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Earthquakes and Home Prices: The Napa and Ridgecrest Quakes

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ABSTRACT
A comparison of residential home sales six months before and after the 2014 South Napa and 2019 Ridgecrest earthquake sequences shows that prices dropped substantially, and that the effects on individual home prices were directly related to the intensity with which the earthquakes were felt at the location of each home.

KEYWORDS
Earthquakes; home prices

The three most important things in real estate are location, location, location. Beyond the square footage, number of bathrooms, and other physical characteristics, home prices depend on proximity to various amenities and disamenities, such as schools, parks, and metro stations (Goodman & Thibodeau, 2003); gravel mines (Hite, 2006); landfills (Hite et al., 2001; Ready, 2010); air pollution (Ridker & Henning, 1968); noise pollution, water pollution, hazardous waste sites; and overhead power lines (Boyle & Kiel, 2001).

Our vulnerability to natural disasters is a growing concern. In 2020, there were a 22 weather and climate disasters in the United States (which cost more $1 billion), compared to an average of 16.2 such disasters during the preceding 5 years and 7.1 during the past 40 years (Bin, 2021).

In California, earthquakes are such an important risk that the California Geological Survey maintains an online interactive fault map, with most residents living within 30 miles of an active fault (California Earthquake Authority, undated). The California Natural Hazards Disclosure Act requires real estate sellers and brokers to disclose whether a property is within an earthquake fault zone (or other designated hazard areas, including flood and fire). However, these disclosure forms are signed relatively late in the buying process and homebuyers may pay little attention to them.

In addition, there is considerable evidence that people have difficulty assessing the chances of low-probability, high-impact events (Barberis, 2013). Thus, Tversky and Kahneman (1992, p. 303) argue that "the (probability weighting) function is not well-behaved near the endpoints, and very small probabilities can be either greatly overweighted or neglected." For example, Lichtenstein et al. (1978) reported that people overestimate the probability of contracting a rare disease, but Botzen et al. (2015) found

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that most homeowners living in New York City floodplains underestimated the probability of flooding caused by hurricanes.

A related question is whether earthquake risk assessments are affected by the occurrence of a major quake. We analyze residential real estate prices six months before and after the 2014 South Napa and 2019 Ridgecrest earthquake sequences to explore how individual home prices were affected by the intensity with which the quake sequences were felt at each home.

Background

There have been several studies of how perceived earthquake risk affects home prices. Bernknopf et al. (1990) found that the distribution of earthquake and volcano hazard notices in Mammoth Lakes, California, had a negative effect on property values. Singh (2019) examined the effects of changes in California earthquake fault maps and concluded that placement in a fault zone reduced property values by an average of 6.6 percent. A study of three towns near San Diego found that the value of homes at greatest risk for earthquakes, floods, wildfires, and other natural disasters were 10 to 13 percent lower than for homes of average risk (Bin, 2021).

Keskin et al. (2017) looked at how home prices in different geographic sections of Istanbul (during a five-year period with no earthquake activity) were related to soil quality and proximity to fault lines. Willis and Asgary (1997) asked 173 Tehran real estate agents to estimate the market prices of two hypothetical identical 1600-square-foot new homes, with one built in conformance with new earthquake-resistant uniform building codes to withstand an earthquake of magnitude 8 on the Richter scale without major human and structural damage. They found that the average price estimate was 16 percent lower for the nonresistant home.

There have also been studies of how earthquake occurrences have affected home prices. Fekrazad (2019) looked at California home prices after high-casualty earthquakes occurred outside North America and found that home price indexes in high-seismic-risk California ZIP codes fell by 6 percent relative to home price indexes in low-seismic-risk ZIP codes, though the effects dissipated within a month of the earthquake occurrence.

Onder et al. (2004) found that the negative price effects of the 1999 Marmara quake in Turkey were greatest for homes close to fault lines. A study of increased earthquake activity in Oklahoma, evidently due to oil and gas extraction, concluded that the prices of homes located near moderate-to-intense earthquake activity declined by 3.5 to 10.3 percent, while the prices of homes that experienced low-intensity earthquakes increased slightly (Cheung et al., 2018).

