**Fracking and Asset Prices: The Role of Health Indicators for House Prices Across Oklahoma’s Counties**

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**Abstract**

The paper extends Apergis’s (2019) study on the role of fracking activities in housing prices across Oklahoma countries by explicitly considering the role of certain indicators determining the health profile of the population. The analysis employs a panel model approach using data from 76 Oklahoma counties, spanning the period 1996-2015. The findings clearly indicate that the overall impact of fracking on housing prices is negative, given that the health indicators are explicitly considered, i.e. fracking has lowered housing prices.

**Keywords**: fracking; housing prices; health indicators; Oklahoma counties

**JEL Codes**: Q30; G10; G12; I12; C33

**1 Introduction**

Hydraulic fracturing (commonly known as fracking)is a method of tapping unconventional oil and gas reserves with the help of horizontal drilling.The process involves the injection of a mixture of water, sand, and chemicals at high pressure into deep rock formations which allow for the extraction of oil and gas from shale resources previously believed to be commercially inaccessible (Ferreira et al., 2018). The rapid growth in fracking activities has been accompanied by a debate regarding the potential benefits and costs of this development.

There exist quite a few studies that document the advantages of fracking from an economic point of view. For instance, Feyrer et al. (2017) examine the geographic and temporal propagation of local economic shocks from new oil and gas production generated by hydrofracturing and demonstrate that each million dollar of new production generates about $80,000 in wages income and $132,000 in royalty and business income within a county. The estimates obtained further suggest that new oil and gas extraction between 2005 and 2012 increased employment by 640,000 new jobs. Hausman and Kellogg (2015) document that between 2007 and 2013 the shale gas revolution led to an increase in the welfare of $48 billion per year for natural gas consumers and producers. The substantial increase in natural gas production has translated into increased supply and lower home heating costs for the consumers (Linn et al., 2014). Additionally, natural gas is used as an input in the petrochemical industry and, therefore, an increase in the production of former lowers the production costs of fertilisers which in turn benefits agricultural production, lowering costs and prices (US Energy Information Administration 2014; Mason et al., 2014).

However, such economic benefits come with significant potential health costs. Colborn et al. (2011) analyse the potential health impact of gas drilling in relation to the chemicals used during drilling, fracking, processing, and delivery of natural gas. The study identifies 632 chemicals out of which more than 75% could affect the skin, eyes and other sensory organs, respiratory and gastrointestinal systems. 40-50% of the chemicals could affect the nervous system, as well as the immune and cardiovascular systems and kidneys, 37% could affect the endocrine system, and 25% could cause cancer and mutations. Carpenter (2016) posits that fracking practices impose a number of significant threats to human health due to air pollution from volatile organic compounds (containing carcinogens, such as benzene and ethyl-benzene) which, in turn, may have adverse neurologic and respiratory effects. Levels of formaldehyde-a respiratory irritant-are elevated around fracking sites due to truck traffic. Moreover, there are major concerns about water contamination, because the chemicals used can get into both ground and surface water. A number of empirical studies have also documented the negative effects that fracking exerts on mental and physical well-being (Casey et al., 2016; Currie et al., 2017; Maguire and Winters, 2017; Casey et al., 2018).

Consequently, despite the hyped economic benefits of fracking drilling, there is strong public apprehension about its negative effects on health and environment in the areas closer to the exploration activities (Cotton et al., 2014).Yet, the existing evidence on the impact of fracking on property prices is mixed (Metz et al., 2017). Krupnick and Echarte (2017) review 16 studies that examine how changes in housing prices are related to the proximity to unconventional oil and gas developments. Housing prices can diminish in value (up to -26.6%, depending on the distance to well or well pads) for groundwater-dependent homes within 2 kilometres of a well pad. Conversely, proximity to fracking activities can lead to higher prices for close-in homes with piped water (up to 3.4%, depending on the distance to well or well pads). In other words, this disparity in the public perception and, in turn, the behaviour of housing prices can be attributed to the risk of exposure to groundwater contamination (Liu et al., 2016).

The existing literature on the fracking-housing prices nexus in Oklahoma is scant and has solely focused on the direct impact of fracking on the latter. It can be hypothesised that regardless of the direct effect of fracking drilling activities on housing prices in Oklahoma, the real impact on housing prices can be influenced by the simultaneous impact of such activities on the health profile of the population. Apergis (2019) investigates the impact of fracking on housing prices across Oklahoma's counties, spanning the period 2000-2015. Through certain panel methods, his results document a positive effect on housing prices, while this positive effect gains statistical significance only over the period after the 2006 threshold fracking boom. However, Apergis (2019) does not explicitly consider the mediating role of the health profile of the population in Oklahoma in the context of housing assets. Despite the positive effect of drilling activities on housing prices in Oklahoma, the real impact on housing prices can be influenced by the impact of such drillings on the health profile of the population. We hypothesise that despite the positive (direct) effect of drilling activities on housing prices, the real impact can be influenced by the effect of such drillings on the health profile of the population. In this context, given the public health concerns of fracking activity, this paper examines the impact of fracking oil and natural gas drilling activities on housing prices in Oklahoma, while jointly accounting for the influence of such fracking activities on the health profile of the population. Although the new findings still support that the impact of fracking on housing prices remains positive, this positive effect is offset by the negative effect that fracking activities exert on certain health indicators, thereby, turning the net impact on housing prices to be negative*.* Given the widespread public health concerns of fracking activities, this paper contributes to an important policy debate about the joint effect of fracking activities on property assets, as well as on public health indicators.

