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Induced earthquakes and housing markets: Evidence from Oklahoma

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ABSTRACT

This paper examines the impact of earthquakes on residential property values using sales data from Oklahoma from 2006 to 2014. Before 2010, Oklahoma had only a couple of earthquakes per year that were strong enough to be felt by residents. Since 2010, seismic activity has increased, bringing potentially damaging quakes several times each year and perceptible quakes every few days. Using repeat-sales and difference-in-differences models, we estimate that prices decline by 3–4 percent after a home has experienced a moderate earthquake measuring 4 or 5 on the Modified Mercalli Intensity Scale. Prices can decline 9 percent or more after a potentially damaging earthquake with intensity above 6. We also find significant increases in the time-on-market after earthquake exposures. Our findings are consistent with the experience of an earthquake revealing a new disamenity and risk that is then capitalized into house values.

1. Introduction

The long-term negative externalities associated with extractive industries have long been part of the public discourse, though the effects of industries ancillary to extraction have often proven difficult to examine. The management and disposal of wastewater from oil and gas operations, for instance, has only recently risen to prominence over concerns about water contamination from hydraulic fracturing, or “fracking,” and over concerns of increases in earthquake frequency and severity near areas with booming oil and gas industries.[3] Oklahoma has been the state most affected by induced changes in earthquake frequency. It recorded more magnitude 3.0 (M 3.0) or higher earthquake events than California in 2014, and more than the other 47 contiguous states combined in 2015.[4] The two largest earthquakes in Oklahoma history, an M 5.7 earthquake in Prague on November 5, 2011, and an M 5.8 earthquake in Pawnee on September 3, 2016, are thought to have been induced (Keranen et al., 2013; Yeck et al., 2017).[5]

Documentation of earthquakes caused by underground injection of fluid reaches at least as far back as the study by Healy et al. of the 1962–1979 earthquakes near Rocky Mountain Arsenal, Colorado (Healy et al., 1968; Petersen et al., 2016). Induced earthquakes occurred there following the injection of chemical manufacturing waste by the US Army. Induced earthquakes from wastewater disposal have since been recorded in Ashtabula, Ohio; Perry, Ohio; and Cold Lake, Alberta, Canada (Nicholson and Wesson, 1990).[6] Reductions in wastewater injection volume have been associated with lagged decreases in seismicity in these cases. More recent seismicity, including earthquakes in Milan, Kansas (peak M 4.9; Choy et al. (2016)); Youngstown, Ohio (peak M 3.7; Kim (2013)); Timpson, Texas (peak M 4.8; Frohlich et al. (2014)); and Dagger Draw, New Mexico (peak M 4.1;

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[3] Fracking itself has induced some earthquakes in Oklahoma, though the number of induced earthquakes and the peak recorded magnitude of these earthquakes (M 2.9) are far smaller than for earthquakes induced by wastewater injection: See Holland (2013).

[4] Magnitude 3 earthquakes approach the smallest that can be felt by humans: See Dengler and Dewey (1998).

[5] The next largest earthquake, an M 5.5 event in El Reno on April 9, 1952, has been postulated to be induced by injection-well activity, though evidence is sparse: See Hough and Page (2015).

[6] Earthquakes can be induced by underground injection wells, fluid reservoirs, and energy-resource-extraction practices (Ellsworth, 2013).

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Pursley et al. (2013)), has been induced by the disposal of waste fluids from oil and gas development operations.

In this paper, we examine the external welfare impacts of severe changes to earthquake frequency and intensity induced by fluid injection in Oklahoma. Fluids injected for disposal in Oklahoma largely consist of saltwater (>95 percent) extracted along with oil and natural gas. Injections also contain "flowback" water (<5 percent), which is waste fluid that returns to the surface following a hydraulic fracturing operation (Abualfaraj et al., 2014; Walsh and Zoback, 2015). These wastewaters' high concentrations of total dissolved solids makes it uneconomical to use them for any other purpose, and they must be disposed of properly to protect public safety (Guerra et al., 2011). Injecting the wastewater into underground injection control (UIC) wells is the lowest-cost acceptable disposal method. If the water has to be transported from a production site to a disposal site, then transportation costs make up the vast majority of disposal costs (Welch and Rychel, 2004). Relative cost efficiency can be obtained by injecting large amounts of fluids into a large reservoir using a single well, though these same high-volume wells are thought to be the wells most likely to induce earthquakes in Oklahoma. The injection of large volumes of wastewater increases pore pressure in the rock formation they are injected into; this pressure can propagate below the injection site, eventually spreading to active faults in basement rock (Walsh and Zoback, 2015). The recent increases in injection into the Arbuckle formation, an Oklahoma rock formation that sits directly above basement rock, then can explain recent increases in seismicity (Murray, 2014). Wastewater management costs are a major factor in oil and gas production, and the elimination or severe regulation of the most cost-efficient management strategy would increase costs for producers in a state with substantial economic dependence on oil and gas production.

