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The costs of induced seismicity: A hedonic analysis ☆

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HIGHLIGHTS

- Earthquakes due to wastewater injection became prevalent in Oklahoma in 2010.
- The external cost of these earthquakes is found using a hedonic analysis.
- The revealed cost is between 3.15% and 4.7% of home prices.

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ABSTRACT

New developments in drilling technology and hydraulic fracturing have brought unprecedented change to energy markets domestically and internationally. Unintended effects of this extraction technique have been felt, quite literally, due to induced seismicity from wastewater injection. This research measures the costs of induced seismicity through changes in home prices using a hedonic price analysis within a differences-in-differences framework. We find the revealed cost to be between 3.15%–4.7% of home values, up to a $6660 reduction at the average.

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1. Introduction and background

Along with an unprecedented supply of new oil and natural gas, the process of hydraulic fracturing[1] has drastically increased the supply of produced water.[2] Much of this produced water is pumped back underground or "injected" as wastewater into class II injection wells, though some areas are recycling wastewater in industrial practices. In Oklahoma wastewater injection is common practice. In 2009 over 849 million barrels of wastewater were injected. This amount grew dramatically to 1538 million barrels injected in 2015. The ramifications of these practices are being felt through induced seismic activity with 20 earthquakes that registered as a magnitude 3.0 or greater in 2009 and 581 in 2015 (Murray, 2015). The Oklahoma experience is not anecdotal, and there is broad scientific consensus that swarms of induced earthquakes are correlated with injection (Weingarten et al., 2015). Indeed, the relationship between earthquakes and wastewater disposal has been established within the scientific literature for nearly 50 years (Healy et al., 1968).

While induced seismicity is an ongoing research subject geologically, the impacts through economic channels are less well-defined. However, this recent and unanticipated earthquake activity lends itself to a 'natural experiment' setting where unintended costs may be calculated through home price changes. Given consumer theory, and assuming households are mobile, one would expect that homes in 'high risk areas' (those that have witnessed more earthquakes) would be priced lower than equivalent homes in lower-risk areas. These equalizing differences may be recovered using a hedonic price model in the tradition of Rosen (1974).

Hedonic pricing models are a common way to price externalities, and a number of studies have already used the technique

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[1] Colloquially referred to as "fracking".

[2] Excess saltwater and wastewater produced during the drilling process.

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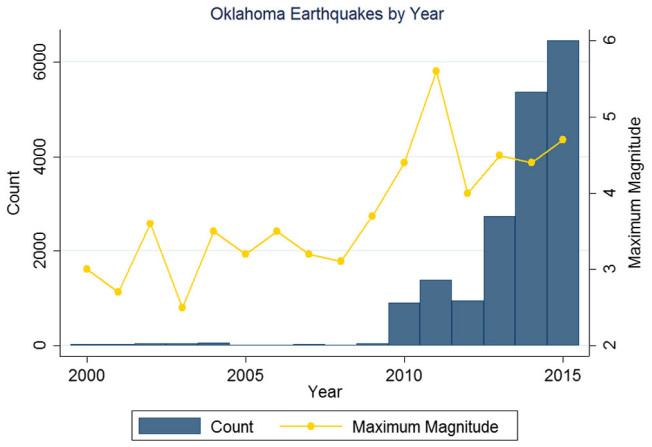

Fig. 1. Earthquake count and maximum magnitude by year.

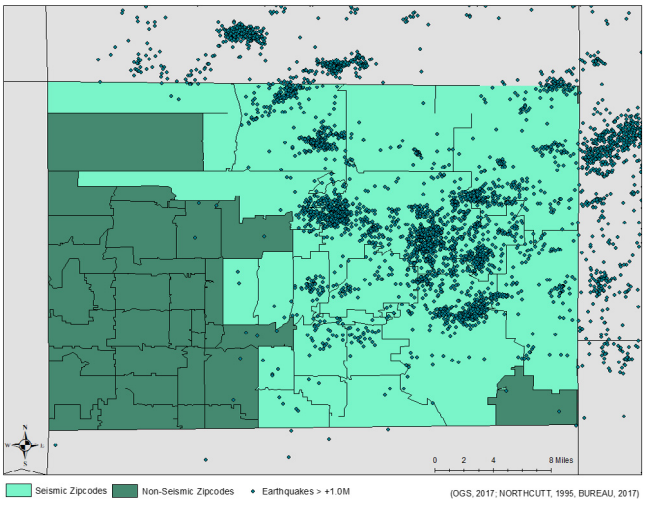

Fig. 2. Earthquake epicenter location map.