The rest of the paper is structured as follows: Section 2 reviews the relevant literature, while Section 3 presents the methodology and the econometric model employed. Section 4 describes the data used in the study and Section 5 conducts the empirical analysis. Finally, Section 6 concludes.

**2 Economic Effects of Fracking and the Related Literature**

**2.1 Economic Effects of Drilling Activities**

The fracking procedure requires the injection of pressurized fracturing fluid that includes water, sand, and chemicals into layers of rock with the help of horizontal drilling (Armstrong et al., 1995; Stevens, 2012). In the US, technological progress has allowed fracking activities to create a ‘shale boom’. Overall, the US is the global leader in shale gas exploration and controls the foreign oil and gas markets. The proliferation of fracking activities in the US has reduced energy prices, improved energy security, and significantly stimulated profits (Cotton et al., 2014; McNally et al., 2018). In addition to the perceived economic gains, the shale gas exploration has caused an increase in gas production by 17%, on an annual basis, between 2000 and 2006 (Wand and Krupnick, 2013) and 48% between 2006 and 2011 (US EIA, 2011). As a result, the share of shale gas in the total US gas production has risen from 1.6% in 2000 to 34% in 2011 (US EIA, 2013). It is expected that the US will turn to be a net exporter of natural gas, as well as the largest oil producer over the coming years (Mackey, 2012; David, 2013).

In the US, local responses to hydraulic fracturing have varied widely. Overall, some states have fully embraced the fracking revolution, while others have completely banned it, or halted it temporarily. Fracking activities may be associated with a higher or lower price of the housing, but this depends on whether the returns of the drilling activity outweigh the costs. A new strand of the literature has analysed the effect of fracking oil and natural gas drilling activities on housing assets. Cheung et al. (2018) provide evidence that the experience of an earthquake depresses house prices between 3 to 10 percent in Oklahoma, depending on the scale and intensity of the earthquake. Gopalakrishnan and Klaiber (2014) show that the proximity to shale gas wells is associated with lower property values. Similarly, James and James (2014) highlight that the proximity of the housing to shale gas development negatively impacts house prices in Weld County, Colorado. By contrast, Boslett et al. (2014) document that the housing values in New York would have been higher in case New York had not imposed a moratorium on fracking. Similarly, Weber et al. (2014) demonstrate that properties in Texas have higher prices within the proximity (measured by zip codes) to hydraulic fracking.

Another strand of the literature has shown that fracking provides economic advantages where local areas facing shale gas development, i.e. through lower unemployment figures, expansion of local businesses, higher income for private landlords who sign gas leases, and increases in government revenues through higher tax revenues (Kay, 2011)[[1]](#footnote-1). Furthermore, hydraulic fracturing and natural gas drilling lead to job creation in related industries and attracts more people to the area (Marchand and Weber, 2017). Weber (2012) provides solid evidence that the shale boom caused an increase in total employment by 12% per year across boom counties.

Technological advancements in the shale and gas extraction of oil and natural gas from hydraulic fracturing and natural gas drilling activities have transformed societies and brought controversy in the policy arena. As a result, shale gas extraction from unconventional oil and gas developments from the North-eastern part of the US has become efficient and economical and contributes a large share to US gas supply. Furthermore, natural gas is significantly important due to its important bridging role in energy independence due to domestic sourcing and providing cleaner energy with reduced emissions. However, these fracking activities have been strongly opposed due to their potential role in damaging the population’s health profile, because of potential for damages from methane leakages, water contamination, and local air pollution (Mason et al., 2015 for a survey review). Moreover, empirical evidence suggests that the shale boom is associated with higher crime rates, rental costs of properties, and poor air quality due to air pollution (Lovejoy 1977; Albrecht 1978; Freudenburg 1982).

Boudet at al. (2013) suggest that people in the US are unaware and undecided about fracking issues. Almost 50% of the respondents had no information about fracking (heard nothing at all or only a little about it). Among those who had no information, more than 50% were either undecided or did not know whether to support or oppose fracking. Finally, the respondents with an opinion are clearly divided between support and opposition of fracking. Such activities have become highly controversial as the unconventional oil and gas production impacts public health and the environment, yet the research on these issues is inadequate (Finkel and Law, 2011).

**2.2 Health and Other Implications of Fracking**

As mentioned earlier, there is strong public apprehension about its negative effects on health and the environment in the areas closer to these exploration activities. For example, there has been a growing controversy around the introduction of drilling methods of fracking in Pennsylvania. Using detailed location data on maternal addresses and [GIS](https://www.sciencedirect.com/topics/social-sciences/geographical-information-systems) coordinates of gas wells, Hill (2018) examines singleton births to mothers residing close to a shale gas well, spanning the period 2003 to 2010. The research finds that the introduction of fracking in Pennsylvania has a detrimental effect on humans’ health. The study illustrates that an additional well is associated with a 7 percent increase in low birth weight, a 5g reduction in term birth weight, and a 3 percent increase in premature births.