Mothorpe and Wyman (2021) examined the negative effects on Oklahoma City home prices of earthquakes induced by hydraulic fracturing ("fracking"). Earthquake intensity was measured by the US Geological Survey's "Did You Feel It?" (DYFI) system which aggregates the real-time responses of internet users to survey questions such as

> *How would you describe the shaking? (Not specified, Not felt, Weak, Mild, Moderate, Strong, Violent)*

> *Did you hear creaking or other noises? (Not specified, No, Yes slight noise, Yes loud noise)*

One advantage of the DYFI system is the rapid data collection. A weakness is the potential for biases and errors in the internet user responses. In addition, the

> *data flow after major damaging earthquakes may be limited by power outages, excessive Internet traffic, infrastructure damage, and the more important priorities of users.* (Wald et al., 2011, p. 705)

Also, the underlying DYFI intensities are not measured at individual locations, but are averaged over 1-km squares; Mothorpe and Wyman use weighted averages of the values of all 1-km squares that are within 5 km of each home.

Murdoch et al. (1993) looked at home prices after the Loma Prieta earthquake. They used dummy variables for California counties, but did not measure the distance of individual homes from the quake (California counties are quite large). Kawawaki and Ota (1996) looked at the Hanshin-Awaji earthquake. They used asking prices (not transaction prices), only considered apartment housing, and only included these home characteristics: floor space, age of structure, floor the unit is on, and the availability of parking; they did not consider distance from the quake.

Naoi et al. (2009) concluded that owner-provided, self-assessed home values in risk-prone areas of Japan fell after major earthquakes, indicating that homeowners had previously underestimated earthquake risk. On the other hand, an analysis by Beron et al. (1997) of home prices before and after the 6.9 Loma Prieta 1989 earthquake in California concluded that the negative effects of exposure to earthquake risk diminished after the quake, indicating that homeowners had previously overestimated the potential damages. They did not consider the distance of homes from the earthquake.

A meta analysis concluded that perceived earthquake risk reduces home values by an average of 1.3 to 2.9 percent; however, the effects of actual earthquakes on home prices are ambiguous (Koopmans & Rougoor, 2017).

We add to this literature by studying individual home prices near two recent major California quakes, taking into account that earthquakes generally involve a sequence of shocks and measuring the intensity with which the shocks were felt at individual homes based on the home's distance from the epicenter and the earthquake's moment magnitude and hypocentral depth.

The 2014 South Napa and 2019 Ridgecrest Earthquakes

The two most recent major earthquakes in California were the South Napa quake in 2014 and the Ridgecrest quake in 2019.

Napa is 80 kilometers north of San Francisco, in the heart of the Napa Valley wine industry. The United States Geological Survey (USGS) identified 12 substantial earthquakes during the 2014 South Napa earthquake sequence from August 24, 2014, through September 11, 2014 (USGSa, undated), with the most powerful being a 6.0 quake on August 24, the largest quake in the San Francisco Bay Area since the 1989 Loma Prieta earthquake. One person was killed and 200 injured, with $500 million in estimated damage (USGS, 2015).

Ridgecrest is approximately 200 kilometers northeast of Los Angeles and has historically been affected by many earthquakes related to the Eastern California Sheer Zone

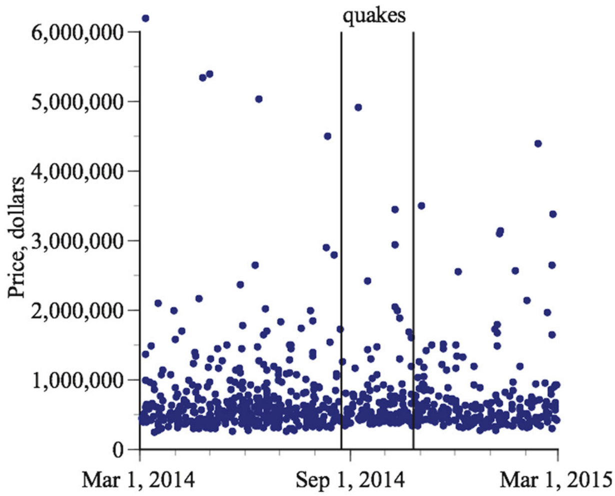

Figure 1. South Napa home prices.

