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Household valuation of energy development in amenity-rich regions

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Abstract

The juxtaposition of oil and gas wells against the Rocky Mountains on Colorado's Front Range provides a picture of the complicated interaction between Colorado's natural resources above and below ground. As hydraulic fracturing has increased oil and gas development—bringing jobs and money to an already highly sought after amenity-rich area—it has also increased concerns about the impact on natural amenities, such as water quality and mountain views. Using data on housing sales between 2006 and 2014, we estimate how shale development is capitalized into housing prices in a booming market when households are in close proximity to other natural amenities. We find that shale development negatively impacts house prices, more so for houses with private water and houses that are closer to the mountains, but that competition for land along the Front Range has driven up house prices overall in the region. Our results also suggest the policy responses to shale development may differ for growing, amenity-rich regions.

1 | INTRODUCTION

Nestled at the foot of the Rocky Mountains, Colorado's Front Range attracts people seeking to enjoy its majestic views and natural amenities. If new migrants want a house near these mountains, especially one with a mountain view, they have to be willing to pay a higher price. In 2014, Colorado's population growth was second only to North Dakota's, with 80% of Colorado's migrants locating along the Front Range (Svaldi, 2015). Like North Dakota, Colorado has also attracted people recently for what is under the ground, as the Front Range has experienced a boom in oil and gas production.

This boom is due to innovations in oil and gas extraction, specifically from horizontal drilling and hydraulic fracturing that opened up previously uneconomical oil and gas reserves in shale plays across the U.S. The increased demand for land from shale development and the various positive economic benefits of oil and gas extraction, such as royalty payments from mineral rights and new employment, can bid up the price of land, increasing housing prices. This is in addition to the impact from an increased demand for housing driven by natural amenity-led in-migration. However, the associated negative externalities from oil and gas production, including the negative impact on the natural amenities and associated esthetics, as well as pollution, noise, stress on infrastructure and public services, and even seismic risks, can all negatively affect the values of surrounding properties. With these opposing forces pushing prices in opposite directions, we examine the resulting impact on the housing market in Colorado's Front Range and how natural amenities affect the capitalization of recent shale development activity in Colorado.

Although oil and gas activity has increased in areas like Texas, with a well-established history of oil and gas development, much of the focus of research on this dramatic change in energy markets in the U.S. has been on the local impact in Pennsylvania, where there was little to no oil and gas development activity before the new boom. Several previous studies focused on Pennsylvania have studied the impact of shale gas development on housing values (Gopalakrishnan & Klaiber, 2014; Muehlenbachs, Spiller, & Timmins, 2015). They find that the proximity to producing wells negatively affects housing prices, especially for those houses that rely on private water (well water), indicative of concerns about the impact of hydraulic fracturing on water quality. Yet, some recent research has failed to find a significant effect of unconventional drilling on housing prices in Pennsylvania (Boslett, Guilfoos, & Lang, 2019; Delgado, Guilfoos, & Boslett, 2016).

The impact of shale development activity in Pennsylvania may be quite different than that in Colorado. In Pennsylvania, due to the topography and forest cover, it is sometimes harder to see (or hear) shale development activity on a well pad, even if it is nearby. However, in Colorado, due to the relatively flat topography east of the Rocky Mountains, shale development is more visible than in Pennsylvania. Additionally, Colorado has an abundance of natural amenities, including access to and views of the Rocky Mountains. Seeing active oil and gas wells may act as a very visible reminder of various shale development concerns (pollution, noise, etc.) but may also impact natural views, such as those coveted mountain views. Thus, we take a unique approach to examining the impact of shale development by considering how the visibility and proximity of active wells are capitalized into housing values and how proximity to and views of amenities affect this. In Colorado, the negative externalities from shale development may have a larger negative capitalization effect due to the importance of natural amenities to local residents or simply differences in how residents value natural amenities and the environment. At the same time, Colorado's housing market and trends, especially along the Front Range, also differ from Pennsylvania—the housing market grew substantially before and through the shale boom due to in-migration associated with the state's high quality of life (including access to amenities). In Colorado, policymakers may need to consider how energy development affects a broader range of amenities, rather than just water, as well as addressing issues related to growth and how it impacts their residents differently.

We thus investigate the impact of shale development along the Front Range of Colorado and how it is capitalized into housing values. We use micro-level data on housing sales and on shale oil and gas wells from 2006 to 2014. We measure the proximity of each house that is sold to active shale wells as well as whether it may have a view of these wells. We also control for a range of other factors, including the presence of other potential disamenities. Importantly, we also control for the proximity of each house to natural amenities, including proximity to the mountains and whether or not it has a mountain view.

Our results suggest that the impact of shale development on housing prices in this region differs from the experience in Pennsylvania. We find that the number of nearby producing wells and the visibility of these wells negatively affect the prices of all homes, not just those on private water as in Muehlenbachs et al. (2015). Similar to Pennsylvania, we find evidence that people who own houses with private water have concerns about the impact of shale oil and gas activity on water quality. We also find that the visibility of wells matters—with the presence of any visible wells decreasing house prices by about 0.8% (nearly $3,000). Our results also indicate that it is important to account for nearby amenities as proximity to the mountains affects how shale development is capitalized into housing prices. In stark contrast to previous research, we find that as shale development has come in closer proximity to residential development in a tight housing market, it has likely bid up the price of land, further increasing the cost of housing for Colorado residents. This raises additional questions about housing affordability that were not an issue in Pennsylvania.

In what follows, we provide an overview of the study region, recent developments in oil and gas extraction from shale, and the relevant previous literature. We then describe our methodology and data and review the results. In the final section, we conclude and provide some additional comments related to policy.

2 | GROWTH, NATURAL AMENITIES, AND THE HOUSING MARKET IN COLORADO

For decades, Colorado has experienced impressive population growth as well as high job growth and a robust economy. As seen in Figure 1a, Colorado's long-term population trends have diverged from the nation and from states like Pennsylvania (which has been the focus of much of the previous shale development studies). Most of this growth has occurred along the Front Range of Colorado, including Denver and nearby counties. These vastly different economic trends have also increased the demand for housing in Colorado (Figure 1b) with Denver leading the nation's metropolitan areas in housing appreciation since 1991 (Svaldi, 2016). Colorado's consistently robust housing markets are arguably the best indicator of its success.

Colorado is very much defined by its natural amenities, particularly the majestic Rocky Mountains that cut the state in two. Using the natural amenity scale developed by David McGranahan at the USDA Economic Research Service, we find that both the state of Colorado and our study area in Northeast Colorado are well above the national average in terms of both scale and rank and significantly higher than states such as Pennsylvania (McGranahan, 1999). Colorado's natural amenities attract more than just tourists as evidenced by the persistent in-migration to Colorado. This is consistent with research by Rappaport (2004) and others showing that higher incomes in the U.S. have led to increases in migration to high amenity areas, including Colorado and the Western U.S. (as well as the Southern Sunbelt). In other words, as incomes increase, people place more importance on amenities, including environmental amenities, and move to high amenity and high quality of life areas. This has been especially true in the U.S., where incomes are comparatively quite large. A wealth of previous research has focused on the role of natural amenities, such as mountains, on migration and the general economic growth of U.S. regions (Glaeser, Kolko, & Saiz, 2001; Graves, 1976; Partridge, 2010). There is also some evidence of the interplay between natural amenities and environmental disamenities in migration decisions, especially of highly educated people. Stephens and Partridge (2015) examine population changes in the Great Lakes region and find that proximity to natural amenities is important for highly educated (a proxy for higher income) people even in the face of historic industrialization.

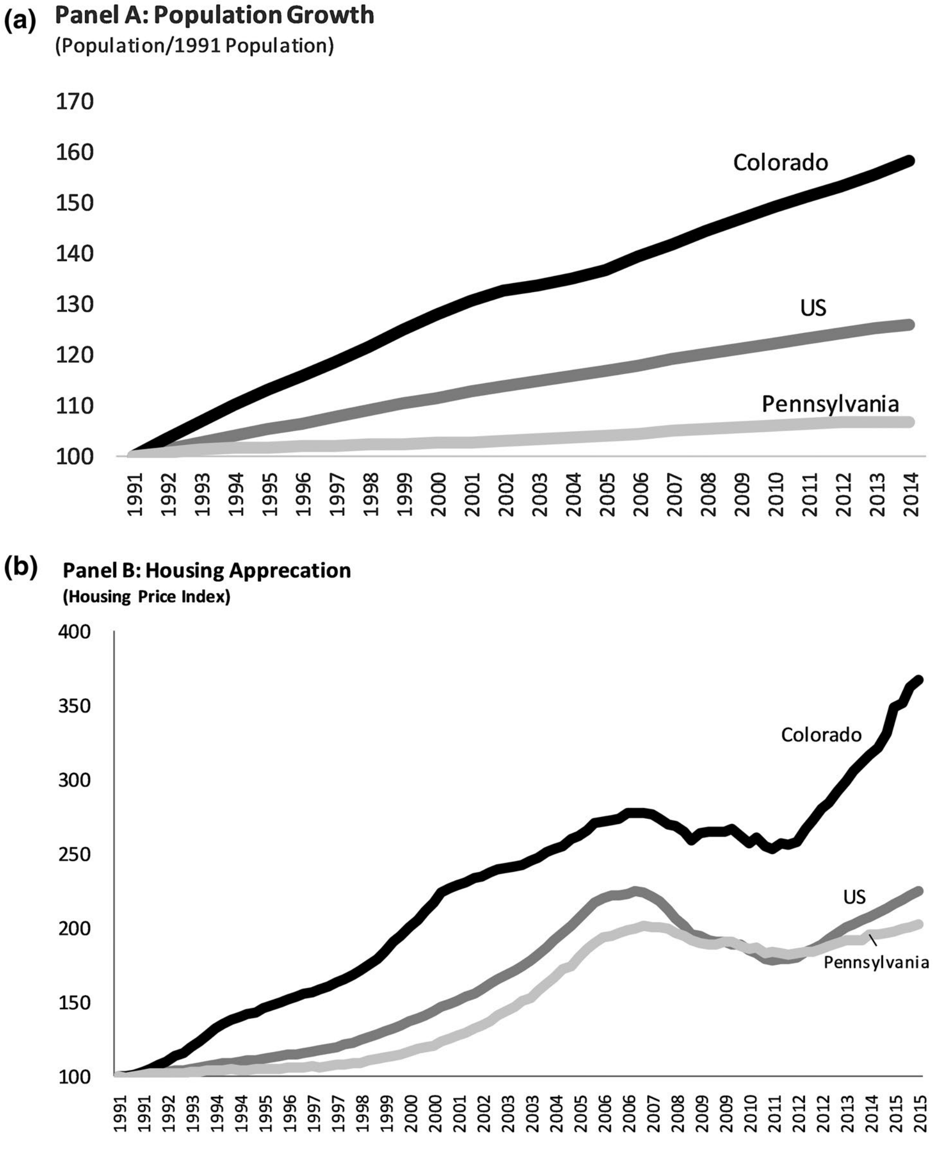

FIGURE 1 Colorado growth in population and housing outpaces the nation. *Source:* BEA (2016) economic profile. Federal Housing Finance Agency (2016), Seasonally Adjusted HPI (Purchase Only)

