Inattention to Earthquake Risk in Home Values

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Abstract

I estimate the impact of earthquake risk on residential home prices. Using USGS earthquake hazard map updates, I find that changes in earthquake risk in a county do not impact its house prices. There is no differential impact in counties with ex-ante higher earthquake risk, counties that experience the largest earthquake risk increase or when the updated earthquake risk reaches a level that can cause moderate potential damages to construction when before it did not. These findings suggest increases in earthquake risk as reported by the USGS, even when large and potentially damaging to construction, have no causal effect on home values.

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1 Introduction

Underlying risk that is publicly available and has a probability to impact the value of an asset in the future is supposed to be priced in the asset's present value. Economic theory would suggest that if there are changes in such risk then current prices should reflect those changes. In this paper, I investigate how differences in underlying earthquake risk measured by the United States Geological Survey (USGS) impact house prices. Houses and nearby public infrastructure can be partially damaged or destroyed in the event of a large earthquake which would lower house values. Increases in earthquake risk in the house's county should lower its current value. If current house values do not respond to increases in earthquake risk, it would suggest market participants are inattentive to at least this source of information on risk that standard economic theory predicts should impact a house's current value.

I provide estimates that show that housing values do not respond to changes in earthquake risk as reported in USGS Hazard Maps. The USGS provides earthquake risk estimates at the geographic coordinate grid level and revises a national version of such maps every six years starting in 1996. In this paper I leverage the 2008 USGS earthquake hazard map and its 2014 update. First, I construct measures of earthquake risk at the county level with data from these seismic maps. I define earthquake risk as the maximum ground acceleration that can happen with a probability of 2% in the next 50 years. With these measures I then define variables that assess changes in earthquake risk to quantify new information when the 2014 USGS Hazard Map was released compared to the 2008 version. As the USGS updates its hazard maps through improved data collection and earthquake risk modeling, changes in earthquake risk published in the hazard maps should be orthogonal to county level conditions that can impact housing values concurrently such as local economic forces.

I find that when a county's level of earthquake risk increases, housing values do not decrease using the release of the 2014 USGS Hazard Map as a plausible exogenous source of variation of earthquake risk. There is no decrease in house prices when there is an increase in the maximum ground acceleration that can happen in the county with a probability of 2% in the next 50 years. Using the earthquake risk measure in logs, I show that a percentage increase in a county's earthquake risk also does not decrease house values. More importantly, coefficients on the increase in earthquake risk are estimated to have a near-zero effect on house values consistently using different ways to construct changes in earthquake risk from the seismic hazard maps.

I perform robustness tests to assess if earthquake risk changes from the hazard maps impact home values non-linearly or based on ex-ante earthquake risk characteristics of the county. I show that counties that had a high earthquake risk before the 2014 USGS Hazard Map update do not have housing values change differently than those counties with a low risk when the new seismic information is released. High-risk counties ex-ante could have been more attentive to any change in earthquake risk as their baseline risk was high. County home values also do not change when there are extreme increases in earthquake risk or when the updated hazard map places the county at risk of a construction-damaging earthquake when it was not before. These results suggest that market participants are inattentive to any type of increase in earthquake risk that can impact future housing values as reported in the USGS Hazard Maps.[1]

Related Literature

Prior work studying earthquakes and home values in the US has focused on California, one of the states with highest earthquake risk. Using updates in fault maps from the California Department of Conservation, Singh (2019) shows that census tract housing prices decrease by 6.6 percent when the tract is designated to be over a fault. In an earlier and seminal study, Brookshire et al. (1985) find that house prices declined by 3.3 percent and 5.6 percent in the San Francisco Bay Area and Los Angeles, respectively, when houses were located in fault zones as revealed by the first public releases of fault maps in the mid-1970s. I show that while California is indeed at higher earthquake risk overall, changes in earthquake risk according to the USGS Hazard Maps are prevalent

[1]Stroebel et al., 2014 shows that housing market participants are attentive to contract terms between 100-year leaseholds and freeholds as they know with certainty the change in the house value and its timing even if its hundreds of years in the future

across the US and such changes do not appear to systematically impact house prices nationwide.

It has also been studied how earthquakes in other areas impact home values in California as it could make earthquake risk more salient to market participants. Using Zillow zip-code level data, Fekrazad (2019) finds that ex-ante high earthquake risk zip codes's house values respond differently to news about earthquakes that occur in other countries. When there is an earthquake with high casualties in other countries, home values decline by 5% in zip codes that have high earthquake risk relative to those with low risk. I estimate what are the effects on house prices when the underlying true earthquake risk changes and not the perception of earthquake risk in all counties in the US.

The relation between earthquake risk and home values has also been studied in Japan where a higher proportion geographically of the country is at risk of earthquakes. Through surveys, Naoi et al. (2009) measures people's earthquake risk perception before and after massive earthquakes. They find that people overestimate the true underlying earthquake risk shortly after earthquake events than beforehand.[2] Similar to my paper, Hidano et al. (2015) study the effect on home values of changes in underlying earthquake risk as measured by a government agency. They find that housing units in areas where the relevant government agency revised earthquake risk estimates upward do experience a decrease in value. They also find that new information on earthquake risk does not impact newer apartment prices as they are more likely to be earthquake-resistant than older homes.

More broadly on the relation between natural disasters and household behavior, there is evidence on how natural disasters impact home values and insurance take-up decisions. When there is a fire nearby, only housing prices in high-risk areas decrease as the fire risk becomes more salient (McCoy and Walsh, 2014). When there is a flood, residents in nonflooded communities but in the same television media market as where the flood occurred increase their flood insurance take-up (Gallagher, 2014).[3] Other studies show how

[2]On the other hand and focusing on the 1989 Loma Prieta earthquake in the San Francisco Bay Area, Beron et al. (1997) finds that the hedonic house price of earthquake risk fell following the earthquake.

[3]Atreya et al. (2015) similarly finds that recent flood events temporarily increase flood insurance purchases focusing in Georgia.

hurricanes, floods and increase in risk of sea level rises can lower house values (Bernstein et al., 2019; Bin and Landry, 2013; Hallstrom and Smith, 2005; Ortega and Taspinar, 2018; Zhang, 2016). As part of estimating the housing term structure of discount rates, Giglio et al. (2015) show that when the fraction of property listings that mention climate change doubles, there is an approximate 2% decrease in the prices of properties that are in the flood zone compared to other similar properties in the same zip code.

Beyond natural disasters, other research has focused on the saliency of features that can impact final prices paid by buyers in other settings such as shipping costs (Hossain and Morgan, 2006), taxes (Chetty et al., 2009) or financial news (Cohen and Frazzini, 2008; DellaVigna and Pollet, 2009; Huberman and Regev, 2001). In this paper, I focus on earthquake risk as measured by USGS being a factor that market participants may be inattentive to when they assess home values.

The rest of the paper is organized as follows. In Section 2, I describe the data on seismic risk from the USGS and present some basic statistics. In Section 3, I show my main empirical methodology and in Section 4, I report results and robustness checks. Section 5 discusses the findings, the paper's limitations, and concludes.

2 Data

2.1 Background on USGS National Seismic Hazard Maps

The USGS is the government agency that estimates potential earthquake risk at a national level. Every six years since 1996, the USGS releases comprehensive hazard maps reporting earthquake risk across different geographic coordinates (latitude and longitude, rounded to the closest first decimal). The main purpose of the hazard maps is to improve earthquake-resilient construction in the United States.[4].

The data reported by the USGS and used in this paper, is the maximum Peak Ground Acceleration (PGA) that can happen with a probability of 2% in the next 50 years for each geographical coordinate. PGA is the maximum ground acceleration experienced by

[4]Introduction to the National Seismic Hazard Maps: https://earthquake.usgs.gov/hazards/learn/

a particle due to earthquake shaking at a location. Its unit of measurement is as a fraction of the acceleration of gravity, g, that equals 9.8 m/s^2.

