Master's Thesis

Effects of High Magnitude Earthquakes: Change in Implicit Price of Earthquake Risk and the Reaction of Real Estate Market and Municipalities

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Abstract

Earthquakes are an undeniable reality in Japan. However, it is not always the case that individuals price earthquake risk correctly. In this analysis, I observe the implicit price of earthquake risk under a big information shock, which is massive earthquake instances. I use hedonic price model with DID framework to estimate the marginal willingness to pay for earthquake risk and how it changes after an earthquake. I also employ 2SLS regression to address the shortcomings of using objective risk measures as a proxy for subjective risk perception. My study shows evidence that properties in the earthquake zone are sold at a discount, and the negative implicit price for earthquake risk decreases even more after an earthquake. The most probable explanation for the decrease in the implicit price of earthquake risk after an earthquake is that individuals underestimate the earthquake risk unless they receive an information shock. The second analysis of the paper shows how the properties in the real estate market change in reaction to high-magnitude earthquakes by using DID setting. The analysis shows the overall effect of high-magnitude earthquakes on the composition of the real estate market depends on the earthquake risk of the region. I also analyse how municipalities react to massive earthquakes by analysing their yearly budgets. I use interaction-weighted event study setting to overcome the treatment effect heterogeneity and contamination of even study coefficients. My results provide evidence that after a high-intensity earthquake, municipalities react by increasing their economic activity as both their expenditures and revenues increase significantly.

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1 Introduction

Japan is one of the most natural disaster-prone regions in the world, especially earthquakes and tsunamis. Situated along the Pacific Ring of Fire, an area characterized by intense seismic activity, Japan experiences a significant number of earthquakes each year. In fact, according to Japan Meteorological Agency (JMA), in the 20-year period starting in 2000, a staggering 1814 earthquakes with a magnitude of 4 or higher on the Shindo scale were recorded in the Japanese region. Such frequent seismic events have significant implications for various aspects of Japanese society, including the real estate market.

Natural disasters impact economies through various channels. In her paper, Deryugina (2017) studies the fiscal cost of hurricanes between 1979 and 2002 in the US through both direct costs (disaster aid) and indirect costs (social safety net programs). Her results show that during her study period, an additional $155 to $160 per capita was allocated through disaster aid programs per hurricane. She also shows that considering only direct costs would lead to a significant underestimation of the fiscal cost of hurricanes. In addition to direct costs, an additional $780 to $1,150 per capita was allocated through non-disaster social insurance throughout the following 10 years after a hurricane.

In the literature, both the magnitude and the direction of the effect of natural hazards on the real estate market are ambiguous. Wang (2017) employs spatial difference in difference model based on floodplain boundary discontinuity to observe the effect of change in flood risk on full-time single-family residential (SFR) property prices in Juniata County and Perry County, two neighboring counties in Pennsylvania. The paper's results show every 1 percent increase in flood risk decreases SFR property prices by 5 to 6 percent at the location of interest. In their paper, Indaco et al. (2019) compare trends in both house prices and sales activities for properties on the floodplain to properties located in the same area but not on the floodplain for Virginia Beach and Miami Beach. In contrast with the results of Wang (2017), their results show no evidence of discounted prices or lower sales activity for floodplain properties.

There are also a few studies that specifically study the implicit price of earthquake risk. Nakagawa et al. (2007) study Tokyo Metropolitan Area between the years 1980 and 2001 and presents an 8% discount for lands located in earthquake-prone areas compared to lands located in safe regions. Brookshire et al. (1985) study single-family residences located in San

Francisco Bay and Los Angeles County area in 1978 to evaluate the expected utility model by using earthquake risk. Their study shows properties located in Special Study Zones (SSZ), which are designated areas of high earthquake risk, are sold at a $2,490 discount in San Francisco Bay area and a $4,650 discount in Los Angeles County compared to identical houses located outside of SSZ.

People's understanding of natural hazards is not always in line with objective risk measures at a given time. Individuals can simply overestimate or underestimate the actual natural disaster risk they are facing. One obvious shortcoming of estimating the implicit price of the risk they perceive is that the risk perception of individuals is usually not available to be observed and measured. The usual underlying assumption in papers that study the economic effects of natural hazards is that objective risk measures are valid proxies for people's subjective risk perception in the estimation of the implicit price of natural hazards.

Assuming the initial subjective risk perception of the individuals is different than objective risk measures and individuals' risk aversions are constant, an information shock at a given time can reduce the gap between subjective risk perception of individuals and objective risk measures and thus might significantly change how people behave under the same objective risk measures. The most probable explanation for a change in implicit price in the presence of an information shock is that people misestimate the natural hazards unless an information shock occurs. This means the change in the implicit price of objective risk measures after an information shock would capture the effects due to the changes in individuals' subjective risk perception.

However, the same difference is also one of the common issues in trying to capture the discount in property prices associated with any natural hazard. The systematic difference between the actual risk of natural disasters and the individuals' subjective perception of risk, which is called transformation bias and information bias, might lead to faulty implicit price estimates of natural hazards, according to Kask and Maani (1992). In this study, I carefully examine why using objective risk measures might lead to faulty estimation of the implicit price of natural hazards and how one can overcome this issue.

In the real world, actual natural disasters usually act as big information shocks. Similar to the implicit price of natural hazards, the magnitude and direction of the changes in the implicit price of natural hazards in the presence of an information shock are also ambiguous. Bin and Landry (2013) study changes in the implicit price of flood risk after a major storm event, using Hurricane Fran and Hurricane Floyd in difference in difference framework. Prior to Hurricanes Fran and Floyd, they find no initial price difference between properties in flood zones and those outside of them in Pitt County, North Carolina. However, they also found that after the hurricanes the implicit price of hurricane risk was reduced by 5.7% and 8.8% after Hurricane Fran and Floyd respectively. On the other hand, Beron et al. (1997) reaches different results while studying the effects of the Loma Prieta Earthquake in Kern County, California. They compare the prices of residential properties before and after the devastating earthquake and discover that the implicit price of living in SSZ increased from $\$-11,800$ to $\$-8,800$ after the disaster. They draw the conclusion that people overestimated the risk of earthquakes before Loma Prieta and adjusted their perception in response by decreasing it after the earthquake. Naoi et al. (2009), which is the most similar to this paper in terms of empiric methods, uses hedonic price analysis to obtain the implicit price of earthquake risk after a major earthquake in Japan. The authors' main results show no prior significant discount for the properties located in high earthquake-risk regions compared to the properties in safe regions; however, contrary to the results of the Beron et al. (1997), the post-earthquake period shows a significant decline in the implicit price of earthquake risk as in a given post-earthquake year, a 0.2% rise in annual earthquake risk results in a 3.8 million ¥ discount on house values and a 10,000 ¥ discount on rents.

I contribute to the outstanding literature by first showing how individuals respond to high-magnitude earthquakes in their valuation of real estate conditioned on the earthquake risk of the property in Japan. As previously mentioned, there are similar papers that study the implicit price changes of earthquake risk in the real estate market in the event of massive earthquakes, such as Naoi et al. (2009). However, Naoi et al. (2009) contains only 4944 houses from the Keio Household Panel Survey (KHPS), which does not contain house sales but only self-valuation of the owner of the property. In this study, I use actual real estate transaction data from Japan, which contains over 500,000 condominium and 1,000,000 building transactions between the years 2008 and 2020, to estimate both the implicit price of earthquake risk in the real estate market and its change after a high-intensity earthquake. I also differentiate my analysis between condominiums and buildings, unlike Naoi et al. (2009), estimating different implicit prices and implicit price changes of earthquake risk for both. Finally, while they use earthquakes with an intensity equal to or higher than 6^{-} as a threshold, they also annualize the 30-year earthquake risk measures, assuming the risk is equal every year in 30 year period. I use 5^+ earthquakes as the threshold for information shock, as they are strong enough to push people to alter their behavior in the following years. I also use 30-year risk measures as they are, as people usually make their real estate purchase decisions not only considering the year of the purchase but also the upcoming years, which makes the interpretation of our estimates slightly different.

I employ a simple hedonic price regression model with DID framework for estimating the change in the implicit price of earthquake risk after a high-magnitude earthquake. The results of my main analysis show that while marginal willingness to pay for earthquake risk is already significantly negative prior to the earthquake for both condominiums and buildings, it decreases even more after a massive seismic activity. The most probable explanation for the effect is even if individuals have some understanding of earthquake risk, they probably underestimate it until an earthquake happens. In my analysis, I also show that the overall effect of high-magnitude earthquakes is different for regions with low earthquake risk and regions with high earthquake risk. High-magnitude earthquakes have a positive effect on property prices in low earthquake risk regions, however, they have a decreasing effect on property prices in high earthquake risk regions. Then I continue with addressing transformation and information bias by employing a 2SLS regression setting, introducing an instrument to overcome the difference between objective risk measures and subjective risk perception of individuals.

In the second analysis of the paper, I use DID framework to observe how both the number of property sales and the characteristics of the sold properties react to a high-magnitude earthquake. I show that high-magnitude earthquakes have an increasing effect on the ages of the properties in the real estate markets in low earthquake risk regions, while they have the opposite effect in regions with high earthquake risk. I also show that massive earthquakes have a decreasing overall effect on the number of rooms in condominiums in the real estate market in low earthquake risk regions while having an increasing overall effect in high earthquake risk regions. I also show the effects of high-magnitude earthquakes on sales volume and the area of condominiums and buildings, however, the results are not robust to different specifications, and thus not generalizable.

I also contribute to the literature by estimating how municipalities react to a high-magnitude earthquake. I use event study setting to estimate the response of municipalities to a massive earthquake. In particular, I use interaction-weighted estimator introduced by Sun and Abraham (2021) to address the heterogeneity in treatment effect among different cohorts of municipalities, which may result in contamination of event study coefficients and misleading average treatment of the treated estimations as well as invalid parallel trend checks. My study shows municipalities respond to earthquakes by increasing their budgets as both their expenditures and revenues increase immediately after such a catastrophe. As expected, disaster relief expenditures increase immediately after the event and persist over years, followed by an increase in civil engineering and dwelling expenditures starting a year after the event and an increase in road and bridge expenditures starting two years after the event. On the revenue side, while property income and rent and fee revenue decrease after an earthquake, local tax allocation, prefecture, and treasure disbursements increase, which leads to a significant increase in total revenues.

This paper is structured as follows. In section 2 I describe the various data sources that I use for my analysis and present some descriptive statistics that are applicable to the context of the analysis. Then I continue with explaining the empirical models that my analysis is based on, possible shortcomings of the presented models, and my approach to overcoming these issues in section 3. In section 4 I conduct my quantitative analysis and present my empiric findings and interpretations of the results. Finally, in section 5 I summarize the general findings of the paper and discuss possible extensions.

2 Data

2.1 Earthquake risk and history

I obtain earthquake history data from the JMA website. JMA measures and stores the records of all readings across Japan for all earthquakes in the Japanese region. In addition to the Richter scale, they also measure earthquakes on their own unique scale called JMA Seismic Intensity Scale (Shindo scale). Shindo is a 10-level scale of the ground motion caused by earthquakes, from the lowest possible level 0 to the maximum level 7, with double measures for 5 and 6 (5^-, 5^+, 6^-, and 6^+).

Shindo magnitudes are calculated by the seismic intensity meters, which are installed on the first floor or ground floor of buildings. The main difference of the Shindo scale, which makes it easier and better to use in this paper's setup, is that Shindo is a scale of the actual motion that happened at a certain location for all locations that are somewhat affected by the earthquake, rather than the magnitude of the earthquake itself at the epicenter of the earthquake, which means, in contrast to the Richter scale, there are multiple location-specific Shindo measures of a given earthquake that vary across locations. This also means an earthquake with a higher magnitude on the Richter scale can have a lower Shindo level compared to an earthquake with a lower magnitude on the Richter scale because the ground motion that an earthquake creates at a certain location also depends on the earthquake's attributes, such as the depth of the earthquake or location-specific attributes including the ground type and distance to the epicenter.

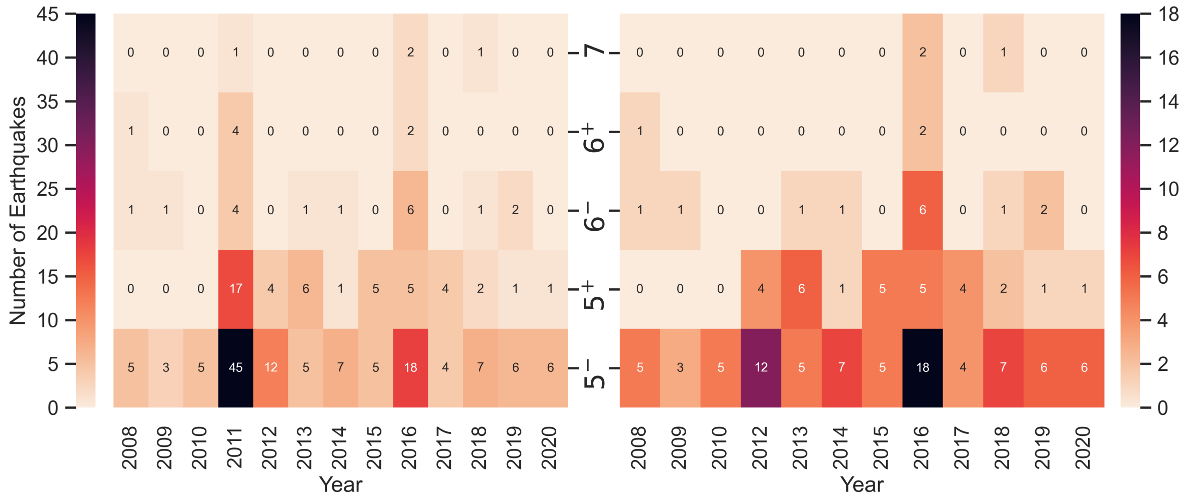
I extracted all measured Shindo intensities from JMA Earthquake Database[1] for earthquakes that have at least one 5^- or higher intensity measured between 2008 and 2022. For most of the municipalities, there are multiple Shindo measures. I aggregated Shindo measures to the municipality level as the maximum Shindo scale measured in a municipality.

Between the years 2008 and 2020, there had been 132 earthquakes with a maximum intensity of 5^- on the Shindo scale and 51 earthquakes with a maximum intensity of 5^+. A total of 212 earthquakes with an intensity equal to or higher than 5^- occurred during the period. Figure 1a shows the yearly distribution of earthquakes throughout the period. 2011 was the most seismically active year for Japan for this period, with a total of 70 earthquakes with

[1] https://www.data.jma.go.jp/eqdb/data/shindo/

Figure 1: Yearly number of earthquakes

(a) With 2011 (b) Without 2011

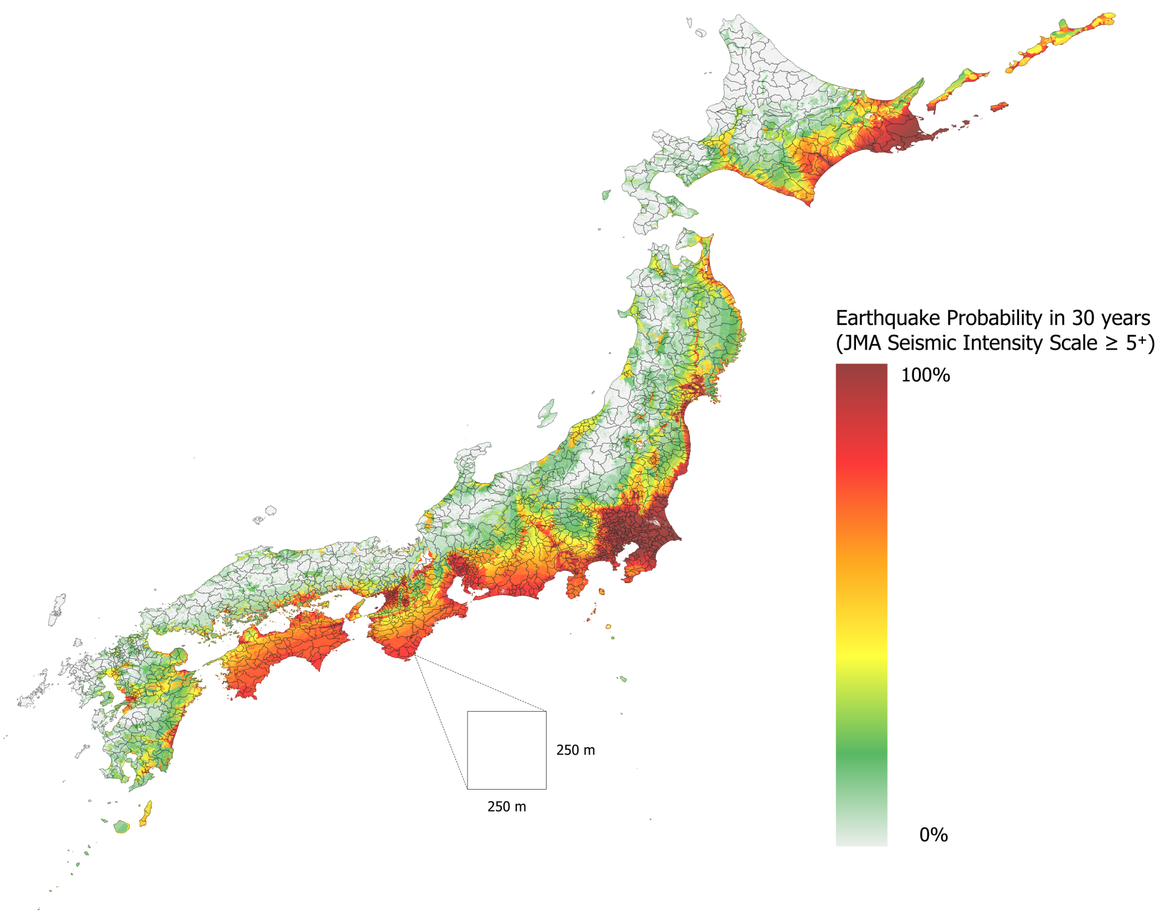


an intensity equal to or higher than 5^-. Figure 1b omits the year 2011 in order to make the variation between other years more visible. I use earthquakes with an intensity equal to 5^+ as a threshold for information shock for the hedonic price analysis and all earthquakes with an intensity equal to or higher than 5^+ as the treatment for DID setting as they occur often enough during the period and are also strong enough to possibly affect both economic outcomes and provoke people to respond. I also use both 5^+ and 6^- intensity as the threshold to analyse how municipalities react financially to earthquakes with an intensity equal to or higher than the threshold.