Some researchers suggest that migration to "nice" areas has only occurred because these locations also happened to be locations with ample job opportunities (e.g., Storper & Scott, 2009). However, Partridge (2010) directly pits job-led models against amenity-led migration models to determine which more accurately describe recent growth patterns in the U.S. and concludes the following:

> "Growth patterns have been very consistent with amenity-led migration to places endowed with high levels of natural amenities such as nice climates, pleasant landscapes, lakes/oceans and mountains. Probably the strongest evidence of this is the growth in the Rocky Mountain region." (Page 21)

Growth in Colorado is also consistent with the quality of life research. According to Gabriel, Mattey, and Wascher (2003), Colorado's qualify of life has been increasing. Compared to other large metropolitan areas, Denver has been ranked among the best places to live in the country, along with places like Portland, Oregon, and San Diego, California (Beeson & Eberts, 1987). In other rankings of cities by quality of life, Denver ranked third (Blomquist, Berger, & Hoehn, 1988) and twelfth (Gabriel & Rosenthal, 2004). This suggests that Colorado's natural amenities, particularly the Rocky Mountains, have been driving migration to Colorado which in turn has been driving its growth. Not only has the Rocky Mountain region grown faster because of its natural amenities, but there is also evidence that natural amenities are more important for growth than in other areas such as in Pennsylvania. For example, using geographically weighted regression, Partridge, Rickman, and Rose Olfert (2008) find that, in Colorado, topography (specifically related to hilly and mountainous terrain) is more likely to lead to growth than in other areas such as Pennsylvania.

In recent years, amenity-led growth and job-led growth have converged somewhat. In the past, the locations that attracted people based on natural amenities and high quality of life have tended to be different than the locations that attract firms for their high quality of business environment (Chen and Rosenthal, 2008; Gabriel & Rosenthal, 2004). However, Chen and Rosenthal find that the correlation between quality of life and quality of business environment has risen over time. Households and firms are increasingly choosing the same places to locate; and these are places that offer a high quality of life, including abundant natural amenities. As a result, natural amenities have been associated with overall growth in the U.S., especially in the last few decades; with Colorado's growth consistent with these trends. As natural amenities attract people (and firms), the demand for housing (and property) near these natural amenities increases, bidding up the price of land and housing (see Figure 1b). The increase in prices can raise issues related to affordability. At the same time, the increase in demand for land will make it more likely that housing and other development (including oil and gas development) will occupy the same space.

3 | OIL AND GAS DEVELOPMENT IN COLORADO

While oil and gas development in Colorado has been around for some time, the increased use of horizontal drilling and hydraulic fracturing caused a boom in oil and gas development in Colorado (and elsewhere). These technologies have allowed oil and gas companies to extract oil and gas that was previously deemed uneconomical from shale plays around the country, especially in the five-county region in the Front Range of Colorado which we examine. This region is located on the eastern side of the Rocky Mountains and within an hour's drive of downtown Denver. Whereas Pennsylvania has made impressive gains in natural gas production, most of Colorado's growth has been in oil production.

While shale development in eastern Colorado began in limited form in the 1990s, of the roughly 19,000 horizontal wells in eastern Colorado, only 7.6% started production prior to 2008. Production ramped up in 2011 (as shown in Figure 2), when 20% of the wells became active. New production in 2012 and 2013 was close to 20%, with most of the new production in Weld County. As oil and gas production in Colorado has increased, it has bid up the price of especially productive land parcels. In 2011, the Colorado State Land Board's mineral rights auction brought in a record per-acre bid of $5,850 in Weld County (Proctor, 2011). By 2017, the record-breaking mineral per acre bid was $12,550—also in Weld County (Silvy, 2017).

As both shale development operations and housing developments expand, residents are more likely to find active shale wells virtually in their backyards. Between 2006 and 2014, Weld County added

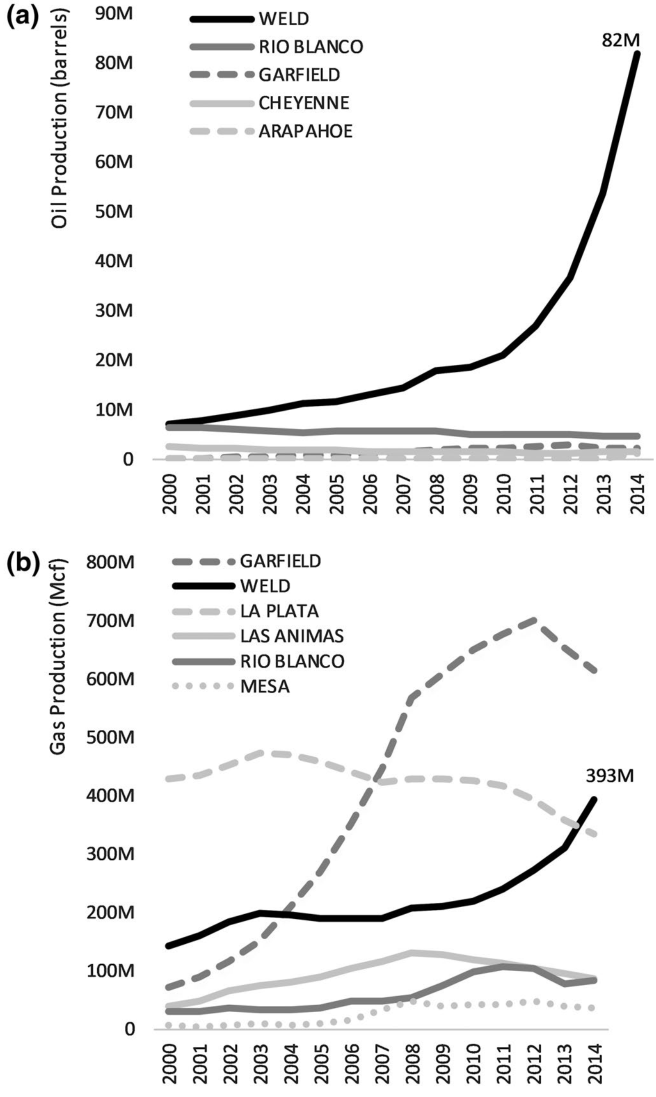

FIGURE 2 Increasing oil and gas production by county in Colorado. *Source:* Colorado Oil & Gas Conservation Commission (2015a, 2015b)

nearly 47,000 residents and issued just over 12,000 privately owned single-family residential building permits to meet the growing demands placed on its housing market (U.S. Census Bureau). In Weld County, especially, housing and shale development activity no longer occupy completely separate spaces. Colorado regulations state that drilling wells may be located just 500 feet from a house (Denver Business Journal, 2016). After 2011, in the five counties we examine, there is a marked increase in the average number of producing wells within just one mile of a house and a marked decrease in the average distance to the nearest producing horizontal well (Figure 3). Shale development activities and housing development are coming head-to-head in a heated competition for land in Colorado.

In contrast to Colorado, Farren, Weinstein, Partridge, and Betz (2013) find that competition for land in Pennsylvania between households and shale development has been minimal. They suggest that this is largely because Pennsylvania, with much slower population growth (and where some areas impacted by shale development had previously experienced population declines), has adequate nearby

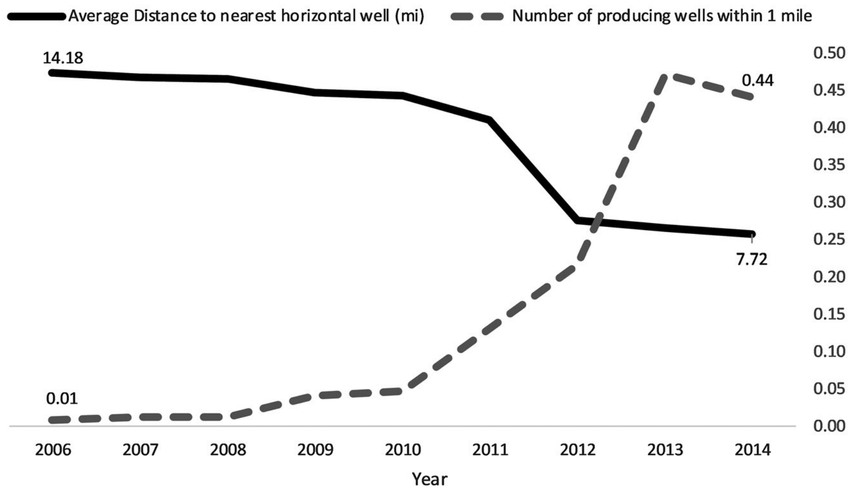

FIGURE 3 Housing's increasing proximity to shale development activity in Colorado. *Source:* Calculated using Corelogic (2016) Housing Data and DrillingInfo Data (2015)

housing stock and that any expansion of the housing stock through new housing construction was sufficient to meet the increased demand for housing from temporary and more permanent shale-related employment.

In Colorado, due to the high quality of life that has been leading to its growth, new shale development may result in a larger share of permanent rather than temporary oil and gas employment.[1] At the same time, despite the increase in residential building permits in Northeast Colorado, new housing construction may not be sufficient to meet the increases in housing demand from all of Colorado's new migrants. In fact, Colorado housing prices have increased so rapidly that Colorado policy makers have even considered allowing rent control (a measure that failed—Wingerter, 2019). Furthermore, the higher incomes and wages associated with the oil and gas industry and the subsequent overall higher wages in the locality may increase further the demand for housing, exacerbating housing concerns in Colorado.

New shale development will also increase incomes from leasing and royalty payments (a share of the production value) to landowners. If the mineral rights are not severed from the estate (in other words, if homeowners own their mineral rights), then oil and gas development could increase the price of housing if homeowners are benefitting from royalty payments. Brown, Fitzgerald, and Weber (2016) find that royalty rates can vary by county and by shale region, although they do not include Colorado counties in their analysis (due to data limitations). Delgado et al. (2016) examines three western counties in Colorado and suggests that accounting for split estates (where the government owns the mineral rights) is important in estimating the impact of oil and gas development on housing prices, especially in considering how households value the environmental costs of oil and gas development. This is consistent with the findings from a survey of landowners in West Virginia by Collins and Nkansah (2015), which found that dissatisfaction with shale development was higher among those who did not own the mineral rights. However, until recently, many homeowners themselves in Colorado did not know if their mineral rights had been severed (Conlin & Grow, 2013). Many homebuilders and developers in Colorado were keeping the mineral rights of the properties they sold without disclosing this to homebuyers (Conlin & Grow, 2013). As a result, in 2016, Colorado passed new legislation that requires sellers to disclose mineral estate rights as well as any oil and gas activity (O'Connell, 2017).