Higher PGAs are directly linked to higher construction damages. An area that experiences an earthquake with a PGA of less than 0.18g is subject to no or light potential damages when an earthquake happens. A PGA between 0.18g and 0.65g is associated with moderate potential damages while a PGA of 0.65 and above is expected to sustain heavy or very heavy damage. [5]

USGS revises its earthquake risk assessments, and hence its hazard maps, through new seismic data collected since its most recent prior estimate and improvements in computational modeling. Such new data includes improved GPS movement sensors that allows scientists to measure movements in wider areas with more precise estimates. Crucially, for the purpose of this paper, earthquake risk estimates are revised independent of local housing market and broader economic trends. I focus on the 2014 USGS National Seismic Hazard Map update as my main source of exogenous variation on information about earthquake risk. This is due to the lack of coverage in housing value data available prior to 2010 from my data source and to avoid potential confounding with the Great Recession's home price boom and bust.

As my main indicator of earthquake risk at the county level, I use the median PGA of all the geographic coordinates that fall in the county. I first overlay the USGS hazard maps provided in raster grid form by latitude and longitude (rounded to the closest first decimal) over the U.S. county map. Each grid point, along with the earthquake risk assessed at that point, is then assigned to a county if its located within its geographical boundaries. As the number of geographic coordinates that fall in a county depend on the county's geographical size, I use the median as the summary measure that is less susceptible to outliers. For the rest of the paper, the median PGA will be referred to as the county's earthquake risk unless otherwise noted.

[5] For reference, the Haiti 2010 earthquake had a 0.5g PGA

2.2 Trends in Earthquake Risk

Figures 1 and 2 show the earthquake risk by county in the US for hazard maps released by USGS in 2008 and 2014, respectively. The maps show each county color-coded by the median PGA of all geographic coordinates that lie in mainland US.

In both versions of the hazard maps, counties in the West, New England and in the Interior Highlands stretching to the East Coast have the highest risk of a high-magnitude earthquake. Counties in central and upper Midwest, and in southern Texas stretching along the Gulf Coast to Florida have little risk of a high-magnitude earthquake.

The previous figures do not reveal the full extent of differences in earthquake risk measured by the USGS between its 2008 and 2014 versions. Figure 3 shows counties color-coded by the difference in earthquake risk — as measured by median county PGA — between the 2014 and 2008 USGS hazard maps. Counties in the Midwest and close to the Gulf Coast — shaded in dark blue — had the same or even lower earthquake risk when USGS revised their previous estimates in 2014. However, counties in the rest of the country experienced an increase in earthquake risk. Counties in the West Coast, the Interior Highlands and New England, that were already in high risk in 2008, have an even higher increase in risk when USGS updated its estimates in 2014. More broadly, most counties in the West experienced an increase in earthquake risk. Counties in Oklahoma and the Mid-Atlantic are also other pockets of increased earthquake risk from 2008 to 2014.

Most countries in the US experience an increase in earthquake risk from 2008 to 2014. Table 1 provides summary statistics on the earthquake risk as measured by PGA in 2008 and 2014. The mean PGA is 0.124g and 0.119g in 2014 and 2008, respectively. The average change in earthquake risk is an increase of 0.005g in the PGA scale while the median difference is an increase of 0.0005. The top quartile difference in PGA starts at 0.01g or 10% in percentage terms.

To show other details in the earthquake risk distribution, Figure 4 plots histograms of earthquake risk in 2014 and in 2008. The top panel plots the count along different bins of the difference in PGA between 2014 and 2008. The bottom panels plots the count of PGA risk in 2014 and 2008 separately. In both earthquake hazard map releases, most countries fall below 0.18g where expected earthquakes will cause no or light potential damages. While there is a spike around zero in the change of earthquake risk between 2008 and 2014, there are counties that experience large increases or decreases in earthquake risk across both hazard map releases.

The earthquake risk measure published in the USGS Hazard maps predicts subsequent large earthquakes. Table 2 shows the regression estimates using the 2008 USGS PGA earthquake risk county measure to predict large earthquakes after July 2008 when the hazard maps were released. Large earthquakes are defined as significant earthquakes by the National Oceanic and Atmospheric Administration (NOAA). NOAA lists an earthquake as significant if it meets at least one of the following criteria: approximately $1 million or more in damages, 10 or more deaths, has a magnitude of 7.5 or greater, a modified Mercalli Intensity of X or greater, or the earthquake generated a tsunami. The estimates predict that if the 2008 PGA earthquake risk increased by one g, there is an increase of 7 percentage points in the probability the county will experience a subsequent large earthquake.

2.3 Zillow House Prices

Zillow is an online real estate company that tracks home sales across the US. Zillow estimates a set of indexes that track and predict home values and rental prices at a monthly frequency and at different geographic levels. I use the Zillow Home Value Index (ZHVI) at the county level as my main house value outcome variable. The ZHVI attempts to estimates the median transaction price for the actual stock of homes in a given geographic unit and point in time. I use the ZHIVI from July 2012 up to June 2016 as I focus on the impact of changes in earthquake risk in the 2014 USGS hazard maps compared the the 2008 maps. The ZHVI is available for over 1,9000 counties in this time period. To complement the analysis of the effect of changes in earthquake risk on housing values, I also use as an outcome variable in some specifications the Zillow Rent Index (ZRI) and the median list price per square foot. The ZRI is the median monthly rental rate for the current stock of homes in a geographic unit at each point in time.

2.4 Other Data Sources

To control for time-varying local economic conditions, I collect data on median income, population, share of 25-60 years old with bachelors' degrees or higher, employment rate, and owner-occupancy rate from the American Community Survey (ACS) county level 5-year estimates. To match the higher time frequency in the monthly Zillow data, I interpolate the statistics by year in between the years when the survey is conducted.

3 Methodology

To test the impact of changes in earthquake risk on home values, I estimate the following equation in a difference-in-differences framework:

$$Y_{ist} = \alpha + \beta EarthquakeRisk_{ist} + \gamma X_{ist} + \delta_{st} + \eta_i + \epsilon_{ist} \tag{1}$$

where Y_{ist} is the housing value, in log, for county i in state s in year-month t. δ_{st} and η_i are parameters estimated from state-time and county-level fixed effects, respectively. These control for unobserved time-invariant county level home value factors and time-varying factors that impact home values in all counties in a state equally.[6] ϵ_{ist} is the error term that contains additional factors that can impact house values. X_{ist} is a vector of control variables that include log median income, log population, share of 25-60 years old with bachelors' degrees or higher, employment rate, and owner-occupancy rate.

The main coefficient of interest is β which is the coefficient on $EarthquakeRisk_{ist}$. I use two main earthquake risk measures at the county level: 1) an indicator once the county experiences an increase in earthquake risk and 2) the median PGA over time for months around the release of the revised 2014 USGS hazard maps. For the purpose of this

[6] In other specification estimates shown in the tables, I use only time and county-level fixed effects as alternative forms of controlling for these unobserved factors. Main results remain unchanged.

paper, earthquake risk is the PGA that can happen with a probability of 2% in the next 50 years in the county as represented by the median PGA of all geographical coordinate that are in the county. In the first earthquake risk measure, $EarthquakeRisk_{ist}$ is an indicator variable that is zero from July 2012 to June 2014 for all counties. Starting in July 2014, it becomes one if a county experiences an increase of any kind in earthquake risk in the 2014 USGS Hazard Maps compared to the ones released in 2008. Otherwise, the variables remains zero also after June 2014. When this earthquake risk measure is used in the equation estimated above, β measures the effect on home values when a county is deemed to be more at risk by a future earthquake, to any extent, when the USGS released revised hazard maps in 2014.

In the second risk measure, median county PGA is the same from July 2021 to June 2014 and changes to the new median PGA reported by USGS from July 2014 onwards. The β on this variable measures the effect of an increase in the g scale of the county's earthquake as measured by median PGA from 2008 to 2014. To assess the effect of a percentage changes in earthquake risk to home values, in other specifications, I use the earthquake risk measure in logs as the main explanatory variable.