To identify earthquake risks for municipalities, I used probabilistic seismic hazard maps (PSHM) published by Japan Seismic Hazard Information Station (J-SHIS) based on the research products of National Research Institute for Earth and Science and Dsaster Prevention (NIED) (2023). J-SHIS publishes yearly updated earthquake hazard maps starting in 2008 for 250 × 250 meter mesh codes. PSHM contains the probability of an earthquake with an intensity equal to or higher than a certain threshold (5^-, 5^+, 6^-, and 6^+ on the Shindo scale) within 30 years. Figure 2 shows 2022 probability of an earthquake with an intensity of 5^+ or higher within 30 years. In the period of interest of the paper, the only year without a PSHM publication from NIED is 2015. I use the 2014 earthquake risk measures for 2015 as it is the most recent previous study.

I link earthquake risk information for 250 km^2 areas with Japanese municipalities by using a geographic information system (GIS). I aggregate the data and created a municipality-level earthquake risk by taking the mean of all the 250 km^2 meshes that are contained by the municipality. I also calculated the standard deviation of the earthquake risk of the 250 km^2 meshes inside municipalities to use it as an instrument to address the difference between individuals' earthquake risk perception and objective risk measures.

Figure 2: Japan probabilistic seismic hazard map - 2022



2.2 Real estate transactions

To conduct the analysis of this paper, I create a data set of real estate transactions and earthquake occurrences. The main data of the hedonic price analysis of this paper is Real Estate Transaction-price Information (RETI) data from Japan. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) publishes quarterly real estate price information of transactions at municipality level to ensure the transparency and accurate information of real estate markets (The Ministry of Land, Infrastructure, Transport and Tourism; 2023). MLIT conducts a questionnaire survey with the involved individuals after a transaction is realized. All data from RETI is anonymized and consists of transaction price and quarter, property characteristics, such as total floor area, construction year, and number of rooms, which allows running a hedonic price analysis.

The RETI data consists of both building and condominium transactions. To eliminate outliers from the analysis, I excluded the top and bottom 2.5 percentiles from both condominium and building datasets after omitting incomplete records. In the final version, the condominium dataset consists of 516,938 condominium transactions between 2008 and 2020 from 563 municipalities across all 47 prefectures, which had a total population of 90,736,887 and accounted for approximately 72 percent of Japan's total population in 2020 according to the latest census. 472,925 sold condominiums in the dataset are used as houses. In addition to condominium transactions, the data also contains 1,095,848 building transactions from 1485 of a total of 1831 municipalities in the period of interest. Of these 1,095,848 building transactions, 1,020,567 are sold as houses[2].

Table 1 and Table 2 show the descriptive statistics of the transaction dataset that is used for the paper's analysis. The mean condominium sales price is 21,496,350 ¥ with a maximum sales price of 67,000,000 ¥ and a minimum sales price of 2,700,000 ¥. The average condominium age that is sold in this period is 18.45 and it has 3.44 rooms on average with an average of 58.63 m^2 area. Most of the condominiums are within 0 to 10 minutes distance to the nearest station and have either or both steel frame-reinforced concrete or reinforced concrete structures. The mean and median sales prices for buildings are 27,657,075 ¥ and 18,000,000 ¥ respectively. The maximum building sales price in the dataset is 120,000,000 ¥ and the minimum sales price for buildings is 2,400,000 ¥. The average building that is sold during the period is 16.23 years of age with an average of 212.88 m^2 area. Most of the buildings are within 15-30 minutes distance to the closest public transportation station. Finally, buildings almost exclusively have Wooden structures.

As previously discussed, 2011 was one of the most seismically active years in Japan. Columns

[2] Table 13 and Table 14 in the appendix show the descriptive statistics of condominiums and buildings that were sold as houses between 2008 and 2020

Table 1
Yearly real estate transactions statistics

Year	Condominiums				Buildings			
		Price (Million ¥)				Price (Million ¥)		
	Sold	Mean	Median	Std. Dev.	Sold	Mean	Median	Std. Dev.
2008	32,534	20.073	18.000	12.307	72,075	27.921	25.000	19.202
2009	36,483	20.001	18.000	12.212	72,233	26.719	24.000	18.241
2010	40,982	20.310	18.000	12.434	79,295	26.955	25.000	18.163
2011	37,810	19.949	18.000	12.361	76,865	26.846	24.000	18.204
2012	38,478	19.471	17.000	12.058	83,577	26.695	24.000	18.327
2013	42,187	19.877	18.000	12.351	88,992	27.031	24.000	18.637
2014	40,396	20.435	18.000	12.542	86,510	27.149	24.000	19.379
2015	42,432	21.201	19.000	12.883	91,180	27.567	24.000	19.721
2016	42,581	21.981	20.000	13.205	89,125	28.127	25.000	20.230
2017	40,603	22.580	20.000	13.273	88,754	28.349	25.000	20.286
2018	39,147	23.390	21.000	13.511	85,512	28.456	25.000	20.494
2019	39,733	24.066	22.000	13.774	83,940	28.421	25.000	20.282
2020	43,572	24.536	22.000	13.822	96,425	28.895	26.000	19.666
Total	516,938	21.426	19.000	12.970	1,094,483	27.657	25.000	19.367

Notes: This table presents the descriptive statistics of the yearly condominium and building transactions of this paper's sample obtained from Real Estate Transaction-price Information (RETI).

two and three at the Table 2 show the average characteristics of the condominiums and buildings that were sold during the prior 2 years, which were relatively stagnant in terms of seismic activity with only 1 earthquake with an intensity equal to or higher than 5^{+}, and the following 2 years of Great East Japan Earthquake.

2.3 Municipality level information

Finally, to be used in all analyses of the paper, I obtain municipality attributes from the Statistics Bureau of Japan, The Portal Site of Official Statistics of Japan website (2023) (e-stat). I used the attributes that are available every year as they are, while I imputed the ones that are only available every five years.

Municipality-level population data are available at every census year.[3] For the years between the two censuses, I imputed population data for all municipalities. Given that Japan's pop-

[3]Population censuses are conducted every five years in Japan. The last census was in 2020.

Table 2
Yearly condominium and building attributes statistics

Variables	2008-2020		2009-2010		2011-2012	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Condominiumns						
Real Estate Sales Price	21.426	12.970	20.165	12.330	19.708	12.212
Age of Property	18.41	11.65	14.47	10.72	16.60	10.77
Area (m^2)	58.63	22.72	60.67	21.72	60.22	22.32
Nearest Station 0-5 min (=1)	0.228	0.420	0.213	0.410	0.220	0.414
Nearest Station 5-10 min (=1)	0.346	0.476	0.330	0.470	0.341	0.474
Nearest Station 10-15 min (=1)	0.198	0.398	0.202	0.401	0.195	0.396
Nearest Station 15-30 min (=1)	0.170	0.376	0.189	0.391	0.181	0.385
Nearest Station 30-60 min (=1)	0.051	0.220	0.059	0.236	0.055	0.227
Nearest Station 1-1.5 h (=1)	0.005	0.074	0.006	0.076	0.006	0.078
Nearest Station 1.5-2 h (=1)	0.001	0.031	0.001	0.029	0.001	0.035
Nearest Station 2+ h (=1)	0.001	0.032	0.001	0.029	0.001	0.035
Number of Rooms	3.44	0.98	3.55	0.96	3.51	0.96
Reinforced Concrete (=1)	0.703	0.457	0.698	0.459	0.698	0.459
Steel Frame Reinforced Concrete (=1)	0.293	0.455	0.297	0.457	0.297	0.457
Steel Frame (=1)	0.006	0.077	0.006	0.075	0.006	0.079
Buildings						
Real Estate Price (Million ¥)	27.657	19.367	26.843	18.200	26.767	18.268
Age of Property	16.23	16.73	14.27	14.64	14.94	15.44
Area (m^2)	212.88	202.31	207.09	193.76	209.37	200.78
Nearest Station 0-5 min (=1)	0.055	0.228	0.054	0.226	0.056	0.230
Nearest Station 5-10 min (=1)	0.175	0.380	0.171	0.377	0.171	0.376
Nearest Station 10-15 min (=1)	0.184	0.387	0.182	0.386	0.183	0.387
Nearest Station 15-30 min (=1)	0.326	0.469	0.325	0.468	0.327	0.469
Nearest Station 30-60 min (=1)	0.182	0.386	0.187	0.390	0.184	0.387
Nearest Station 1-1.5 h (=1)	0.048	0.214	0.051	0.220	0.049	0.216
Nearest Station 1.5-2 h (=1)	0.016	0.127	0.017	0.128	0.016	0.127
Nearest Station 2+ h (=1)	0.013	0.115	0.013	0.113	0.013	0.114
Reinforced Concrete (=1)	0.033	0.179	0.034	0.180	0.034	0.181
Steel Frame Reinforced Concrete (=1)	0.002	0.048	0.003	0.054	0.003	0.051
Steel Frame (=1)	0.077	0.266	0.098	0.297	0.072	0.259
Light Steel Structure (=1)	0.063	0.243	0.044	0.205	0.072	0.258
Concrete Block (=1)	0.002	0.047	0.002	0.046	0.002	0.047
Wooden (=1)	0.829	0.376	0.827	0.378	0.824	0.381

Notes: This table presents the descriptive statistics of various real estate characteristics of the paper's sample for three different time periods. 2008-2020 is the full period of the paper. The second column shows the 2-year period prior to the Great East Japan Earthquake, and the last column shows the following 2-year period.

ulation is consistent over the years between 2005 and 2020, I impute population values for missing years by assuming all the years between the two censuses have the same population growth rate. Growth rates between two census years are calculated in a way that the population increase rate equal to the calculated growth rate in each year between censuses will lead the population of the first census to the population of the next census in the next census year.

$$Pop_{i,cen_2} = Pop_{i,cen_1} \times (1 + g_{i,cen_2,cen_1})^{(cen_2 - cen_1)} \tag{1}$$

Equation 1 shows how the population imputations are conducted. $Pop_{i,cen2}$ is the population in a given census year in municipality i. cen_1 is the year of the initial census, and cen_2 is the year of the next census. g_{i,cen_2,cen_1} is the growth rate in the years between cen_1 and cen_2 for municipality i.

Similar to the population data, municipality-level information on the number of employed and unemployed people is also only available every census year and only yearly for prefectures. However, the unemployment rates are more sensitive to yearly shocks compared to the population, which might make imputation with the same method misleading. Thus, I impute the unemployment rate conditioned not on the unemployment rates at the two censuses, but on the unemployment performance against the prefecture that the municipality is part of. The unemployment performance of a municipality against its prefecture in a given census changes constantly every year in a way that the change will lead the unemployment performance of the municipality to its actual performance at the next census.

$$Unemp_{i,t} = \left(\frac{Unemp_{i,cen_1}}{Unemp_{j_i,cen_1}} + \left(\frac{Unemp_{i,cen_2}}{Unemp_{j_i,cen_2}} - \frac{Unemp_{i,cen_1}}{Unemp_{j_i,cen_1}} \right) \times \frac{t - cen_1}{cen_2 - cen_1} \right) \times Unemp_{j_i,t} \tag{2}$$

Equation 2 shows how the unemployment imputations are conducted. $Unemp_{i,t}$ is the unemployment rate in year t at municipality i. j_i is the prefecture that i is part of. This imputation method takes into account the fluctuations of the prefecture's unemployment rate, making it more reliable to yearly unemployment shocks, which makes the imputed rates more valid.

I also obtain financial record information from e-stat to use in my event study analysis to estimate the effect of earthquakes on the economic activities of municipalities. E-stat provides financial record information of all municipalities every fiscal year. Fiscal years in Japan start on the 1st of April and end on the 31st of March. Public expenditure information provided includes health expenditure, social welfare expenditure, and disaster relief expenditure, which allows analysis of which items are affected and how.

1456 municipalities have expenditure and revenue information without any missing data between the fiscal years 2010 and 2020. Of these 1456 municipalities, 284 experienced an earthquake with an intensity equal to or higher than 6^{-}. Table 3 shows the descriptive statistics of the budgets of these 256 municipalities and the rest of the 1172 municipalities before and after the seismic event.

Table 3
Municipality expenditures and revenues statistics

Variables	Treatment Group ($N = 284$)				Control Group ($N = 1172$)	
	Before Quake		After Quake			
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Expenditures						
Total Expenditures (Thousand ¥)	688.719	485.099	1,166.716	10,719.960	586.857	352.318
Welfare Expenditures (Thousand ¥)	160.580	58.842	246.779	1,722.657	151.661	58.172
Disaster Relief Expenditures (Thousand ¥)	0.983	23.774	79.641	1,063.770	2.670	40.512
Civil Engineering Expenditures (Thousand ¥)	73.529	82.817	247.819	3,598.510	59.999	40.845
Road and Bridge Expenditures (Thousand ¥)	31.527	37.836	65.411	948.808	26.080	29.104
Dwelling Expenditures (Thousand ¥)	10.304	27.705	134.123	2,788.252	6.235	10.183
Revenue						
Total Revenues (Thousand ¥)	719.653	511.398	1,255.097	11,435.848	614.917	377.496
Local Tax Revenues (Thousand ¥)	130.306	83.568	152.566	228.380	124.445	51.964
Local Transferred Tax Revenues (Thousand ¥)	7.068	6.488	7.191	26.729	6.775	6.008
Local Allocation Tax Revenues (Thousand ¥)	251.021	254.467	280.837	2,327.873	206.077	197.736
Rent and Fee Revenues (Thousand ¥)	11.829	14.653	9.040	35.200	10.589	11.705
Treasury Disbursements (Thousand ¥)	75.472	103.534	292.731	3,644.530	74.377	52.900
Prefecture Disbursements (Thousand ¥)	54.432	80.256	116.195	894.632	46.549	56.526
Property Income (Thousand ¥)	5.322	16.449	4.183	14.819	3.881	6.253
Net Excess of Revenue Ratio	5.906	4.250	8.379	8.280	5.492	4.249

Notes: This table presents descriptive statistics of municipal-level expenditures and revenues between 2010 and 2020 for 1456 municipalities that have no missing information during the period. The first column shows the statistics of the 284 municipalities in the treatment group, which contain municipalities that experienced high-magnitude earthquakes during the period. The second column shows the 1172 municipalities in the control group, which are the municipalities that are not part of the treatment group.

3 Empirical Approach

3.1 Hedonic price analysis

3.1.1 The model

Hedonic price regressions are extensively used in real estate market research. The introduction of the hedonic price regression was made by Court (1938)[4]. Two additional crucial contributions have been made to hedonic price theory by Lancaster (1966) and Rosen (1974).