As new shale development comes in closer proximity to Colorado residents, households will become more directly affected by the associated activity, through the positive economic impact on jobs, earnings, and royalty payments, but also through the various negative externalities such as potential noise, traffic, air and water pollution, as well as the degradation of scenic views and other effects on esthetics. Recent research has tended to find a positive, though rather modest, impact on the local community in terms of both jobs and earnings (Brown, 2014; Munasib & Rickman, 2015; Paredes, Komarek, & Loveridge, 2015; Tsvetkova & Partridge, 2016; Weber, 2012, 2014; Weinstein, 2014; Weinstein & Partridge, 2011; Weinstein, Partridge, & Tsvetkova, 2018). At the same time, there is some evidence that residents of Colorado have concerns about the negative externalities as shale development and households have increasingly occupied the same space. Figure 4 shows that the number of formal complaints filed with the Colorado Oil and Gas Conservation Commission (COGCC, 2019) has been increasing. As shown in Figure 5, a large share of the complaints relate to water concerns as well as to concerns about air quality, noise, and esthetics.

By examining the impact of oil and gas development on housing prices in this region, we can directly compare how households take into account all of the positive and negative effects associated with shale development and how they are jointly capitalized into housing values.

4 | PREVIOUS RESEARCH ON HOUSING PRICES AND THE VALUATION OF NATURAL AMENITIES AND SHALE DEVELOPMENT

Indirect valuation methods allow us to uncover the implicit value that people place on various attributes of housing using the housing transactions in a single housing market. One such method, the hedonic price method, has been used extensively to estimate the value of amenities, such as natural amenities, as well as disamenities, such as pollution, and has a long history dating back to Rosen (1974). Consumers maximize utility in their choice of a house, which varies based on its attributes (Palmquist, 2005; Rosen, 1974; Taylor, 2003). With marginal changes in attributes, the observed

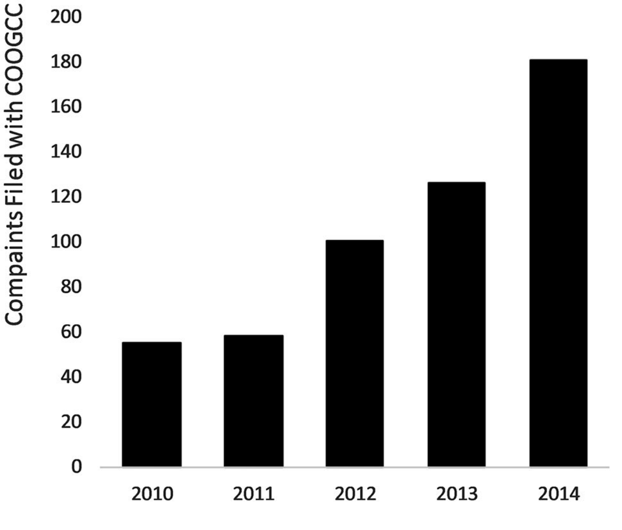

FIGURE 4 Increasing complaints as shale development comes in closer contact with households. *Source:* Author calculations of Colorado Oil & Gas Conservation Commission (2019) complaints for the counties in our study. https://cogcc.state.co.us/data2.html#/downloads

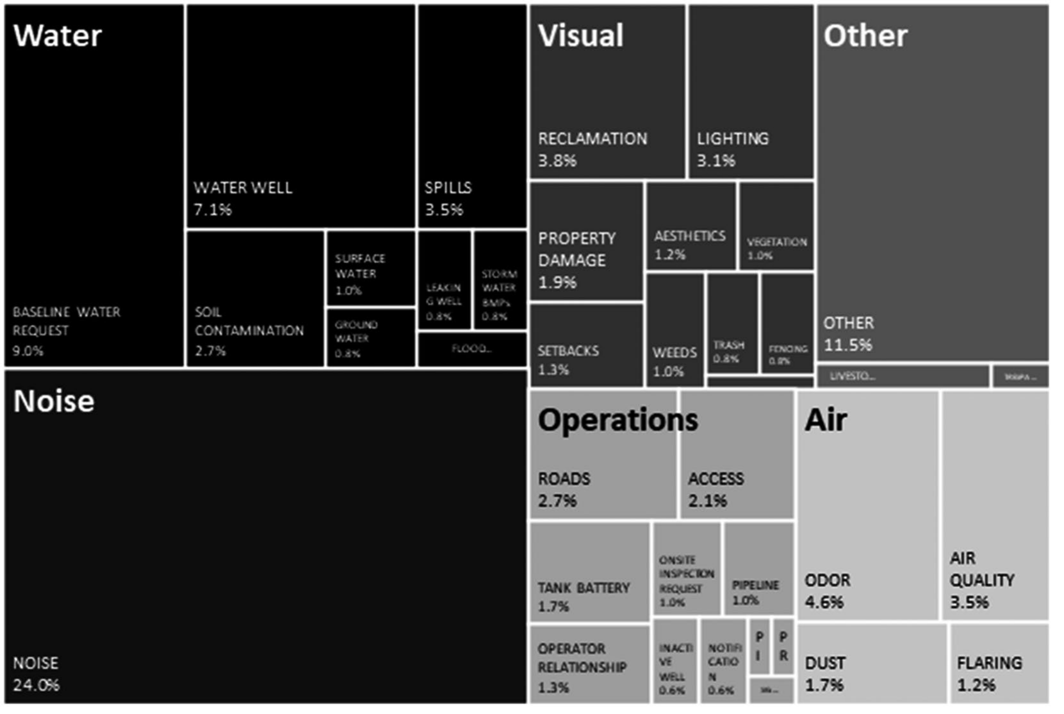

FIGURE 5 Share of complaints by issue category. *Source:* Author compilations of Colorado Oil & Gas Conservation Commission (2019) complaints for the counties in our study. https://cogcc.state.co.us/data2.html#/downloads

sales price reflects their value of or their willingness to pay for these attributes in a competitive market. With non-marginal changes in attributes, the sales price will reflect the net capitalization these changes into housing prices (Kuminoff, Parmeter, & Pope, 2010; Kuminoff & Pope, 2014).

Previous studies that have considered the impact of amenities, have estimated the value of amenities such as open space and green belts (Cho, Poudyal, & Roberts, 2008; Correll, Lillydahl, & Singell, 1978; Irwin, 2002), access to public lands (Wasson, McLeod, Bastian, & Rashford, 2013), lakes and beaches (Gopalakrishnan, Smith, Slott, & Brad Murray, 2011; Lansford & Jones, 1995; Taylor and Smith, 2000), views of trees and farmland (Cavailhes et al., 2009), and scenic views such as mountain views (Benson, Hansen, Schwartz, & Smersh, 1998; Cassel & Mendelsohn, 1985; Walls, Kousky, & Chu, 2015; Wasson et al., 2013). Paterson and Boyle (2002) and Li and Brown (1980) find that visibility measures are important determinants of house prices and that ignoring them may lead to incorrect conclusions about other variables including other environmental variables. However, previous studies of the impact of scenic views (such as Benson et al., 1998), have relied on small sample sizes because they used visual inspection to determine a property's scenic view. The sample size of houses in Colorado's hotbed of recent shale development activity is comparatively quite large. And, visibility may be especially important in a region like the Front Range of Colorado where mountain views are abundant, and where an active oil or gas well may be visible from a considerable distance, potentially affecting more residents. Failure to account explicitly for nearby amenities and views could lead to incorrect conclusions about the impact of shale development.

Hedonic valuation methods have also been used in the environmental economics literature and other fields to estimate the value of nearby disamenities or the value of mitigating nearby disamenities (examples include Bin, Czajkowski, Li, & Villarini, 2017; Boxall, Chan, & McMillan, 2005;

Brasington & Hite, 2005; Leggett & Bockstael, 2000; Li & Brown, 1980; Mastromonaco, 2014; among others). In a recent related example, Koster and Ommeren (2015) find that housing prices in the Netherlands decreased because of the higher incidence of earthquakes associated with conventional natural gas extraction.

The dramatic increase in new shale development using horizontal drilling and hydraulic fracturing has resulted in a non-marginal change in the presence of producing wells throughout the U.S. Several previous studies have used hedonic techniques to try to uncover the net capitalization effect of the positive and negative aspects of shale development. However, as mentioned above, most studies have focused on Pennsylvania and the concerns over water quality. In Washington County, Pennyslvania, Gopalakrishnan and Klaiber (2014) find that nearby shale development has a small negative impact on all nearby housing values whereas Muehlenbachs, Spiller, and Timmins (2013) find a larger negative effect only for properties with private groundwater wells. In a more comprehensive study of 36 counties across Pennsylvania, Muehlenbachs et al. (2015) find that shale development has a large negative impact on nearby houses with private wells (indicative of concerns over the impact of shale wells on water quality) and a small positive impact for other houses (indicative of the increased value of homes due to mineral rights and increases in economic activity).[2] Recent papers (such as Weber, Burnett, & Xiarchos, 2016, examining Texas zip codes; Boslett et al., 2019, examining counties in Western Colorado; Bennet & Loomis, 2015, examining Weld County in Colorado; and a working paper by Keeler & Stephens, 2018, examining West Virginia) have begun to expand the analysis of shale development's impact on housing into other areas. Most relevant to our research is the work by Bennett and Loomis (2015) that considers the impact of oil and gas development in Weld County, Colorado, finding a small negative (less than 1%) impact on housing prices. While Bennett and Loomis provide an initial examination of the impact of shale development in Colorado, they do not account for water source (as Muehlenbachs et al., 2013, 2015 show is important) or for split estates (as Boslett et al., 2019; Collins & Nkansah, 2015 suggest may be important); nor do they account for proximity to other disamenities, such as feedlots (as Eyckmans, DeJaeger, & Rousseau, 2013; Keeney, 2008; Kim & Goldsmith, 2009 find affects home values). They also fail to account for natural amenities such as mountain views (as Paterson & Boyle, 2002, and others have found to be important in the natural amenity valuation literature) and that we posit could have a significant impact on how oil and gas development is capitalized into housing prices in Colorado.

As described above, Colorado has a vastly different housing market (and general economic trends) as well as topography and natural amenities than Pennsylvania, thus the impacts from shale development may be quite different than those found in the studies in Pennsylvania. At the foot of the Rocky Mountains, Colorado's topography is comparatively flat with sparse tree cover, making shale wells much more visible than in places like Pennsylvania that are hillier and more forested. If shale development lowers the quality of natural amenities, it also may lower the appeal of Colorado for amenity-driven migrants (and highly educated migrants), especially if Colorado residents tend to place a higher value on natural amenities and the environment. In fact, compared to Pennsylvania, educational attainment rates in Colorado tend to be higher with nearly 40% of adults in Colorado having a college degree, compared to just under 30% in Pennsylvania (U.S. Department of Agriculture Economic Research Service [USDA ERS], 2018). Additionally, General Social Survey (GSS) data suggest that Colorado residents are more concerned about the environment than U.S. residents are overall and much more than residents in Pennsylvania (see Appendix A). We suspect that these differences may lead Colorado residents to value shale development differently than Pennsylvania residents, especially as it affects natural amenities such as mountain views.