4 Results

4.1 The Effect of Earthquake Risk on House Values

Changes in earthquake risk have no impact on house values when using its revisions from the 2014 USGS nationwide hazard maps. Table 3 reports estimates from the baseline regression specification following Equation 1. Across all columns, the outcome variable is the log of ZHVI and data is restricted to two years around the July 2014 USGS Hazard Maps release date. Estimations use data from July 2012 to June 2016. In the first two columns, the measure of earthquake risk is the indicator variable if there was an increase in earthquake risk in the county between the 2014 and 2008 USGS Hazard Maps. Columns (3) and (4) show results using earthquake risk as the main explanatory variable measured by maximum PGA a county can experience with a probability of 2% in the next 50 years.

Such risk measure is updated only in July 2014. The last two columns use the same PGA over time but expressed in log form.

For each pair of columns with different earthquake risk measures, the first one includes time fixed effects and the second one includes more flexible state-time fixed effects which allow to control for aggregate unobservable variables that change by state and time. For conciseness, in this paper I focus on summarizing results using estimations with state-time fixed effects as it can control for a larger set of unobservable variables. All columns include county fixed effects and standard errors are clustered at the county level to allow for.

On the extensive margin, as reported in Column (2), when a county experiences an increase in earthquake risk, this leads to a statistically insignificant 0.4 percentage increase in home prices in the two years after the revised 2014 hazards are released. When there is a one unit increase in PGA risk, there is a positive, yet also statistically insignificant, increase in home values. As PGA is measured in g, the acceleration of gravity, a one unit increase means the county is susceptible to a potentially dangerous earthquake no matter the pre-2014 earthquake risk. Even in this extreme scenario, this appears to not decrease home values. To provide magnitudes closer to what is observed in the data, Table 1 shows that standard deviation of the difference in earthquake risk is 0.029g between 2014 and 2008. An increase of 0.029g in the county's earthquake risk is associated with a statistically insignificant near zero increase — 0.029×3 percent = .087 percent — in county home values.

Regarding the effect of percentage changes in earthquake risk, Column (6) reports a coefficient of 0.002 when the log of earthquake risk is used as the main explanatory variable. Hence, a one percent increase in a county's earthquake risk leads in a 0.002 percent increase in home prices. However, the confidence interval places the estimate of the effect around zero.

To assess the effect of earthquake risk changes on other measures of housing, I use as outcomes the Zillow ZRI and median list price per square foot both measured in logs. Tables 4 and 5 show the estimation for each outcome, respectively. Regarding rents, an increase in earthquake risk or a percent increase in it has no statistically effect on rents as shown in Columns (2) and (6). When there is a one unit increase in PGA risk, there is a positive and statistically significant ten percentage point increase in home rents as shown in Column (4). As renters are not the house's equity holders and are potentially short-term residents they may ignore even more any changes in earthquake risk when considering their rent.

When I use the log median list price per square foot as an alternative for house value outcomes, estimation results show similar patterns as when I use the ZHVI as reported in 5. In preferred estimates accounting for state-time trends, when a county experiences an increase in earthquake risk there is a statistically insignificant 0.3% increase in median list prices per square foot as shown in Column (2). Column (4) and (6) show that a one unit increase in or one percent increase in PGA does not have a statistical significant impact on median list prices per square foot. Additionally, in all these cases, the effect of an increase in earthquake risk on median list prices per square foot cannot be rejected to be different than zero.

4.2 Parallel Trends

The results above indicate that counties that have large increases in earthquake risk when the 2014 Hazard Maps are updated do not appear to have different house values compared to counties that have smaller or even decreases in earthquake risk. A key assumption for the methodology used is that such information in the revised hazard maps is new and does not appear to be incorporated in housing values in any noticeable manner before the revisions. To do this, I construct a treatment and control group based on changes in earthquake risk in 2014 Hazard Maps compared to the 2008 Hazard Maps.

First, I define a county as treated if they have an increase in earthquake risk as measured by median PGA from 2008 to 2014. To account for time-varying local economic conditions, I residualize the main outcome, Log ZHVI, from the control variables as shown in Equation 1 but I omit the earthquake risk measure. I then calculate the average of the residuals by treated and control group. The plot of such averages is shown in the

the top panel of Figure 5. As an alternative definition of the treatment group, I use the top quartile of counties in terms of differences in median PGA from 2008 to 2014 as the treatment group while the counties in the bottom three quartiles are the control group.

In both definitions of treatment based on differences in earthquake risk over time, there appear to be no significant differences in house values in months leading up to the public release of the 2014 Hazard Maps. Both the average of the treatment group, with larger increases in earthquake risk, and the control group are close to zero and have large overlaps in their confidence intervals. When I define the treatment group as either counties with an increase in earthquake or in the top quartile of increases there is no significant change in housing values compared to the corresponding control group in July 2014 or closely around when the hazard maps are released or in the next following year. Only after a year and when the treatment group is defined as counties with an increase in earthquake risk there appears to be an increase in the average of the residualized log housing value for the treatment group. Even in this comparison, there is still a large overlap in the confidence intervals with the control group and shows that increased earthquake risk does not decrease housing values.

Similar patterns in pre-trends exist when I define treatment groups based on percentage changes in earthquake risk as measured by the median PGA from 2008 to 2014. In Figure 6 I show similar graphs as in Figure 5, where treatment groups are defined based on percent changes in earthquake risk as measured by median PGA from 2008 to 2014 instead of differences. The top panel shows the residualized log house value when the treatment group is defined as the counties that are above the median in percent changes in earthquake risk from 2008 to 2014 while the bottom panel shows it when the treatment group is defined as counties that are in the top quartile of percent changes in earthquake risk. Similar to patterns shown in Figure 5, in both definitions of treatment groups there is a similar near-zero pre-trend compared to the respective control group. The lack of differential pre-trends suggests that counties that experience higher increases in earthquake risk in 2014 do not show markedly long-run differences with counties with lower differences in earthquake risk before July 2014. In addition, the figures further suggest the release of the 2014 earthquake revisions is not associated with any significant changes in housing values between counties with high and low differences or percentage changes in earthquake risk.

4.3 Robustness Checks

Ex-ante Earthquake Risk

Counties that have a higher ex-ante earthquake risk can be more attentive to changes in the risk assessed to the area when the USGS updates their estimates. As these areas are already exposed to higher earthquake risk, such as counties in the West Coast, its housing market participants can be more aware of potential damages an earthquake can cause and more salient to any changes in that risk. To differentiate home value responses by ex-ante earthquake risk, I classify counties depending on their PGA risk as reported in the 2008 USGS Hazard Maps and prior to the 2014 update. According to USGS guidelines, a county with a PGA of 0.18g or above is at risk of an earthquake that at least can potentially cause moderate damages to construction.[7] I construct an indicator if the county is has a PGA of 0.18g or higher in the 2008 USGS Hazard Map. Therefore it is considered high-risk ex-ante before any new earthquake risk information is released with the 2014 USGS Hazard Map update.

To obtain differential effects that depend on a county being at risk ex-ante, I interact earthquake risk in the county with the indicator variable if the county was considered at-risk of an earthquake causing at least moderate potential damages to construction before the 2014 USGS Hazard Map update. I include this interaction variable in the following form:

$$\begin{aligned} Y_{ist} = &\alpha + \beta EarthquakeRisk_{ist} + \rho EarthquakeRisk_{ist} \times ExanteHighRisk \\ &+ \gamma X_{ist} + \delta_{st} + \eta_i + \epsilon_{ist} \end{aligned}$$

[7] More information in Wald et al. (2006)

The variable of interest to examine heterogenous effects is ρ. It shows any additional effect that changes in earthquake risk have on house values in counties that already had a high risk even before the revised seismic hazard maps were released.

Table 6 reports the impact of earthquake risk on home values by ex-ante earthquake risk. Estimates show that counties that have a high ex-ante earthquake risk do not respond to changes in earthquake risk differently than counties that had a low ex-ante earthquake risk. When measuring earthquake risk as an increase indicator, in levels or logs, the coefficient on the interaction term between earthquake risk and ex-ante risk is positive yet very close to zero and not statistically significant. These results suggest that there is no differential impact of earthquake risk on home values depending on a county's ex-ante earthquake risk.