Research has also shown that fracking has a negative impact on the quantity of the available groundwater sources as it requires 2-10 million gallons of water per well and per fracture and may cause the depletion of ground water sources. Furthermore, fracking may lead to the contamination of groundwater, as this unconventional oil/gas drilling results in the release of drilling wastewater that is not sufficiently treated to account for toxic materials, chemicals and methane from gas wells into underground water aquifers (Soederand and Kappel, 2009; Kargbo et al., 2010). [Colborn et al. (2011)](https://www.sciencedirect.com/science/article/pii/S0167629617304174" \l "bib0110) provide solid evidence that more than 75% of the chemicals used during the fracking process can harm skin, eyes, respiratory and [gastrointestinal systems](https://www.sciencedirect.com/topics/medicine-and-dentistry/gastrointestinal-system). Chronic exposure is significantly important as its negative long-term health impacts may not appear soon after the completion of a well. Chronic exposure can harm the brain, the immune system, kidneys, the [endocrine system](https://www.sciencedirect.com/topics/social-sciences/endocrine-systems), cancer and [mutations](https://www.sciencedirect.com/topics/social-sciences/mutation). Finkel and Law (2011) suggest that no state in the US has adequate regulations on fracking, in particular on the release of polluted water. The drilling firms are expected to provide water management plans, as well as any violations to the environmental protection agencies, but they do not do so voluntarily. As a result, many drilling firms have been charged with illegal water withdrawals, while some other companies have been operating without permits in Pennsylvania. Therefore, there are serious anxieties among the public that the health of residents may suffer due to contaminated water.

As a result of public anxieties discussed in Section 2.1, Maryland established the Marcellus Shale Safe Drilling Initiative in 2011 to determine how fracking can be carried out to produce shale gas without any risks to public health, security, and the environment. The Maryland Institute for Applied Environmental Health (2014) shows that fugitive methane emission during the production and distribution of fracking can significantly impact public health. Sangaramoorthy (2019) also presents the experiences of a first health impact study to assess the effect of fracking on public health in Maryland. He describes that the research highlights that fracking activities can cause a negative impact on public health in Western Maryland. The respondents show great concerns for potential health risks associated with fracking operations due to the heavy transportation of trucks, the release of toxic chemicals for the horizontal drilling during fracking, while these issues lead to health problems, including gastrointestinal, skin, breathing, mental health, stress and cardiovascular issues. Finkel and Law (2011) document that chemicals used during the fracking process can damage the lungs, liver, kidneys, blood, and the brain. Their study shows that some harmful effects of fracking on health appear fairly straight away, while some serious health consequences appear after months or years after the exposure process, such as certain forms of cancer, damages to the reproductive system, and developmental effects.

**2.3 A Brief Review of Research on Housing Prices**

A recent strand of literature has started analyzing the impact of fracking activities on housing assets. Ferreira et al. (2018) recover hedonic estimates of property value impacts from fracking drilling activities in a single Oklahoma County, an area that is significantly affected by rising seismic activity. The study finds that the seismic activity in a close proximity (within 2km) of the housing assets has increased the perception of risks associated with waste-water injections. Their results show that earthquakes have depressed the prices of the residential properties in Oklahoma. Similarly, Ng'ombe and Boyer (2009) use data from Oklahoma County, an area that has experienced an expansion in oil and gas production since 2009, but this rise has been also associated with an upsurge in increased seismic activity. They provide evidence that earthquakes in Oklahoma since 2009 are very likely to be triggered by wastewater injection from horizontal drilling and hydraulic fracturing activities by oil and gas companies. As a result, a large population is seriously concerned about potential induced earthquake damages to their property values, with the average value of earthquake damage liability on oil and gas companies being 75%. These findings are consistent with the experience of fracking activities revealing risks that could lead to a decline in housing assets. In addition, Lucija et al. (2015) use data from Pennsylvania County and provide hedonic estimates of property value impacts from shale and gas developments that vary with the water source, well productivity, and visibility. Their study displays that the perceived risk of groundwater contamination has a large negative impact on groundwater-dependent properties in the 1-1.5km neighborhood of drilled and producing wells. In contrast, the value of the piped-water dependent properties exhibits smaller positive impacts from being in proximity of such wells due to royalty payments.

In a recent paper, Gibbons et al. (2016) study the impact of public concerns about fracking drilling on prices of housing assets in locations that have been licensed for such activities in the UK. Their study finds robust evidence that house prices fell by 2.7-4.1 percent in the area where fracking activities led to seismic activity. These findings are strongly supported by an official assessment report[[2]](#footnote-2) of the effect of hydraulic fracturing activities in the UK. The [Shale Gas Rural Economy Impacts](https://t.co/mii16ytcdY) report by the Department for Environment, Food & Rural Affairs (Defra) warns that house prices near the fracking wells are likely to fall. Potentially, housing assets can lose the value of up to 7 percent within the one-mile neighbourhood of the fracking wells.

Till date, Apergis (2019) remains the only study to have investigated the impact of fracking activities on housing prices across all of Oklahoma 76 counties. The study conducts the analysis using panel model methods, spanning the time period 2000-2016. It concludes that fracking exerts a positive impact on housing prices. Moreover, this positive effect gains statistical significance only post-2006 owing to the fracking boom. While discussing future research avenues, Apergis ends by emphasising the potential negative role of fracking in health outcomes. Consequently, this study extends the 2019 paper by reexamining the fracking-housing prices nexus, taking explicitly into consideration the health profile of the population. In other words, Apergis (2019) examines only the direct impact of fracking, whereas our study illustrates that there also exists an indirect impact at work (via the health channels).