In his consumer theory, Lancaster (1966) made significant contributions to hedonic price theory by establishing the foundational framework for investigating utility-based characteristics. His work not only laid the groundwork for exploring utility-bearing attributes but also expanded the application of this approach across various domains, including the analysis of housing markets (Herath and Maier; 2010). Rosen (1974) contributes to hedonic price theory by integrating it into standard economic theory in an attempt to clarify the meanings and interpretations of the results of hedonic price analyses, which is first-stage regression in an econometric sense, by creating a model that provides a structure behind the hedonic price analysis.

In this section, I provide a simple hedonic price model that my analysis is based on, which allows me to observe the relationship between different house and neighbor characteristics as well as the household response to a high-magnitude earthquake event. Similar models have been used in different research settings, such as Ehrlich and Becker (1972) MacDonald et al. (1987), Kask and Maani (1992), and Naoi et al. (2009).

Representative agents in the economy maximize their expected utility function $U(h, x)$ under earthquake occurrence uncertainty. h is a vector of household characteristics, including house attributes, and environmental and neighborhood attributes, and x is the amount of numeraire goods consumption where $\partial U/\partial h \gtreqless 0$, $\partial U/\partial h^2 < 0$ and $\partial U/\partial x > 0$, $\partial U/\partial x^2 < 0$.

There are two states of the world, 1 and 0, which are high-magnitude earthquake and non-high-magnitude earthquake states respectively, and π is the risk of high-magnitude earthquakes occurring. Consumer income also varies depending on the state of the economy, and

[4] Even though it's not as accepted as A. Court, some papers such as Colwell and Dilmore (1999) claim hedonic price regression was first used 15 years prior to the Court's article in 1992 by Haas (1922a,b).

y_1 and y_0 are the stage contingent income of consumers. I assume y_0 to be higher than y_1 and $L = y_0 - y_1$ is the income loss that households bear when a high-magnitude earthquake occurs.

Hedonic price theory suggests that the price of a house is a function of household characteristics and other location-specific characteristics such as environment and neighborhood attributes. Which makes the price function of a house can be written as follows:

$$p = p(h, \pi)^5 \tag{3}$$

Given Equation 3, the amount of numeraire goods consumed when the economy is at states 0 and 1 can be written as $x_0 = y_0 - p(h, x)$ and $x_1 = y_1 - p(h, x)$, which makes the household's objective function as it is described in Equation 4.

$$\max E[U] = \pi U(h, y_1 - p(h, \pi)) + (1 + \pi)U(h, y_0 - p(h, \pi)) \tag{4}$$

The first order conditions of Equation 4 define the necessary equilibrium conditions for the optimal levels of the jth housing/location attributes and earthquake risk.

$$\frac{\partial p}{\partial h_j} = \frac{\pi(\partial U^1/\partial h_j) + (1 - \pi)(\partial U^0/\partial h_j)}{\pi(\partial U^1/\partial x) + (1 - \pi)(\partial U^0/\partial x)} \gtreqless 0 \tag{5}$$

$$\frac{\partial p}{\partial \pi} = \frac{U^1 - U^0}{\pi(\partial U^1/\partial x) + (1 - \pi(\partial U^0/\partial x)} < 0 \tag{6}$$

According to Equation 5, the implicit price of a certain house and location characteristics is what one would expect to receive in terms of utility. On the other hand, Equation 6 suggests that the utility difference between states 1 and 0, indicated as $U_1 - U_0$, is reflected in the implicit price associated with the probability of an earthquake occurring. Assuming that the denominator of both equations is the marginal utility of numeraire good, these implicit price estimates provide a practical way to determine the marginal willingness to pay (MWP).

3.1.2 Transformation and information bias

One common problem with similar models is transformation bias, which is the difference between objective risk measures of a certain event happening and the subjective risk perception

[5] Earthquake π is written additionally to household and location characteristics simply because of its importance to this paper's research setting.

of households[6]. If subjective risk perception is indeed different from objective risk measures, any estimation that assumes they are the same will end up with biased MWP estimates.

The model that is described in the last section assumes there is no transformation bias as the household takes the objective measures of high-magnitude earthquake risk into consideration. Suppose there is transformation bias and the households measure objective risk with an error and have differentiated high-magnitude earthquake risk perception.

$$\pi^s = f(\pi^o, I) \tag{7}$$

π^s is the subjective risk perception of the household, while π^o is the objective measure of high-magnitude earthquake risk, and I is the level of information. With the introduction of subjective risk perception, households will take their own perception into account instead of objective measures of risk, which will lead to substituting objective earthquake risk measures with earthquake risk perception in previous equations.

$$\frac{\partial p}{\partial \pi^s} = \frac{U^1 - U^0}{\pi^s(\partial U^1/\partial x) + (1 - \pi^s(\partial U^0/\partial x)} < 0 \tag{8}$$

Replacing π^o with π^s shows the implicit price of subjective risk measure would give us an unbiased MWP. In a case where information has no effect on individuals' risk perception, which means $\partial f/\partial I = 0$, we would expect individuals' risk perception to be equal to objective risk measures no matter the level of information at a given time. This also means that, under information shock, individuals' MWP would stay the same, assuming their risk aversion is constant. However, this is not plausible, as it is highly possible that individuals might overestimate or underestimate objective risk measures and change their risk perception when new information arises. In this case, the estimation using objective risk measures has the chance to be a biased estimator of MWP for individuals' subjective risk perception. In this paper's analysis section, I address this issue by using city-level objective earthquake risk measure variation as an instrument as it is described by Naoi et al. (2009).

[6] Kask and Maani (1992) shows individuals are overestimating the risks of the low-probabilistic events while underestimating the risks of the events that have a high risk of happening. Viscusi et al. (1987) finds individuals' risk perception increases with additional information for high-probabilistic events. Their results also show individuals' risk perception decreases with additional information for individuals with an initial risk perception higher than average.

3.2 Dynamic event study with heterogeneous treatment effect

3.2.1 Event study specification

Event study setup is a widely used approach in empirical economics to analyse the effect of a specific event or events and measure the average treatment effect. In this paper's event study setup, I first start by defining cohort-specific average treatment effect of the treated ($CATT_{e,l}$)

$$CATT_{e,l} = E[Y_{i,e+l} - Y^{\infty}_{i,e+l} \mid E_i = e] \tag{9}$$

Equation 9 shows the cohort-specific average treatment effect formula, where $CATT_{e,l}$ is the cohort-specific average treatment effect for individuals who are part of the cohort that received their treatments at the calendar time e, which means $E_i = e$, and at a l relative time period distance to e.

Two identifying assumptions are usually made for general event study setups. The first assumption is the parallel trend assumption. $\forall s \neq t \quad \forall s < E_i,\ E[Y^{\infty}_{i,t} - Y^{\infty}_{i,s} \mid E_i = e]$ is the same $\forall e \in E_i$. This assumption implies any trends before cohorts receive any treatment are the same, and both treatment and control groups follow the same path before treatment. This assumption will be put to the test in later sections of this paper's analysis. The second identifying assumption is that there is no pre-treatment effect. The treatment effect only occurs once the cohort is treated and not before, which means cohorts do not adjust the outcome variable due to any knowledge of future treatment that they will receive. This assumption is very plausible for this paper's analysis, given that no one really knows when, where, and how great an earthquake will happen, it is unlikely that people will adjust their behavior by foreseeing a specific treatment.

$$Y_{i,t} = \beta_0 + \mu_g \sum_{l=0}^{T} D^l_{i,t} + \kappa_i + \lambda_t + \epsilon_{i,t} \tag{10}$$

Equation 10 shows standard static event study estimator specification with two-way fixed effects, that is widely used to estimate the ATT_l under the identifying assumptions. κ_i is individual fixed effect, and λ_t is calendar time fixed effect. $D^l_{i,t}$ is an indicator of being in l relative time period distance to the treatment for individual i at calendar time t, $D^l_{i,t} := 1\{t - E_i = l\}$ where E_i is the treatment calendar time for individual i. μ_g is the event study coefficient for time period bin g. In the static specification, there is only one set of g, which is $g = [0, T]$.

Different than static specification, dynamic event study specification allows more than one set of relative time period bin $g \in G$ to be, which means the treatment effect can vary nonparametrically across different relative time bins. Since the full dynamic specification allows the treatment effect to change over all relative time periods, g is substituted by relative time period l in the full dynamic specification, as it becomes a singleton with only one l.

$$Y_{i,t} = \beta_0 + \sum_{l=-K, l \neq -1}^{T} \mu_l D_{i,t}^l + \kappa_i + \lambda_t + \epsilon_{i,t} \tag{11}$$

Equation 11 is the full dynamic event study specification with two-way fixed effects. μ_l is the event study coefficients for relative time period l. Now, μ_l can vary across different relative time periods in contrast to μ_g in Equation 10.

Researchers mostly assume estimations of μ_l as a convex average of $CATT_{e,l}$, and under the assumption that there is no treatment effect heterogeneity, which means the treatment effects are the same for every cohort at every relative period, it is interpreted as a convex average of ATT_l. Sun and Abraham (2021) put this notion to the test by decomposing μ_l under different sets of identifying assumptions and came to the conclusion that even though the two identifying assumptions hold, in the presence of treatment effect heterogeneity, μ_l can be contaminated by relative time periods that are not l.

3.2.2 Decomposition of μ_g under treatment effect

$$\begin{aligned}\mu_l = & \sum_e \omega_{e,l}(E[Y_{i,e+l} - Y_{i,0}^{\infty} \mid E_i = e] - E[Y_{i,e+l} - Y_{i,0}^{\infty}]) \\ & + \sum_{l' \neq l} \sum_e \omega_{e,l'}(E[Y_{i,e+l'} - Y_{i,0}^{\infty} \mid E_i = e] - E[Y_{i,e+l'} - Y_{i,0}^{\infty}]) \\ & + \sum_e \omega_{e,l^{excl}}(E[Y_{i,e+l^{excl}} - Y_{i,0}^{\infty} \mid E_i = e] - E[Y_{i,e+l^{excl}} - Y_{i,0}^{\infty}])\end{aligned} \tag{12}$$

Equation 3.2.2[7] is a small adaptation of the generic version of the decomposition of μ_g calculated by Sun and Abraham (2021), to the decomposition of μ_l with the full dynamic event study specification with only one excluded time period l^{excl}. According to Equation 3.2.2,

[7]This equation is a direct result of regression mechanics. The formal derivation of the equation is available in the Appendix section of Sun and Abraham (2021)

event study coefficient estimation is a linear weighted combination of the difference in trends at the relative time period of interest l, the difference in trends at relative time periods different than the relative period of interest that is part of the estimation ($l' \neq l$), and the difference in trends at the excluded relative time period as a reference period to avoid multicollinearity (l^{excl}).

Assuming parallel trend and no pre-treatment effect changes Equation 3.2.2 as below:

$$\mu_l = \sum_e \omega_{e,l} CATT_{e,l} + \sum_{l' \neq l, l' > 0} \sum_e \omega^g_{e,l'} CATT_{e,l'} + \sum_e \omega^g_{e,l^{excl}} CATT_{e,l^{excl}} \tag{13}$$

Under the assumption of parallel trends, the difference between trends in Equation 3.2.2 transforms to $CATT_{e,l}$. Secondly, under the assumption of no pre-treatment effect, all relative time periods $l < 0$ are dropped out of the equation.

The second and third elements in the Equation 13 show the contamination of m_l by the relative time periods that are not l. Under the assumption of parallel trends and no pre-treatment effect, and assuming that the excluded relative period as reference is the period prior to the treatment period, the third term will drop altogether. However, the second term will persist if the treatment effect homogeneity does not hold. This means our event study coefficients for a relative time period l can be contaminated by other relative time periods, which will prevent us from obtaining real $CATT_{e,l}$ at a given relative time period. This also means under these conditions, the test of parallel trends by checking event study coefficients for $l < 0$ might not be valid, as event study coefficients for $l < 0$ might be non-zero, even if the parallel trends assumption holds, given that μ_l is contaminated by relative time periods $l > 0$.

The contamination of the m_l is caused by the interaction between weights $\omega_{e,l'}$ and $CATT_{e,l'}$. In their paper, Sun and Abraham (2021) show that these weights are non-linear functions of cohort distributions, which are typically non-convex, non-zero, and not bounded by [0, 1].

3.2.3 Interaction-weighted estimator

To overcome the contamination of the event study coefficient problem and improve the non-convex and non-zero features of usual weights, Sun and Abraham (2021) propose a new way of calculating weights which is a more interpretable way to calculate weights that are robust to contamination.

$$Pr\{E_i = e \,|\, E_i \in [-l, T-l]\} \tag{14}$$

The proposed weight is the probability of a cohort to experience at least l periods relative to the treatment, calculated according to Equation 14. The new weights are sum to 1, convex and non-negative by construction.

$$Y_{i,t} = \beta_0 + \sum_{e \notin C} \sum_{l \neq -1} \delta_{e,l}(1\{E_i = e\}D^l_{i,t}) + \kappa_i + \lambda_t + \epsilon_{i,t} \tag{15}$$

Equation 16 shows the baseline IW estimator equation. C is the cohort to be excluded as a reference cohort, which is the cohort that has never received the treatment at any period. If no cohort has never received the treatment, then it is the cohort that received the treatment last. Relative period -1 is excluded as the reference period.

The first step of estimating the IW estimator is estimating $\widehat{\delta_{e,l}}$, which is an estimator of $CATT_{e,l}$. The second step is calculating new weights proposed by Sun and Abraham (2021), in Equation 14. Finally take the weighted average of the estimates of $CATT_{e,l}$ to calculate the IW estimator.

$$\hat{\nu}_l = \sum_e \widehat{\delta_{e,l}} \widehat{Pr}\{E_i = e \,|\, E_i \in [-l, T-l]\} \tag{16}$$

In the following section, I use the IW estimator to address the contamination of event study coefficients under treatment effect heterogeneity when estimating the effects of earthquakes on municipality expenditures and revenues.

4 Quantitative Analysis

4.1 Change in implicit price of earthquake risk after an earthquake

In the upcoming analysis, I take earthquakes with an intensity equal to or higher than 5^+ as information shocks, and by using hedonic price analysis, observe how households' MWP change after an information shock. To obtain the implicit price of earthquake risk and its relationship with high-magnitude earthquakes as information shocks, I use the following baseline hedonic price regression specification:

$$ln(p_{i,t}) = \alpha + \beta EQ_{i,t} + \gamma R_{i,t} + \eta X_{i,t} + \kappa_{j_i} + \lambda_t + \epsilon_{i,t} \tag{17}$$

Equation 17 shows the baseline specification of hedonic regression in this paper. $p_{i,t}$ is the transaction price of property i that is sold in time t (year-quarter). $EQ_{i,t}$ is a post 5^+ or higher earthquake indicator dummy variable. $R_{i,t}$ is the yearly objective risk measure provided by NIED. $X_{i,t}$ is property and location-specific hedonic attributes including building age, number of rooms, proximity to public transport station, area, building coverage ratio, floor/area ratio, structure type, municipality education controls, population, and unemployment rate of the municipality in which the property is located. κ_{j_i} is the municipality fixed effect that property i is located, and λ_t is time fixed effect.

As it is shown in the previous section, the γ estimate is the implicit price of Earthquake risk and is also an estimate of the MWP. The second specification of the analysis is adding an interaction term between $R_{i,t}$ and $EQ_{i,t}$ to the baseline specification.

$$ln(p_{i,t}) = \alpha + \beta EQ_{i,t} + \gamma R_{i,t} + \mu EQ_{i,t} \times R_{i,t} + \eta X_{i,t} + \kappa_{j_i} + \lambda_t + \epsilon_{i,t} \tag{18}$$

Adding an interaction term would allow me to estimate the change in the implicit price of the earthquake risk after an information shock due to a high-magnitude earthquake event. μ is the estimate of the change after such an event. A significant μ estimate would mean information shocks affect individuals' perception of earthquake risk, and they adjust their behavior by taking new information into consideration. In addition to that, a negative μ estimate would mean MWP decreases after an information shock and would imply individuals are underestimating the earthquake risk, and a positive μ estimate would mean MWP increases after an information shock and would imply individuals initially overestimate the earthquake risk.