We measure the welfare effects of these earthquakes by examining their impacts on housing prices. As Koster and van Ommeren (2015) outline, earthquakes may affect housing prices through one of three mechanisms: earthquakes can cause property damage; changes in earthquake frequency may change expectations of future earthquake damages; and even if properties remain undamaged, earthquakes are unpleasant to live with because of injury, discomfort, or fear thereof. Although the analysis presented in this paper is unable to distinguish between these mechanisms, each is more likely to manifest in the Oklahoma property market than in Koster and Ommeren's area of study in the Netherlands because of the larger frequency and severity of earthquakes in Oklahoma. The peak magnitude is M 5.7 in Oklahoma within the period of study, versus M 3.5 in the Netherlands.

The arrival of induced earthquakes appears to be an exogenous shock to Oklahoma real estate markets. Home sales from a census tract before the induced quakes began can serve as a control group while home sales in the tract post-earthquake serve as the treatment group. We assume buyers and sellers did not anticipate the earthquakes. While it has been known for decades that wastewater disposal can cause seismic activity, some regions with UIC wells experience little or no seismic activity. The experience of a quake reveals to home buyers and sellers that the region has the type of geology that makes it susceptible.

When it becomes known that quakes can occur in their region, current homeowners lose equity proportional to the new risk and disamenity. Until recently, earthquakes were rare in Oklahoma, and they are not usually covered in homeowners insurance policies. In response to the seismic activity, Oklahoma homeowners have begun adding earthquake coverage (Kaelynn, 2015). This expense should be capitalized into home prices (Nyce et al., 2015). To set prices, insurers have to draw on their experiences in naturally earthquake-prone regions and make assumptions about how intense the quakes might become. They also need to adjust for any differences in building practices that are used in earthquake-prone areas but were not thought necessary in Oklahoma. Some home buyers might predict that because the quakes are caused by human activity, the state will ban the activity in the near future, the quakes will subside, and the expense will end (Philips, 2016). Alternately, buyers may consider that the economic benefits to the state are too large for the state government to introduce a ban, and the quakes will continue as long as the demand for oil and gas justify the continued wastewater disposal.

In our analysis, we use information on home sales in Oklahoma from 2006 to 2014, along with a catalog of earthquakes from 2001 to 2014 to measure changes in sale prices due to changes in earthquake exposure. The 2009–2010 onset of earthquakes in Oklahoma, persisting and increasing in frequency to the end of the study period, creates a 3–4 year baseline period of little to no earthquake exposure and a 3–4 year period of geographically varying exposure. Results suggest that there is a minimal, negative if not slightly positive effect of "noticeable" yet nondamaging earthquakes. A negative housing-market impact of earthquakes can be detected for potentially damaging earthquakes, with estimated impacts as large as a 9-percent decrease in prices following the largest earthquake observed.

This paper proceeds as follows: Section 2 reviews the literature on the impacts of earthquakes and other spatially distributed externalities. Section 3 describes the data used in this study. Section 4 presents an econometric model, Section 5 describes the summary statistics, and Section 6 reports results. Section 7 concludes.

2. Literature

Rosen (1974) is the seminal work on hedonic models, noting that the value of goods can be considered a function of their characteristics and that consumers' marginal willingness to pay for certain attributes of a good can be derived from regression analyses. Brookshire et al. (1985) were the first to apply this model to earthquake risks, modeling them as characteristics of houses and examining the reaction of the California housing market to new information on earthquake risk by region. Although it was known that all Californian households were exposed to earthquake risk, risk maps displaying risk by region created an information shock comparable to that of an actual earthquake event. Brookshire et al. estimated that values differed between high- and low-risk zones by an average of $4650.

Beron et al. (1997) were the first to implement this model for an earthquake event, using the 1989 California Loma Prieta earthquake. They find that consumer perceptions of earthquake risk decreased between 26 and 35 percent after the earthquake, indicating initially inflated risk perceptions. Naoi et al. (2009), however, find the opposite result in Japan, indicating that regional expectations of earthquake risk will in part determine market reaction to actual earthquake events. Nakagawa et al. (2007) use a hedonic model based on a recently updated earthquake risk map to examine how consumers' price sensitivity to earthquake risk can change across time. They find that the difference in discounting of earthquake risk between low- and high-risk areas varied from 3 to 8 percent, increased over time, but did not change in response to major recent earthquake events such as the Great Hanshin-Awaji earthquake. Koster and van Ommeren (2015) were the first to use a hedonic model to examine the impacts of induced seismic events on housing prices, finding that each "noticeable" earthquake leads to a 1.9 percent decrease in property values, with a maximum of 7 earthquakes experienced by a single household. Using a dataset from Groningen, Netherlands, and using an earthquake-attenuation function to estimate household experiences of earthquake events from 2001 to 2013, they examine the impact of small-magnitude-earthquake events on a region and the impact of induced seismic events on a region with little to no previous seismicity. Using a separate measure of exposure to earthquakes that cannot be felt by humans, they argue that their measure of earthquake exposure for "noticeable" earthquakes is conditionally spatially independent of other spatiotemporally correlated factors. They estimated that the total nonmonetary costs of "noticeable" earthquakes in the region amounted to €600 per household, which is comparable in