**3 Methodology**

The empirical analysis is focused on measuring the influence of fracking oil and natural gas drilling activities on housing prices, taking, however, explicitly into consideration the fact that such fracking activities explicitly impact the health profile of the population in Oklahoma. The modelling framework as in Apergis (2019), yields the following equation:

*hpit = a1i + 𝛽1 dwit + 𝛽2 yit + 𝛽3 popit + 𝛽4 Dcrisis + β5 lifeit x dwit + β6 mortit x dwit +*

*β7 cancit x dwit + β8 cardit x dwit + β9 respit x dwit + 𝜀it* (1)

where, hp represents county’s real housing prices, dw represents the annual county drilling activity, y is county’s real personal income, pop is the county-year population, Dcrisis is a dummy variable that explicitly considers the recent global financial crisis in 2008 (taking 1 at 2008, and zero otherwise), life proxies for life expectancy, mort depicts the mortality rate, canc stands from cancer registrations, card is for cardiovascular diseases, and resp proxies respiratory diseases. a1i represents county fixed effects, while 𝜀 is the error term. To address concerns over local economic factors, the analysis also controls for dynamic changes in personal income and county population. The interaction terms measure the simultaneous impact of fracking drilling activities on health indicators and how this interaction affects housing prices. The statistical significance of such interaction terms highlights the role of the counties’ health profile to detect the role of fracking activities for housing prices.

The empirical analysis applies a panel methodology which takes into account cross-section and time dimensions of the data, as well as cross dependence, to estimate the relationship described in Equation (1). When the errors of a panel regression are cross-sectionally correlated then standard estimation methods can lead to inconsistent estimates and incorrect inference (Phillips and Sul, 2003). In order to consider the cross-sectional dependence, we implement a novel econometric methodology, namely, the Common Correlated Effects (CCE) by Pesaran (2006). The proposed methodology allows individual specific errors to be serially correlated and heteroskedastic. Pesaran (2006) adopts a multifactor residual model, such as:

*hpit = a1i + 𝛽1 dwit + 𝛽2 yit + 𝛽3 popit + 𝛽4 Dcrisis + + β5 lifeit x dwit + β6 mortit x dwit*

*+ β7 cancit x dwit + β8 cardit x dwit + β9 respit x dwit + 𝜀it*

and

*εit = λ’iFt + uit*  (2)

where subscript *it* is the ith cross section observation at time *t*, for and i . is the mx1 vector of unobserved common factors. Pesaran (2006) considers the case of weakly stationary factors. However, Kapetanios et al. (2011) show that Pesaran’s CCE approach continues to yield consistent estimation and valid inference even when common factors are unit root processes (I(1)). To deal with the residual cross section dependence Pesaran (2006) uses cross sectional averages, as observable proxies for common factors . Slope coefficients as well as their means, can be consistently estimated within the following auxiliary regression:

*hpit = ai + 𝛽1 dwit + 𝛽2 yit + 𝛽3 popit + 𝛽4 Dcrisis + β5 lifeit x dwit + β6 mortit x dwit +*

\_\_ \_\_

*β7 cancit x dwit + β8 cardit x dwit + β9 respit x dwit + α1 hpt + α2 dwt +*

\_ \_\_\_ \_\_\_\_\_\_ \_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_

*α3 yt + α4 popt + α5 lifet x dwt + α6 mort x dwt + α7 canct x dwt +*

\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

*α8 cardt x dwt + α9 respt x dwt + εit* (3)

where a bar above certain variables indicates the mean of those variables. Pesaran (2006) refers to the resulting OLS estimators of the individual specific slope coefficients , as the ‘Common Correlated Effect’ (CCE) estimators:

,

where: , , , , , and

\_\_ \_\_ \_ \_\_\_ \_\_\_\_\_\_ \_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

*ht = (1, hpt, dwt, yt, popt,,life x dw, mort x dw, canc x dw, card x dw, resp x dw)* as the ‘Common Correlated Effect’ (CCE) estimators. The ‘Common Correlated Effects Mean Group’ (CCEMG) estimator is the average of the individual CCE estimators :

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The new CCEMG estimator follows asymptotically the standard normal distribution. Specifically:

. (4)

In a series of Monte Carlo experiments, Pesaran (2006) and Kapetanios et al. (2011) show that the CCE estimators have the correct size, and in general have better small-sample properties than alternatives that are available in the literature. Furthermore, they have shown that small-sample properties of the CCE estimators do not seem to be much affected by the residual serial correlation of the errors.

**4 Data**

The number of drilled oil and natural gas wells serves as the measure of non-conventional (fracking) oil and gas development. The drilling wells data for the analysis are collected from the relevant state oil and gas and or geologic agency, i.e. The Oil and Gas Division of The Oklahoma Corporation Commission. Data are collected, spanning the period 1996-2015, totaling 1,520 observations (20 years x 76 counties). In terms of housing prices, data on average housing price transactions provided by Corelogic are obtained. In addition to those index data, associated information on whether the house is groundwater-dependent was also provided. Moreover, the analysis considers some additional control variables that also affect housing prices, such as population, measured as total county residents according to the 2012 census estimates, and county income, with data coming as households’ income from each county. Data on population and personal income at the county level are obtained from the Bureau of Economic Analysis (BEA). All data come on an annual basis, and they are also turned into logarithmic values, essentially denoting elasticity (percentage) terms.