4.1.1 Results

Table 4
Hedonic price analysis baseline model

Model	Condominiums 2008-2020 [1]		Residential Condominium 2008-2020 [2]		Buildings 2008-2020 [3]		Residential Building 2008-2020 [4]	
Dependent variable	Log Price		Log Price		Log Price		Log Price	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Earthquake Risk Measure 5^+	-0.101^{***}	0.000	-0.098^{***}	0.000	-0.066^{***}	0.000	-0.072^{***}	0.000
Post Quake Dummy	0.020^{***}	0.000	0.025^{***}	0.000	0.043^{***}	0.000	0.045^{***}	0.000
Age of the Property	-0.028^{***}	0.000	-0.028^{***}	0.000	-0.026^{***}	0.000	-0.026^{***}	0.000
Area(m^2)	0.018^{***}	0.000	0.018^{***}	0.000	0.001^{***}	0.000	0.001^{***}	0.000
Number of Rooms	0.042^{***}	0.000	0.038^{***}	0.000	-	-	-	-
Floor/Area Rate	0.000^{***}	0.000	0.000^{***}	0.000	0.001^{***}	0.000	0.000^{***}	0.000
Building Coverage Rate	0.002^{***}	0.000	0.001^{***}	0.000	-0.003^{***}	0.000	-0.003^{***}	0.000
Unemployment Rate	-2.546^{***}	0.000	-2.472^{***}	0.000	-2.684^{***}	0.000	-2.654^{***}	0.000
Population (10.000 people)	0.018^{***}	0.000	0.017^{***}	0.000	0.015^{***}	0.000	0.014^{***}	0.000
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	516,938		471,061		1,094,483		1,020,567	
R^2	0.782		0.784		0.656		0.671	
Adjusted R^2	0.782		0.784		0.655		0.671	

Notes: I use the R package Stargazer (Hlavac; 2022) for the analysis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

This table shows the coefficient estimates and p-values of the baseline hedonic price regression with DID framework with two-way fixed effects for four different specifications corresponding to Equation 17. The dependent variable $Log\,Price$ is the log transaction price for all models. $Earthquake\,Risk\,Measure\,5^+$ is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years for the municipality the property is located in. $Post\,Quake\,Dummy$ is a dummy variable equal to 1 when the municipality the property is located in experienced an earthquake with an intensity equal to or higher than 5^+ in the quarter of the transaction. The table also presents the coefficient estimations for several household characteristics ($Age\,of\,the\,Property$, $Area(m^2)$, $Number\,of\,Rooms$, $Floor/Area\,Ratio$, $Building\,Coverage\,Rate$) and municipal-level controls ($Unemployment\,Rate$, $Population\,(10,000\,people)$). Models also contain $Proximity\,to\,public\,transport\,station$, $Building\,structure$, $City\,Planning$, and municipal-level education controls, but the results are omitted from the table.

Table 4 shows the results of the baseline hedonic regression model without the interaction term for four different population specifications. The first model contains all condominium sales in the dataset between 2008 and 2020. The second model contains condominium sales only if the condominiums sold are used as houses. The third model contains all building sales in the dataset between the years 2008 and 2020, and the last model contains building sales only if the building contains at least one housing unit. The high explanatory power of all models, increases the reliability of the used hedonic model.

Coefficients of 5^+ or higher earthquake risk measure at Table 4 show the MWP of earthquake risk. In line with the literature (Beron et al. (1997), Brookshire et al. (1985), Nakagawa et al. (2007)), individuals purchase real estate located in high earthquake-risk areas at a discount. For all 4 models, the MWP of earthquake risk is significantly negative. The discount rates are higher for condominiums by -0.101 and -0.098 for models [1] and [2] respectively compared to discounts for buildings, which are -0.066 and -0.072. These coefficients can be interpreted as the demanded percent discount to buy a condominium or a building in a zone that has a 100 percent probability of an earthquake with a magnitude 5^+ or higher in the next 30 years, compared to buying a condominium or a building in an earthquake-free zone. This means individuals demand a 5 percent (3.3 − 3.6 percent) discount to buy a condominium (building) after a 50 percent increase in 5^+ earthquake risk[8] for the next 30 years.

Table 4 also shows that an instance of an earthquake increases real estate prices. The coefficients of the post-earthquake dummy can be interpreted as the percentage change in real estate prices after an earthquake. For all 4 models, the effect of an earthquake with an intensity equal to or higher than 5^+ is positive and statistically significant. Condominium prices increase 2 percent (2.5 percent for residential condominiums) after a high-magnitude earthquake, and building prices increase 4.3 percent (4.5 percent for residential buildings).

Table 5
Hedonic price analysis extended model

Model	Condominiums 2008-2020 [1]		CResidential ondominium 2008-2020 [2]		Buildings 2008-2020 [3]		Residential Building 2008-2020 [4]	
Dependent variable	Log Price		Log Price		Log Price		Log Price	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Earthquake Risk Measure	-0.093^{***}	0.000	-0.090^{***}	0.000	-0.054^{***}	0.000	-0.059^{***}	0.000
Post Quake Dummy	0.092^{***}	0.000	0.100^{***}	0.000	0.091^{***}	0.000	0.095^{***}	0.000
Post Quake Dummy × Earthquake Risk Measure	-0.125^{***}	0.000	-0.128^{***}	0.000	-0.099^{***}	0.000	-0.103^{***}	0.000
Age of the Property	-0.028^{***}	0.000	-0.028^{***}	0.000	-0.026^{***}	0.000	-0.026^{***}	0.000
Area(m^2)	0.018^{***}	0.000	0.018^{***}	0.000	0.001^{***}	0.000	0.001^{***}	0.000
Number of Rooms	0.042^{***}	0.000	0.038^{***}	0.000	-	-	-	-
Floor/Area Rate	0.000^{***}	0.000	0.000^{***}	0.000	0.001^{***}	0.000	0.000^{***}	0.000
BC_rate	0.002^{***}	0.000	0.001^{***}	0.000	-0.003^{***}	0.000	-0.003^{***}	0.000
Unemployment Rate	-2.618^{***}	0.000	-2.531^{***}	0.000	-2.740^{***}	0.000	-2.713^{***}	0.000
Population (10.000 people)	0.019^{***}	0.000	0.018^{***}	0.000	0.016^{***}	0.000	0.015^{***}	0.000
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	516,938		471,061		1,094,483		1,020,567	
R^2	0.782		0.785		0.656		0.671	
Adjusted R^2	0.782		0.784		0.655		0.671	
Notes:	I use the R package Stargazer (Hlavac; 2022) for the analysis.						*** p < 0.01, ** p < 0.05, * p < 0.1	

This table shows the coefficient estimates and p-values of the extended hedonic price regression with DID framework with two-way fixed effects for four different specifications corresponding to Equation 18. The dependent variable *Log Price* is the log transaction price for all models. *Earthquake Risk Measure* 5^+ is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years for the municipality the property is located in. *Post Quake Dummy* is a dummy variable equal to 1 when the municipality the property is located in experienced an earthquake with an intensity equal to or higher than 5^+ in the quarter of the transaction. $PostQuakeDummy \times EarthquakeRiskMeasure$ is the interaction term between the first two independent variables. The table also presents the coefficient estimations for several household characteristics ($Age\,of\,the\,Property$, $Area\,(m^2)$, $Number\,of\,Rooms$, $Floor/Area\,Ratio$, $Building\,Coverage\,Rate$) and municipal-level controls ($Unemployment\,Rate$, $Population$ $(10,000\ people)$). Models also contain *Proximity to public transport station*, *Building structure*, *City Planning*, and municipal-level education controls, but the results are omitted from the table.

Table 5 shows the results of the extended model as it is shown in Equation 18. After the addition of the interaction term, the coefficient of the earthquake risk measure now estimates the MWP of earthquake risk independent of high-magnitude earthquake instances. The estimation of earthquake risk stayed rather consistent, with a small decrease for all models but stayed strictly negative and statistically significant. The coefficients of earthquake risk are

[8] To provide more context about earthquake risk in Japan, approximately 27 percent of Japan soil has more than 50 percent probability of an earthquake with a magnitude 5^+ or higher in the next 30 years and the mean probability of a 5^+ or higher earthquake is 19.6 percent according to 2022 PSHM

-0.093 and -0.90 for condominiums and -0.054 and -0.59 for buildings.

The coefficient of post-earthquake now shows the effect of high-magnitude earthquakes independent of earthquake risk, which means the overall effect of high-magnitude earthquakes is contained by both the coefficient of post-earthquake dummy and the coefficient of the interaction term. The coefficient of the post-earthquake dummy stayed positive and statistically significant but increased substantially for all models compared to the baseline specification without the interaction term. The extended model estimates the increase in real estate prices after a massive earthquake 9.2 percent for all condominiums and 9.5 percent for all buildings. However, the overall effect of high-magnitude earthquakes on property prices is ambiguous, as the coefficient of the interaction term shows the decreasing effect of high-magnitude earthquakes on property prices conditioned on earthquake risk, which means high-magnitude earthquakes have a decreasing effect on property prices in regions with high earthquake risk and an increasing effect on property prices in regions with low earthquake risk.

The coefficient of the interaction term in the model can also be interpreted as the change in MWP of earthquake risk after an earthquake of 5^+ or higher magnitude. The main result of the extended baseline model shows individuals' MWP for earthquake risk decreases significantly after such an earthquake. According to the estimations, individuals demand a 12.5 percent discount on all condominiums on average and a 12.8 percent discount for residential condominiums located in earthquake-prone areas after a massive earthquake, in addition to the discount that they are demanding even before the event of an earthquake, which is 9.3 percent and 9.0 percent respectively. The same applies to buildings as well, as the demanded discount increases by an additional 9.9 percent and 10.3 percent after a high-magnitude earthquake. The most plausible explanation for this outcome is that individuals are aware of the earthquake risk pre-earthquake period, however, they significantly underestimate the risk as they increased their demanded discount to more than double for condominiums and almost triple for buildings after such an instance.

4.1.2 Robustness check

I conduct the same analysis but this time for a shorter period of time, which is 2008 to 2013, as a robustness check against whether misspecification of the period is one of the factors that drives the results from the previous section. The first three years of the short period were relatively quiet in terms of seismic activity, as there were only three earthquakes with an equal or higher intensity than 5^+. On the other hand, the rest of the period was one of the most seismically active in the recent history of Japan.

Table 6
Hedonic price analysis baseline and extended model 2008-2013

Model	Condominiums 2008-2013 [1]		Residential Condominium 2008-2013 [2]		Buildings 2008-2013 [3]		Residential Building 2008-2013 [4]	
Dependent variable	Log Price		Log Price		Log Price		Log Price	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Panel 1: Baseline Model								
Earthquake Risk Measure 5^+	-0.043^{***}	0.000	-0.044^{***}	0.000	-0.054^{***}	0.000	-0.062^{***}	0.000
Post Quake Dummy	0.040^{***}	0.000	0.040^{***}	0.000	0.031^{***}	0.000	0.035^{***}	0.000
Age of the Property	-0.030^{***}	0.000	-0.030^{***}	0.000	-0.026^{***}	0.000	-0.027^{***}	0.000
Area(m^2)	0.017^{***}	0.000	0.017^{***}	0.000	0.001^{***}	0.000	0.001^{***}	0.000
Number of Rooms	0.052^{***}	0.000	0.051^{***}	0.000	-	-	-	-
Floor/Area Rate	0.000^{***}	0.000	0.000^{***}	0.000	0.000^{***}	0.000	0.000^{***}	0.000
Building Coverage Rate	0.001^{***}	0.000	0.001^{***}	0.000	-0.004^{***}	0.000	-0.003^{***}	0.000
Unemployment Rate	-0.909^{***}	0.003	-0.860^{***}	0.004	-1.607^{***}	0.000	-1.815^{***}	0.000
Population (10.000 people)	0.003^{*}	0.077	0.003^{*}	0.088	-0.005^{***}	0.006	-0.005^{***}	0.006
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	228,474		227,525		473,037		440,764	
R^2	0.789		0.788		0.653		0.669	
Adjusted R^2	0.789		0.788		0.652		0.668	
Panel 2: Extended Model								
Earthquake Risk Measure	-0.038^{***}	0.000	-0.039^{***}	0.000	-0.050^{***}	0.000	-0.057^{***}	0.000
Post Quake Dummy	0.103^{***}	0.000	0.102^{***}	0.000	0.058^{***}	0.000	0.066^{***}	0.000
Post Quake Dummy × Earthquake Risk Measure	-0.099^{***}	0.000	-0.098^{***}	0.000	-0.046^{***}	0.000	-0.054^{***}	0.000
Age of the Property	-0.030^{***}	0.000	-0.030^{***}	0.000	-0.026^{***}	0.000	-0.027^{***}	0.000
Area(m^2)	0.017^{***}	0.000	0.017^{***}	0.000	0.001^{***}	0.000	0.001^{***}	0.000
Number of Rooms	0.052^{***}	0.000	0.051^{***}	0.000	-	-	-	-
Floor/Area Rate	0.000^{***}	0.000	0.000^{***}	0.000	0.000^{***}	0.000	0.000^{***}	0.000
BC_rate	0.001^{***}	0.000	0.001^{***}	0.000	-0.004^{***}	0.000	-0.003^{***}	0.000
Unemployment Rate	-0.821^{***}	0.006	-0.772^{***}	0.009	-1.589^{***}	0.000	-1.795^{***}	0.000
Population (10.000 people)	0.004^{**}	0.022	0.004^{**}	0.026	-0.005^{***}	0.009	-0.004^{***}	0.010
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	228,474		227,525		473,037		440,764	
R^2	0.789		0.789		0.653		0.670	
Adjusted R^2	0.789		0.788		0.652		0.668	

Notes: I use the R package Stargazer (Hlavac; 2022) for the analysis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

This table shows the coefficient estimates and p-values of both baseline and extended hedonic price regression with DID framework with two-way fixed effects between the years 2008 and 2013 for condominiums and buildings corresponding to Equation 17 and Equation 18. Panel 1 shows baseline model results and Panel 2 shows extended model results. The dependent variable *Log Price* is the log transaction price for all models. $Earthquake\,Risk\,Measure\,5^+$ is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years for the municipality the property is located in. *Post Quake Dummy* is a dummy variable equal to 1 when the municipality the property is located in experienced an earthquake with an intensity equal to or higher than 5^+ in the quarter of the transaction. $Post\,Quake\,Dummy \times Earthquake\,Risk\,Measure$ is the interaction term between the first two independent variables. The table also presents the coefficient estimations for several household characteristics ($Age\,of\,the\,Property$, $Area\,(m^2)$, $Number\,of\,Rooms$, $Floor/Area\,Ratio$, $Building\,Coverage\,Rate$) and municipal-level controls ($Unemployment\,Rate$, $Population\,(10,000\,people)$). Models also contain *Proximity to public transport station*, *Building structure*, *City Planning*, and municipal-level education controls, but the results are omitted from the table.

Table 6 shows both the baseline and extended specification estimations of the robustness check analysis. MWP for earthquake risk is still negative and significant, which validates the findings of the first analysis. The magnitude of the effect is quite robust for the buildings, as there is not much difference between the main analysis and the robustness check estimations. The MWP for earthquake risk is estimated as -0.054 and 0.062 in baseline robustness check analysis and -0.050 and -0.057 in extended robustness check for buildings. The difference in condominium estimation of MWP for earthquake risk is relatively higher. The MWP for earthquake risk is estimated -0.043 and -0.044 for all condominiums and residential condominiums respectively in baseline robustness check analysis. The same numbers are -0.038 and -0.039 for the extended robustness check.

The price difference associated with an event of a high-magnitude earthquake independent of earthquake risk is also highly similar between the main analysis and the robustness check. In all specifications, the effect of a high-magnitude earthquake happening is positive and significant. For condominiums, the magnitude of the coefficients is also almost identical for both baseline and extended models. In the baseline robustness check, massive earthquakes have a 4 percent increasing effect for both all condominiums and residential condominium, while in the main analysis, it was 2 percent and 2.5 percent respectively. In the extended model, the increasing effect of an earthquake on condominium prices is even more similar, as it is estimated as 10.3 and 10.2 percent for all condominiums and residential condominiums in robustness check. The same applies to buildings as well. The estimation of the robustness check and main analysis are quite similar. The effect of a high-magnitude earthquake instance on real estate prices is estimated as 3.1 percent for all buildings, 3.5 percent for buildings with housing units for baseline robustness check, and 5.8 and 6.6 for extended specification of robustness check. The overall effect of high-magnitude earthquakes is strictly positive in the robustness check, as the absolute value of the positive effect of high-magnitude earthquakes independent of earthquake risk is higher than the absolute value of the negative effect of the interaction term for all four models. However, the overall effect is very close to 0 for regions with high earthquake risk, especially for condominiums, to a degree that makes it economically insignificant.

The robustness check also validates the main outcome of the previous analysis, which is the change in MWP for earthquake risk after a great seismic activity. The extended specification of robustness check shows the additional decrease in MWP in the presence of a great earthquake, which is estimated as -0.099 for all condominiums and -0.098 for residential condominium. The same estimates are -0.058 and -0.066 for buildings. As it is in the main analysis as well, robustness check shows a high-magnitude earthquake decreases MWP for earthquake risk even more and increases the discount demanded by around 10 percent for condominiums and 5.8 to 6.6 percent for buildings in 100 percent earthquake-prone areas compared to the condominiums and buildings in earthquake-free zones.