(Miller et al., 2001), including a 5.8 shock in 1995 (Southern California Earthquake Data Center, undated).

The 2019 Ridgecrest earthquake sequence consisted of 67 substantial shocks from July 4, 2019, through July 16, 2019, and included shocks of magnitudes 6.4 on July 4, 5.4 on July 5, and 5.0, 7.1, 5.5, and 5.0 on July 6 (USGSb, undated). The 7.1 shock on July 6 was the most powerful California earthquake in 20 years and was felt by approximately 30 million people in California, Arizona, Nevada, and Mexico (Jones, 2019). One person died, 25 were injured, and there was an estimated $1 billion in damages to homes, gas lines, highways and other structures (California Earthquake Authority, 2019) and $5 billion in damages to the Naval Air Weapons Station at China Lake (Los Angeles Times, 2019).

In the aftermath of the 2019 Ridgecrest sequence, it was reported that, "With consumers now re-awakened to the reality of the risk that earthquakes pose," the chief economist at Realtor.com predicted "a slowdown in the short-term in the housing market in and around Ridgecrest" (Passy, 2019).

Model

We used real estate sales data for the six months preceding and following each of these two earthquake sequences to investigate the effects on home prices. Figures 1 and 2 show the prices of single-family homes sold within 12-month intervals centered in the Napa and Ridgecrest quakes. (A Napa house that sold for $17,300,000 on October 19, 2014, is omitted from this chart and was also excluded from the statistical analysis because the sale closed during the quake window described later.)

These two figures do not show any obvious change in home prices before or after the two earthquake sequences. The two-sided *p*-value for a trend line relating price to time is 0.94 for the South Napa sequence and 0.79 for the Ridgecrest sequence. However, to get a more satisfactory answer, we need to take into account any variations in the types of homes that were sold during these time periods. For example, a drop in home prices after the quakes may be masked by an increase in the size of homes that were sold.

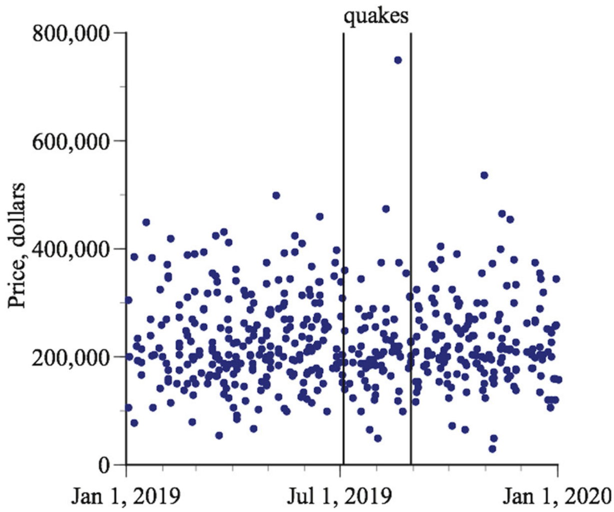

Figure 2. Ridgecrest home prices.

Hedonic regression models are often used to value the characteristics of heterogeneous products such as houses (Lancaster, 1966; Rosen, 1974). In the housing market, for example, a data set that includes the market prices of homes of different sizes and with different features—such as the number of bedrooms and bathrooms—can be used to estimate the marginal market value of square footage, bedrooms, and bathrooms. The coefficients in multiple regression models are *ceteris paribus*, so that the coefficient of each characteristic is a measure of how highly that specific characteristic is valued by homebuyers.

Two popular functional forms for hedonic pricing models are a linear model of the form

$$P = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ \dots \ + \beta_k X_k + \varepsilon$$

and a semi-log model of the form

$$\ln[P] \ = \gamma_0 + \gamma_1 X_1 + \gamma_2 X_2 + \ \dots \ + \gamma_k X_k + \nu$$

where P is the price and the X_i are the explanatory variables. The estimated effect on P of a *ceteris paribus* change in X_i is given by β_i in the linear model and by $\beta_i P$ in the semi-log model.