In terms of the public health proxies, relevant data are also obtained. Although there are different measures for health, studies in the health literature have frequently used life expectancy (life) at birth and the mortality rate (mort) as indicators of the health output (Kennelly et al., 2003; Besley and Kudamatsu, 2006; Lorentzen et al., 2008; Aghion et al., 2011; Bayati et al., 2013). Data on both life expectancy and mortality rates across counties are sourced from the Institute for Health Metrics and Evaluation (IHME) at the University of Washington. In addition, data on three other public health indicators are obtained. According to the OECD health care quality indicator project, a set of indicators have been developed that can be used to investigate issues concerning the quality of health care across countries (OECD, 2006). The objective was that such indicators should be used as the basis for investigation to understand differences in the quality of health across countries, as well as what can be done to improve health care systems across all countries. In particular, data on cancer registrations (canc), measured as patients with diagnosed cancer, are sourced from the Oklahoma Central Cancer Registry (OCCR), those on cardiovascular diseases (card), measured as the number of cardiovascular diseases deaths, are obtained from the Heart Disease and Stroke Statistical Update made available by the American Heart Association (AHA), and finally those on respiratory (resp) diseases, measured as the number of hospital visits of patients with respiratory diseases (including the number of deaths due to such diseases), are obtained from the Oklahoma State Department of Health database. Table 1 in the Appendix reports a number of descriptive statistics (all on their actual levels).

**[Insert Table 1 about here]**

**5 Empirical Analysis**

We employ panel cointegration to investigate the long-run equilibrium across the variables under study. The study makes use of the Durbin-Hausman test, recommended by Westerlund (2008), to explore the presence of cointegration. This test does not rely on a priori knowledge of the integration order of the variables included in the modelling approach (Equation (1)). Two panel cointegration tests are employed: the panel test (DHg) and the group mean test (DHp). The tests have different probability limits under the cointegration alternative hypothesis, while sharing the property of consistency under the no co-integration null hypothesis.

The results of the DHg and DHp tests are reported in Table 2. The findings clearly illustrate that the null hypothesis of no-cointegration is rejected at the 1% significance level for both tests, indicating that there exists a significant long-run equilibrium among housing prices, fracking drilling wells, real income, county population, and the interaction terms of fracking drilling activities with the five health indicators.

**[Insert Table 2 about here]**

Next, Table 3 reports the results of unit root tests. In particular, two second-generation panel unit root tests are employed to determine the degree of integration in the variables under investigation. The Pesaran (2007) panel unit root test in which the null hypothesis is a unit root and the bootstrap panel unit root tests by Smith et al. (2004). Both tests by Smith et al. (2004) are constructed with a unit root under the null hypothesis. The results of these panel unit root tests support the presence of a unit root across all variables under consideration.

**[Insert Table 3 about here]**

The results reported in Table 4 provide the estimates of Equation (1). The findings with respect only to the 𝛽5 coefficient highlight a positive and statistically significant housing price effect, indicating that adding more drilling fracking wells leads to an increase in housing prices, which is in line with the findings of Apergis (2019). Both county population and income exert a positive and statistically significant effect on housing prices. In terms of the crisis variable, the impact on housing prices in Oklahoma is negative and statistically significant.

When it comes to the five public health indicators, the results clearly document that the estimated coefficients are negative and all statistically significant at 1%. There is a lot of public apprehension surrounding fracking. As Thomas et al. (2016) and Gibbon (2016) note, individuals, especially those who live locally, tend to have a negative perception about fracking when it comes to environmental impacts. A number of empirical studies do provide evidence in support of these apprehensions. For instance, there exist multiple studies which argue that shale gas developments lead to increased concentrations of pollutants in the air which, in turn, contributes towards an increased risk of morbidity and mortality (Shonkoff et al., 2014; Carpenter, 2016). Some studies have shown that residential living in close proximity to well pads is at greater risk for health effects from shale developments (McKenzie et al., 2012). Many studies have documented systemic evidence of methane contamination of water resources associated with shale gas extraction (Osborn et al. 2011; Jackson et al. (2013). Consequently, people may tend to move away from such activities in order to mitigate the health hazards despite their economic benefits. In fact, the negative coefficient values on the health indicators not only mitigate the individual effect of fracking drilling activities on housing prices, which continues to be positive, but also turn the overall impact of such activities negative on housing prices. To estimate now what is the marginal effect of a change in 𝑑𝑤𝑖𝑡 on ℎ𝑝𝑖𝑡 after considering the combined effect across both fracking and interaction terms, we need to calculate:

𝜕(ℎ𝑝𝑖𝑡)/𝜕(𝑑𝑤𝑖𝑡) = 𝛽1 + 𝛽5 𝑙𝑖𝑓𝑒𝑖𝑡 + 𝛽6 𝑚𝑜𝑟𝑡𝑖𝑡 + 𝛽7 𝑐𝑎𝑛𝑐𝑖𝑡 + 𝛽8 𝑐𝑎𝑟𝑑𝑖𝑡 + 𝛽9 𝑟𝑒𝑠𝑝𝑖𝑡 (5)

Then by inserting the estimated coefficients, as well as the mean values for the five health indicators from Table 1 into Equation (5), we get that the effect of fracking activities on housing prices is -4.966. Provided that the average housing prices across all counties and over the period under study is 85,784 dollars, a 4.966% reduction implies a 4,260.03 dollars loss for homeowners.

Finally, commenting on the negative coefficient surrounding the variable of life expectancy (a point raised by a referee), the literature has generated mixed results. According to the Life Cycle Hypothesis, those who save (housing is an important vehicle of saving) cause a stronger demand for housing and thus, housing prices increase. In contrast, those who dis-save (e.g. retirees) need additional funds for consumption and sell their houses, leading to lower housing prices. Consequently, the impact on house prices of the above-mentioned forces depends on which of the two is the stronger. Apparently, in our study the demographics play the major role here leading to lower housing prices, but the exact investigation of this goes beyond the scope of this paper.