to study the 'fracking' boom. Muehlenbachs et al. (2015) used differences in home water supply and distance to drilling sites to quantify externalities of shale development. These authors find there to be a positive effect due to access to royalties, but that this effect goes away if a home is reliant on well-water. Their conclusion is that the risk of groundwater contamination, even if misinformed, is capitalized into the home price as a compensating risk differential. Boslett et al. (2016) quantify the costs and benefits of shale development using state-to-state policy differences. These authors find that homes outside of New York witnessed a steeper increase in value because they were able to receive royalty payments.[3]

We estimate the revealed cost of induced seismicity using a differences-in-differences treatment effect framework with data on single-family home sales in Oklahoma county.[4] This method compares the change in home prices in seismically-active regions before and after the onset of the earthquake boom to the change in prices in non-active areas while controlling for relevant home features. This enables us to filter effects from global or national factors (e.g. changes in the prime rate) and isolate the external cost due to seismicity.

In addition to standard hedonic models that account for house characteristics we also estimate individual home fixed effects models. In these specifications we control for the exact same house being sold at different points in time. This method refines our estimate of the impact of seismicity by accounting for unseen, or at least undocumented, home attributes. Across specifications we find that the onset of earthquakes has reduced home prices in seismically-active regions by 3.15%–4.7%.

We compare our results directly with a working paper by Cheung et al. (2016) which we consider a complementary paper. These authors find that affected home prices have fallen by 3%–4%. While the present paper comes to a similar conclusion quantitatively, we differ in a number of meaningful ways. First, the present study encompasses a longer time-frame of sales records while Cheung et al. (2016) uses state-wide home sales.[5] Second, we use a treatment effect model whereas Cheung et al. (2016) relies on indicator variables for various magnitudes and the cumulative count of earthquakes at various magnitudes. Thus, we confirm the results of Cheung et al. (2016) using a different modeling strategy.

Table 1
Summary statistics.

	Avg	Std dev	Min	Max
Home price	139,272	101,583	30,000	995,000
Home sf	1767	772.1	500	8025
Land sf	15,304	34,572	2000	863,359
Bedrooms	3.088	0.655	1	8
Bathrooms	1.911	0.705	0.750	6.500
Year built	1970	22.85	1895	2015
Garage dummy	0.892	0.311	0	1
Seismic period dummy	0.354	0.478	0	1
Seismic region dummy	0.413	0.492	0	1

Notes: $N = 94211$.

2. Data description

Records on single family home sales price(s), location, characteristics, and quality were purchased through the Oklahoma County Assessor. We limit the analysis to homes which were sold multiple times from 2000 to June 2016.[6] Earthquake location and magnitude data come from the Oklahoma Geological Survey. Fig. 1 displays 1.0+ magnitude earthquake counts and the maximum magnitude for each year since 2000. It is clear that the number of earthquakes per year has increased dramatically since 2010 with more than 6000 earthquakes occurring in 2015 alone. Using various magnitude qualifications and radii surrounding earthquake epicenters[7] we define seismically-active regions to merge with our home price and characteristics data.

The baseline specification defines a region as seismically-active if there are more than 50 magnitude 1.0+ earthquakes within a 10km distance of the zipcode's centroid. Evidence from U.S. Geological Survey's "Did You Feel It?" program shows that magnitude 1.0–2.0 earthquakes are certainly felt within this distance.[8] While lower magnitude events may not cause damage to a home, they

[3] We note here that royalty payment differences are not relevant to the present study because these studies cover an area in which there was little to no oil and gas activity historically. Oklahoma has a long history of oil and gas development, and, almost universally, land and mineral rights are severed.

[4] Oklahoma County covers 371 square miles of land, and contains the state capital, Oklahoma City. The real-estate makeup in Oklahoma county is very diverse with homes located in suburbs, exurbs, historic districts, etc.

[5] We also make use of different data sources for home price and characteristics information. Our data comes from State Assessors whereas their data is through MLS records.

[6] We also eliminate home sales with likely errors, such as price per sq ft below $15 and above $500, and homes with less than 500 sq ft. We also restrict the analysis to only include homes with a sale price between $30k and $1mil.

[7] Haversine formula distances.

[8] Did You Feel It? (n.d).