In conclusion, the robustness check validates the findings of the main analysis as it does not show any significant deviation from the main analysis' results. Both the main analysis and robustness check present evidence of a significant negative MWP for earthquake risk. Especially for buildings the MWP for earthquake risk is quite similar, while the MWP estimations vary from -0.038 to -0.093 for condominiums in extended models. The effect of high-magnitude earthquakes is also very similar in both the main analysis and the robustness check, which solidifies the validity of the model. Finally, the robustness check also shows the drastic decrease in MWP for earthquake risk after a great earthquake, strengthening the results of the main analysis and the possible intuition of underestimation of the earthquake risk at pre-earthquake periods.

4.1.3 Addressing transformation bias with IV estimator

Negative μ estimates from Table 4 and Table 5 show the decrease in the implicit price of earthquake risk after an information shock, which means a decrease in MWP for earthquake risk and an increase in the discount rate for properties in earthquake-prone zones after a high-magnitude earthquake. However, Kask and Maani (1992) suggests these results under uncertainty might be biased due to the transformation and information bias discussed in the previous section. To address this issue, I use 2SLS regression setup. In accordance with the recent literature (Naoi et al.; 2009; Kniesner et al.; 2007) I specify the difference between subjective risk perception and objective risk measures with a measurement error framework. Thus, the empirical model that is specified in Equation 18, changes as follows:

$$R^s_{i,t} = R^o_{i,t} + u_{i,t} \tag{19}$$

$$ln(p_{i,t}) = \alpha + \beta EQ_{i,t} + \gamma R^s_{i,t} + \mu EQ_{i,t} \times R^s_{i,t} + \eta X_{i,t} + \kappa_{j_i} + \lambda_t + \epsilon_{i,t} \tag{20}$$

One obvious issue with this setup is, $R^s_{i,t}$ is not a measure that we can observe, thus we cannot use it to estimate true MWP using it. We can, however, substitute $R^s_{i,t}$ in Equation 20 with $R^o_{i,t}$ according to Equation 19.

$$\begin{aligned} ln(p_{i,t}) &= \alpha + \beta EQ_{i,t} + \gamma(R^o_{i,t} + u_{i,t}) + \mu EQ_{i,t} \times (R^o_{i,t} + u_{i,t}) + \eta X_{i,t} + \kappa_{j_i} + \lambda_t + \epsilon'_{i,t} \\ &= \alpha + \beta EQ_{i,t} + \gamma R^s_{i,t} + \mu EQ_{i,t} \times R^s_{i,t} + \eta X_{i,t} + \kappa_{j_i} + \lambda_t + \epsilon'_{i,t} \\ \epsilon'_{i,t} &= \epsilon_{i,t} + \gamma u_{i,t} + \mu EQ_{i,t} \times u_{i,t} \end{aligned} \tag{21}$$

From Equation 4.1.3, it can clearly be seen as $\epsilon'_{i,t}$ is correlated with $R^o_{i,t}$ as $R^o_{i,t} = R^s_{i,t} - u_{i,t}$ thus $Cov[R^o_{i,t}, e'_{i,t}] \neq 0$. To overcome this issue, I introduce an instrumental variable as described in Naoi et al. (2009). For an instrument to be valid, first it has to have a strong correlation with variable $R^o_{i,t}$, and second, it has to be independent from measurement error $u_{i,t}$. Naoi et al. (2009) argues in their paper that using neighborhood variation of earthquake risk is a valid instrument for subjective earthquake perception. Suppose that property k is neighbor to property i which means subjective earthquake perception against property k in time t is a $R^o_{k,t}+u_{k,t}$. If we assume $u_{k,t}$ is purely idiosyncratic, that would imply $R^o_{k,t}$ is indeed independent of the measurement error of property i while still having a strong correlation with $R^o_{i,t}$ which makes it a valid instrument to overcome the difference between subjective risk perception and objective risk measures.

The validity of the instrument depends on the difference between objective risk measures and subjective risk perception caused by measurement error. If this notion does not hold and the misestimation of objective risk measures is related between households located in the same municipality, or the measurement errors for different households in the same municipalities, $u_{i,t}$ and $u_{k,t}$, related in any way that municipality and time fixed effect can not capture, the estimation of the IV estimator will continue to be biased just as the estimation of MWP for earthquake risk will stay unreliable.

Table 7 shows the results from both first and second-stage regressions of 2SLS regression. The first step is estimating the objective earthquake risk measure by using municipality-level objective earthquake risk measure variation. It also includes an interaction term between the post-quake indicator and earthquake risk measure variation, the rest of the controls, and the municipality and period fixed effect.

The second part of the Table 7 shows the results from the second-stage regression. The overall results of the 2SLS regression are in line with the main analysis. The effect of experiencing a high-magnitude earthquake is positive, significant, and almost identical to the results with Table 5. The MWP of earthquake risk is also rather similar to the main results, as for all specifications, the estimates are negative and statistically significant. The IV estimations of MWP for earthquake risk are lower than the main analysis estimations, as Table 7 shows that a 50 percent increase in perceived earthquake risk decreases condominium prices by 9.75 percent, compared to 4.65 percent in the main analysis. The decrease is even higher for buildings, as 2SLS estimations show that in the presence of a 50 percent increase in earthquake risk, MWP will decrease by 13.65 percent. After an event of a high-magnitude

Table 7
Hedonic price analysis 2SLS model

Model	Condominiums 2008-2020 [1]		Residential Condominium 2008-2020 [2]		Buildings 2008-2020 [3]		Residential Building 2008-2020 [4]	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Panel 1: First Stage Regression	Earthquake Risk Measure 5^+		Earthquake Risk Measure 5^+		Earthquake Risk Measure 5^+		Earthquake Risk Measure 5^+	
EQ Risk In Municipality St.Dev.	-1.455^{***}	0.000	-1.473^{***}	0.000	-0.988^{***}	0.000	-0.999^{***}	0.000
Post Quake Dummy	-0.010^{***}	0.000	-0.012^{***}	0.000	0.025^{***}	0.000	0.024^{***}	0.000
Post Quake Dummy × EQ Risk In Municipality St.Dev.	0.107^{***}	0.000	0.120^{***}	0.000	0.059^{***}	0.000	0.055^{***}	0.000
Hedonic Controls	Yes		Yes		Yes		Yes	
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	516,938		471,061		1,094,483		1,020,567	
R^2	0.956		0.953		0.940		0.940	
Adjusted R^2	0.955		0.953		0.940		0.940	
Panel 2: Second Stage Regression	Log Price		Log Price		Log Price		Log Price	
IV Earthquake Risk	-0.195^{***}	0.000	-0.174^{***}	0.000	-0.263^{***}	0.000	-0.259^{***}	0.000
Post Quake Dummy	0.090^{***}	0.000	0.100^{***}	0.000	0.108^{***}	0.000	0.111^{***}	0.000
Post Quake Dummy × IV Earthquake Risk	-0.124^{***}	0.000	-0.129^{***}	0.000	-0.123^{***}	0.000	-0.125^{***}	0.000
Age of the Property	-0.028^{***}	0.000	-0.028^{***}	0.000	-0.026^{***}	0.000	-0.026^{***}	0.000
Area(m^2)	0.018^{***}	0.000	0.018^{***}	0.000	0.001^{***}	0.000	0.001^{***}	0.000
Number of Rooms	0.042^{***}	0.000	0.038^{***}	0.000	-	-	-	-
Floor/Area Rate	0.000^{***}	0.000	0.000^{***}	0.000	0.001^{***}	0.000	0.000^{***}	0.000
BC_rate	0.002^{***}	0.000	0.001^{***}	0.000	-0.003^{***}	0.000	-0.003^{***}	0.000
Unemployment Rate	-2.569^{***}	0.000	-2.503^{***}	0.000	-2.893^{***}	0.000	-2.853^{***}	0.000
Population (10.000 people)	0.020^{***}	0.000	0.020^{***}	0.000	0.020^{***}	0.000	0.019^{***}	0.000
Hedonic Controls	Yes		Yes		Yes		Yes	
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	516,938		471,061		1,094,483		1,020,567	
R^2	0.782		0.784		0.656		0.672	
Adjusted R^2	0.782		0.784		0.655		0.671	
Notes:	I use the R package Stargazer (Hlavac; 2022) for the analysis.						*** p < 0.01, ** p < 0.05, * p < 0.1	

This table shows the coefficient estimates and p-values of 2SLS regression for condominiums and buildings corresponding to Equation 4.1.3. Panel 1 shows the first stage results of the 2SLS regression. The dependent variable for the first stage regression is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years for the municipality the property is located in. *EQ Risk In Municipality St.Dev.* is the inside municipality standard deviation of 5^+ or higher earthquake risk. *Post Quake Dummy* is a dummy variable equal to 1 when the municipality the property is located in experienced an earthquake with an intensity equal to or higher than 5^+ in the quarter of the transaction. *Post Quake Dummy* × *EQ Risk In Municipality St.Dev.* is the interaction term between the first two independent variables. Panel 2 shows the second stage of the 2SLS regression, which is the extended hedonic price regression with DID framework with two-way fixed effects. The dependent variable for the second stage of the 2SLS regression *Log Price* is the log transaction price for all models. *IV Earthquake Risk* is the earthquake risk estimation from the first stage of the 2SLS regression. *Post Quake Dummy* × *IV Earthquake Risk* is the interaction term between the two independent variables. The table also presents the coefficient estimations for several household characteristics (*Age of the Property*, *Area* (m^2), *Number of Rooms*, *Floor/Area Ratio*, *Building Coverage Rate*) and municipal-level controls (*Unemployment Rate*, *Population* (10,000 *people*)). Models also contain *Proximity to public transport station*, *Building structure*, *City Planning*, and municipal-level education controls, but the results are omitted from the table.

earthquake, the MWP for earthquake risk decreases by approximately -0.125 for all models, which means after an instance of a high-magnitude earthquake, people increase the discount they demand for a given earthquake risk, which is also consistent with the main findings of the paper.

Table 8 shows 2SLS regression results for robustness check specifications. The results of 2SLS regression of the shortened period are consistent with the findings of all specifications yet, as it shows individuals buy real estate at a discounted price in earthquake-prone zones, a high-magnitude earthquake instance has a positive relationship with real estate prices, and finally, a massive earthquake as an information shock decreases the MWP for earthquake risk even more, which leads to additional discounts demanded after the massive earthquake

Table 8
Hedonic price analysis 2SLS model 2008-2013

Model	Condominiums 2008-2013 [1]		Residential Condominium 2008-2013 [2]		Buildings 2008-2013 [3]		Residential Building 2008-2013 [4]	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Panel 1: First Stage Regression	Earthquake Risk Measure 5^+		Earthquake Risk Measure 5^+		Earthquake Risk Measure 5^+		Earthquake Risk Measure 5^+	
EQ Risk In Municipality St.Dev.	-1.534^{***}	0.000	-1.532^{***}	0.000	-1.101^{***}	0.000	-1.112^{***}	0.000
Post Quake Dummy	-0.039^{***}	0.000	-0.039^{***}	0.000	0.015^{***}	0.000	0.015^{***}	0.000
Post Quake Dummy × EQ Risk In Municipality St.Dev.	0.375^{***}	0.000	0.375^{***}	0.000	0.144^{***}	0.000	0.141^{***}	0.000
Hedonic Controls	Yes		Yes		Yes		Yes	
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	228,474		227,525		473,037		440,764	
R^2	0.936		0.936		0.904		0.905	
Adjusted R^2	0.936		0.936		0.903		0.904	
Panel 2: Second Stage Regression	Log Price		Log Price		Log Price		Log Price	
IV Earthquake Risk	-0.083^{***}	0.000	-0.083^{***}	0.000	-0.124^{***}	0.000	-0.121^{***}	0.000
Post Quake Dummy	0.113^{***}	0.000	0.113^{***}	0.000	0.084^{***}	0.000	0.092^{***}	0.000
Post Quake Dummy × IV Earthquake Risk	-0.116^{***}	0.000	-0.115^{***}	0.000	-0.090^{***}	0.000	-0.096^{***}	0.000
Age of the Property	-0.030^{***}	0.000	-0.030^{***}	0.000	-0.026^{***}	0.000	-0.027^{***}	0.000
Area(m^2)	0.017^{***}	0.000	0.017^{***}	0.000	0.001^{***}	0.000	0.001^{***}	0.000
Number of Rooms	0.052^{***}	0.000	0.051^{***}	0.000	-	-	-	-
Floor/Area Rate	0.000^{***}	0.000	0.000^{***}	0.000	0.000^{***}	0.000	0.000^{***}	0.000
BC_rate	0.001^{***}	0.000	0.001^{***}	0.000	-0.004^{***}	0.000	-0.003^{***}	0.000
Unemployment Rate	-1.027^{***}	0.001	-0.976^{***}	0.002	-1.816^{***}	0.000	-1.988^{***}	0.000
Population (10.000 people)	0.006^{***}	0.001	0.006^{***}	0.001	-0.002	0.327	-0.002	0.294
Hedonic Controls	Yes		Yes		Yes		Yes	
Proximity to public transport station dummy	Yes		Yes		Yes		Yes	
Building structure dummy	Yes		Yes		Yes		Yes	
City Planning dummy	Yes		Yes		Yes		Yes	
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	228,474		227,525		473,037		440,764	
R^2	0.789		0.789		0.653		0.669	
Adjusted R^2	0.789		0.788		0.652		0.668	

Notes: I use the R package Stargazer (Hlavac; 2022) for the analysis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

This table shows the coefficient estimates and p-values of 2SLS regression for condominiums and buildings between the years 2008 and 2013 corresponding to Equation 4.1.3. Panel 1 shows the first stage results of the 2SLS regression. The dependent variable for the first stage regression is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years for the municipality the property is located in. *EQ Risk In Municipality St.Dev.* is the inside municipality standard deviation of 5^+ or higher earthquake risk. *Post Quake Dummy* is a dummy variable equal to 1 when the municipality the property is located in experienced an earthquake with an intensity equal to or higher than 5^+ in the quarter of the transaction. *Post Quake Dummy* × *EQ Risk In Municipality St.Dev.* is the interaction term between the first two independent variables. Panel 2 shows the second stage of the 2SLS regression, which is the extended hedonic price regression with DID framework with two-way fixed effects. The dependent variable for the second stage of the 2SLS regression *Log Price* is the log transaction price for all models. *IV Earthquake Risk* is the earthquake risk estimation from the first stage of the 2SLS regression. *Post Quake Dummy* × *IV Earthquake Risk* is the interaction term between the two independent variables. The table also presents the coefficient estimations for several household characteristics (*Age of the Property*, *Area* (m^2), *Number of Rooms*, *Floor/Area Ratio*, *Building Coverage Rate*) and municipal-level controls (*Unemployment Rate*, *Population* (10,000 *people*)). Models also contain *Proximity to public transport station*, *Building structure*, *City Planning*, and municipal-level education controls, but the results are omitted from the table.

in earthquake-prone zones.

Both Table 7 and Table 8 also show the ambiguous effect of high-magnitude earthquake instances, as earthquakes with an intensity equal to or higher than 5^+ have a negative overall effect on property prices in high earthquake risk regions, while they have a positive overall effect on property prices in low earthquake risk regions. Similar to Table 6, the overall effect is very close to 0 in Table 8.

4.2 Change in real estate market following an earthquake

In the second analysis of the paper, I analyse how the properties in the real estate market change following an earthquake with an intensity equal to or higher than 5^+, by using DID framework. First, I look at how the amount of price sales in a municipality is associated with earthquake risk and how it changes after a high-magnitude earthquake. To obtain the relationship, I employ the following specification:

$$SALES_{j,t} = \alpha + \beta EQ_{j,t} + \gamma R_{j,t} + \mu EQ_{j,t} \times R_{j,t} + \eta X_{j,t} + \kappa_j + \lambda_t + \epsilon_{j,t} \tag{22}$$

$SALES_{i,t}$ is the number of sales in municipality j in time t (year-quarter). $EQ_{j,t}$ is a post 5^+ or higher earthquake indicator dummy variable, and $R_{j,t}$ is the yearly objective risk measure. $X_{j,t}$ is municipality controls including population, unemployment rate, and education controls. κ_j and λ_t are municipality and time fixed effects.