**[Insert Table 4 about here]**

The next stage of the empirical analysis estimates the presence of break(s) and its(their) location through the Matsuki and Usami (2008) panel-based unit root test that permits multiple breaks in the level of the trend function at various unknown dates for each cross-sectional unit. It is based on the test proposed by Maddala and Wu (1999) and defined as follows:

N

MU\_B = -2 ∑logpi

i=1

where pi denotes a p-value associated with the minimum ti-test. The statistic has a chi-square distribution with 2N degrees of freedom. The findings are reported in Table 5. From those results we can notice that housing prices across Oklahoma counties have been subject to the presence of two breaks, with the breaking points coinciding with the dates 2006 and 2008. The first date touches the boom in fracking activities Oklahoma state experienced (EPA, 2015; Neilson, 2019), while the second date occurs with the burst of the financial (real estate) crisis. When it comes to the health indicators, the findings postulate the presence of a single break that coincides with the 2006 booming fracking activities.

**[Insert Table 5 about here]**

Given that the break date test identified the year 2006 as a break event, the next step of the empirical analysis carries on the investigation of the presence of cointegration across the two regimes (i.e., prior and after the 2006 break point). Once again, Westerlund (2008) cointegration results, reported in Table 6, display that over both regimes the statistics reject the null of no cointegration at the 1% significance level and confirm that there is a long-run relationship between housing prices and the remaining drivers provided by Equation (1).

**[Insert Table 6 about here]**

Given the presence of cointegration across both regimes, we next obtain the long-run estimates using once again the Common Correlated Effects (CCE) approach. The new results are reported in Table 7, with the findings providing evidence that prior to 2006 fracking was exerting a positive, albeit statistically insignificant, impact on housing prices, while the interactive terms also turn to be statistically insignificant, clearly indicating the fracking activities are not exerting any impact on housing prices over this period. The overall marginal effect was -0.603. By contrast, over the period after the 2006 fracking boom, both the single coefficient of drilling activities and the interaction terms with the public health indicators turn out to be statistically significant (the single coefficient remains positive, while the interaction terms are negative), indicating that health dynamics has substantially turned the effect on housing prices negative. As a matter of fact, the overall marginal effect in the second regime was -7.471. Finally, the remaining variables retain their sign and statistical significance across both regimes.

**[Insert Table 7 about here]**

This sub-section extends the baseline results by considering the distance of houses from the drilling wells. The distances have been determined through the Resource for the Future’s Center for Energy Economics and Policy that uses Geographic Information System (GIS) technology. Thus, we divide the drilling wells that are within 1km, 5km, 10km and 20km or more from properties. The analysis introduces a dummy variable, Ddistance, that takes 1 if the distance between the drilling well and the house is within 1km, or 5km, or 10km or or 20km or more, and 0 otherwise. In addition, a new dummy variable is introduced, Dwater, that considers whether the house is groundwater dependent. Hence, this dummy variable takes the value of 1 if the house is ground water-dependent, and 0 otherwise. The new model to be estimated yields:

*hpit = ai + 𝛽1 dwit + 𝛽2 yit + 𝛽3 popit + 𝛽4 Dcrisis + 𝛽5 Ddistance + 𝛽6 Dwater +*

*𝛽7 Dcrisis + β8 lifeit x dwit + β9 mortit x dwit + β10 cancit x dwit + β11 cardit x dwit +*

*β12 respit x dwit + vit* (6)

The new results of the DHg and DHp tests are reported in Table 8. These new findings highlight again that the null hypothesis of no-cointegration is rejected at the 1% significance level for both tests, indicating that there exists a significant long-run equilibrium among housing prices and the new set of control variables in Equation (6).

**[Insert Table 8 about here]**

Next, Table 9 reports the estimates of the model (6) across various distances from wells. The new findings clearly document again the positive (direct) effect of the fracking drilling wells on housing prices, with the distance dummy exerting a declining impact as we are moving away from wells. However, in terms of the marginal effect, the results show a clear negative impact on housing prices. The remaining control variables have retained their explanatory size and significance. The groundwater-dependent dummy also exerts a negative effect on housing prices. This finding is in line with other studies, such as, Muehlenbachs et al. (2014) who report a negative impact on groundwater-dependent homes and a positive impact from having drilling in a property’s vicinity in Pennsylvania and New York.

**[Insert Table 9 about here]**

Finally, this part of the empirical analysis offers new estimates about the role of fracking activities in housing prices by explicitly separating the health indicators considered above from the fracking activities (this point was raised by a referee). In that sense, Equation (2) changes into:

*hpit = a1i + 𝛽1 dwit + 𝛽2 yit + 𝛽3 popit + 𝛽4 Dcrisis + β5 lifeit + β6 mortit + β7 cancit +*

*β8 cardit + β9 respit + ηit* (6)

Table 10 confirms the presence of cointegration in Equation (6), while the new results, presented in Table 11, provide some new interesting findings: the coefficient of fracking drilling activities β1 remains positive, albeit significant only at 10%, while all three health diseases indicators are shown to exert a negative effect on housing prices.