The relevant question for choosing between these models is whether the price effect of a one-unit increase in the value of an explanatory variable is constant or is proportional to the price of the house. Arguments can be made either way. The value of adding square footage might depend mainly on construction costs, which are largely unrelated to the current market price of a home. On the other hand, the potential damage to a house from an earthquake might well be proportional to the price of the house. In practice, there is often little difference between the results with linear and semi-log models (Follain & Malpezzi, 1980). We use both functional forms in order to check the robustness of our results.

The explanatory variables we used are listed in Table 1 and include several standard housing characteristics used in home pricing models as well as variables gauging

Table 1. Explanatory variables in hedonic pricing equations.

Measurement Units	Variable Definitions
SQFT:	living space, square feet
GarageSQFT:	garage size, square feet
LotSize:	property size, acres
NumBeds:	number of bedrooms
NumBaths:	number of bathrooms
NumStories:	number of stories
Pool:	1 if swimming pool, 0 otherwise
YearBuilt:	Year constructed
RenYear:	Year renovated (equal to year constructed if no major renovations)
New:	1 if new construction, 0 otherwise
D:	For the South Napa sequence, $D = 0$ before August 23, 2014, and $D = 1$ after September 11, 2014. For the Ridgecrest sequence, $D = 0$ before July 3, 2019, and $D = 1$ after August 30, 2019
MMI2:	Number of MMI = 2 quakes experienced before house sale
MMI3:	Number of MMI = 3 quakes experienced before house sale
MMI4:	Number of MMI = 4 quakes experienced before sale
MMI5:	Number of MMI = 5 quakes experienced before sale
MMI6+:	Number of MMI = 6 or higher quakes experienced before sale
CumMMI:	sum of MMI quake values this home experienced before its sale

earthquake exposure. A survey of the explanatory variables appearing most often in hedonic models of real estate prices found age to be the most common characteristic (Sirmans et al., 2005). We chose to measure age in three ways: the year the home was originally built, the year there were major renovations (equal to the year constructed if there have been no major renovations), and whether the home was new (to capture the initial nonlinear effects of age).

Not counting the earthquake variables, our other explanatory variables are all among the 12 most commonly used explanatory variables. We did not include basement, fireplace, or air conditioning because of the heterogeneity and unreliability of the Multiple Listing Services (MLS) data we used. For similar reasons, we did not attempt to measure distance to good schools, attractive parks, and other amenities. We did not include a time-on-market variable because the MLS data we received from realtors did not include either time-on-market or date-entered-market data.

We measured the impact of earthquakes by the Modified Mercalli Intensity (MMI) scale (Wood & Neumann, 1931; Dewey et al., 1995). In contrast to magnitude scales that give a single measure of the strength of an earthquake, the MMI scale measures the intensity with which a quake is felt by humans and structures at various locations relative to the quake's epicenter. The MMI scale ranges from 1 to 12 with interpretations such as 1 (felt by very few people), 5 (felt by all, some dishes and windows broken), and 12 (most masonry and frame structures destroyed, rails bent).

Atkinson and Wald (2007) report an equation for estimating MMI based on the magnitude and depth of an earthquake and the distance from the epicenter:

$$\text{MMI} = 12.27 + 2.270(M–6) + 0.1304(M–6)^2 – 1.30\log[R] – 0.0007070R + 1.95B – 0.577(\text{M})\log[R]$$

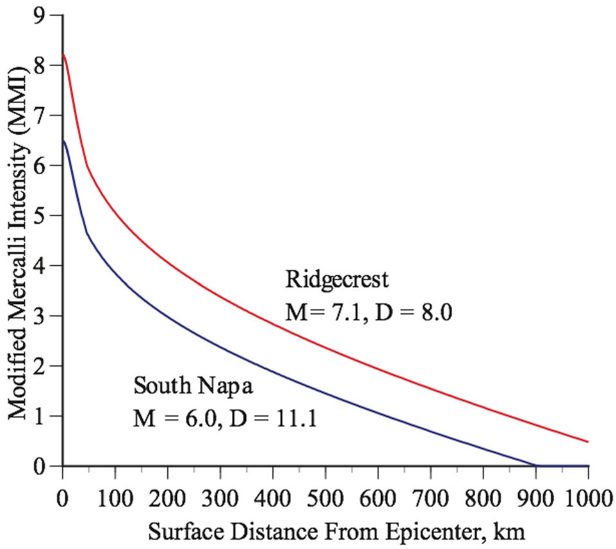

Figure 3. MMIs for the largest earthquakes in the Ridgecrest and South Napa sequences.