Then I continue analysing how the characteristics of sold properties differentiate after a high-magnitude earthquake.

$$Y_{i,t} = \alpha + \beta EQ_{i,t} + \gamma R_{i,t} + \mu EQ_{i,t} \times R_{i,t} + \eta X_{i,t} + \kappa_{j_i} + \lambda_t + \epsilon_{i,t} \tag{23}$$

Equation 23 shows the specification used for the analysis. $Y_{i,t}$ is various characteristics of the property i that is sold in time t. $EQ_{i,t}$, $R_{i,t}$ and $X_{j_i,t}$ are the same as shown in Equation 22. κ_j and λ_t are municipality and time fixed effects.

4.2.1 Results

Table 9 shows the results of DID regression described in Equation 22. The first model contains all condominium sales in the dataset between 2008 and 2020, while the second model contains residential condominium sales. The third model contains all building sales in the dataset between the years 2008 and 2020, and finally, the last model contains residential building sales.

The results from Table 9 show there is no significant effect of earthquake risk on the volume of condominium sales independent of high-magnitude earthquake instances, as in both models [1] and [2], the estimation earthquake risk measure is statistically insignificant. However,

Table 9
Number of property sales DID

Model	Condominiums 2008-2020 [1]		Residential Condominium 2008-2020 [2]		Buildings 2008-2020 [3]		Residential Building 2008-2020 [4]	
Dependent variable	Sold Property Volume		Sold Property Volume		Sold Property Volume		Sold Property Volume	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Earthquake Risk Measure	0.525	0.363	0.440	0.429	2.443^{***}	0.000	2.416^{***}	0.000
Post Quake Dummy	1.531^{***}	0.000	1.492^{***}	0.000	0.943^{***}	0.001	0.957^{***}	0.000
Post Quake Dummy × Earthquake Risk Measure	-4.803^{***}	0.000	-2.941^{***}	0.000	-1.453^{***}	0.001	-1.467^{***}	0.001
Unemployment Rate	-115.955^{***}	0.000	-90.654^{***}	0.000	18.889^{***}	0.000	20.455^{***}	0.000
Population (10.000 people)	3.902^{***}	0.000	0.198	0.396	1.709^{***}	0.000	1.545^{***}	0.000
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	24,944		24,541		62,809		61,654	
R^2	0.933		0.913		0.940		0.937	
Adjusted R^2	0.931		0.911		0.939		0.935	

Notes: I use the R package Stargazer (Hlavac; 2022) for the analysis. *** p < 0.01, ** p < 0.05, * p < 0.1

This table shows the coefficient estimates and p-values of DID regression corresponding to Equation 22 for municipalities in Japan. The dependent variable $SoldPropertyVolume$ is the number of sales in a given quarter-year for all models. $Earthquake\ Risk\ Measure\ 5^+$ is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years in a municipality. *Post Quake Dummy* is a dummy variable equal to 1 when a municipality experiences an earthquake with an intensity equal to or higher than 5^+ in a quarter. The table also presents the coefficient estimations for $Unemployment\ Rate$ and $Population\,(10,000\,people)$ as municipal-level controls. Models also contain municipal-level education controls, but the results are omitted from the table.

unlike condominium sales, earthquake risk has a positive effect on building sales. Approximately 1 additional building sold with every 40% increase in the risk of an earthquake with an intensity equal to or higher than 5^+ in the next 30 years. The effect is almost the same for residential buildings. Considering that residential buildings almost exclusively have wooden structures according to Table 2, one possible explanation for this effect might be that households prefer houses with wooden structures in earthquake-prone areas to protect themselves from earthquakes.

The effect of a high-magnitude earthquake appears both by itself and in the interaction term. Table 9 shows that, independent of earthquake risk, high-magnitude earthquakes have a positive effect on property sales numbers in all four models. A high-risk earthquake instance increases quarterly property sales by 1.5 for condominiums and 1 for buildings. However, the overall effect of earthquakes is ambiguous as the estimation of the interaction term is negatively significant in all models, which means in high earthquake risk areas, the negative effect of earthquakes on property sales numbers is even higher. Other than the increasing effect of earthquakes on sales volume independent of earthquake risk, in 100% earthquake risk zones, there is an additional -4.8 decreasing effect on all condominiums, -2.94 on residential condominiums, and approximately -1.5 on both all buildings and residential buildings, which makes the overall effect of a high-magnitude earthquake negative. In conclusion, while earthquakes have a positive overall effect on property sales volume for municipalities with low earthquake risk, they have a negative effect on property sales numbers for municipalities with high earthquake risk.

Table 10
Sold properties characteristics

Model	Condominiums 2008-2020 [1]		Residential Condominium 2008-2020 [2]		Buildings 2008-2020 [3]		Residential Building 2008-2020 [4]	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Panel 1: Area(m^2)								
Earthquake Risk Measure	0.728**	0.033	0.745**	0.030	0.578	0.785	0.059	0.973
Post Quake Dummy	−0.415	0.291	−0.282	0.447	−2.885	0.188	−3.561**	0.048
Post Quake Dummy × Earthquake Risk Measure	1.376**	0.017	1.275**	0.020	3.781	0.283	6.228**	0.031
Unemployment Rate	34.577***	0.000	37.677***	0.000	40.854	0.461	−26.505	0.566
Population (10.000 people)	−0.481***	0.000	−0.478***	0.000	−2.040***	0.000	−2.191***	0.000
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	516,938		471,061		1,094,483		1,020,567	
R^2	0.324		0.326		0.206		0.247	
Adjusted R^2	0.324		0.325		0.205		0.246	
Panel 2: Number of Rooms								
Earthquake Risk Measure	0.082***	0.000	0.083***	0.000	-	-	-	-
Post Quake Dummy	−0.041**	0.013	−0.034*	0.055	-	-	-	-
Post Quake Dummy × Earthquake Risk Measure	0.085***	0.001	0.076***	0.003	-	-	-	-
Unemployment Rate	2.037***	0.000	2.084***	0.000	-	-	-	-
Population (10.000 people)	−0.009***	0.000	−0.010***	0.000	-	-	-	-
Education Controls	Yes		Yes		-		-	
Municipality Fixed Effect	Yes		Yes		-		-	
Quarter - Year Fixed Effect	Yes		Yes		-		-	
Observation	516,938		471,061		-		-	
R^2	0.345		0.347		-		-	
Adjusted R^2	0.345		0.346		-		-	
Panel 3: Age of the Property								
Earthquake Risk Measure	1.415***	0.000	1.377***	0.000	−0.911***	0.000	−0.836***	0.000
Post Quake Dummy	0.687***	0.001	0.575***	0.005	0.033	0.828	−0.037	0.816
Post Quake Dummy × Earthquake Risk Measure	−0.841***	0.006	−0.841***	0.008	−0.583**	0.019	−0.449*	0.081
Unemployment Rate	30.691***	0.000	28.234***	0.000	−47.283***	0.000	−50.476***	0.000
Population (10.000 people)	−0.264***	0.000	−0.276***	0.000	−0.338***	0.000	−0.325***	0.000
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	516,938		471,061		1,094,483		1,020,567	
R^2	0.118		0.117		0.102		0.101	
Adjusted R^2	0.117		0.116		0.101		0.099	

Notes: I use the R package Stargazer (Hlavac; 2022) for the analysis. *** p < 0.01, ** p < 0.05, * p < 0.1

This table shows the coefficient estimates and p-values of DID regression corresponding to Equation 23 for municipalities in Japan. Panel 1 shows DID regression with $Area(m^2)$ as the dependent variable. Panel 2 shows DID regression with $Number of Rooms$ as the dependent variable and Panel 3 shows DID regression with $Age of the Property$ as the dependent variable. *Earthquake Risk Measure* 5^+ is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years in the municipality the property is located in. *Post Quake Dummy* is a dummy variable equal to 1 when the municipality the property is located in experienced an earthquake with an intensity equal to or higher than 5^+ in the quarter of the transaction. The table also presents the coefficient estimations for *Unemployment Rate* and *Population* $(10,000\,people)$ as municipal-level controls. Models also contain municipal-level education controls, but the results are omitted from the table.

Table 10 shows the results of DID regression for three property characteristics: area (m^2), number of rooms, and property age. The coefficient can be interpreted as the change in the characteristics of the properties in the real estate market. The results show that an increase in earthquake risk, independent of high-magnitude earthquake instances, is associated with higher areas for condominiums, as a 100% increase in earthquake risk is associated with a $0.728m^2$ increase on average in the property area. The increase in area associated with earthquake risk independent of earthquake instance is $0.745m^2$ for residential condominiums. However, there is no significant relation between the earthquake risk of a municipality and the area of the property sold in that municipality. Earthquake risk, independent of high-magnitude earthquake occurrences, also has a positive relationship with the number of rooms in condominiums sold. A 100% increase in earthquake risk in 30 years is associated with a

0.082 and 0.083 increase in the number of rooms for all condominiums and for residential condominiums respectively. Earthquake risk also has a positive relationship with the age of condominiums sold. A 100% increase in earthquake risk in 30 years leads to a 1.415 year age increase in the age of all condominiums and a 1.377 year age increase in the age of residential condominiums on average. The same effect is in the opposite direction for buildings, as earthquake risk has a negative relationship with the age of the buildings. A 100% increase in earthquake risk in 30 years decreases the age of the buildings -0.911 for all buildings and -0.836 for residential buildings.

There is no significant effect of high-magnitude earthquakes independent of earthquake risk on the area for condominiums. On the other hand, while there is no significant effect of high-magnitude earthquakes on building area, they have a negative significant effect on residential buildings. The area of buildings sold decreases by $3.561m^2$ on average following a high-magnitude earthquake event. However, the overall effect of earthquake instances on the area of residential buildings is ambiguous, as earthquake instances, conditioned on earthquake risk, have a positive significant effect on the area of residential buildings. A 100% increase in earthquake risk increases the area of the residential buildings by $6.228m^2$ on average. The estimation of the interaction term is also positive and significant for condominiums, which means a 100% increase in earthquake risk increases the area of condominiums by $1.376m^2$ and residential condominiums by $1.275m^2$.

The overall effects of earthquakes on the number of rooms and the age of condominiums are also uncertain, as the effect of earthquake instances independent of earthquake risk and the effect of earthquake instances conditioned on earthquake risk have different directions for all condominium models. Independent of earthquake risk, a high-magnitude earthquake event decreases the number of rooms in condominiums sold by -0.041 on average. The same number is -0.034 for only residential condominiums. On the contrary, the coefficient of the interaction term is positive and significant for condominiums, which means that as the earthquake risk increases, the positive effect of earthquakes on the number of rooms increases as well. A 100% increase in 5^+ or higher earthquake risk in the following 30 years leads to an increase in the number of rooms by 0.085 for all condominiums and 0.076 for residential condominiums on average.

The effect of high-magnitude earthquakes, independent of earthquake risk, on the age of the property is positive and significant for condominiums in both models. Independent of earthquake risk, a high-magnitude earthquake instance increases the age of sold condominiums by 0.687 on average for all condominiums and 0.575 for residential condominiums. However, the effect of earthquakes conditioned on the earthquake risk of the municipality on the age of the property is negative and statistically significant. A 100% increase in earthquake risk in the municipality decreases the age of condominiums sold by −0.841 for all condominiums. For buildings, while there is no statistically significant effect of high-magnitude earthquakes independent of earthquake risk, there is a negative significant effect of earthquakes conditioned on earthquake risk. A 100% increase in earthquake risk leads to a −0.583 years of age decrease in the age of all buildings on average with 95% confidence level and leads to a −0.449 years of age decrease in the age of residential buildings on average with 90% confidence level.

4.2.2 Robustness check

I use the same specification to check the results that I used in the previous analysis as a robustness check. I run the same analysis for a shortened period of time, which is the period between 2008 and 2013.

Table 11
Number of property sales DID 2008-2013

Model	Condominiums 2008-2013 [1]		Residential Condominium 2008-2013 [2]		Buildings 2008-2013 [3]		Residential Building 2008-2013 [4]	
Dependent variable	Sold Property Volume		Sold Property Volume		Sold Property Volume		Sold Property Volume	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Earthquake Risk Measure	1.432^{***}	0.006	1.418^{***}	0.006	1.745^{***}	0.000	1.735^{***}	0.000
Post Quake Dummy	-0.315	0.605	-0.320	0.600	-1.537^{***}	0.000	-1.474^{***}	0.000
Post Quake Dummy × Earthquake Risk Measure	-1.916^{**}	0.027	-1.891^{**}	0.029	1.129^{**}	0.044	1.117^{**}	0.041
Unemployment Rate	-112.079^{***}	0.000	-112.931^{***}	0.000	-26.833^{***}	0.009	-24.444^{**}	0.015
Population (10.000 people)	2.882^{***}	0.000	2.857^{***}	0.000	2.687^{***}	0.000	2.533^{***}	0.000
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	11,324		11,324		28,248		27,725	
R^2	0.925		0.924		0.943		0.940	
Adjusted R^2	0.921		0.920		0.940		0.937	
Notes:	I use the R package Stargazer (Hlavac; 2022) for the analysis.						*** p < 0.01, ** p < 0.05, * p < 0.1	

This table shows the coefficient estimates and p-values of DID regression corresponding to Equation 22 for municipalities in Japan between the years 2008 and 2013. The dependent variable *Sold Property Volume* is the number of sales in a given quarter-year for all models. *Earthquake Risk Measure* 5^+ is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years in a municipality. *Post Quake Dummy* is a dummy variable equal to 1 when a municipality experiences an earthquake with an intensity equal to or higher than 5^+ in a quarter. The table also presents the coefficient estimations for *Unemployment Rate* and *Population* $(10,000\ people)$ as municipal-level controls. Models also contain municipal-level education controls, but the results are omitted from the table.

Table 11 shows the results of robustness check specification for property sales numbers. The effect of earthquake risk independent of high-magnitude earthquake occurrence on condominium sales is still positive, but higher in magnitude, and unlike the results from Table 9, it is statistically significant. The same effect for building sales is rather similar to the previous analysis' result, as the magnitude of the effect decreases from 2.443 for all buildings and 2.416

for residential buildings to 1.745 and 1.735 respectively, but stays positive and statistically significant.

The results from Table 11 show significant variation compared to Table 9 regarding the overall effect of high-magnitude earthquakes. The effect of high-magnitude earthquake instances independent of earthquake risk decreases in magnitude and loses its significance for both condominium models. The estimations of the interaction term decrease as well, from -4.803 for all condominiums and -2.941 for residential condominiums to -1.916 and -1.891 respectively, but still stay negative and significant, which verifies the results of the previous analysis for condominiums. The effect of earthquake events on buildings, however, changes completely, turning from increasing to decreasing. The coefficient estimations fall from 0.943 for all buildings and 0.957 for residential buildings to -1.537 and -1.474, which implies that the results from the first analysis are not generalizable. The interaction term estimations also change direction, turning from a decreasing effect on building sales volume to an increasing effect as the effect of high-magnitude earthquake events conditioned on earthquake risk changes from -1.453 for all buildings and -1.467 for residential buildings to 1.129 and 1.117 respectively.