Highest Earthquake Risk Increase

Increases in earthquake risk may impact house prices non-linearly. Increases in a county's underlying earthquake risk may only be salient to market participants when the increase is significantly higher than in other counties in the US. To estimate if only such extreme increases in earthquake risk impact house values, I construct an indicator if the difference or percentage change in earthquake risk from 2008 to 2014 in a county is in the top quartile among all counties in the US. As reported in Table 1, this would indicate that the county experienced an increase of at least 0.01g or 10.3% in earthquake risk from the 2008 to 2014 USGS Hazard Maps.

Table 7 shows estimates that test if only large increases in earthquake risk impact home values. When a county's increase in earthquake risk is in the top quartile with the revised 2014 USGS Hazard Map, there is a near zero (0.1%) effect on house prices. There also a near zero effect (-0.03%) on house values when the top quartile is defined by percentage changes in the seismic hazard maps among all US counties.

Earthquake Risk Increase to Potentially Dangerous

USGS guidelines (Wald et al., 2006) point out that an earthquake with a PGA of or above 0.18g can potentially lead to slight damages to construction. A PGA of or above 0.65g can lead to considerable damage in specially designed structures including partial collapse where buildings can be shifted off foundations. PGA movements of these magnitudes can especially lead to damages to housing properties or nearby public infrastructure that can lower housing value in the event they occur. Given these are USGA guidelines about how PGA is associated with structural damaging earthquakes, house prices can potentially respond to changes in earthquake risk only when a county's earthquake risk moves from below 0.18g to 0.18g or above, or from below 0.65g to 0.65g or above. It may be that changes in earthquake risk will not impact prices until this more relevant change places the county at risk of experiencing an earthquake that can cause at least moderate potential damages to construction when before it was not.

I construct two indicator variables to estimate the effect on house values of a county becoming at-risk of a structural damaging earthquake according to the USGS guidelines. In both indicator variables it is equal to zero for all counties before July 2014. The first variable equals one on July 2014 onwards if the county had an earthquake risk below 0.18g PGA before and increased to 0.18g PGA or above when the USGS released its revised hazard maps. The second variable equals 1 on July 2014 onwards if the county had an earthquake risk below 0.65g PGA before and increased to 0.65g PGA or above when the USGS released its revised hazard maps. These variables capture the effect reflected from USGS guidelines that define that the county is now at risk of experiencing an earthquake that could cause at least moderate potential damages to construction when before the 2014 USGS Hazard Map release it was not at risk to the same degree.

In Table 8, the first two columns show that the effect of a county becoming susceptible to an earthquake that can cause slight damages to construction when before the 2014 USGS Hazard Map it was not. The latter two columns show the effect of a county becoming susceptible to an earthquake that can cause considerable damage when before it was not. In my preferred estimates, when a county becomes susceptible to an earthquake that can cause slight damages to construction — PGA greater than 0.18g — the coefficient points to an effect that is 1 percent and very close to zero. When a county becomes susceptible to an earthquake that can cause considerable damages to construction — PGA greater than 0.65g — the coefficient shows a negative effect of 1 percent but close to zero as well. In both cases, the estimate is not statistically significant and it cannot reject the null that it is equal to zero as in previous robustness tests.

Increase in the Probability of Hazardous Earthquake

In all previous results, I have defined earthquake risk as the maximum PGA earthquake a county could experience with a probability of 2% in the next 50 years. Given the feature of the USGS hazard maps, I can also construct the probability of an earthquake of at least a certain PGA a county will experience in a certain time period using the 2008 and 2014 hazard maps. As in the previous section, I focus on PGAs of at least 0.18g or 0.65g as these represent thresholds the USGS provides as examples of earthquakes that can cause slight and considerable damage, respectively.

I calculate the difference in probabilities of a county experiencing an earthquake of a PGA that is at least 0.18g or 0.65g between 2008 and 2014 hazard maps. For each of the two fixed PGAs, I then create an indicator if the difference in probabilities is above the median across all counties. This variable intends to capture if house prices decrease in counties with the highest increase in probability to experience an earthquake that can cause slight or considerable damage when the hazard maps are updated in 2014 compared to the 2008 version.

Similar to the estimation for Table 6, I also construct classifiers if counties were already at high risk to experience damaging earthquakes with PGAs of 0.18g or 0.65g. Differences in a county's underlying probability to experience a damaging earthquake may only be relevant or salient if the county is already at high risk compared to other counties in the US. I classify a county to have an ex-ante high probability to experience a PGA of at least 0.18g or 0.65g if such probability is above the median across all probabilities listed for all counties in the 2008 USGS Hazard Maps. I interact this ex-ante classifier variable with the difference in probability to observe if there are additional effects of differences in probabilities on house values if the county already had a high probability of experiencing a damaging earthquake.

Table 9 shows the results of the effect on house values when earthquake risk is measured as differences in probability of experiencing a serious earthquake reported in the 2008 and 2014 hazard maps. The first two columns show the effect when considering differences in probability of a county experiencing an earthquake of at least 0.18g and the latter two show the effect for differences in probability of a county experiencing an earthquake of at least 0.65g. If a county is above the median in differences in probability to experience a 0.18g or 0.65g earthquake, there is no statistically significant effect on house values. Counties with an ex-ante high probability to experience an earthquake of those magnitudes do not show differential effect on their house values compared to counties with an ex-ante low probability.

5 Conclusion

Using earthquake revisions in the 2014 USGS Hazard Maps to the 2008 version, I find that differences in earthquake risk at the county level did not have an impact on home values. House values in a county do not decrease when there is an increase in earthquake risk as measured by an indicator, difference or percentage change in PGA comparing the information reported between the 2014 and 2008 seismic hazard maps. In robustness checks, I show that house values do not change when I focus on the largest increases in earthquake risk or respond differentially in counties that were at high-risk ex-ante.

A main limitation of this work is that it relies on a geographic aggregate measure of housing value and earthquake risk that can omit important differences within counties. Earthquake risk revealed by the earthquake hazard maps may need to be more precise to impact a house's value. I use the median earthquake risk of all geocoordinates that are in a county as my measure to avoid being susceptible to outliers. However, within county and with property level data, it could be possible to observe that prices do react to earthquake risk in properties close to the outlier PGA. In addition, the type of earthquake-resiliency construction a property has and insurance decisions can impact how the property value can change when there is new information about earthquake risk.

Broadly, the results in the paper show that not all information about earthquake risk is incorporated into housing values. Prior work has largely focused on certain areas that are at risk of earthquakes both in scale and frequency along with other specific information treatments about changes in underlying earthquake risk. This paper provides evidence that US housing market participants are inattentive to new information coming from the USGS through revisions in their hazard maps. The interplay of different earthquake information sources, when a source becomes salient and how to best ensure such relevant information is incorporated to prices is of interest for future work and policymakers.

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Figure 1: **2008 Earthquake Risk Map**. This figure shows earthquake risk by county in the US as reported by the 2008 USGS Hazard Map. Earthquake risk is measured as the maximum PGA the county will experience with a probability of 2% in the next 50 years. Maximum PGAs provided at the geocoordinates grid level in the 2008 USGS Hazard Map are summarized at the county level by the median PGA of all geocoordinates that are in the county.