Thus, it is important to estimate how residents in fast-growing and high-amenity areas like Colorado value recent developments in oil and gas development, as the results may be quite different than in

Pennsylvania. Housing prices will reflect how shale development is being capitalized into housing values and this net capitalization will account for both the positive effects of shale development associated with jobs, wages, and royalty payments, and the negative impacts on natural amenities and the environment. Due to the importance of accounting for visibility measures, we make a significant contribution to the literature by examining the impact of the visibility of both mountains and shale wells on a large sample of houses and how these visibility measures may interact in affecting the capitalization of shale development. These results offer insight into the impact of energy development in a high-amenity, high-growth area, providing guidance for policy makers.

5 | METHODOLOGY

We utilize the hedonic pricing methodology to examine the impact of oil and gas development on nearby houses in Northeast Colorado counties. Given the non-marginal change in the presence of producing wells, our results will indicate how shale development is being capitalized into housing prices (Kuminoff et al., 2010; Kuminoff & Pope, 2014).

We follow guidance from Rosen (1974), Coulson (2012), Black (1999), Palmquist (2005), Kuminoff et al. (2010), and others, in setting up estimation model. Our primary estimation equation is a semi-log or log-linear estimation model with spatial fixed effects, as shown in Equation (1):

$$\ln\left(p_{it}\right) = \beta_0 + \sum\nolimits_j \beta_j X_{ijt} + \sum\nolimits_k \beta_k C_{ikt} + \gamma D_{it-1} + \alpha A_{it} + \theta A_i D_{it-1} + \tau_t s_c + \varepsilon_{it} \quad (1)$$

where the $\ln\left(p_{it}\right)$ is the natural log of the normalized sales price (adjusted into 2006 dollars) for each house i sold in time t. The use of the natural log of the normalized sales price $\ln\left(p_{it}\right)$ controls for changes in prices due to inflation, reduces the range of housing prices and better deals with outliers, and allows attributes to affect prices proportionately (as a percentage of the sales price). X_{ijt} is a vector of all the j main housing characteristics (including housing size (in square feet), number of bedrooms, number of bathrooms, lot size (in acres), age, whether or not the house has a garage, and whether the house is new construction). X_{ijt} also includes age squared to account for the fact that the age effect diminishes. We also include a vector of k other community level factors C_{ikt}—including distance to I-25 (the main north–south interstate highway through the region) and distance to the nearest city.

D_{it-1} measures shale development activity (the number of producing wells, proximity to producing wells, or views of producing wells—based on producing wells in the year prior to sale). A_{it} measures natural amenities and other factors which may affect the valuation of shale development (water source, distance to mountains, mountain views, or distance to feedlot).

In various models we include interaction terms between the amenities measures (A_{it}) and shale development (D_{it-1}), which provides an estimate of how the presence of these factors affect the capitalization of shale development. A key contribution of our analysis is that we estimate how the capitalization of shale development may be affected by whether a house has a view of the mountains. And, our use of visibility measures addresses the potential bias of omitting visibility as identified in Paterson and Boyle (2002) and Li and Brown (1980).

Finally, we include $\tau_t s_c$ which are interacted year (τ_t) fixed effects and spatial (s_c) fixed effects, where τ_t is based on the year in which the house is sold and s_c is defined using Census county divisions (which we refer to as community fixed effects). Census county divisions are developed jointly by the Bureau of the Census and state and local governments as proxies for communities in areas without incorporated entities and "are designed to represent community areas focused on trading centers or, in some instances, major land use areas. They have visible, permanent, and easily described boundaries."

(U.S. Department of Commerce, 1994). In our five-county study region there are 40 Census county divisions, excluding those in the cities of Denver and Fort Collins. The interaction of the year and community fixed effects allows us to control for unobservable community-level factors that affect housing prices such as employment opportunities, schools, parks, and other community-level services and amenities which may change over time. While we believe that our community fixed effects interacted with year fixed effects provide the most appropriate spatial fixed effect to control adequately for unobservable factors over time, we also estimate models without the interaction of the spatial and year fixed effects (Appendix C), where we report the year fixed effects; this verifies that we are controlling for changes in the overall housing market. We find that relative to 2006, there are some declines in overall housing prices at first, but that after 2012, the market rebounds. We also estimate models using the interaction of Census Tract fixed effects and year fixed effects (Appendix D). While many of the results using Census Tract fixed effects are similar, these geographically smaller fixed effects leave little variation in terms of some of our key variables (such as distance to feedlots), and thus make identification of the capitalization effect more difficult.

We also estimate a number of different model specifications as robustness checks. In Appendix E, we report models estimated on a subsample of housing transactions using propensity score nearest neighbor matching. Our approach of looking at continuous effects (through distance and visibility), does not easily lend itself to matching techniques that require a discrete treatment. Despite some differences with our main results, the key takeaway regarding the impact of visibility and the interactions between amenities and shale development is still apparent. We believe that in order to test the effects of visibility and distance measures, which do not have a discrete treatment effect, that our rich data set and our fully specified flexible regression model with fixed effects provide more robust results. We also split our sample by time, size of lot, and price of house to see if there are differences based on these factors. These models are discussed further below.

6 | DATA

Our main data set contains data on houses sold from 2006 through 2014 in the Colorado counties of Weld, Larimer, Morgan, Adams, Boulder, Jefferson, Broomfield, and Arapahoe and purchased from Corelogic (2016). The data set includes housing attributes and the sale price of the houses. We focus our analysis on the counties in Northeast Colorado where the most intensive shale development is occurring; however, we exclude houses within the city limits of Denver and Fort Collins where there is limited shale development.[3] This provides us with a more homogenous sample of houses within a single extended combined labor and housing market, which helps address the issue of omitted variable bias and allows us better to identify the impact of shale development using the hedonic method. Figure 6 depicts the location of our sample within the State of Colorado.

Housing prices are adjusted for inflation using the Consumer Price Index for housing from the Bureau of Labor Statistics and are in 2006 dollars. As noted above, our models also include typical housing characteristics including age, age-squared, the size of the house (in square feet), number of bedrooms, number bathrooms, presence of a garage, and acres of land. Once we remove observations with missing housing attributes and outliers, we are left with a sample size of 157,959 housing transactions in this region. Because the housing stock in Colorado has experienced substantial growth, we also include an indicator for whether a house is new construction. Following the previous literature on other factors associated with housing prices, we calculate the distance to the nearest city[4] and distance to Interstate 25 (I-25). Summary statistics for our sample are provided in Table 1.

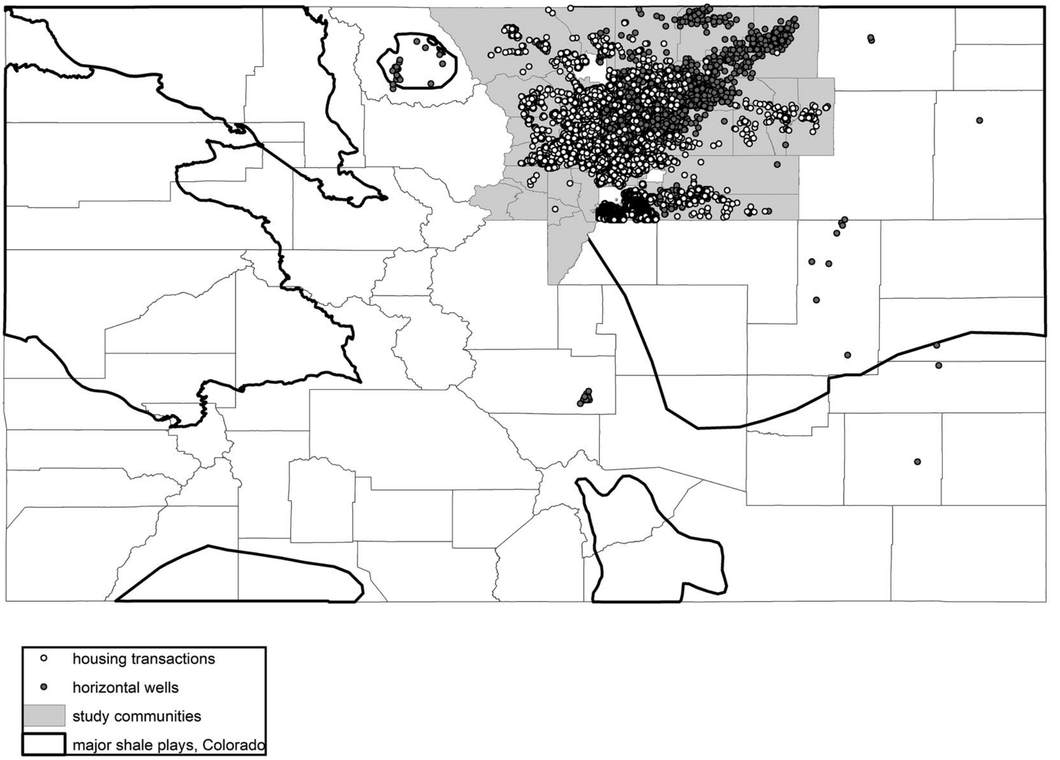

FIGURE 6 Oil and gas wells and housing transactions in northeast Colorado, 2006–2014. *Source:* Drillinginfo.com (2015) and Corelogic (2016)

To estimate the impact of shale development, we incorporate Drillinginfo.com (2015) data on active producing well locations and calculate various measures of intensity of and proximity to shale development for each house—including distance to the nearest producing well and the number of producing wells within 1 mile. For this analysis, we focus on producing horizontal wells. We consider a well to be producing if it was active in the year prior to the sale (to avoid reverse causation issues). We also use topographical information and ArcGIS to calculate how many producing wells are likely visible from the house. Given the number of observations for both houses and wells, most of the traditional ArcGIS tools were unable to handle this analysis. Instead, we use ArcGIS 3D Analyst Extension "Construct Sight Lines" (from observer to target points) and "Line of Sight" tools to determine visibility for all combination of observer and target points.[5]

To estimate the impact of the visibility of the Rocky Mountains and examine how this amenity affects household valuation of shale development, we use ArcGIS and topographical information to calculate whether houses likely have a view of the mountains (and how many) using the same approach as for the wells. Given the flat terrain of our study area and the height of the mountains, most of the houses have a view of at least one mountain. Thus, we construct a dummy variable "views of many mountains" for houses with more than 100 potentially visible mountains. We also calculate the distance to the nearest mountain. Including both visibility and distance measures is important as Walls et al. (2015) found that the value of views may be different than that of access or proximity. However, views of the mountains are likely to improve with proximity to the mountains and proximity to the mountains may also measure the quality of access to recreational activities.