Table 12 shows the results of DID regression results for sold property characteristics with robustness check specifications. Unlike the results from Table 10, there is no significant effect of high-magnitude earthquake instances or earthquake risk on the area of the sold property for both condominiums and buildings, which fails to validate the results from the previous analysis. On the contrary, the results for the number of rooms and property age are rather similar. The effect of earthquake risk independent of high-magnitude earthquakes on the number of rooms for sold condominiums decreases from 0.82 for all condominiums and 0.83 for residential condominiums to 0.36 for both specifications, however, stays positive and significant. The effect of high-magnitude earthquake instances independent of earthquake risk on the number of rooms for condominiums sold stays almost the same in the robustness check, however, it lost its significance with a p-value of 0.167 for model [1] and 0.173 for model [2]. The interaction term estimations are also almost identical, as they are estimated at 0.072 for all condominiums and 0.071 for residential condominiums. This validates the results from the previous analysis as Table 12 shows the direction of the overall effect of high-magnitude earthquakes depends on the earthquake risk of the region, as high-magnitude earthquakes have an increasing effect on the number of rooms of condominiums in the real estate market

Table 12
Sold properties characteristics DID 2008-2013

Model	Condominiums 2008-2013 [1]		Residential Condominium 2008-2013 [2]		Buildings 2008-2013 [3]		Residential Building 2008-2013 [4]	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
Panel 1: Area(m^2)								
Earthquake Risk Measure	−0.266	0.490	−0.245	0.525	0.246	0.918	0.983	0.607
Post Quake Dummy	−0.765	0.193	−0.747	0.203	4.621	0.239	3.160	0.324
Post Quake Dummy × Earthquake Risk Measure	0.983	0.189	0.941	0.208	−5.228	0.332	−1.015	0.817
Unemployment Rate	−0.643	0.972	−0.797	0.965	-210.705^{*}	0.080	-176.641^{*}	0.074
Population (10.000 people)	0.277^{***}	0.007	0.285^{***}	0.005	-1.656^{**}	0.017	-1.440^{**}	0.012
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	228,474		227,525		473,037		440,764	
R^2	0.296		0.298		0.211		0.261	
Adjusted R^2	0.294		0.296		0.209		0.259	
Panel 2: Number of Rooms								
Earthquake Risk Measure	0.036^{**}	0.035	0.036^{**}	0.034	-	-	-	-
Post Quake Dummy	−0.038	0.167	−0.038	0.173	-	-	-	-
Post Quake Dummy × Earthquake Risk Measure	0.072^{**}	0.042	0.071^{**}	0.045	-	-	-	-
Unemployment Rate	−0.013	0.988	0.033	0.968	-	-	-	-
Population (10.000 people)	0.010^{**}	0.024	0.010^{**}	0.020	-	-	-	-
Education Controls	Yes		Yes		-		-	
Municipality Fixed Effect	Yes		Yes		-		-	
Quarter - Year Fixed Effect	Yes		Yes		-		-	
Observation	228,474		227,525		-		-	
R^2	0.331		0.332		-		-	
Adjusted R^2	0.329		0.330		-		-	
Panel 3: Age of the Property								
Earthquake Risk Measure	0.526^{***}	0.007	0.521^{***}	0.008	-0.909^{***}	0.000	-0.853^{***}	0.000
Post Quake Dummy	0.727^{**}	0.011	0.736^{***}	0.010	0.464^{**}	0.043	0.396^{*}	0.099
Post Quake Dummy × Earthquake Risk Measure	−0.334	0.412	−0.341	0.402	-1.212^{***}	0.001	-1.096^{***}	0.002
Unemployment Rate	13.209	0.208	12.990	0.216	6.497	0.483	8.682	0.367
Population (10.000 people)	-0.240^{***}	0.000	-0.238^{***}	0.000	-0.142^{***}	0.008	-0.150^{***}	0.007
Education Controls	Yes		Yes		Yes		Yes	
Municipality Fixed Effect	Yes		Yes		Yes		Yes	
Quarter - Year Fixed Effect	Yes		Yes		Yes		Yes	
Observation	228,474		227,525		473,037		440,764	
R^2	0.092		0.093		0.095		0.093	
Adjusted R^2	0.090		0.090		0.092		0.090	

Notes: I use the R package Stargazer (Hlavac; 2022) for the analysis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

This table shows the coefficient estimates and p-values of DID regression corresponding to Equation 23 for municipalities in Japan between the years 2008 and 2013. Panel 1 shows DID regression with $Area(m^2)$ as the dependent variable. Panel 2 shows DID regression with $Number of Rooms$ as the dependent variable and Panel 3 shows DID regression with $Age of the Property$ as the dependent variable. *Earthquake Risk Measure* 5^+ is the probability of an earthquake happening with an intensity equal to or higher than 5^+ in the following 30 years in the municipality the property is located in. *Post Quake Dummy* is a dummy variable equal to 1 when the municipality the property is located in experienced an earthquake with an intensity equal to or higher than 5^+ in the quarter of the transaction. The table also presents the coefficient estimations for *Unemployment Rate* and *Population* $(10,000\ people)$ as municipal-level controls. Models also contain municipal-level education controls, but the results are omitted from the table.

in high earthquake risk municipalities, while the same effect is negative in low earthquake risk municipalities.

The results for property age are also very similar to the main analysis. The positive relationship between earthquake risk independent of high-magnitude earthquakes and sold property age for condominiums decreases significantly in robustness check analysis, from 1.415 to 0.526 for all condominiums and from 1.377 to 0.521 for residential condominiums. However, it remains positive and significant. The same values are almost identical in the robustness check compared to the previous analysis for buildings. A 100% increase in earthquake risk, independent of high-magnitude earthquake events, is associated with a −0.909 decrease in building age for all buildings and with a -0.853 decrease in the age of residential buildings, which are -0.911 and -0.836 in the main analysis respectively. The effect of high-magnitude earthquake events independent of earthquake risk is almost the same for condominiums. High-magnitude earthquake events lead to a 0.727 increase for all condominiums and a 0.736 increase for residential condominiums. The same effects are 0.687 and 0.575 in the main analysis. The effect of earthquakes independent of earthquake risk on property ages for buildings increases in magnitude and gains significance in robustness check specifications. Robustness check results show that a high-magnitude earthquake instance, independent of earthquake risk, increases the ages of buildings in the real estate market by 0.464 for all buildings and 0.396 for residential buildings.

The effect of high-magnitude earthquakes conditioned on the earthquake risk of the municipality is negative and statistically significant for all four models, just like in the main analysis. The effect of high-magnitude earthquake instances conditioned on earthquake risk on condominium ages decreases, and most importantly, loses its significance in robustness check analysis. The results also show a 100% increase in earthquake risk leads to a -1.212 decrease in the ages of all buildings and a -1.096 decrease in the ages of residential condominiums in the real estate market after a high-magnitude earthquake. This shows that the direction of the overall effect of a high-magnitude earthquake on building prices varies depending on the earthquake risk of the municipality and validates the results of the previous analysis. While it has an increasing effect in municipalities with low earthquake risk, it has the opposite effect in municipalities with high earthquake risk.

4.3 Municipal-level response to earthquakes

In the upcoming analysis, I employ interaction-weighted (IW) event study setting to analyse the effect of earthquakes with at least 6^- magnitude on municipal economic activity.

$$Y_{i,t} = \beta_0 + \sum_{e \notin C} \sum_{l \neq -1} \delta_{e,l} (1\{E_i = e\} D^l_{i,t}) + \alpha X_{i,t} + \lambda_t + \epsilon_{i,t} \tag{24}$$

Equation 24 shows the IW event study specification that I use for various municipal financial activity indicators. $Y_{i,t}$ is various variables of interest for municipality i for financial year t. E_i is the year for experiencing a high-magnitude earthquake, which has an intensity equal to or higher than 6^- for the specification of this analysis, during the analysis period for municipality i. e is the cohort group that experienced a high-magnitude earthquake in time period

e. $D^l_{i,t}$ is an indicator that municipality i is l relative year away from an earthquake with 6^- or higher intensity at the financial year t. $X_{i,t}$ is a vector of municipality characteristics including population, unemployment rate, earthquake risk, and education controls, and λ_t is the financial year fixed effect. I do not use the prefecture fixed effect for this setting. The reason is that there are a significant number of municipalities that received the treatment quite early into the analysis period (around 2011), and given the geographic characteristics of the earthquakes, treatments are usually received all around the prefectures. Thus, the prefecture fixed effect naturalizes some of the variations due to the earthquakes for these municipalities that this study tries to capture. Results from the event study with prefecture fixed effect are presented in the Appendix.

4.3.1 Results

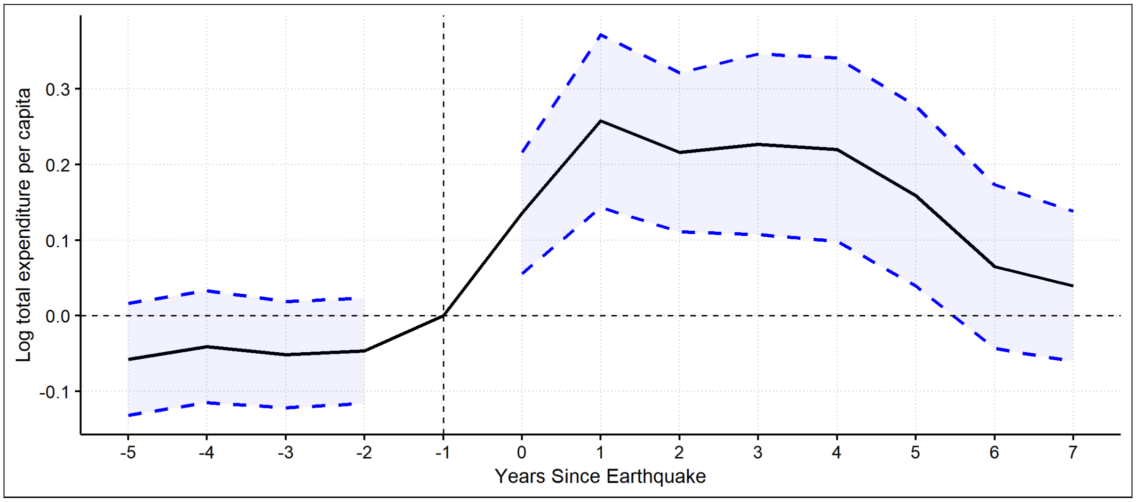
Figure 3 shows the IW event study coefficients for per capita total expenditure and total revenues for municipalities. Blue dashed lines mark the 95% confidence intervals of the coefficients. Event study coefficients reflect the ATT of high-magnitude earthquakes and can be interpreted as the percentage change in the variable of interest compared to the reference time period -1 caused by the treatment, which is earthquakes with an intensity equal to or higher than 6^-.

Figure 3a shows the percent change in per capita municipality expenditures in years relative to the time of an earthquake occurrence with an intensity equal to or higher than 6^-. Before the earthquake period, there is no significant difference in trends between municipalities in the treatment group and the control group. Starting from the financial year the earthquake occurred, the earthquake has an increasing effect on per capita total expenditures of municipalities, and the positive-significant effect persists over the years. Over the following 4 financial years after the earthquake, the seismic event has a positive-significant effect varying from 13.6 percent to 25.8 percent on per capita total municipal expenditure compared to the pre-earthquake period relative to the control group. The effect falls starting from the 5th year following the event, and the study shows there is no significant effect of the earthquake on municipality expenses starting from the 6th year.

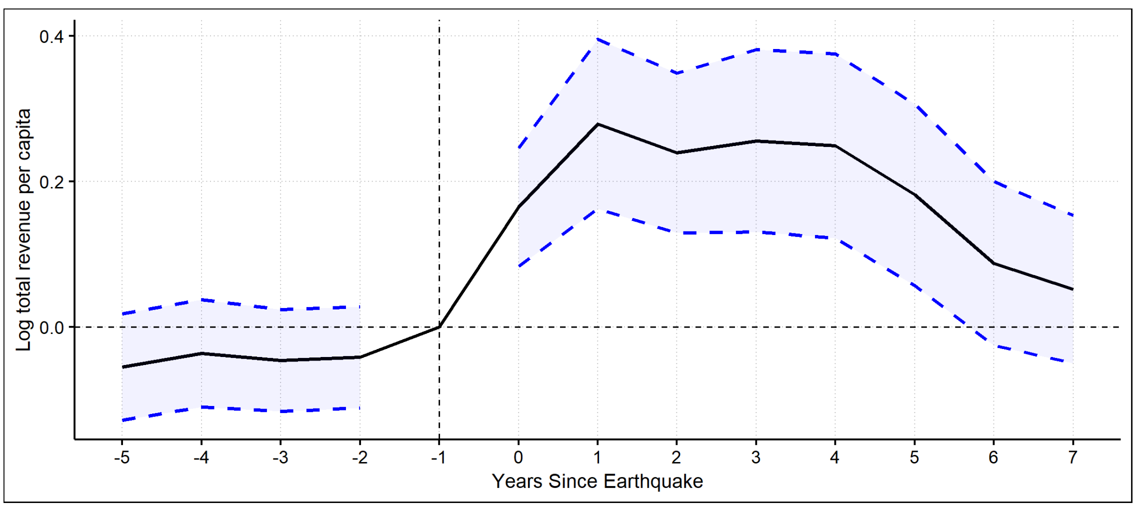
Figure 3b shows the percent change in per capita revenue of municipalities in years relative to the time of a massive seismic event. Similar to the expenditures, there is no significant

Figure 3: Municipality per capita expenditures and revenues

(a) Total expenditure (log)



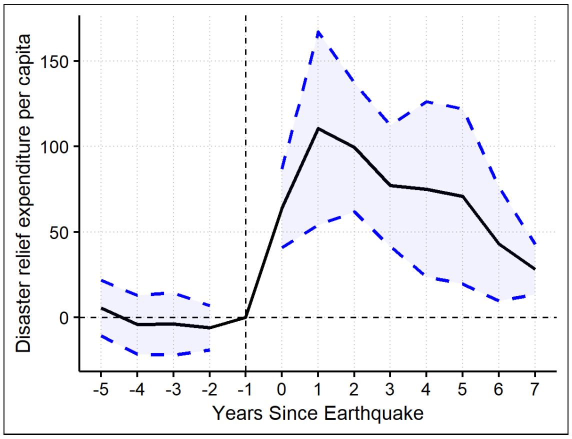
(b) Total revenue (log)



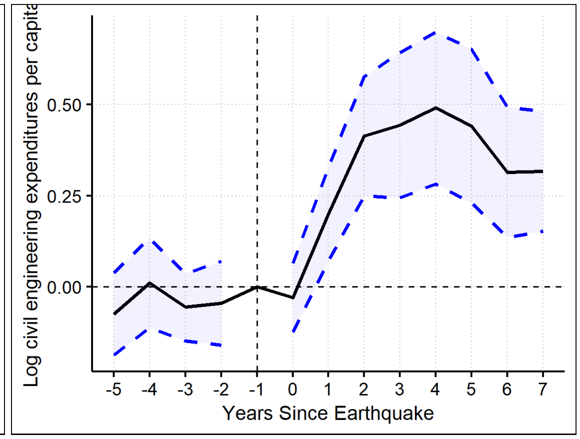
difference in trends prior to the event, as none of the coefficients are significant. Starting from the event period, municipalities that experienced high-magnitude earthquakes increased their per capita revenues relative to municipalities that did not. The increase in per capita revenue caused by the event persists over the years. Similar to the per capita expenditure, for the first 4 financial years following the event, the effect of the event on municipality revenues varies between 16.5 percent and 27.8 percent. The effect starts to fall off in the 5th year following the event, and there is no significant effect of earthquakes on revenue starting from the 6th year on.

Figure 4: Municipality expenditure components

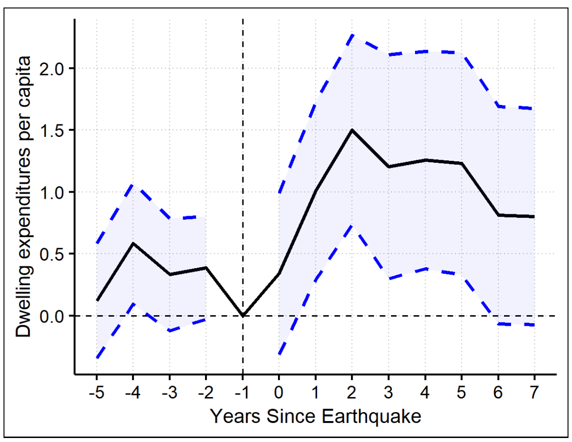
(a) Disaster relief expenditure (log)



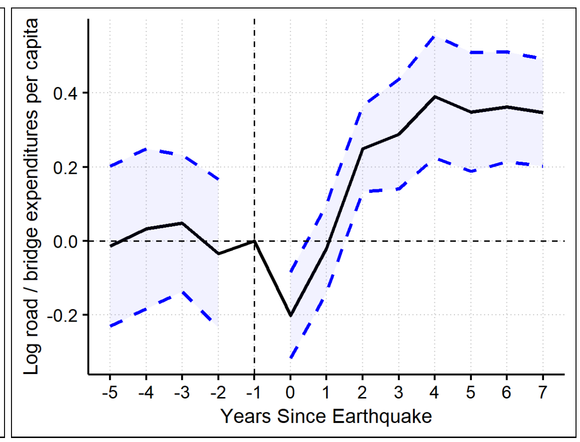
(b) Civil engineering expenditure (log)



(c) Dwelling expenditure (log)



(d) Road and bridges expenditure (log)



(e) Welfare expenditure (log)

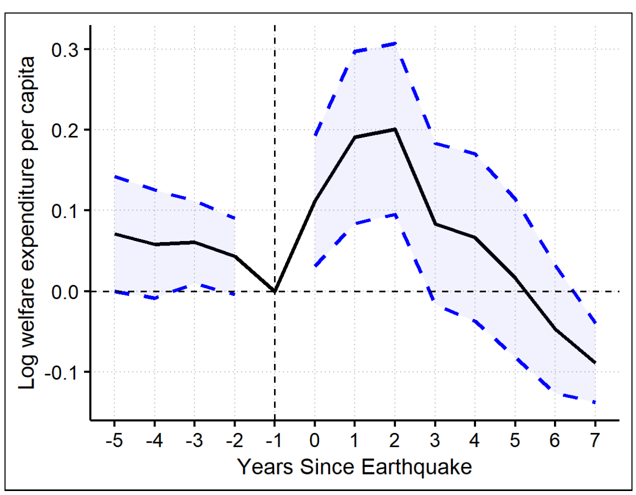


Figure 3 clearly shows evidence of the increasing effect of high-magnitude earthquakes on municipality economic activities. To see which expense categories push the per capita total expenditure to increase, Figure 4 shows different components of municipality expenses after such an event. All expenditure components are reported as percent changes in per capita levels except disaster relief expenditure, which is reported as per capita actual value change.