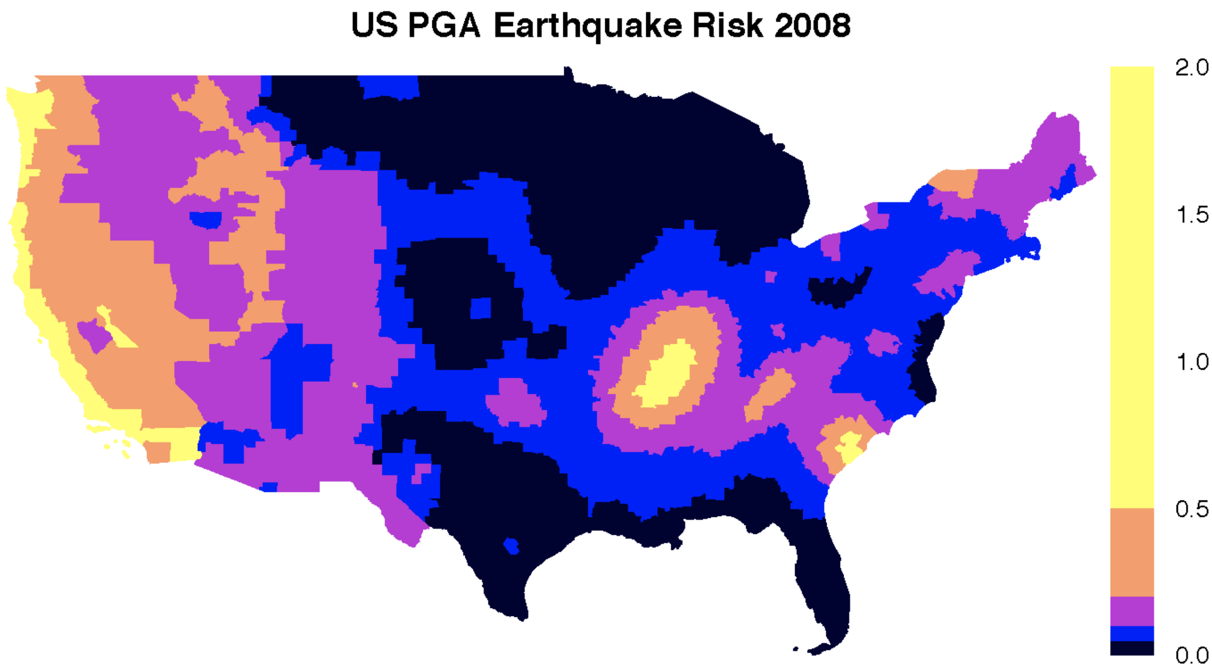

Figure 2: **2014 Earthquake Risk Map**. This figure shows earthquake risk by county in the US as reported by the 2014 USGS Hazard Map. Earthquake risk is measured as the maximum PGA the county will experience with a probability of 2% in the next 50 years. Maximum PGAs provided at the geocoordinates grid level in the 2014 USGS Hazard Map are summarized at the county level by the median PGA of all geocoordinates that are in the county.

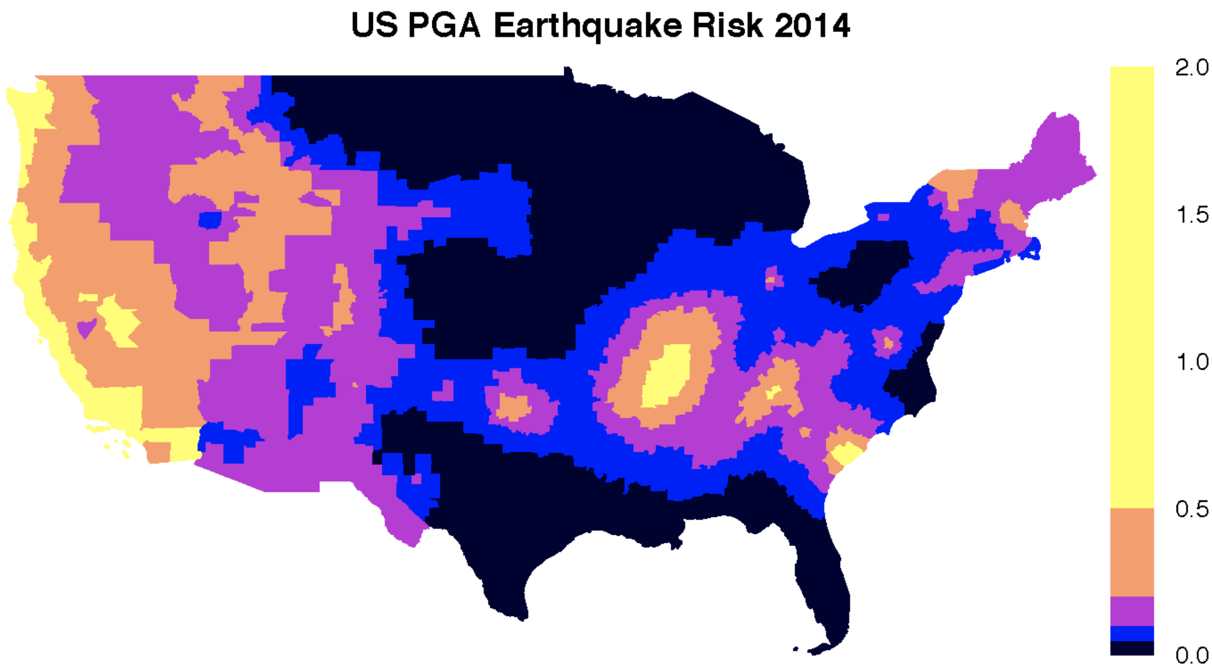

Figure 3: **Earthquake Risk Difference between 2014 and 2008**. This figure shows the difference in earthquake risk by county in the US between the 2008 and 2014 USGS Hazard Maps. Earthquake risk in each year is measured as the maximum PGA the county will experience with a probability of 2% in the next 50 years.

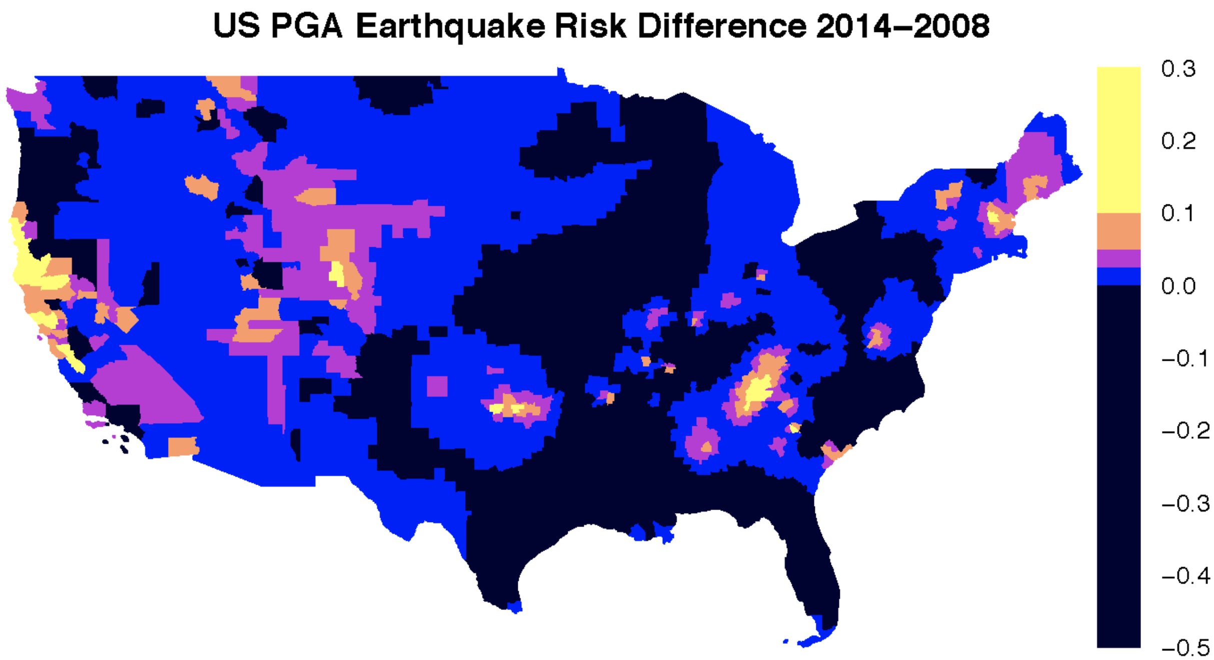

Figure 4: **Histogram Earthquake Risk**. This figure shows histograms count of earthquake risk by county in the US. Earthquake risk in each year is measured as the maximum PGA the county will experience with a probability of 2% in the next 50 years. The top panel shows the histogram for the difference in a county's earthquake risk between the 2014 and 2008 USGS Hazard Maps. The bottom panels shows the histograms for count earthquake risk in the 2008 and 2014 USGS Hazard Maps.

