0.028)
C3. Share of Housing Units Vacant	
	-0.010**
	(0.005)
C4. Log(Acres of Agricultural Land)	
	-0.099
	(0.144)
Fracing Exposure Group	Top Quartile
Control Group	Quartiles 1-3
Play Fixed Effects	Y

Notes: This Table shows regressions of the change in different housing outcomes between 2000 and 2009-2013 (with the exception of acres of agricultural land, which is measured in 2002 and 2012) on a measure of fracing exposure. Fracing exposure is measured using an indicator for the county being in the fourth quartile of the Rystad max prospectivity score among counties within the shale with a non-missing Rystad value, and the control group are quartiles one through three. The fracing exposure measure is included by itself, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported estimates are for the balanced sample. 2013-2009 housing data come from the American Community Survey. 2000 Housing data come from the Decenniel Census. 2002 and 2012 agricutlural land data come from the 2002 and 2012 Census of Agriculture respectively. All housing values are converted to 2010 dollars. Observations are weighted by the number of owner (renter) occupied units in the county. Non-mobile specific regressions are adjusted for changing owner (renter) occupied housing characteristics. Housing characteristics included are: fraction of units with 0, 1, 2, 3, or 5 or more bedrooms, fraction of units with full indoor plumbing, fraction of units with a complete kitchen, fraction of units that are mobile units, fraction of units by type of electricity, and fraction of units by age of unit. Robust standard errors are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Sample: Includes all counties in any shale play. Panels A1, A3, B1, B2, C1, C2, and C3 contain observations from 404 total counties, of which 65 Rystad top quartile and 253 outside top quartile counties are in the balanced sample. Panel C4 contains observations from 345 total counties, of which 53 Rystad top quartile and 211 outside top quartile counties are in the balanced sample.

Table 9: Play specific Estimates

	All (1)	Bakken (2)	Barnett (3)	Fayetteville (4)	Haynesville (5)	Marcellus (6)	Woodford, Anadarko (7)	Woodford, Ardmore (8)	Woodford, Arkoma (9)	Permian Plays (10)		Joint F-test (11)	Eagle Ford (12)
Panel A: Average Characteristics of Top Quartile Counties													
Population (2000)	64,860	6,307	109,202	24,046	24,576	112,911	45,516	19,537	9,955	15,221			36,836
Oil Share of Hydrocarbon Production Value (2011)	0.33	0.94	0.42	0.00	0.01	0.07	0.34	0.48	0.01	0.64			0.65
Panel B: Hydrocarbon Production													
B1. Total Value of Hydrocarbon Production													
	409***	972**	322*	69	1,730*	185***	-452***	123*	199	169	F-stat	11.4	1,412***
	(123)	(414)	(183)	(78)	(903)	(70)	(65)	(70)	(158)	(134)	p-value	0.00	(270)
Panel C: Labor Markets													
C1. Log(Mean household total income)													
	0.058***	0.293***	0.045*	0.099	0.080	0.049***	0.069	-0.013	0.000	0.170***		5.4	-0.015
	(0.012)	(0.083)	(0.025)	(0.110)	(0.053)	(0.012)	(0.084)	(0.079)	(0.134)	(0.049)		0.00	(0.046)
C2. Log(Mean household wage and salary income)													
	0.075***	0.286***	0.031	-0.014	0.078	0.078***	0.079	-0.028	0.075	0.177***		5.5	-0.003
	(0.012)	(0.100)	(0.030)	(0.133)	(0.064)	(0.014)	(0.102)	(0.095)	(0.161)	(0.059)		0.00	(0.056)
C3. Log(Mean household rent, dividend, and interest income)													
	0.093**	0.833***	0.061	0.671	0.078	0.086*	-0.171	0.116	0.495	-0.006		1.7	0.173
	(0.038)	(0.313)	(0.095)	(0.417)	(0.201)	(0.045)	(0.319)	(0.297)	(0.505)	(0.183)		0.09	(0.174)
C4. Log(Population)													
	0.027*	0.130***	0.071	-0.014	-0.045	0.018	0.060	0.042	-0.038	-0.007		1.4	-0.090*
	(0.016)	(0.045)	(0.053)	(0.115)	(0.055)	(0.024)	(0.117)	(0.075)	(0.089)	(0.039)		0.20	(0.048)
Panel D: Housing Prices													
D1. Log(Median home values)													
	0.057***	0.228***	-0.046	0.018	-0.071	0.089***	-0.074	-0.032	0.051	0.029	F-stat	6.0	-0.021
	(0.012)	(0.086)	(0.030)	(0.111)	(0.057)	(0.014)	(0.091)	(0.082)	(0.138)	(0.051)	p-value	0.00	(0.055)
Panel E: Annual Change in WTP for Amenities and Welfare per Household, Using Change in Mean Home Values (dollars)													
E1. Change in amenities	-1,405*	-1,906	-1,660	32	-3,246*	-852	-2,677***	3,024	822	-4,638***			-409
	(734)	(2,585)	(1,534)	(705)	(1,770)	(750)	(811)	(2,999)	(1,322)	(1,686)			(1,350)
E2. Change in welfare	2,397***	11,592***	-460	2,576***	-285	2,096***	-361	2,480	4,484***	1,441			-93
	(738)	(2,696)	(964)	(848)	(1,875)	(698)	(763)	(2,518)	(1,528)	(2,155)			(1,609)
Top Quartile Counties	65	8	5	1	5	28	1	4	2	11			7
Outside Top Quartile Counties[a]	253	27	41	13	21	95	10	5	7	34			21