TABLE 1 Summary statistics ($N = 155{,}791$)

Variables	Mean	*SD*	Min	Max
Price ($)	338,426	216,465	25,523	4.010e+06
Year			2006	2014
Acres of land	0.321	0.885	0.000500	20
House size (thousands of square feet)	3.175	1.326	1	9.968
Garage (0/1)	0.937	0.242	0	1
Number of bedrooms	3.271	0.834	2	8
Number of bathrooms	2.811	0.933	1	7
House age	22.27	19.63	0	114
New construction	0.153	0.360	0	1
Distance to I-25 (in miles)	6.727	5.639	0.0249	77.48
Distance to nearest city (mi)	10.12	5.596	0.0421	64.07
Government-owned minerals (0/1)	0.00218	0.0466	0	1
Property is not located in public water district (0/1)	0.751	0.432	0	1
Distance to nearest mountain peak (mi)	32.24	8.498	1.368	105.0
Distance to nearest producing horizontal well (mi)	11.37	8.627	0.0277	50.20
Distance to nearest feedlot (miles)	27.49	11.32	0.206	47.35
House has view of many mountains	0.809	0.393	0	1
Visible producing wells? (0/1)	0.756	0.429	0	1
Number of producing wells within 1 mile	0.176	1.812	0	84
Any producing wells within 1 mile (0/1)	0.0222	0.147	0	1

We also incorporate data from the State of Colorado on public water access (whether or not a house is on well water or public water) and government ownership of mineral rights. While we do not have data on private ownership of mineral rights, as noted above, many buyers did not know if their mineral rights had been severed during this time. Thus, even if we had data on private mineral rights ownership, it would be unlikely to change our results, as the homeowner did not know if the mineral rights had been severed and thus would have valued the house the same. We also use ArcGIS and public data from the State of Colorado on feedlot locations to calculate the distance of each house to the nearest feedlot. This also allows us to compare the household valuation of the feedlot disamenity to another potential disamenity, oil and gas development.

7 | RESULTS

The results for our key factors are shown in Table 2. Models 1 and 2 are our baseline models, which consider distances and views separately. Appendix Table B verifies that the coefficients for the typical housing characteristics are consistent across various model specifications and consistent with previous hedonic studies (e.g., households prefer newer homes, larger homes, and homes with more bedrooms and bathrooms). Perhaps because we exclude the center cities of Denver and Fort Collins, in our sample of Colorado houses, it appears that residents prefer not to be near a city but farther away. These preferences may also be indicative of households in Colorado generally preferring more open

TABLE 2 Housing prices (log price, in 2006 dollars) and shale production

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
House has view of many mountains (0/1) = 1	0.0180***		0.0252***	0.0253***		0.0252***	0.0220***	0.0222***	0.0238***
	(0.0017)		(0.0017)	(0.0017)		(0.0017)	(0.0026)	(0.0017)	(0.0017)
Visible producing wells? (0/1) = 1	−0.0048***		−0.0086***	−0.0085***		−0.0087***	−0.009062***	−0.006656***	−0.008509***
	(0.0014)		(0.0014)	(0.0014)		(0.0014)	(0.003046)	(0.001376)	(0.001377)
Many mountain views * visible producing wells							0.002372		
							(0.003247)		
Distance to nearest mountain peak (mi)		−0.0147***	−0.0151***	−0.0154***	−0.0153***	−0.0153***	−0.0222***	−0.0293***	−0.0156***
		(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0005)	(0.0008)	(0.0003)
Distance to nearest producing well (mi)		−0.0031***	−0.0032***	−0.0038***	−0.0037***	−0.0032***	−0.0170***	−0.0025***	0.0036***
		(0.0003)	(0.0003)	(0.0003)	(0.0004)	(0.0003)	(0.0010)	(0.0003)	(0.0010)
Private Water (0/1) = 1	−0.0326***	−0.0562***	−0.0564***	−0.0705***	−0.0694***	−0.0567***	−0.0736***	−0.0575***	−0.0572***
	(0.0017)	(0.0018)	(0.0018)	(0.0031)	(0.0031)	(0.0018)	(0.0031)	(0.0018)	(0.0018)
Private Water * distance to nearest producing well				0.0010***	0.0009***		0.0012***		
				(0.0002)	(0.0002)		(0.0002)		
Government-owned minerals (0/1) = 1	−0.0466**	−0.0292	−0.0267	−0.0256	−0.0265	−0.0270	−0.0416**	−0.0518***	−0.0315
	(0.0194)	(0.0191)	(0.0191)	(0.0191)	(0.0191)	(0.0191)	(0.0193)	(0.0193)	(0.0192)
Distance to nearest feedlot (miles)	0.0107***	0.0049***	0.0046***	0.0044***	0.0046***	0.0045***	0.0042***	−0.0116***	0.0048***
	(0.0002)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0010)	(0.0003)
Number of visible producing wells					−0.0000				
					(0.0000)				
Number of visible mountain summits					0.0002***				
					(0.0000)				
Distance to nearest mountain peak * distance to nearest producing well							0.0004***		
							(0.0000)		

(Continues)

TABLE 2 (Continued)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Distance to nearest mountain peak * distance to nearest feedlot								0.0005***	
								(0.0000)	
Distance to the nearest feedlot * distance to the nearest producing well									−0.0002***
									(0.0000)
Number of producing wells within 1 mile						−0.0013***			
						(0.0004)			
Constant	11.2107***	11.9528***	11.9563***	11.9763***	11.9522***	11.9665***	12.2388***	12.4599***	11.9380***
	(0.0090)	(0.0187)	(0.0188)	(0.0191)	(0.0191)	(0.0191)	(0.0243)	(0.0331)	(0.0190)
Community × year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	155,791	155,791	155,791	155,791	155,791	155,791	155,791	155,791	155,791
R^2	.8103	.8133	.8136	.8137	.8136	.8136	.8142	.8143	.8137
Adjusted R^2	.810	.813	.813	.813	.813	.813	.814	.814	.813

Note: Models also include the housing characteristics as shown in Equation (1): house size (in square feet), house age, age-squared, whether the house has a garage, whether the house is new construction, the distance to I-25 (in miles) and the distance to the nearest city (in miles) (these results are contained in Appendix B). Robust standard errors in parentheses.

***$p < .01$; **$p < .05$; *$p < .1$.

space and better views of the mountains than the nearby suburbs provide. We explore that further in our main results.

7.1 | Amenities

The relatively flat terrain that leads up to the Rocky Mountains means that for some households the mountains may be visible from relatively far away. There may also be a lot more that is visible to households than in places with hillier (and tree covered) terrain such as in Pennsylvania. At the same time, being physically closer to the mountains means easier access to the recreational activities they provide. As expected, Table 2 shows households value views of the mountains and prefer to live closer to them. Specifically, we find that a house with mountain views sells for approximately 2.5% or over $8,000 more (Model 3) and that each additional mountain peak increases house prices by 0.02% (Model 5). At the same time, even after controlling for the view, Model 3 also shows that households were willing to pay 1.5% more for a house that is one mile closer to the mountains (which amounts to around $5,000). Combined, this is evidence that households value this natural amenity—both its proximity and the scenic views it provides.

7.2 | Shale development activity

We now examine the impact of recent oil and gas development in Colorado. We examine the visibility of active producing wells (whether or not a well is visible and how many are visible), the intensity of shale production (how many producing wells are within one mile), and the proximity of nearby shale production (whether there is any active producing well within one mile or the distance to the nearest producing well). Overall, we find consistent evidence that households negatively value being able to see a well site. For example, in Model 3, having at least one visible well is associated with a more than 0.8% decrease in house value (nearly $3,000). We also find evidence that nearby shale gas production is perceived negatively. Each additional producing well within one mile is associated with a (0.1%) decrease in housing values (Model 6). Despite the results showing that visible and producing shale activity lowers housing prices, we also find seemingly contradictory results that proximity to shale development (the distance to the nearest well) increases housing prices. We explore this further below.

In Model 7, we examine the interaction between visible producing wells and mountain views. Our results suggest that there is no statistically significant interaction effect between the two visibility variables; however, unfortunately, our method for measuring visibility did not allow us to distinguish whether or not the mountain view was obstructed by the view of a well (in other words, if they can see a well and a mountain at the same time). Overall, these results suggest that all households share the disamenity of being able to see a well and the amenity of being able to see the mountains. We also interact the distance to the nearest well and the distance to the mountains. In this case, we find a positive and statistically significant effect (though small) for the interaction (Model 7). This suggests that shale development activity has a more negative effect on the price of a house for households that are closer to the mountains. Residents willing to pay more to be closer to the majestic Rocky Mountains may be especially concerned about the environmental disamenities associated with shale development.

7.3 | Water

We next examine the impact of shale development on houses where residents may be concerned about the potential impact of shale wells on groundwater quality (due to their house being on well water or private water). All models consistently show that households generally prefer public water to private water. When the private water variable is interacted with the distance to the nearest well, we also see evidence that residents on private water would prefer to be farther away from shale development, suggesting some concerns about water quality (Model 4). Additionally, in Table 3, we find evidence that the overall value of public water has increased over time as shale development has increased in our sample counties.

7.4 | Other factors

We are also able to provide some perspective on how shale development is being capitalized into housing prices as a disamenity compared to another disamenity, feedlots. As shown in other research, residents prefer to be farther away from feedlots and the associated animal odors, with higher housing prices as the distance to the nearest feedlot increases. We find that being located one mile closer to a feedlot is associated with a 0.4% decrease in house price (just over $1,500), significantly less than the 0.8% decrease in house price associated with having at least one visible producing well within one mile (Model 3). When we interact the distance to the nearest feedlot (a disamenity) with the distance to the nearest producing well (Model 9), we find that households near feedlots are less concerned about shale development activity (in contrast to Model 7 that showed households near mountain amenities were more concerned about shale development). When we interact distance to the mountains with distance to the nearest feedlot, we find that the negative capitalization effects from feedlots are more significant closer to the mountains (Model 8). Similar to the interaction between proximity to the mountains and active producing wells, we find residents willing to pay more to be closer to the majestic Rocky Mountains may be especially concerned about the environmental disamenities associated with feedlots. Interestingly the negative capitalization effect for a house a given distance from the mountains is about the same magnitude from being closer to a feedlot as from being closer to an active shale well (about 0.04%). While this is small, it makes the impact of shale development, which has a smaller footprint and is more temporary, appear quite large.