where M is the earthquake's moment magnitude, $\boldsymbol{R} = \sqrt{\boldsymbol{S}^2 + \boldsymbol{D}^2 + \mathbf{14}}$, S is surface distance from the epicenter, D is the hypocentral depth of the quake, and $B = \max[0, \log(R/30)]$. The logarithms are base 10 and all distances are measured in kilometers.

Atkinson et al. (2014) report that subsequent data showed that the 2007 equation predicted unreasonably large intensities for large earthquakes at close distances. They consequently revised the equation, which we use here for estimating MMI:

$$MMI = 0.309 + 1.864M - 1.672\log[R] - 0.00219R + 1.77B - 0.383M\log[R]$$

where B is now $\max[0, \log(R/50)]$.

Figure 3 shows the relationship between MMI and surface distance for the largest earthquakes in the 2014 South Napa and 2019 Ridgecrest sequences.

We used USGA data on the magnitude and depth of each earthquake, and the longitude and latitude of the epicenter. Because of the small distances between the homes and quake epicenters, the Haversine formula was used with each home's longitude and latitude to calculate the surface distance from the home to the center of each earthquake.

For home sales that occurred after the earthquake sequence, we tabulated the number of earthquakes in each MMI category:

$\boldsymbol{MMI_i^h} =$ number of earthquakes in category h experienced by house i before home sale

It would be useful to have a single statistic that summarizes both the frequency and intensity of earthquakes felt at different locations. There is no clearly superior way of doing this since the MMI data are categorical, based on how people, buildings, and the environment are affected by a quake. Nonetheless, we considered a crude cumulative MMI statistic:

$\boldsymbol{cumMMI_i} =$ sum of MMI values experienced by house i before home sale

Data

Data were collected on houses sold in the cities of Napa and Ridgecrest during 12-month intervals centered on the earthquakes listed by the USGS as part of the South Napa Earthquake Sequence from August 24, 2014, through September 11, 2014, and the Ridgecrest Earthquake Sequence from July 4, 2019, through July 16, 2019. Specifically, our Napa sale price data were taken from MLS records for the period March 1, 2014, through February 28, 2015, and the Ridgecrest data were taken from MLS records for the period January 3, 2019, through January 2, 2020.

None of the homes we analyzed had suffered any earthquake damage. The MLS home-characteristics data were double-checked with various real estate websites and some entries were manually corrected—for example, a home listing that reported "Stories: 0" when the photo of the house showed a 2-story home. Other homes were dropped because of inconsistencies—for example, in the number of bedrooms or bathrooms.

The earthquake dummy variable D divides the sample period surrounding each quake sequence into three parts. For the period before the first earthquake in the sequence, $D = 0$. For the period beginning 45 days after the last earthquake in the sequence, $D = 1$. Sales closed during the intervening days were omitted from the analysis. The 45-day gap was based on the report of an experienced realtor (Stevens, 2020) that the time between the signing of the purchase & sale agreement and the actual closing is typically around 45 days. Thus, closings before the beginning of the earthquake sequence were not affected by the subsequent earthquakes and closings that occurred more than 45 days after the end of the earthquake sequence were generally completed with full knowledge of the earthquake sequence.

The data for MMI6 and higher quakes were combined because none of the South Napa properties experienced a quake of MMI7 or higher and all but one of the Ridgecrest homes experienced both one MMI6 quake and one MMI7 quake.

Tables 2 and 3 show descriptive statistics for the variables. There were no MMI4 observations for Napa.