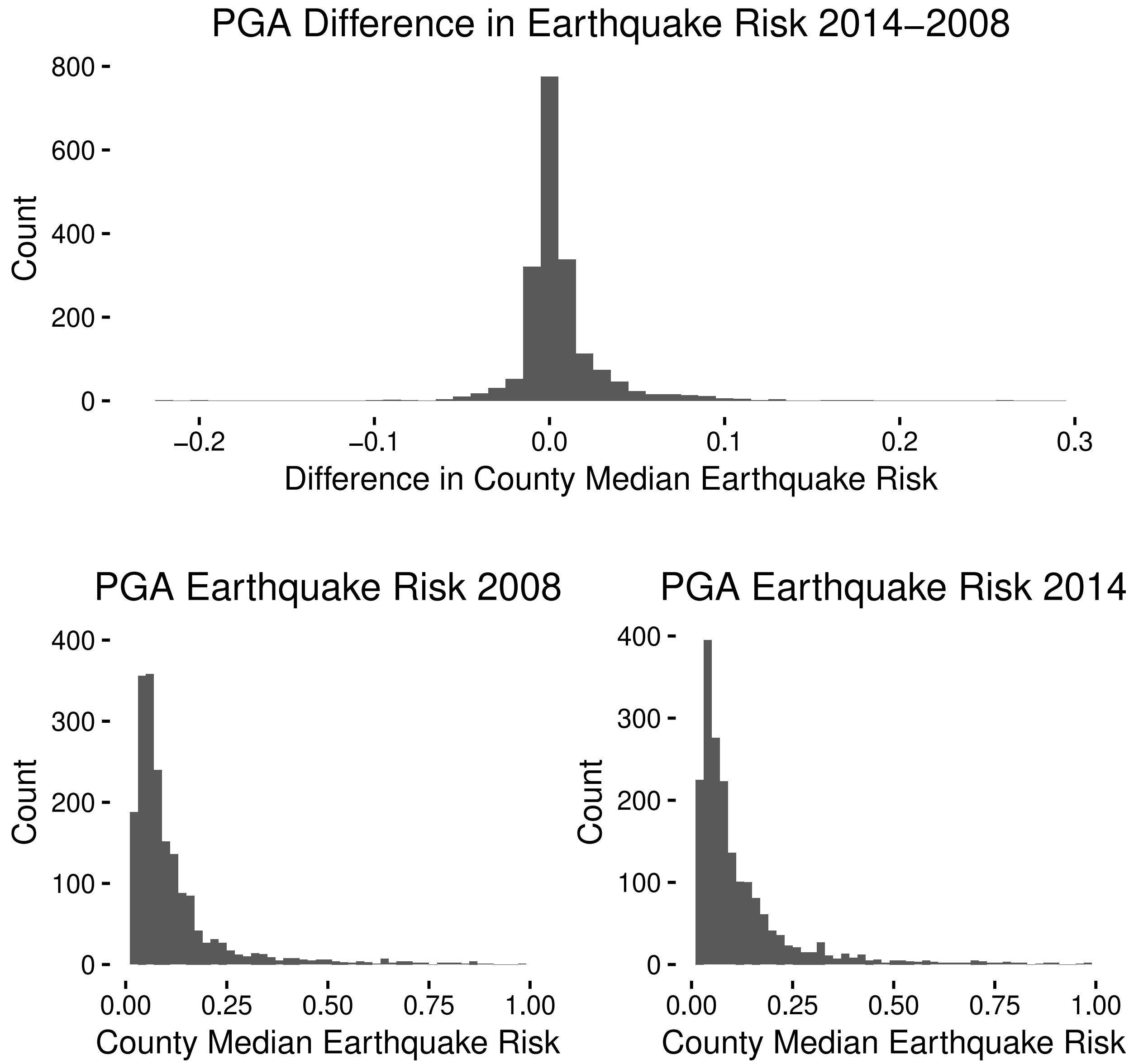

Figure 5: **Pre-trends Based on Differences in Earthquake Risk from 2008 to 2014.** Both panels in this figure show the residualized average of log home value following Equation 1 and omitting the earthquake risk measures. The top panel shows the average for counties that experience an increase in earthquake risk versus those that do not in the 2014 USGS Hazard Maps compared to 2008. The bottom panel shows shows the average for counties that experience an increase in earthquake risk in the top quartile versus those in the remaining bottom three quartiles.

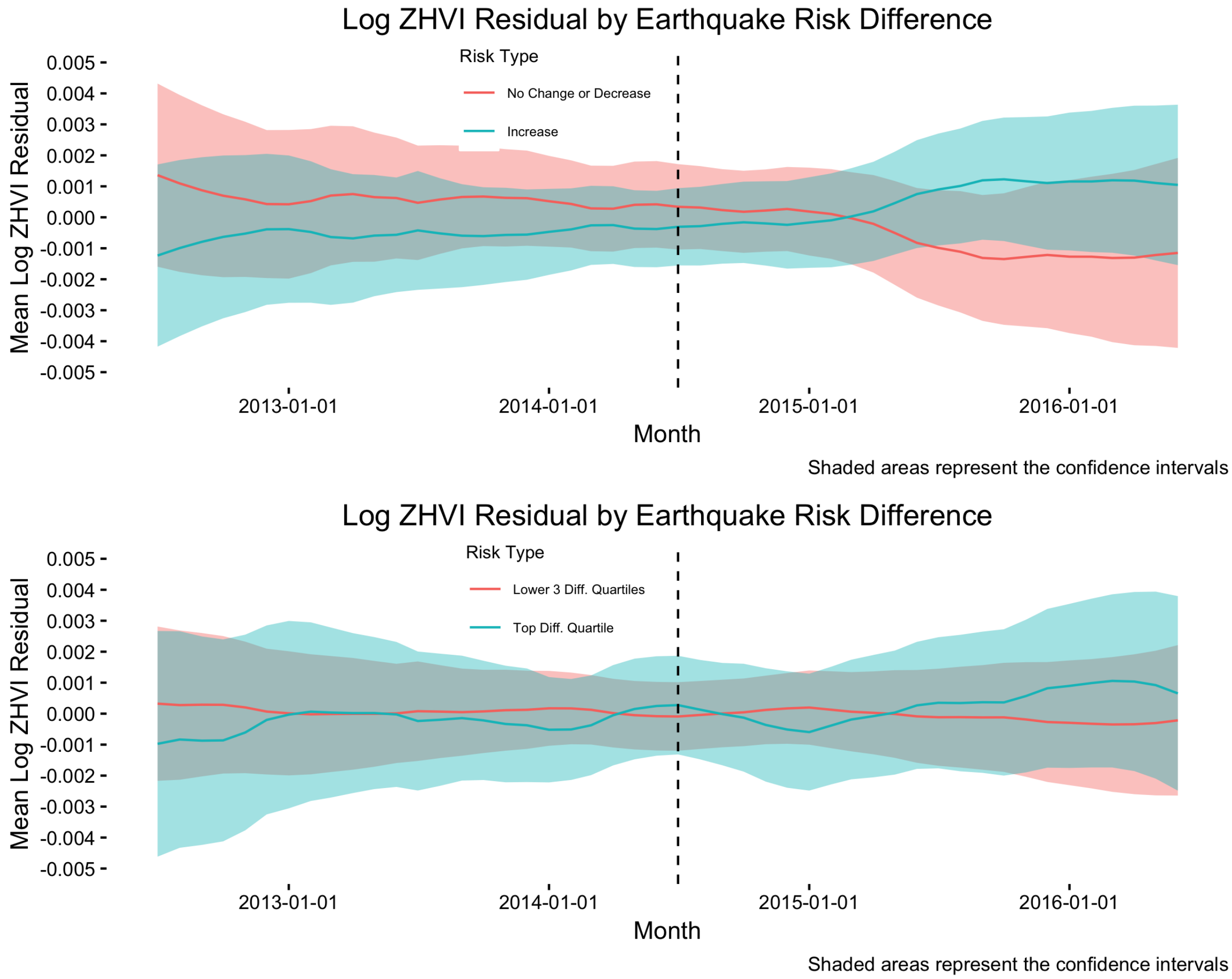

Figure 6: **Pre-trends Based on Percent Changes in Earthquake Risk from 2008 to 2014**. Both panels in this figure show the residualized average of log home value following Equation 1 and omitting the earthquake risk measures. The top panel shows the average for counties that experience a percentage change in earthquake risk above the median versus those below in the 2014 USGS Hazard Maps compared to 2008. The bottom panel shows shows the average for counties that experience a percentage change in earthquake risk in the top quartile versus those in the remaining bottom three quartiles.