Because shale development may increase the value of a house (through the value of mineral rights), we also include information on whether mineral rights are government owned (split estate). In some models, the coefficient is statistically insignificant, but in all cases, it is negative. From Model 7, government owned minerals are associated with a 4% decrease in house prices (or about $13,000). This is evidence (consistent with the previous literature) that residents value mineral rights (whether they would choose to lease their land or not).[6] However, the inclusion of this variable did not significantly affect our key shale development or amenity variables.

7.5 | Over time

Interestingly, from Table 2, other than houses with private water, we generally find that there appears to be an increase in house prices closer to active producing wells. This could suggest that for households with public water, the benefits of shale oil and gas production (e.g., royalty payments from mineral rights) outweigh the various costs—though our results that suggest visible wells are negatively valued for all households would seem to cast some doubt on this explanation. Additionally, Figure 3 shows that as the market for housing and the market for oil and gas have boomed concomitantly, households in Northeast Colorado are left with little choice other than to locate near active wells. Figure 4 also illustrates that as shale development activity has increased, bringing it in closer proximity to residents, the number of complaints in our sample area has also increased.

TABLE 3 Housing prices (log price, in 2006 dollars) and shale production, over time

	Year								
Variables	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
House has view of many mountains (0/1) = 1	0.0163***	0.0226***	0.0296***	0.0236***	0.0301***	0.0257***	0.0297***	0.0158***	0.0270***
	(0.0044)	(0.0050)	(0.0055)	(0.0058)	(0.0058)	(0.0062)	(0.0052)	(0.0045)	(0.0043)
Visible producing wells? (0/1) = 1	−0.0075***	−0.0150***	−0.0170***	−0.0107**	0.0038	−0.0070	0.0148***	0.0085*	0.0028
	(0.0029)	(0.0037)	(0.0043)	(0.0045)	(0.0043)	(0.0050)	(0.0054)	(0.0046)	(0.0043)
Distance to nearest mountain peak (mi)	−0.0130***	−0.0149***	−0.0184***	−0.0178***	−0.0153***	−0.0180***	−0.0185***	−0.0185***	−0.0180***
	(0.0009)	(0.0010)	(0.0012)	(0.0013)	(0.0012)	(0.0013)	(0.0011)	(0.0008)	(0.0008)
Distance to nearest producing well (mi)	0.0138***	0.0169***	0.0109***	0.0108***	0.0112***	0.0052**	−0.0237***	−0.0250***	−0.0225***
	(0.0015)	(0.0020)	(0.0024)	(0.0025)	(0.0023)	(0.0022)	(0.0018)	(0.0013)	(0.0013)
Private water (0/1) =1	−0.0539***	−0.0723***	−0.0867***	−0.0449***	−0.0486***	−0.0669***	−0.0823***	−0.0778***	−0.0916***
	(0.0111)	(0.0120)	(0.0137)	(0.0140)	(0.0128)	(0.0129)	(0.0106)	(0.0082)	(0.0083)
Private water * distance to nearest producing well	0.0013***	0.0020***	0.0015**	0.0001	0.0001	−0.0001	0.0029**	0.0032***	0.0043***
	(0.0005)	(0.0005)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0011)	(0.0009)	(0.0009)
Government-owned minerals (0/1) = 1	−0.0651	−0.0401	0.0425	−0.0372	0.0715	−0.0889	−0.0549	−0.0554	−0.0624
	(0.0591)	(0.0468)	(0.0409)	(0.0605)	(0.0934)	(0.0808)	(0.0523)	(0.0608)	(0.0422)
Constant	12.1464***	12.1711***	12.1503***	12.0719***	12.0439***	12.0642***	12.1874***	12.4374***	12.5595***
	(0.0518)	(0.0603)	(0.0713)	(0.0791)	(0.0738)	(0.0774)	(0.0634)	(0.0452)	(0.0470)
Community fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	23,281	18,290	13,857	13,213	12,754	12,378	17,056	22,000	22,962
R^2	.8038	.8083	.8137	.8137	.8215	.8196	.8106	.8187	.8069
Adjusted R^2	.803	.808	.813	.813	.821	.819	.810	.818	.806

Note: Models also include the following other factors as shown in Equation (1): house size (in square feet), house age, age-squared, whether the house has a garage, whether the house is new construction, the distance to I-25 (in miles), the distance to the nearest city (in miles), and the distance to the nearest feedlot. Robust standard errors in parentheses.

***$p < .01$; **$p < .05$; *$p < .1$.

To examine these seemingly contradictory results further, we estimate models for each year, the results are shown in Table 3 (all models include the full range of covariates as before, but only the relevant variables are shown here). The valuation of the mountain amenities remains positive throughout our sample period and the valuation of public water increases over time (possibly as a result of increasing water quality concerns). In the earlier years of our study, when there is also less competition for land, there is a negative capitalization effect from proximity to shale development and a positive capitalization effect farther away; suggesting that closer proximity to shale development activity lowers the price of houses. However, over time, as shale development activity becomes closer to housing and competes for land (as shown in Figure 3), the effect reverses. Specifically, the coefficient on the distance to the nearest well changes from positive to negative after 2011. While one possible explanation could be that households in Northeast Colorado have grown more comfortable with shale development activity over time, the increasing importance of public water over time along with the increasing number of complaints filed with the COGCC (Figure 4) casts some doubt on this explanation. Additionally, the sign on the distance to the nearest producing well does not change from positive to negative until 2012 when there is a dramatic drop in the average distance to the nearest well (Figure 3). We posit that household valuation of shale development has not changed over time, but instead the concurrent growth in new housing and increased oil and gas activity has bid up the price of land for landowners. We provide further evidence of this in the next section when we examine different housing segments.

7.6 | Housing segments

Given that the previous literature has suggested that higher income households are more likely to make decisions related to natural amenities, we also consider whether the impact of both shale development and natural amenities may be differ across housing segments (as measured by housing price). We divide our sample of housing transactions using sales prices into the lowest quartile (low), the middle two quartiles (medium), and the highest quartile (high). Table 4 provides the results of this analysis (all models include the full range of covariates as before, but only the relevant variables are shown here).

We find that only prices of houses in the middle and high (highest priced homes) sectors increase in the presence of mountain views and proximity to the mountains, consistent with the previous literature on amenities. However, we find that houses in the high sector are also priced higher when there are visible producing wells or closer to producing wells. At first this seems counterintuitive because households buying higher priced homes who are willing to pay more for mountain amenities should similarly be willing to pay more to avoid the disamenities associated with shale development. However, this increase in prices due to nearby active oil and gas production may be due to the fact that as housing prices have increased, more of the high-valued houses were sold in later periods when there is more competition for land (medium- and high-valued homes also comprise a higher share of new construction homes). This is consistent with our hypothesis of shale production increasing the already intense competition for land in Colorado. Our results are also consistent with the story that higher income people are more likely to value amenities, as we also find that there is a negative impact on house prices for houses in the high sector when views of wells are interacted with mountain views and when distance to the nearest mountain is interacted with distance to the nearest producing well.

Higher priced homes may also be those homes with more land. With more land, shale oil and gas production that is in close proximity to these houses is also more likely to be providing these households with royalty payments. We further explore the impact of shale development and amenities by

TABLE 4 Low, medium, and high housing prices (log price, in 2006 dollars) and shale development

Variables	Low valued properties (bottom 25%)	Medium valued properties (middle 50%)	High valued properties (top 25%)
House has view of many mountains (0/1) = 1	0.0060	0.0150***	0.0625***
	(0.0052)	(0.0020)	(0.0058)
Visible producing wells?(0/1) = 1	−0.0169***	−0.0140***	0.0462***
	(0.0064)	(0.0023)	(0.0062)
Many mountain views * visible producing wells	0.0182***	0.0084***	−0.0604***
	(0.0067)	(0.0025)	(0.0066)
Distance to nearest mountain peak (mi)	0.0045***	−0.0182***	−0.0103***
	(0.0016)	(0.0004)	(0.0009)
Distance to nearest producing well (mi)	0.0039*	−0.0091***	−0.0190***
	(0.0023)	(0.0008)	(0.0018)
Distance to nearest mountain peak * distance to nearest producing well	−0.0001*	0.0002***	0.0002***
	(0.0001)	(0.0000)	(0.0001)
Private water (0/1) =1	0.0115	−0.0382***	−0.1093***
	(0.0089)	(0.0026)	(0.0061)
Private water * distance to nearest producing well	−0.0008	0.0007***	0.0065***
	(0.0005)	(0.0001)	(0.0004)
Government-owned Minerals (0/1) = 1	−0.0898	−0.0223	0.0182
	(0.0737)	(0.0150)	(0.0229)
Distance to nearest feedlot (miles)	0.0077***	0.0003	0.0107***
	(0.0009)	(0.0003)	(0.0009)
Constant	11.2644***	12.6333***	12.7937***
	(0.0794)	(0.0205)	(0.0460)
Community × year fixed effects	Y	Y	Y
Observations	32,216	79,806	38,022
R^2	.3129	.5475	.6036
Adjusted R^2	.306	.546	.601

Note: Models also include the housing characteristics as shown in Equation (1): house size (in square feet), house age, age-squared, whether the house has a garage, whether the house is new construction, the distance to I-25 (in miles) and the distance to the nearest city (in miles).
$^{***}p < .01$; $^{*}p < .1$.

looking at the size of the lots. We divide our sample into those lots with less than or equal to one acre of land and those with more than one acre. The results are in Table 5 (as above, all models include the same full range of covariates as before, but only the relevant variables are shown here). For properties of one acre or less, prices are lower with visible wells, but higher closer to wells, indicative of the tight housing market. However, larger properties actually are priced higher when visible wells are present, perhaps indicating that they are benefiting from royalty payments from the shale development activity.

TABLE 5 Housing prices (log price, in 2006 dollars) and shale development by size of lot

Variables	Less than or equal to 1 acre of land	More than 1 acre of land
House has view of many mountains (0/1) = 1	0.0156***	0.0072
	(0.0025)	(0.0262)
Visible producing wells? (0/1) = 1	−0.0169***	0.0553**
	(0.0029)	(0.0270)
Many mountain views * visible producing wells	0.0115***	−0.0205
	(0.0031)	(0.0281)
Distance to nearest mountain peak (mi)	−0.0208***	−0.0049**
	(0.0005)	(0.0020)
Distance to nearest producing well (mi)	−0.0149***	0.0030
	(0.0010)	(0.0045)
Distance to nearest mountain peak * distance to nearest producing well	0.0003***	−0.0000
	(0.0000)	(0.0001)
Private Water (0/1) = 1	−0.0495***	0.0150
	(0.0030)	(0.0186)
Private Water * distance to nearest producing well	0.0005***	−0.0034**
	(0.0002)	(0.0016)
Government-owned minerals (0/1) = 1	−0.1103***	−0.1008***
	(0.0315)	(0.0260)
Distance to nearest feedlot (miles)	0.0067***	0.0020
	(0.0003)	(0.0022)
Constant	12.2196***	12.3119***
	(0.0240)	(0.1068)
Community × year fixed effects	Y	Y
Observations	148,443	7,348
R^2	.8336	.7393
Adjusted R^2	.833	.728

Note: Models also include the housing characteristics as shown in Equation (1): house size (in square feet), house age, age-squared, whether the house has a garage, whether the house is new construction, the distance to I-25 (in miles) and the distance to the nearest city (in miles). Robust standard errors in parentheses.
***$p < .01$; **$p < .05$; *$p < .1$.