Results

Tables 4 and 5 show the estimated coefficients and two-sided p values for the various models. The estimated coefficients of the housing-characteristic variables are generally reasonable when valued at the mean home prices ($756,880 in Napa and $234,485 in Ridgecrest). The high p-values on the lot-size coefficients in Ridgecrest may be due to the fact that many homes are built on undeveloped land ("dirt patches") that do not seem particularly valuable. The number-of-bedrooms coefficients are *ceteris paribus*, holding constant the other explanatory variables (including square footage), so an additional bedroom means less space for other uses. Similarly, the negative number-of-stories coefficients indicate that homebuyers prefer that a given square footage be on one level. The coefficients of the year built are consistently negative in Napa and positive in Ridgecrest, indicating a slight premium on older homes in Napa and a premium on newer homes in Ridgecrest.

Table 2. Descriptive statistics for South Napa Data, 560 observations.

	Minimum	First Quartile	Median	Third Quartile	Maximum
Price	255,000	430,275	540,000	724,000	4,500,000
SQFT	528	1,247	1,688.5	2,257.5	6,117
GarageSQFT	0	400	460	523	1,916
LotSize	0.05	0.14	0.16	0.27	41.82
NumBeds	1	3	3	4	6
NumBaths	0	2	2	2.5	6
NumStories	1	1	1	2	3
Pool	0	0	0	0	1
YearBuilt	1868	1953	1968	1989	2014
RenYear	1910	1961	1986.5	2007	2016
New	0	0	0	0	1
MMI2	0	1	2	2	6
MMI3	0	3	3	4	5
MMI4					
MMI5	0	0	0	0	1
MMI6+	0	1	1	1	1
CumMMI	22.90	26.01	26.41	26.71	27.67

Table 3. Descriptive statistics for Ridgecrest data, 358 observations.

	Minimum	First Quartile	Median	Third Quartile	Maximum
Price	30,702	175,000	210,000	269,950	537,000
SQFT	780	1,357	1,605	1937.5	3,716
GarageSQFT	0	440	472	518.5	4,640
LotSize	0.10	0.15	0.18	0.23	10.0
NumBeds	1	3	3	4	6
NumBaths	1	2	2	2	5
NumStories	1	1	1	1	2
Pool	0	0	0	0	1
YearBuilt	1946	1973	1984	1990	2019
RenYear	1946	1980	1992	2017	2020
New	0	0	0	0	1
MMI2	5	9	10	13	16
MMI3	42	44	46	46	48
MMI4	5	7	8	9	13
MMI5	0	1	1	1	1
MMI6+	1	2	2	2	2
CumMMI	232.26	238.08	243.45	245.66	250.39

Earthquake Exposure

The first two columns of coefficients in Tables 4 and 5 are for models that measure earthquake exposure with a dummy variable that is equal to zero before the beginning of the earthquake sequence and equal to one when it has been more than 45 days after the conclusion of the earthquake sequence. In three of four cases, the two-sided *p*-values are less than 0.05. In every case, the coefficient estimates are negative and substantial. In Napa, the -$125,573 coefficient in the linear model is 16.6 percent of the mean home price, while the semi-log model gives a 4.7 percent decline. In Ridgecrest, the -$23,101 coefficient in the linear model is 9.9 percent of the mean home price, while the semi-log model gives a 11.7 percent decline.

The third and fourth columns of coefficients are for models with explanatory variables reflecting the number of earthquakes experienced in various MMI categories. The coefficients are mixed and only one *p*-value is below 0.05, presumably because there are not

Table 4. South Napa regressions (estimated Napa coefficients with two-sided *p*-values in brackets).