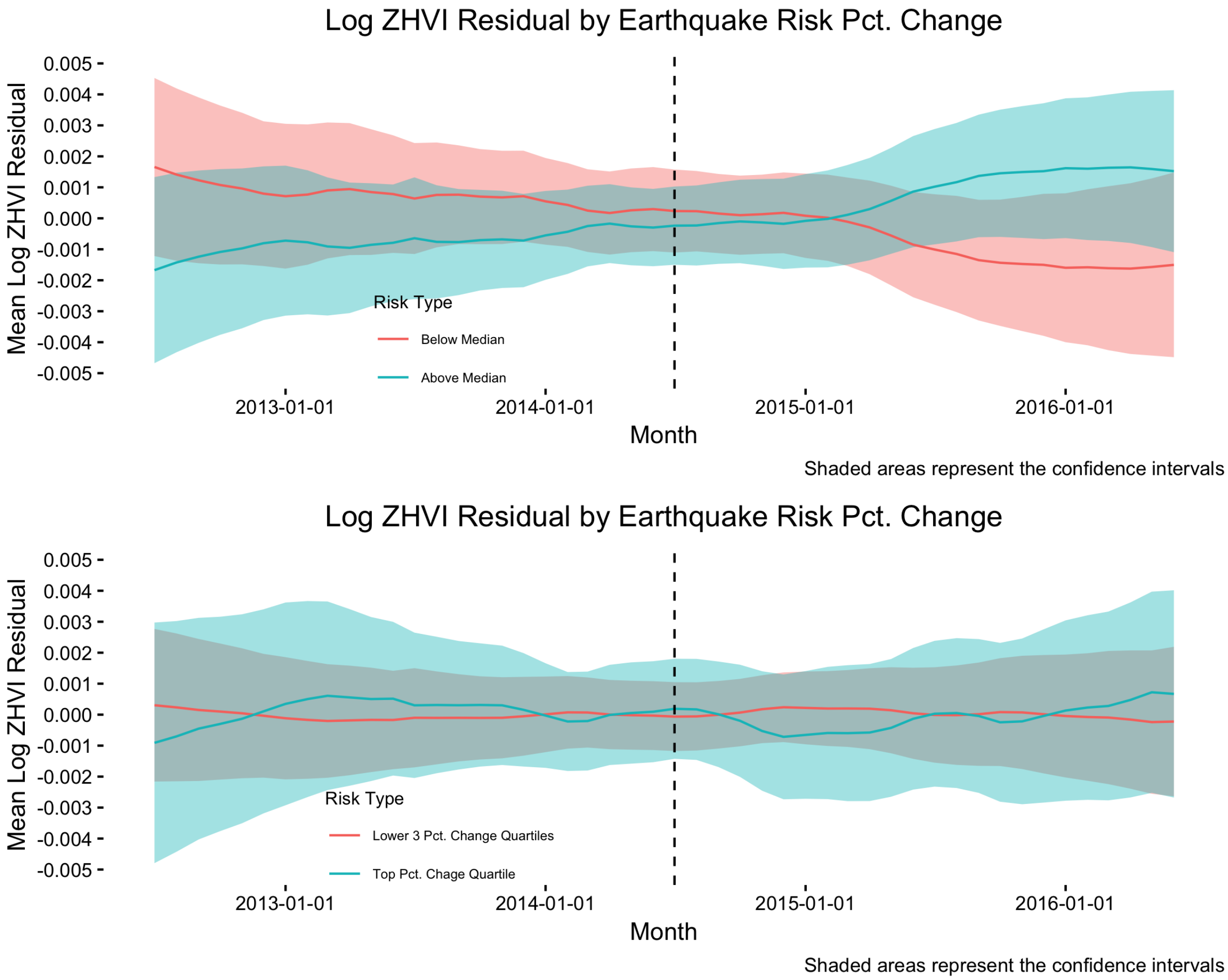

Table 1: **Summary Statistics**. This table reports summary statistics for the earthquake risk measured by USGS in 2008 and 2014. Earthquake risk in each year is measured as the maximum PGA the county will experience with a probability of 2% in the next 50 years. *Diff. PGA 2014-2018* and *Pct. Change. PGA 2014-2018* are the difference and percentage change in earthquake risk between the 2014 and 2008 USGS Hazard Maps. *Inc. PGA 2014-2018* is an indicator if the county has a increase in earthquake risk as reported in the 2014 and 2008 USGS Hazard Maps.

Statistic	N	Mean	St. Dev.	Pctl(25)	Median	Pctl(75)
PGA 2014	1,906	0.124	0.148	0.043	0.074	0.145
PGA 2008	1,906	0.119	0.143	0.047	0.073	0.130
Diff. PGA 2014-2018	1,906	0.005	0.029	−0.005	0.0005	0.010
Pct. Change PGA 2014-08	1,906	0.026	0.171	−0.080	0.010	0.103
Inc. PGA 2014-2018	1,906	0.524	0.500	0.000	1.000	1.000

Table 2: **Earthquake Risk Measure Predicts Future Earthquakes**. This table reports regression estimates of predicting subsequent large earthquakes with prior earthquake risk as measured by the 2008 USGS Hazard Maps. *Large Earthquake* is an indicator if the county experienced a significant earthquake after July 2008 as defined by the NOAA. *Earthquake Risk PGA* is the maximum PGA a county can experience with a probability of 2% in the next 50 years and updated in July 2008.

	Large Earthquake
Earthquake Risk PGA	0.07***
	(0.02)
Observations	1,906
R^2	0.01
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 3: **Regression Estimates**: House Value. This table reports regression estimates of the effect of earthquake risk on log home values. *Large Earthquake* is an indicator if the county experienced a significant earthquake risk since 2014. *Earthquake Risk PGA* is the maximum PGA a county can experience with a probability of 2% in the next 50 years and updated in July 2014. *Log(Earthquake Risk PGA)* is the log of Earthquake Risk PGA. Data restricted from July 2012 to June 2016. Control variables include annual log population, log median income, employment rate and college population share. Standard errors clustered by county are reported in parenthesis.

	Log(ZHVI)					
	(1)	(2)	(3)	(4)	(5)	(6)
Inc. Earthquake Risk PGA	0.01***	0.004				
	(0.003)	(0.003)				
Earthquake Risk PGA			0.23***	0.03		
			(0.05)	(0.04)		
Log(Earthquake Risk PGA)					0.02***	0.002
					(0.01)	(0.01)
Time FEs	X		X		X	
State-Time FEs		X		X		X
County FEs	X	X	X	X	X	X
Controls	X	X	X	X	X	X
Observations	91,146	91,146	91,146	91,146	91,146	91,146
Adjusted R^2	0.98	0.99	0.98	0.99	0.98	0.99

Note: *p<0.1; **p<0.05; ***p<0.01
SEs clustered by county.
Control variables include annual log population, log median income, employment rate and college population share

Table 4: **Regression Estimates: House Rent**. This table reports regression estimates of the effect of earthquake risk on log home rents. *Inc. Earthquake Risk PGA* is an indicator if the county experienced an increase in earthquake risk in the 2014 USGS Hazard Maps compared to 2008. *Earthquake Risk PGA* is the maximum PGA a county can experience with a probability of 2% in the next 50 years and updated in July 2014. *Log(Earthquake Risk PGA)* is the log of Earthquake Risk PGA. Data restricted from July 2012 to June 2016. Control variables include annual log population, log median income, employment rate and college population share. Standard errors clustered by county are reported in parenthesis.