8 | CONCLUSIONS AND POLICY IMPLICATIONS

As unconventional drilling methods have become more prevalent as a means for extracting oil and natural gas from shale reserves across the U.S., it has become increasingly important to understand the impact of this development. Oil and gas development can have both positive and negative impacts. While the most significant benefits are spread thinly across the entire U.S., mainly in the form of lower energy prices, most of the costs are borne specifically by local residents and communities in close proximity to shale development. For this reason, hydraulic fracturing has become contentious in communities and states across the U.S. leading some to enact moratoriums on hydraulic fracturing (New York, for example), as Rahm (2011) and others point out. The capitalization of shale development into housing prices provides evidence of how affected residents, on balance, evaluate and value this development, weighing both the benefits and costs. Furthermore, amenity levels in the area, including water and mountain views, may affect the net capitalization of shale development. Because of Colorado's natural amenities and amenity-led growth (leading to higher educated residents who are more likely to value natural amenities), shale oil and gas development may be valued differently by Colorado's residents than, for example, the residents of Pennsylvania, the focus of much of the previous research.

We find that shale development activity (producing wells) lowers housing prices, providing some evidence that residents in Colorado negatively value this activity regardless of their water source (similar to Gopalakrishnan & Klaiber, 2014 and in contrast to Muehlenbachs et al.'s, 2013 results that suggest that only residents on private water negatively value drilling activity). Specifically, each additional producing well within one mile is associated with a (0.1%) decrease in housing values. Additionally, we find the presence of any visible wells decreases house prices by about 0.8% (nearly $3,000). This negative capitalization of visible wells could be due to the impact that being able to see them has on local esthetics (including mountain views) or it could just be a reminder of any number of negative aspects associated with shale development including water quality concerns and noise. We also find that houses on private water face more negative price capitalization from nearby shale development and that as shale development has increased over time, the value of public water (compared to private well water) has increased.

Our results are consistent with Colorado residents placing significant value on natural amenities, particularly proximity to the mountains and mountain views. We find that Colorado's natural amenities affect the capitalization of shale development into housing prices. A house with views of many mountain peaks sells for approximately 2.5% more, or an average of over $8,000 more, and the prices of houses with mountain views are more negatively affected by shale development activity (in contrast, the prices of houses near a feedlot, a disamenity, are less affected by shale development activity). Our results suggest that there may be significant spatial heterogeneity in how an amenity or disamenity, in this case shale development activity, is capitalized into housing prices. As natural amenities and disamenities vary across space (e.g., distance to mountains and distance to the nearest feedlot), the costs of shale development activity on residents will also vary.

Nevertheless, the number of housing developments in Colorado continues to increase even when that means households will be in close proximity to shale development. We find some evidence that the combined effects of increased shale development and in-migration are increasing prices overall in the housing market in the Front Range of Colorado. Early on, the negative effects of shale development seem to dominate the valuation of its proximity, with households preferring to be farther from shale development activity. Over time, as shale activity has continued and begun to compete for land with new housing developments, the two activities have jointly driven up the cost of land and the price of houses. It seems that in Colorado, residents will accept being in close proximity to shale production if that means they will get to live at the foot of the Rocky Mountains. However, as shale development continues to be in close proximity residents, policy makers should expect oil and gas development-related complaints to continue (see Figure 4 showing the number of complaints from residents over time).

Policy makers in Colorado may need to find new ways to deal with the conflicts that arise as housing construction and shale development increasingly occupy the same space (see Figure 3). In the November (2018) election, Colorado voters decided whether to restrict oil and gas development in the state by keeping wells more than 2,500 feet away from homes (Elliott, 2018). This would have drastically reduced new oil and gas production in the state. While the measure did not pass, the Colorado legislature subsequently passed legislation to overhaul the way the oil and gas industry is regulated in the state shifting its focus more on protecting public health than on oil and gas production (Elliott & Anderson, 2019). Going forward, policy makers may need to focus even more on mitigating the negative impacts of shale development on nearby residents (see Figure 5 showing the types of complaints from residents). Yet, the best way to mitigate the negative effects and drive back down the number of complaints may be to keep shale development away from people. Our results suggest that one option may be to locate them closer to the feedlots where cows seldom complain of the smell or noise, however, due to water concerns that may raise other issues. Policy makers will also need to deal with issues of affordability and the ability of the housing supply to meet the demand, while also protecting the environment and quality of life.

For residents in the Front Range of Colorado, many of whom moved there specifically to be near the Rocky Mountains, it appears there are concerns that shale development is impacting the nearby natural amenities. As policy makers (and voters) continue to make decisions about expansions or limits on shale development activity or the appropriate policies to mitigate the negative effects associated with this development, they may need to consider the preferences of local residents and how that might affect the net valuation of the benefits and costs of such activity. An expansion of oil and gas production in an amenity-rich area will affect the natural capital of the area, thus there is a substitution effect between increased growth from shale oil and gas development and a reduction in the value of amenities. As shale development increases, policy makers may need to consider policies to address this substitution effect and to maintain or even improve upon the natural capital of these areas. Investing the immediate gains (through severance taxes or other fees) from oil and gas extraction into the natural capital of these areas may help ensure these amenity-rich areas maintain their quality of life and continue to experience growth in the long term. Unfortunately, our analysis is unable to determine if this substitution effect is temporary or persistent. Future research should explore this to provide further guidance for policy making.

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ENDNOTES

[1] Weinstein et al. (2018) find a relatively large share of earnings in shale counties across the U.S. leaves the county likely due to temporary workers and other in-migrant workers. Additionally, Kelsey, Shields, Ladlee, and Ward (2011) found that 37% of oil and gas employment in Pennsylvania has gone to non-Pennsylvania residents.

[2] A recent paper by Boslett, Guilfoos, and Lang (2016) finds shale gas development may have had a large positive impact on housing prices for houses with public water. However, there are potential issues with their conclusions, as their methodology does not look at proximity to shale development but simply looks at differences between houses on either side of the Pennsylvania and New York border (a moratorium on drilling was in place in New York) and they only use data over a short timeframe.

[3] As a robustness check, we also estimated all models including housing data from Ft. Collins and the results were similar.

[4] Nearest cities are the nearby 2016 urban areas according to the U.S. Census and include Denver-Aurora, Longmont, Fort Collins, Boulder, Colorado Springs, and Greeley in Colorado, and Cheyenne, Wyoming.

[5] To calculate the views of wells and mountains, we use information on the elevation and location of mountains with peaks over 8,000 feet and the elevation of the location of wells, assuming an average height of 5 m. We then use ArcGIS 3D Analyst Extension “Construct Sight Lines” (from observer to target points) and “Line of Sight” tools to determine visibility for all combination of observer and target points. Since the active producing well head can be up to 40 feet tall (over 12 m) this is a conservative estimate of the ability to see a well, and our results are likely underestimating the visibility effect of oil and gas wells.

[6] Unfortunately, we only have data on government-owned mineral rights of split estates and not privately owned mineral rights of split estates. However, as noted in the text, as there is evidence that most Colorado residents were not adequately informed about the ownership of the mineral rights under their land, we do not believe this is an issue.

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APPENDIX A. GSS ENVIRONMENTAL ATTITUDES BY STATE

Weighted scale—More negative is more concerned about the environment				
	Mean	***SD***	**Min**	**Max**
U.S. (all states)	0.162	0.733	−1.823	2.830
Colorado	−0.590			
Pennsylvania	0.826			

Derived from	
NATENVIR	**(every other year, 2000–2012)**
Are we spending too much, too little, or about the right amount on the environment?	
Too little	1
About right	2
Too much	3
GRNPRICE	(2000 and 2010)
How willing would you be to pay much higher prices in order to protect the environment?	
Very willing	1
Fairly willing	2
Neither willing or unwilling	3
Not very willing	4
Not at all willing	5
GRNTAXES	(2000 and 2010)
How willing would you be to pay much higher taxes in order to protect the environment?	
Very willing	1
Fairly willing	2
Neither willing or unwilling	3
Not very willing	4
Not at all willing	5
GRNSOL	(2000 and 2010)
How willing would you be to accept cuts in your standard of living in order to protect the environment?	
Very willing	1
Fairly willing	2
Neither willing or unwilling	3
Not very willing	4
Not at all willing	5

APPENDIX B. HOUSING PRICES AND SHALE PRODUCTION: HOUSING ATTRIBUTES FOR RESULTS IN TABLE 2

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
House size (thousands of square feet)	0.2197***	0.2167***	0.2163***	0.2162***	0.2165***	0.2163***	0.2158***	0.2159***	0.2166***
	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)
Number of bedrooms	0.0091***	0.0107***	0.0105***	0.0107***	0.0106***	0.0105***	0.0108***	0.0104***	0.0105***
	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)
Number of bathrooms	0.0632***	0.0615***	0.0617***	0.0617***	0.0617***	0.0617***	0.0618***	0.0623***	0.0614***
	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0010)	(0.0010)
Acres of land	0.0579***	0.0576***	0.0575***	0.0574***	0.0576***	0.0576***	0.0569***	0.0562***	0.0570***
	(0.0018)	(0.0018)	(0.0018)	(0.0018)	(0.0018)	(0.0018)	(0.0018)	(0.0018)	(0.0018)
House age	−0.0059***	−0.0065***	−0.0063***	−0.0063***	−0.0063***	−0.0063***	−0.0063***	−0.0062***	−0.0064***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Age of house, squared	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Garage (0/1) = 1	0.0900***	0.0911***	0.0919***	0.0921***	0.0927***	0.0919***	0.0910***	0.0906***	0.0918***
	(0.0034)	(0.0034)	(0.0034)	(0.0034)	(0.0034)	(0.0034)	(0.0034)	(0.0034)	(0.0034)
New construction = 1	0.0178***	0.0185***	0.0206***	0.0199***	0.0194***	0.0207***	0.0205***	0.0218***	0.0210***
	(0.0019)	(0.0019)	(0.0019)	(0.0019)	(0.0019)	(0.0019)	(0.0019)	(0.0019)	(0.0019)
Distance to I-25 (in miles)	0.0039***	0.0075***	0.0081***	0.0077***	0.0074***	0.0080***	0.0089***	0.0086***	0.0061***
	(0.0003)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0005)
Distance to nearest city (mi)	−0.0031***	−0.0013***	−0.0014***	−0.0009**	−0.0005	−0.0013***	−0.0001	0.0006*	0.0008*
	(0.0003)	(0.0003)	(0.0003)	(0.0004)	(0.0004)	(0.0003)	(0.0004)	(0.0003)	(0.0005)

Note: Robust standard errors in parentheses.