Dependent Var	Price	ln[Price]	Price	ln[Price]	Price	ln[Price]
SQFT	479.1483	0.0005	459.2760	0.0005	478.9962	0.0005
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
GarageSQFT	114.9697	0.0002	121.1779	0.0002	114.8142	0.0002
	[0.1176]	[0.0040]	[0.0888]	[0.0029]	[0.1176]	[0.0040]
LotSize	40,968.4935	0.0318	37,397.6921	0.0297	40,904.7345	0.0318
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
NumBeds	−104,334.8942	−0.0674	−91,538.5197	−0.0602	−104,343.3410	−0.0673
	[0.0000]	[0.0000]	[0.0000]	[0.0003]	[0.0000]	[0.0000]
NumBaths	28,997.6122	0.0279	30,177.0941	0.0288	28,811.3664	0.0276
	[0.2397]	[0.2223]	[0.2069]	[0.1989]	[0.2421]	[0.2255]
NumStories	−137,908.4937	−0.0637	−128,994.9628	−0.0531	−137,242.5062	−0.0633
	[0.0000]	[0.0057]	[0.0000]	[0.0194]	[0.0000]	[0.0060]
Pool	119,839.1831	0.1267	96,800.8208	0.1093	119,281.5463	0.1265
	[0.0001]	[0.0000]	[0.0013]	[0.0001]	[0.0001]	[0.0000]
YearBuilt	−2,735.8179	−0.0027	−2,800.8825	−0.0027	−2,747.9009	−0.0028
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
RenYear	671.0286	0.0010	598.3116	0.0009	658.1605	0.0010
	[0.1673]	[0.0272]	[0.2041]	[0.0493]	[0.1751]	[0.0288]
New	70,412.6432	0.1433	81,319.4181	0.1440	72,324.4691	0.1450
	[0.3978]	[0.0631]	[0.3127]	0.0568]	[0.3845]	[0.0600]
Dummy	−125,573.0532	−0.0465				
	[0.0251]	[0.3693]				
MMI2			−174,351.1052	0.1671		
			[0.4954]	[0.4858]		
MMI3			−192,899.6624	0.1150		
			[0.4559]	[0.6354]		
MMI5			1,224,875.0718	−0.5486		
			[0.3478]	[0.6536]		
MMI6orMMI7			783,113.6024	−0.7208		
			[0.5430]	[0.5503]		
CumMMI					−5,429.8401	−0.0024
					[0.0105]	[0.2131]
R-squared	0.7244	0.7624	0.7448	0.7741	0.7252	0.7627

enough data here to obtain accurate estimates of the individual coefficients corresponding to the numerous MMI categories.

The fifth and sixth columns of coefficients are for models in which the data for the individual MMI categories are aggregated into an overall measure of MMI exposure. As with the dummy-variable models in the first two columns of coefficients, three of the four two-sided *p*-values are less than 0.05 and every coefficient estimate is negative and substantial. The estimated effect of a MMI event on home prices is equal to the reported coefficient multiplied by the value of the MMI event.

In the linear model for Napa, an MMI3 event is predicted, *ceteris paribus*, to reduce a home's market price by $5,430(3) = $16,290, which is 2.2 percent of the mean home price. The predicted price difference between a Napa home with no MMI exposure and one with the 26.3 mean cumMMI value is $5,430(26.3) = $142,809 (18.9 percent of the mean home price), which is consistent with the dummy variable coefficient of -$125,573. The semi-log model predicts a price difference of 0.24(26.3) = 6.3 percent for a home with the mean cumMMI compared to one with cumMMI = 0, which is consistent with the 4.7 percent estimated decline in the dummy-variable semi-log model.

In Ridgecrest, the mean cumulative MMI exposure was 242.2, which implies a predicted price difference between a home with an average cumMMI and a home with zero cumMMI of $93.28(242.2) = $22,592 in the linear model (9.6 percent of the mean home

Table 5. Ridgecrest regressions (estimated Ridgecrest coefficients with two-sided *p*-values in brackets).