**[Insert Tables 10 and 11 about here]**

**6 Conclusion**

The paper assesses the influence of fracking oil and natural gas drilling activities on housing prices, taking explicitly into consideration the fact that such fracking activities impact the health profile of the population in Oklahoma. The analysis employs a panel model approach using data on 76 Oklahoma counties spanning the time period 1996-2015. The analysis indicated that the negative impact of fracking received solid empirical support once the health factors were taken into consideration. In fact, the negative impact turned the overall impact of such activities on housing prices negative. For instance, the net effect of drilling activities when cancer registrations were explicitly considered turned out to be -0.060, implying that 1% increase in fracking drilling activities led to a 6% reduction in housing prices, while the individual drilling effect was recommending an increase in housing prices by 4.6%. Similar trend was observed with the remaining health indicators, with the strongest impact coming from that associated with respiratory diseases, with the reduction coming to 21.9%.

The study further checked the robustness of the initial results by considering the distance of houses from the drilling wells and by controlling for groundwater-dependent homes. The new findings clearly documented that while the positive (direct) effect of the fracking drilling wells on housing prices was present, with the distance dummy exerting a declining impact as we were moving away from wells, this positive effect was clearly offset by the negative impact the fracking activities had on all health indicators, so as the net effect remained negative.

As far as policy implications of the econometric findings are concerned, it is a desirable outcome that fracking is leading to an economic boom in the state of Oklahoma by generating income and employment which is reflected in the positive effect on real estate prices. But this is to no avail if the negative health impact of fracking activities is not reigned in. There are two dimensions to this problem: a) the actual negative impact on health of local residents, and b) the perceived threat from these activities. Over the years, the extractive industries have often been granted exemptions from parts of most basic protective laws, including the Clean Air Act, the Clean Water Act, and the Safe Drinking Water Act (Natural Resources Defense Council, 2018). Given the emerging evidence on fracking’s detrimental impact on human health, further vigorous monitoring from the federal government would be recommended. To tackle the latter issue, detailed public surveys should be conducted to capture the perceived risks of the local people for the development of effective strategies surrounding people about the benefits that the industry brings to the local economy.

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**Table 1** Descriptive statistics

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Variable Mean SD

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Housing prices $166,750 538,772

Income $43,748 562,702

Population 65,796 214,653

Fracking drilling wells 4,681 743.39

Life expectancy 42.915 45.474

Mortality rate 0.024 0.022

Cancer registrations 156,600 81,600

Cardiovascular diseases 275,200 76,368

Respiratory diseases 171,000 21,213

Observations: 1,520

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

SD = standard deviation

**Table 2** Westerlund’s panel cointegration tests

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

DHg 12.653[0.00]\*\*\*

DHp 10.852[0.00]\*\*\*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

p-values are reported in brackets. The criterion used in this paper is IC2(K) with the Maximum number of factors (K) set equal to 5. For the bandwidth selection, M was chosen to represent the largest integer less than 4(T/100)2/9, as suggested by Newey and West (1994). \*\*\*: p≤0.01 and indicates the rejection of no co-integration null hypothesis.

**Table 3** Panel unit root tests

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Pesaran | Smith et al. t-test | Smith et al. LM-test |
| CIPS |
| **\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_** | | | |
|  |  |  |  |
| hp | -1.14 | -1.39 | 3.35 |
|  | [0.38] | [0.32] | [0.36] |
| Δhp | -5.49\*\*\* | -6.92\*\*\* | 19.80\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| dw | -1.23 | -1.35 | 3.15 |
|  | [0.31] | [0.26] | [0.30] |
| Δdw | -5.68\*\*\* | -6.62\*\*\* | 21.39\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| y | -1.30 | -1.39 | 3.09 |
|  | [0.42] | [0.35] | [0.33] |
| Δy | -5.74\*\*\* | -6.48\*\*\* | 25.48\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| pop | -1.36 | -1.38 | 2.94 |
|  | [0.29] | [0.27] | [0.25] |
| Δpop | -5.58\*\*\* | -6.17\*\*\* | 25.93\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| life x dw | -1.28 | -1.40 | 2.86 |
|  | [0.41] | [0.32] | [0.36] |
| Δlife x dw | -6.17\*\*\* | -6.32\*\*\* | 24.39\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| mort x dw | -1.34 | -1.45 | 2.77 |
|  | [0.30] | [0.25] | [0.22] |
| Δmort x dw | -6.31\*\*\* | -6.48\*\*\* | 23.96\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| canc x dw | -1.37 | -1.42 | 2.92 |
|  | [0.39] | [0.34] | [0.30] |
| Δcanc x dw | -5.99\*\*\* | -6.17\*\*\* | 22.36\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| card x dw | -1.29 | 1.36 | 2.68 |
|  | [0.36] | [0.32] | [0.28] |
| Δcard x dw | -6.20\*\*\* | -6.39\*\*\* | 23.17\*\*\* |
|  | [0.00] | [0.00] | [0.00] |
| resp x dw | -1.34 | -1.46 | 2.81 |
|  | [0.36] | [0.31] | [0.35] |
| Δresp x dw | -6.07\*\*\* | -6.22\*\*\* | 24.61\*\*\* |
|  | [0.00] | [0.00] | [0.00] |

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Δ = first differences. Rejection of the null hypothesis indicates stationarity. Figures in brackets denote p-values. \*\*\*: p≤0.01.