*** $p < .01$; ** $p < .05$; * $p < .1$.

APPENDIX C. MODELS WITH COMMUNITY AND YEAR FIXED EFFECTS

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
House has view of many mountains (0/1) = 1	0.0173***		0.0243***	0.0244***		0.0243***	0.0201***	0.0213***	0.0238***
	(0.0017)		(0.0017)	(0.0017)		(0.0017)	(0.0026)	(0.0017)	(0.0017)
Visible producing wells? (0/1) = 1	−0.0031**		−0.0058***	−0.0057***		−0.0058***	−0.0078**	−0.0041***	−0.0057***
	(0.0014)		(0.0014)	(0.0014)		(0.0014)	(0.0030)	(0.0014)	(0.0014)
Many mountain views * visible producing wells							0.0040		
							(0.0033)		
Distance to nearest mountain peak (mi)		−0.0145***	−0.0149***	−0.0152***	−0.0152***	−0.0151***	−0.0209***	−0.0294***	−0.0151***
		(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0004)	(0.0008)	(0.0003)
Distance to nearest producing well (mi)		−0.0012***	−0.0012***	−0.0019***	−0.0019***	−0.0011***	−0.0135***	−0.0010***	0.0011
		(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0007)	(0.0001)	(0.0008)
Distance to nearest mountain peak * distance to nearest producing well							0.0003***		
							(0.0000)		
Private water (0/1) = 1	−0.0329***	−0.056-***	−0.0561***	−0.0714***	−0.0701***	−0.0563***	−0.0712***	−0.0574***	−0.0563***
	(0.0017)	(0.0018)	(0.0018)	(0.0030)	(0.0030)	(0.0018)	(0.0031)	(0.0018)	(0.0018)
Private water * distance to nearest producing well				0.0011***	0.0010***		0.0010***		
				(0.0002)	(0.0002)		(0.0002)		
Government-owned minerals (0/1) = 1	−0.0490**	−0.0318	−0.0296	−0.0283	−0.0289	−0.0298	−0.0415**	−0.055-***	−0.0311
	(0.0198)	(0.0195)	(0.0195)	(0.0195)	(0.0195)	(0.0194)	(0.0196)	(0.0197)	(0.0195)
Distance to nearest feedlot (miles)	0.0107***	0.0038***	0.0036***	0.0034***	0.0036***	0.0035***	0.0036***	−0.0127***	0.0036***
	(0.0002)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0010)	(0.0003)
Number of visible producing wells					−0.0000***				
					(0.0000)				
Number of visible mountain summits					0.0002***				
					(0.0000)				

(Continues)

APPENDIX C. (*Continued*)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Number of producing wells within 1 mile						−0.0008**			
						(0.0004)			
Distance to nearest mountain peak * distance to nearest feedlot								0.0005***	
								(0.0000)	
Distance to the nearest feedlot * distance to the nearest producing well									−0.0001***
									(0.0000)
Year = 2007	0.0179***	0.0168***	0.0170***	0.0170***	0.0169***	0.0170***	0.0167***	0.0167***	0.0171***
	(0.0022)	(0.0021)	(0.0021)	(0.0021)	(0.0021)	(0.0021)	(0.0021)	(0.0021)	(0.0021)
Year = 2008	0.0070***	0.0059**	0.0064***	0.0063***	0.0059**	0.0064***	0.0063***	0.0061***	0.0066***
	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)
Year = 2009	−0.0284***	−0.0293***	−0.0288***	−0.0287***	−0.0292***	−0.0287***	−0.0313***	−0.0290***	−0.0278***
	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)
Year = 2010	−0.0195***	−0.0209***	−0.0204***	−0.0203***	−0.0209***	−0.0203***	−0.0232***	−0.0204***	−0.0192***
	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)	(0.0024)
Year = 2011	−0.0249***	−0.0277***	−0.0271***	−0.0269***	−0.0275***	−0.0269***	−0.0319***	−0.0271***	−0.0253***
	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0026)
Year = 2012	0.0371***	0.0294***	0.0310***	0.0308***	0.0298***	0.0313***	0.0241***	0.0317***	0.0330***
	(0.0023)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0025)	(0.0026)
Year = 2013	0.1490***	0.1418***	0.1433***	0.1431***	0.1428***	0.1439***	0.1371***	0.1440***	0.1454***
	(0.0021)	(0.0022)	(0.0023)	(0.002286)	(0.0023)	(0.0023)	(0.0023)	(0.0023)	(0.0024)
Year = 2014	0.2599***	0.2537***	0.2553***	0.2552***	0.2555***	0.2558***	0.2498***	0.2561***	0.2575***
	(0.0020)	(0.0022)	(0.0023)	(0.0023)	(0.0024)	(0.0023)	(0.0023)	(0.0023)	(0.0024)
Constant	11.1989***	11.9423***	11.9428***	11.9634***	11.9436***	11.9497***	12.1810***	12.4543***	11.93567***
	(0.0085)	(0.0184)	(0.0185)	(0.0188)	(0.0188)	(0.0188)	(0.0217)	(0.0330)	(0.0187)

(Continues)

APPENDIX C. (*Continued*)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Community fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	155,791	155,791	155,791	155,791	155,791	155,791	155,791	155,791	155,791
R^2	.8065	.8095	.8098	.8099	.8098	.8098	.8105	.8105	.8099
Adjusted R^2	.806	.809	.810	.810	.810	.810	.810	.810	.810

Note: Models also include the housing characteristics as shown in Equation (1): house size (in square feet), house age, age-squared, whether the house has a garage, whether the house is new construction, the distance to I-25 (in miles) and the distance to the nearest city (in miles). Robust standard errors in parentheses.

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$.

APPENDIX D. MODELS WITH CENSUS TRACT * YEAR FIXED EFFECTS

Variables	Model 1	Model 2	Model 3	Model 4
House has view of many mountains (0/1) = 1	0.0113***		0.0113***	0.0112***
	(0.0018)		(0.0018)	(0.0018)
Visible producing wells? (0/1) = 1	−0.0046***		−0.0045***	−0.0046***
	(0.0014)		(0.0014)	(0.0014)
Distance to nearest mountain peak (mi)		−0.0017	−0.0016	−0.0017
		(0.0012)	(0.0012)	(0.0012)
Distance to nearest producing well (mi)		−0.0013	−0.0013	−0.0031**
		(0.0014)	(0.0014)	(0.0014)
Private water (0/1)=1	−0.0363***	−0.0361***	−0.0366***	−0.0617***
	(0.0037)	(0.0037)	(0.0037)	(0.0060)
Private water * distance to nearest producing well				0.0021***
				(0.0004)
Government-owned Minerals (0/1) = 1	−0.0571***	−0.0563***	−0.0557***	−0.0568***
	(0.0186)	(0.0186)	(0.0186)	(0.0186)
Distance to nearest feedlot (miles)	−0.0028***	−0.0034**	−0.0033**	−0.0031**
	(0.0010)	(0.0013)	(0.0013)	(0.0013)
Constant	11.5486***	11.6571***	11.6409***	11.6581***
	(0.1140)	(0.1286)	(0.1288)	(0.1289)
Census tract * year fixed effects	Y	Y	Y	Y
Observations	155,791	155,791	155,791	155,791
R^2	.8676	.8676	.8676	.8677
Adjusted R^2	.865	.865	.865	.865

Note: Models also include the housing characteristics as shown in Equation (1): house size (in square feet), house age, age-squared, whether the house has a garage, whether the house is new construction, the distance to I-25 (in miles) and the distance to the nearest city (in miles). Dependent variable is log housing price in 2006 dollars. Robust standard errors in parentheses.

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$.

APPENDIX E. MATCHING RESULTS

Variables	Model 3	Model 4	Model 5	Model 7
House has view of many mountains (0/1) = 1	0.0023	0.0017		0.0139**
	(0.0044)	(0.0044)		(0.0068)
Visible producing wells? (0/1) = 1	0.0092***	0.0093***		0.0237***
	(0.0034)	(0.0034)		(0.0083)
Distance to nearest mountain peak (mi)	−0.0188***	−0.0190***	−0.0190***	−0.0229***
	(0.0007)	(0.0007)	(0.0007)	(0.0009)
Distance to nearest producing well (mi)	0.0042***	0.0012	0.0011	−0.0075***
	(0.0010)	(0.0011)	(0.0011)	(0.0019)
Private water (0/1) = 1	−0.0342***	−0.0585***	−0.0588***	−0.0642***
	(0.0048)	(0.0066)	(0.0066)	(0.0066)
Government-owned Minerals (0/1) = 1	−0.1530***	−0.1513***	−0.1526***	−0.1688***
	(0.0388)	(0.0388)	(0.0388)	(0.0395)
Distance to nearest feedlot (miles)	−0.0035***	−0.0035***	−0.0036***	−0.0025***
	(0.0009)	(0.0009)	(0.0009)	(0.0009)
Private Water * Distance to nearest producing well		0.0033***	0.0033***	0.0036***
		(0.0005)	(0.0005)	(0.0005)
Number of visible producing wells			0.0000**	
			(0.0000)	
Number of visible mountain summits			−0.0000	
			(0.0000)	
Many mountain views * visible producing wells				−0.0170*
				(0.0087)
Distance to nearest mountain peak * distance to nearest producing well				0.0002***
				(0.0000)

(Continues)

APPENDIX E. (*Continued*)

Variables	Model 3	Model 4	Model 5	Model 7
Constant	12.2976***	12.3302***	12.3435***	12.4589***
	(0.0435)	(0.0442)	(0.0445)	(0.0494)
Community × year fixed effects				
Observations	29,039	29,039	29,039	29,039
R^2	.8270	.8272	.8272	.8276
Adjusted R^2	.825	.825	.825	.826

Note: Models also include the housing characteristics as shown in Equation (1): house size (in square feet), house age, age-squared, whether the house has a garage, whether the house is new construction, the distance to I-25 (in miles) and the distance to the nearest city (in miles). For purposes of matching, houses are considered treated if they are within 2 miles of a producing horizontal well and potential matched houses are located more than 5 miles away from a well. Matches are determined using propensity score matching with replacement and identifying the four nearest neighbors within a caliper of 0.1. Matching is based on the house size, the number of bedrooms, the number of bathrooms, the age, whether a house has a garage, whether a house is new construction, whether a house is on private water, and the location (latitude and longitude) of a house. Dependent variable is log housing price in 2006 dollars. Robust standard errors in parentheses.

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$.