Notes: This table shows estimates from regressions of outcome variables on Rystad top quartile variables interacted with dummies for being in particular shale plays. Column (1) shows the estimate for all counties with first-frac dates in or before 2008. Columns (2)-(10) show play-specific results for all plays with first-frac dates in or before 2008. Column (11) presents results from the Join F-test that the coefficients are equal for all plays with first-frac dates in or before 2008. Column (12) reports results for the Eagle Ford, the one shale play with a first-frac date in 2009. Panel A shows summary statistics on average county population and the oil share of hydrocarbon production. All specifications except for housing prices are time series estimates corresponding to column (2) in the main tables. Panel B allows for pre-trends, a level shift, and a trend break in the top quartile indicators, and also include play-year fixed effects. The reported estimates in Panel B correspond to the top quartile mean shift coefficient + tau (= T - 2008) times the top quartile trend break coefficient, where T is the latest year of data for the given outcome variable. In practice, this means evaluating the effect of being in a top quartile county 3 years after the start of fracing for Panel B and 4 years after the start of fracing for Panel B. Panels C and D report long difference specifications of the change in the given outcome between 2000 and 2009-2013 on an indicator for being in the Rystad top quartile. Panel D also includes controls for changes in average county owner(renter) occupied housing characteristics. In all panels, all Rystad top quartile variables are included by themselves, as well as interacted with an indicator for being in the unbalanced sample, defined as having a first-frac date after 2008. The reported coefficients are for the balanced sample. Panel B data come from HPDI well data aggregated to the county level. Panel C and D data come from the 2000 Decennial Census and the 2009-2013 American Community Survey. In Panel B standard errors clustered at the county level are reported in parentheses. In Panels C and D, robust standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Panel E reports estimates of the effect of fracing on amenities and welfare in dollars for each shale play. The calculations are made using our preferred values of the share of wage and salary income spent on housing (β) and the standard deviation of idiosyncratic preferences for location (s) of β = .65 and s=.3 respectively. Panel E shows estimates where the change in housings costs is measured using the estimated percentage change in median home prices. We report both the estimated change in amenities and the estimated change in total welfare. The calculations are converted to dollars using the mean household wage and salary income and mean household interest and dividend income in top quartile counties in each shale play. We aggregate these figures to the total impact of fracing in aggregate welfare in top quartile counties assuming a discount rate of 5 percent, and using the mean number of households in top quartile counties and total number of top quartile counties in each shale play. Overall calculations are made excluding the Eagle Ford play.

Table 10: Welfare estimates

	All				i. Owner-Occupied		ii. Renters		iii. Absentee-Landlords	
	Δ in housing costs = 2.9%		Δ in housing costs = 5.7%		Δ in housing costs = 2.9%	Δ in housing costs = 5.7%	Δ in housing costs = 2.9%	Δ in housing costs = 5.7%	Δ in housing costs = 2.9%	Δ in housing costs = 5.7%
					WTP for change in:					
	Amenities	Welfare	Amenities	Welfare	Welfare	Welfare	Welfare	Welfare	Welfare	Welfare
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Annual Impacts per household										
s = .3 and β = .65	-2,225***	1,576***	-1,405*	2,397***	1,576***	2,397***	363	363	576***	787***
	(842)	(584)	(734)	(738)	(584)	(738)	(429)	(429)	(190)	(214)
Panel B: Total Aggregate Impacts for Top Quartile Counties (in billions)										
s = .3 and β = .65	-74***	53***	-47*	80***	39***	60***	3	3	5***	7***
	(28)	(19)	(24)	(25)	(15)	(18)	(4)	(4)	(2)	(2)

Notes: This table reports estimates of the effect of fracing on amenities and welfare in dollars. Different rows report values for different assumptions regarding the standard deviation of idiosynchratic preferences and the share of wage and salary income spent on housing. Columns (1) and (2) report results where the change in housing costs is measured using the estimated percent change in median rents (.029), while Columns (3) and (4) show estimates where the change in housings costs is measured using the estimated percentage change in median home prices. For each measure of the change in housing costs, we report both the estimated change in amenities (Columns (1) and (3)) and the estimated change in total welfare (Columns (2) and (4)). Columns (5)-(10) show how the change in welfare is split between households in owner-occupied housing units, renter-occupied housing units, and absentee landlords. All columns use our preferred parameter values for the standard deviation of household idiosynchratic preferences and the share of income spent on housing of s=.30 and β = .65 respectively. The calculations are converted to dollars using the mean household wage and salary income in top quartile counties of of $45,668 and mean household interest and dividend income in top quartile counties of $3,822. Panel B aggregates these figures to the total impact of fracing in aggregate welfare in top quartile counties assuming a discount rate of 5 percent, and using the mean number of households in top quartile counties of 25,650 and the total number of top quartile counties of 65. Standard errors incorporate both sampling variance in the estimated parameters, as well as uncertainty in the values of s and β. For these calculations, the assumed standard deviation of the standard deviation of idiosyncratic preferences (s) is .09 and for the share of income spent on housing (β) is .1. For more information, see discussion in the text.