**Table 4** Common correlated effects mean group (CCE-MG) estimates

­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Variables Coefficient p-value

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

drilling wells 0.046 0.00

income 0.045 0.00

population 0.042 0.00

crisis dummy -0.587 0.00

life x drilling wells -0.068 0.01

mortality x drilling wells -0.057 0.00

cancer x drilling wells -0.106 0.00

cardiovascular diseases x drilling wells -0.097 0.00

respiratory diseases x drilling wells -0.265 0.00

Adjusted R-squared 0.74

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Table 5** Unit root tests with breaks

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Variable MU\_B (one break) MU\_B(two breaks) Break location(s)**

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

hp 12.76 46.77\*\*\* 2006-2008

dw 56.92\*\*\* 10.96 2006

y 13.44 49.08\*\*\* 2006-2008

pop 12.62 14.58 None

life x dw 58.91\*\*\* 10.74 2006

mort x dw 55.36\*\*\* 12.39 2006

canc x dw 51.49\*\*\* 11.06 2006

card x dw 67.82\*\*\* 9.37 2006

resp x dw 78.46\*\*\* 5.82 2006

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

MU\_B denotes the Matsuki-Usami (2008) test statistics for the null hypothesis of no structural breaks versus the alternative of an unknown number of breaks. In the test procedure both a constant and a trend are included. \*\*\*: p≤0.01.

**Table 6** Westerlund’s panel cointegration results-prior and after the 2006 break point

**Prior the 2006 break event**

DHg 12.514[0.00]\*\*\*

DHp 14.905[0.00]\*\*\*

**After the 2006 break event**

DHg 15.139[0.00]\*\*\*

DHp 17.663[0.00]\*\*\*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

p-values are reported in brackets. The criterion used in this paper is IC2(K) with the Maximum number of factors (K) set equal to 5. For the bandwidth selection, M was chosen to represent the largest integer less than 4(T/100)2/9, as suggested by Newey and West (1994). \*\*\*: p≤0.01 and indicates the rejection of no co-integration null hypothesis at the 1% level of significance.

|  |
| --- |
| **Table 7** CCE-MG estimates-prior and after the 2006 break point  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  ­­­­Variables coefficient p-values  **\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**  **Prior to the 2006 fracking boom**  drilling wells 0.014 0.29  income 0.036 0.00  population 0.039 0.00  life x drilling wells -0.019 0.22  mortality x drilling wells -0.016 0.26  cancer x drilling wells -0.020 0.22  cardiovascular diseases x drilling wells -0.025 0.13  respiratory diseases x drilling wells -0.026 0.11  Marginal effect -0.603  Adjusted R-squared 0.52  **After the 2006 fracking boom**  drilling wells 0.099 0.00  income 0.064 0.00  population 0.049 0.00  life x drilling wells -0.084 0.00  mortality x drilling wells -0.078 0.00  cancer x drilling wells -0.156 0.00  cardiovascular diseases x drilling wells -0.138 0.00  respiratory diseases x drilling wells -0.311 0.00  Marginal effect -7.471  Adjusted R-squared 0.83  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |

**Table 8** Westerlund’s panel cointegration results: the role of the distance from the well

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**1 km**

DHg 11.348[0.00]\*\*\*

DHp 14.561[0.00]\*\*\*

**5 km**

DHg 10.863[0.00]\*\*\*

DHp 12.995[0.00]\*\*\*

**10 km**

DHg 9.359[0.00]\*\*\*

DHp 10.847[0.00]\*\*\*

**20 km or more**

DHg 8.905[0.00]\*\*\*

DHp 9.916[0.00]\*\*\*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Similar to those in Table 2.

**Table 9** CCE-MG estimates: the role of the distance from the well

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Variables Coefficients

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1km 5km 10km 20km**

drilling wells 0.066 0.054 0.041 0.025

[0.00] [0.00] [0.01] [0.03]

income 0.068 0.071 0.070 0.067

[0.00] [0.00] [0.00] [0.00]

population 0.053 0.052 0.055 0.051

[0.00] [0.00] [0.00] [0.00]

life x drilling wells -0.053 -0.044 -0.036 -0.029

[0.00] [0.00] [0.02] [0.03]

mortality x drilling

wells -0.039 -0.033 -0.025 -0.019

[0.00] [0.01] [0.02] [0.04]

cancer x drilling wells -0.089 -0.075 -0.068 -0.049

[0.00] [0.00] [0.00] [0.01]

cardiovascular diseases

x drilling wells -0.059 -0.051 -0.040 -0.032

[0.00] [0.00] [0.00] [0.01]

respiratory diseases

x drilling wells -0.068 -0.060 -0.048 -0.042

[0.00] [0.00] [0.00] [0.01]

Marginal effect -8.63 -6.94 -4.16 -1.55

crisis dummy -0.614 -0.596 -0.609 -0.611

[0.00] [0.00] [0.00] [0.00]

underground

water dummy -0.309 -0.312 -0.319 -0.315

[0.00] [0.00] [0.00] [0.00]

Adjusted R-squared 0.74 0.72 0.65 0.63

Figures in brackets denote p-values.

**Table 10** Westerlund’s panel cointegration tests (Equation 6)

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DHg 10.471[0.00]\*\*\*

DHp 10.773[0.00]\*\*\*

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As in Table 2.

**Table 11** Common correlated effects mean group (CCE-MG) estimates (Equation 6)

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Variables Coefficient p-value

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drilling wells 0.017 0.10

income 0.054 0.00

population 0.046 0.00

crisis dummy -0.542 0.00

life 0.059 0.01

mortality -0.072 0.00

cancer -0.158 0.00

cardiovascular diseases -0.126 0.00

respiratory diseases -0.298 0.00

Adjusted R-squared 0.68

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1. Please see Marchand and Weber (2017) for a detailed survey on the local labor market effects of natural resources. [↑](#footnote-ref-1)
2. See Vaughan and Mason (2015). [↑](#footnote-ref-2)