	Log(ZRI)					
	(1)	(2)	(3)	(4)	(5)	(6)
Inc. Earthquake Risk PGA	0.01***	0.003				
	(0.003)	(0.003)				
Earthquake Risk PGA			0.17***	0.10**		
			(0.05)	(0.05)		
Log(Earthquake Risk PGA)					0.02***	0.01
					(0.01)	(0.01)
Time FEs	X		X		X	
State-Time FEs		X		X		X
County FEs	X	X	X	X	X	X
Controls	X	X	X	X	X	X
Observations	65,990	65,990	65,990	65,990	65,990	65,990
Adjusted R^2	0.97	0.98	0.97	0.98	0.97	0.98

Note: *p<0.1; **p<0.05; ***p<0.01
SEs clustered by county.

Table 5: **Regression Estimates: Median List Price by Square Foot**. This table reports regression estimates of the effect of earthquake risk on the log of median list price by square foot. *Inc. Earthquake Risk PGA* is an indicator if the county experienced an increase in earthquake risk in the 2014 USGS Hazard Maps compared to 2008. *Earthquake Risk PGA* is the maximum PGA a county can experience with a probability of 2% in the next 50 years and updated in July 2014. *Log(Earthquake Risk PGA)* is the log of Earthquake Risk PGA. Data restricted from July 2012 to June 2016. Control variables include annual log population, log median income, employment rate and college population share. Standard errors clustered by county are reported in parenthesis.

	Log(Med. Sq Ft. Price)					
	(1)	(2)	(3)	(4)	(5)	(6)
Inc. Earthquake Risk PGA	0.01	0.003				
	(0.003)	(0.004)				
Earthquake Risk PGA			0.16^{***}	-0.01		
			(0.05)	(0.04)		
Log(Earthquake Risk PGA)					0.02^{*}	0.01
					(0.01)	(0.01)
Time FEs	X		X		X	
State-Time FEs		X		X		X
County FEs	X	X	X	X	X	X
Controls	X	X	X	X	X	X
Observations	69,925	69,925	69,925	69,925	69,925	69,925
Adjusted R^2	0.98	0.99	0.98	0.99	0.98	0.99

Note: *p<0.1; **p<0.05; ***p<0.01
SEs clustered by county.

Table 6: **Regression Estimates by Ex-ante Earthquake Risk**. This table reports regression estimates of the effect of earthquake risk on home values by the county's earthquake risk prior to the 2014 USGS Hazard Map release. *Inc. Earthquake Risk PGA* is an indicator if the county experienced an increase in earthquake risk in the 2014 USGS Hazard Maps compared to 2008. *Earthquake Risk PGA* is the maximum PGA a county can experience with a probability of 2% in the next 50 years and updated in July 2014. *Log(Earthquake Risk PGA)* is the log of Earthquake Risk PGA. *Ex-ante High Risk* is an indicator variable if the county had a maximum PGA of 0.18 PGA or above in the 2008 USGS Hazard Maps. Data restricted from July 2012 to June 2016. Control variables include annual log population, log median income, employment rate and college population share. Standard errors clustered by county are reported in parenthesis.

	Log(ZHVI)					
	(1)	(2)	(3)	(4)	(5)	(6)
Earthquake Risk PGA	0.07	0.03				
	(0.09)	(0.08)				
...×Ex-ante High Risk	0.22^{**}	−0.01				
	(0.10)	(0.09)				
Log(Earthquake Risk PGA)			0.01	−0.0002		
			(0.01)	(0.01)		
...×Ex-ante High Risk			0.07^{***}	0.01		
			(0.02)	(0.02)		
Inc. Earthquake Risk PGA					0.01^{**}	0.004
					(0.003)	(0.003)
...×Ex-ante High Risk					0.03^{***}	−0.001
					(0.01)	(0.005)
Time FEs	X		X		X	
State-Time FEs		X		X		X
County FEs	X	X	X	X	X	X
Controls	X	X	X	X	X	X
Observations	91,146	91,146	91,146	91,146	91,146	91,146
Adjusted R^2	0.98	0.99	0.98	0.99	0.98	0.99

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
SEs clustered by county.

Table 7: **Regression Estimates: Large Increases in Earthquake Risk**. This table reports regression estimates of the effect of large increases in earthquake risk on home values 2014 USGS Hazard Maps compared to 2008. The main explanatory variables are indicator variables if the difference (*PGA Difference, Top Quartile*) or percentage change (*PGA Pct. Difference, Top Quartile*) in the county's earthquake risk is in the top quartile across all counties comparing the 2014 and 2008 USGS Hazard Maps. Data restricted from July 2012 to June 2016. Control variables include annual log population, log median income, employment rate and college population share. Standard errors clustered by county are reported in parenthesis.

	Log(ZHVI)			
	(1)	(2)	(3)	(4)
PGA Difference, Top Quartile	0.01***	0.001		
	(0.003)	(0.003)		
PGA Pct. Difference, Top Quartile			0.004	-0.0003
			(0.003)	(0.003)
Time FEs	X		X	
State-Time FEs		X		X
County FEs	X	X	X	X
Controls	X	X	X	X
Observations	91,146	91,146	91,146	91,146
Adjusted R^2	0.98	0.99	0.98	0.99
Note:	*p<0.1; **p<0.05; ***p<0.01			
	SEs clustered by county			

Table 8: **Regression Estimates by Earthquake Risk Becoming Potentially Dangerous**. This table reports regression estimates of the effect of a county that becomes susceptible to a construction-damaging earthquake on home values. *Earthquake Risk Now Dangerous in 2014* is an indicator if a county has an earthquake risk of 0.18g or above in the 2014 USGS Hazard Maps and was below 0.18g in 2008. emphEarthquake Risk Now Very Dangerous in 2014 is an indicator if a county has an earthquake risk of 0.65g or above in the 2014 USGS Hazard Maps and was below 0.65g in 2008. Control variables include annual log population, log median income, employment rate and college population share. Standard errors clustered by county are reported in parenthesis.

	Log(ZHVI)			
	(1)	(2)	(3)	(4)
Earthquake Risk Now Dangerous in 2014	0.001	0.01		
	(0.01)	(0.01)		
Earthquake Risk Now Very Dangerous In 2014			0.05*	−0.01
			(0.03)	(0.01)
Time FEs	X		X	
State-Time FEs		X		X
County FEs	X	X	X	X
Controls	X	X	X	X
Observations	91,146	91,146	91,146	91,146
Adjusted R^2	0.98	0.99	0.98	0.99
Note:	*p<0.1; **p<0.05; ***p<0.01 SEs clustered by county.			

Table 9: **Regression Estimates by Increase in Probability of Experiencing Damaging Earthquake**. This table reports regression estimates of the effect of an increase in the probability of county experiencing a construction-damaging earthquake on home values. *Above Median Diff. Prob. PGA .18* is an indicator if a county's difference in probability of experiencing an earthquake of at least 0.18g between the 2014 and 2008 USGS Hazard Maps is above the median across all counties. *Ex-ante High Prob. PGA .18* is an indicator if the county's probability of experiencing an earthquake of at least 0.18g is above the median across all counties in the 2008 USGS Hazard Map. *Above Median Diff. Prob. PGA .65* is an indicator if a county's difference in probability of experiencing an earthquake of at least 0.65g between the 2014 and 2008 USGS Hazard Maps is above the median across all counties. *Ex-ante High Prob. PGA .65* is an indicator if the county's probability of experiencing an earthquake of at least 0.65g is above the median across all counties in the 2008 USGS Hazard Map. Control variables include annual log population, log median income, employment rate and college population share. Standard errors clustered by county are reported in parenthesis.

	Log(ZHVI)			
	(1)	(2)	(3)	(4)
Above Median Diff. Prob. PGA .18	0.0004	−0.0000		
	(0.005)	(0.005)		
...×Ex-ante High Prob.	-0.01^{***}	0.004		
	(0.005)	(0.005)		
Above Median Diff. Prob. PGA .65			−0.01	−0.003
			(0.004)	(0.004)
...×Ex-ante Very High Prob.			-0.01^{*}	0.01
			(0.004)	(0.004)
Time FEs	X		X	
State-Time FEs		X		X
County FEs	X	X	X	X
Controls	X	X	X	X
Observations	91,146	91,146	91,146	91,146
Adjusted R^2	0.98	0.99	0.98	0.99

Note: *p<0.1; **p<0.05; ***p<0.01
SEs clustered by county