Dependent Var	Price	ln[Price]	Price	ln[Price]	Price	ln[Price]
SQFT	104.1080	0.0004	103.4287	0.0004	104.1599	0.0004
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
GarageSQFT	23.0674	0.0001	23.7332	0.0001	23.0802	0.0001
	[0.0030]	[0.0736]	[0.0023]	[0.0627]	[0.0030]	[0.0729]
LotSize	1,912.2970	0.0106	2,041.9044	0.0117	1,822.0656	0.0102
	[0.4955]	[0.4649]	[0.4970]	[0.4493]	[0.5162]	[0.4843]
NumBeds	−519.4047	0.0253	−482.7436	0.0267	−554.1243	0.0250
	[0.8884]	[0.1887]	[0.8963]	[0.1607]	[0.8810]	[0.1936]
NumBaths	12,623.2110	0.0413	13,250.7688	0.0442	12,627.1634	0.0414
	[0.0248]	[0.1555]	[0.0185]	[0.1245]	[0.0248]	[0.1554]
NumStories	−11,732.3716	−0.0601	−13,784.9419	−0.0680	−11,693.7958	−0.0601
	[0.2642]	[0.2704]	[0.1913]	[0.2088	[0.2660]	[0.2707]
Pool	22,158.7485	0.1183	21,845.1527	0.1174	22,215.1749	0.1189
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
YearBuilt	1,449.7626	0.0074	1,474.6657	0.0082	1,443.9286	0.0074
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
RenYear	143.2364	0.0013	142.3677	0.0013	143.0313	0.0013
	[0.1870]	[0.0175]	[0.1911]	[0.0248]	[0.1878]	[0.0179]
New	33,927.5381	0.0611	33,667.8851	0.0432	34,090.0757	0.0620
	[0.0042]	[0.3180]	[0.0047]	[0.4767]	[0.0041]	[0.3109]
Dummy	−23,100.8914	−0.1167				
	[0.0188]	[0.0221]				
MMI2			−2,313.3088	−0.0263		
			[0.2080]	[0.0055]		
MMI3			−1,048.9155	0.0058		
			[0.4882]	[0.4528]		
MMI4			−929.4916	−0.0178		
			[0.7640]	[0.2617]		
MMI5			−29,018.8335	−0.1255		
			[0.0756]	[0.1337]		
MMI6orMMI7			42,370.4774	0.0896		
			[0.2585]	[0.6408]		
CumMMI					−93.2803	−0.0005
					[0.0217]	[0.0333]
R-squared	0.8016	0.7358	0.8046	0.7457	0.8015	0.7353

price) and 0.05(242.2) = 12.1 percent in the semi-log model. Both estimates are consistent with the respective 9.9 and 11.7 percent estimates in the dummy-variable model.

Discussion

With the increase in natural disasters in recent years, a natural question for homeowners is not only the extent of the damage after a disaster occurs but, also, the effect on current home prices of possible future disasters. A related question is the extent to which such risk assessments are affected by the occurrence of natural disasters. We focus on earthquakes; future work might consider hurricanes, tornadoes, wildfires, floods, and other natural disasters.

Using a hedonic pricing model to take into account individual housing characteristics, we found that Napa and Ridgecrest home prices were, on average, substantially lower during the six months after the respective 2014 and 2019 earthquake sequences than during the six months preceding the sequences.

In Napa, the estimated *ceteris paribus* effect of the earthquake sequence was to reduce the mean home price by 16.6 percent in the linear model and 4.7 percent in the semi-log model. Since the size of the effect is likely to be related to the value of the home, the 4.7 percent estimate with the semi-log model seems more reasonable. In Ridgecrest, the two models are more consistent, with the earthquake sequence estimated to have reduced the mean home price by 9.9 percent in the linear model and by 11.7 percent in the semi-log model.

The models using cumulative MMI estimates are more nuanced than are models using before-and-after dummy variables, and we found that the price effects across homes were substantially related to the intensity with which the earthquakes were felt. In Napa, the linear model implies that a mean-priced home that experienced a mean-MMI intensity had a price that was 18.3 percent lower than before the earthquake sequence, while the semi-log model implies a price that is 6.3 percent lower. Both estimates are consistent with the models that used a simple before-and-after dummy variable instead of the MMI intensity measure. In both cases, the semi-log estimates are more reasonable.

The Ridgecrest estimates were again more consistent. In the linear model, there is an estimated 9.6 percent price decline for a mean-priced home that experienced a mean MMI intensity; the semi-log model implies a 12.1 percent decline. Both estimates are consistent with the Ridgecrest models that used a simple before-and-after dummy variable.

Overall, our results add to the evidence that earthquake occurrences reduce the market prices of nearby homes, taking into account individual home characteristics, the fact that earthquakes generally involve a series of shocks, and the fact that the intensity with which earthquake shocks are felt at individual homes depends on the home's distance from the epicenter and each earthquake's moment magnitude and hypocentral depth.

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