Figure 4a shows the per capita disaster relief expenditure change due to the high-magnitude earthquake. The reason I use actual values instead of log-transformed values is that there are many 0 disaster relief expenditures for municipalities during the period. $Y+1$ log transformation results are presented in the appendix. According to the Figure 4a, municipalities increase their per capita expenditures by approximately $63,000$ ¥ per capita due to an earthquake immediately after the event. The per capita increase peaks a year after the event with an approximately $110,000$ ¥ increase due to the event, and the effect stays significant overall throughout the 7-year period, however, the amount gradually decreases every year to almost $28,000$ ¥ per capita in the 7th financial year following the event. Massive earthquakes have positive effects on per capita municipal welfare expenditures as well. Per capita welfare expenditures of municipalities increase in the year of the event and the following 2 financial years after the earthquake, varying from 11.1 percent to 20.1 percent. Then the effect fades, as there is no significant effect between years 3 and 6 after the earthquake, and there is a -8.9 percent effect in year 7. However, even though for the majority of the pre-event period the event study coefficients are not significant in 95% confidence interval, they are really close to the lower confidence interval threshold, which indicates there can be a different pre-event trend, which would make the results misleading.

Unlike disaster relief and welfare expenditures, earthquakes do not have an immediate effect on per capita road and bridge, civil engineering, and dwelling expenditures. There is no significant effect of an earthquake instance on per capita dwelling expenditures and civil engineering expenditures in the event financial year, however, it has a positive-significant effect starting from the first year following the event. The effect of earthquakes on per capita dwelling expenditures varies from 100 percent to 150 percent and peaks in the second year following the earthquake, while there is no significant effects in years 6 and 7 after the event. The effect of high-magnitude earthquakes on per capita civil engineering expenditures persists over the 7-year period starting from the year after the event. The effect varies from approximately 19.9 percent to 49.1 percent. Finally, different from the rest, per capita road and bridge expenses are negatively affected by high-magnitude earthquakes in the event year by 20.6 percent. Following the event financial year, the effect starts to increase gradually. It comes back to its pre-event level in year 1 after the earthquake, then continues to increase as earthquakes have a positive and significant effect on per capita road and bridge expenditures of municipalities starting 2 years after the event. The positive significant effect varies from approximately 24.9 percent to 39.1 percent during the 6-year period starting in year 2.

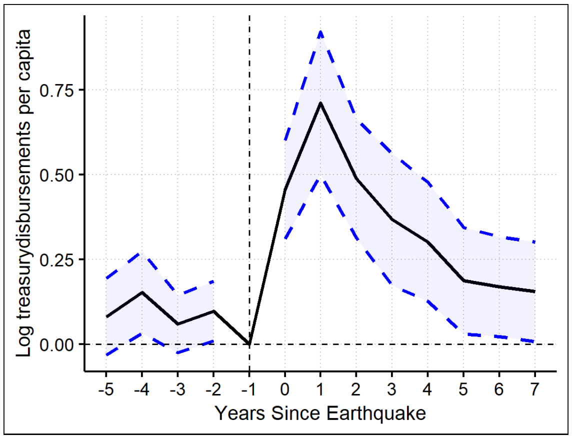
Figure 5 shows the IW event study coefficients for different components of municipality revenue. Figure 5a and Figure 5b show that high-magnitude earthquakes have an increasing effect on both per capita treasury and prefecture disbursements. The event immediately increased both components, starting with the event financial year. High-magnitude earthquakes increase per capita treasury disbursements by 45.6 and 71.1 percent in the year of the event and the following year respectively. Then the effect decreases gradually but persists throughout the 8 years. Similar to treasury disbursements, the positive-significant effect of massive earthquakes on per capita prefecture disbursements peaks in the first 2 years following the event, with 45.9 percent in the year of the event and 52 percent in the following year. The effect starts to gradually decrease after the first year relative to the event while staying significant until year 6.

Figure 5c shows the percent change in per capita local transfer tax revenues of municipalities after a high-magnitude earthquake event. High-intensity seismic events have an increasing effect on local transfer tax revenues, as local transfer tax revenues increased immediately in the year of the event by 11.9 percent, and the positive-significant effect persists over the following 7 years, peaking at 3 years after the event with a 21 percent increase. Figure 5d shows the actual value change in per capita local allocation tax. Local allocation is another revenue stream from the national government to municipalities, similar to treasury disbursements. The reason local allocation tax revenue is reported as actual value changes instead of log-transformed value changes is the same as why disaster relief expenditures are reported the same way. Massive earthquakes increase local allocation tax per capita by $39,000$ ¥ in the year of the event, and the increasing effect continues until 4 years after the event, then fades away starting in the 5th year following the earthquake.

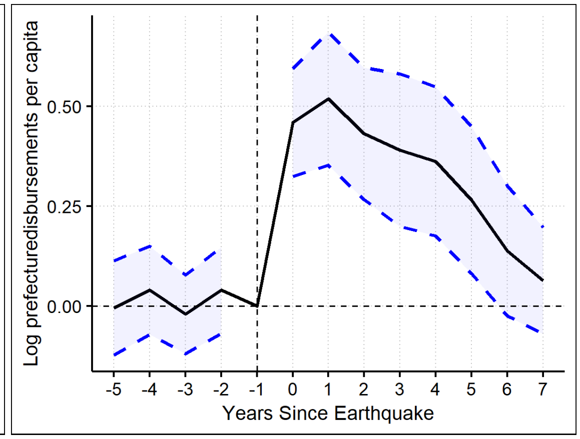
Contrary to the increasing total per capita revenues of municipalities after a high-intensity earthquake, both property income and rent and fees decrease due to earthquake occurrences.

Figure 5: Municipality revenue components

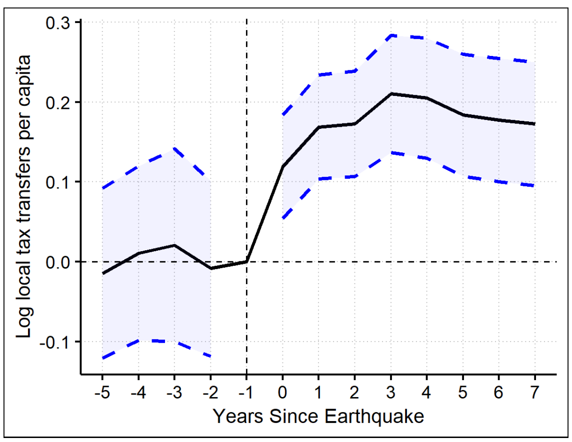
(a) Treasury disbursements (log)



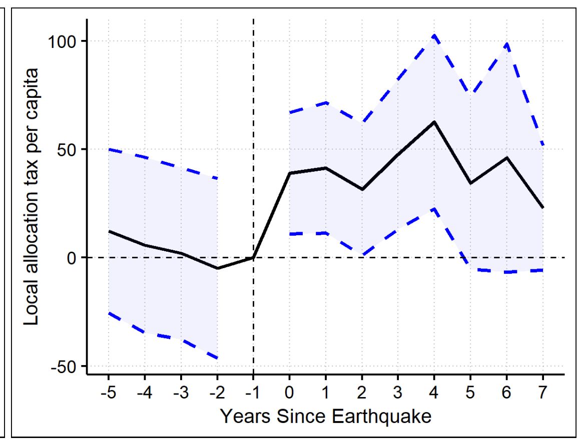
(b) Prefecture disbursements (log)



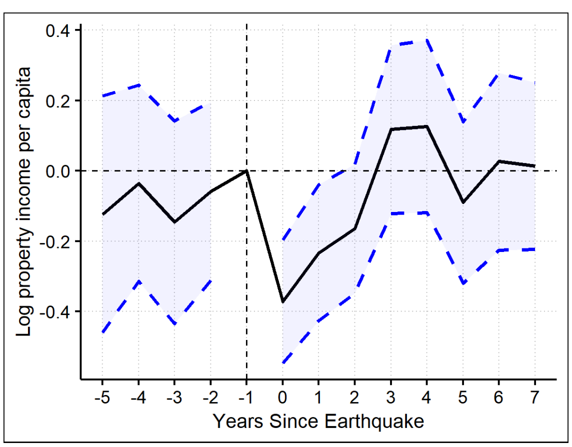
(c) Local transfer tax revenue (log)



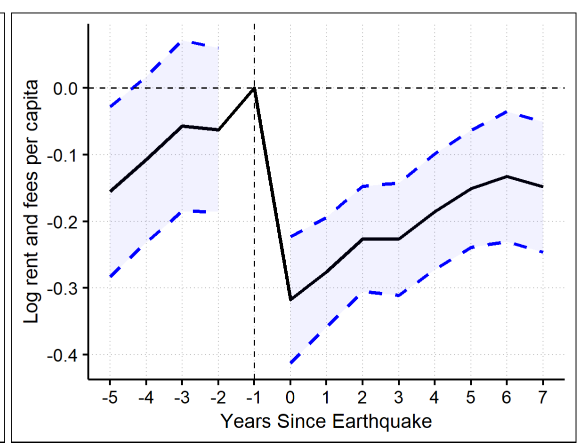
(d) Local allocation tax revenue



(e) Property income (log)



(f) Rent and fee revenues (log)



Massive earthquakes have a decreasing effect on per capita property income by -37.2 percent in the year of the event and -23.4 percent the following year. The decreasing effect diminishes starting 2 years after the event, as there is no significant effect for the rest of the period. Rend and fee revenues also decrease immediately after a high-magnitude earthquake, by -31.8 percent in the event year. The decreasing effect gradually declines after the first year, reaching to -13.3 percent in 6 years and -14.8 in 7 years after the event, but stays significant throughout the 7-year period. However, like welfare expenditures, even though for most parts pre-earthquake period coefficients are insignificant, there seems to be a marginally different pre-trend for the treatment and the control group, which would make the results of Figure 5f unreliable.

4.3.2 Robustness Check

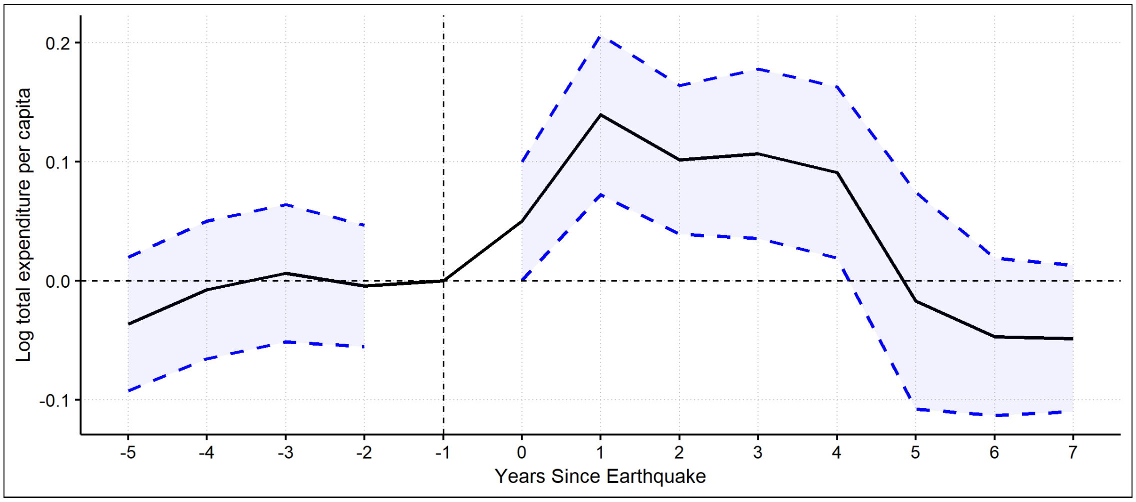
As a robustness check and to see what the different reactions are that municipalities have after earthquakes of different intensities, I run the same analysis with earthquakes of 5^{+} or higher magnitude.

Figure 6 percent change in per capita total revenue and total expenditure in years relative to the time of an earthquake with 5^{+} or higher magnitude. Both Figure 6a and Figure 6b resemble the Figure 3, as municipalities react to a 5^{+} or higher earthquake by increasing both their per capita expenditure and revenue. Municipalities react immediately to earthquakes with equal or higher intensity than 5^{+}, increasing their per capita expenditure between 5 percent and 13.9 percent in the first 5 years and increasing their per capita revenue between 7 percent and 15.6 percent in the same period. The increase is relatively smaller in robustness check specification. The most probable explanation for smaller coefficients in the robustness check is that municipalities increase their expenditures and revenues more when the intensity of the earthquake is higher. The increasing effects also fade off earlier in robustness check as the event has a positive-significant effect for only 5 years compared to 6.

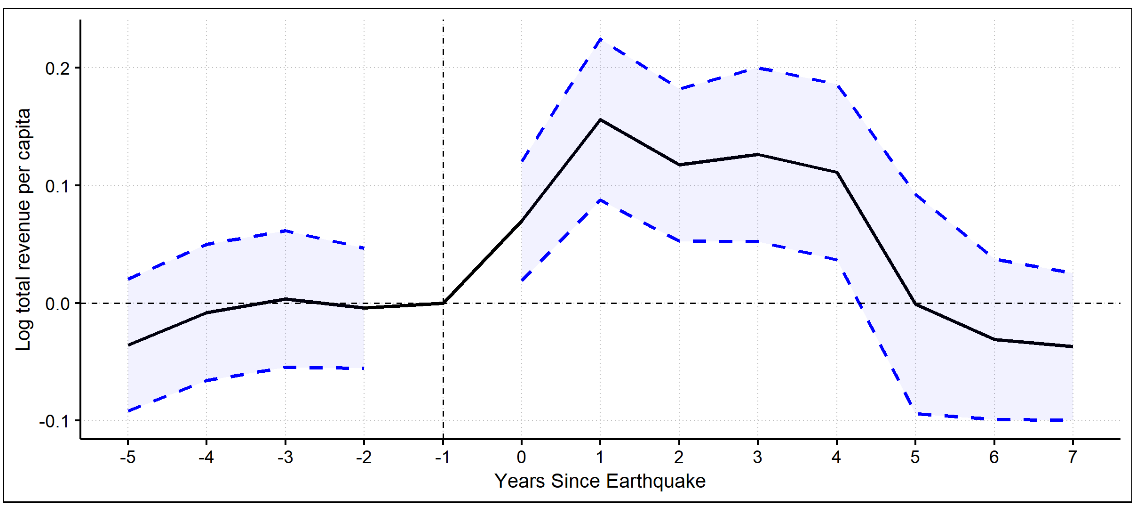
Results from Figure 7 are mostly consistent with the results from the main specification. Municipalities react to earthquakes with an intensity equal to or higher than 5^{+} with an immediate increase in disaster relief expenditures. The amount of increase due to the event is lower in robustness check specification compared to the main analysis, as the increase is $40,000$ ¥ and peaks at $83,000$ in 4 years after the event, which supports the notion that

Figure 6: Municipality per capita expenditures and revenues 5^+

(a) Total expenditure 5^+ (log)



(b) Total revenue 5^+ (log)

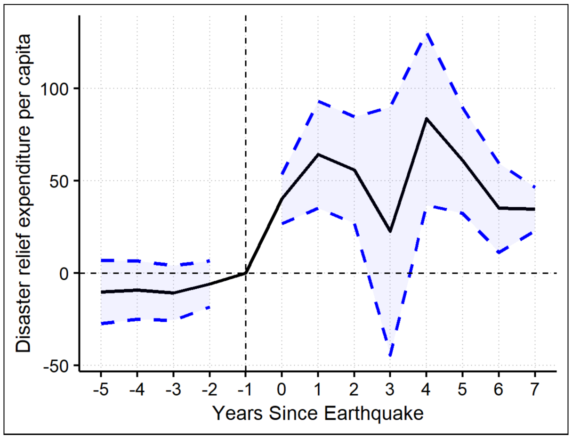


municipalities react by a greater economic activity increase when the intensity of the earthquake is higher. The biggest difference between the disaster relief expenditure response in robustness check and the main specification is the sudden drop in 3 years relative to the earthquake in robustness check.

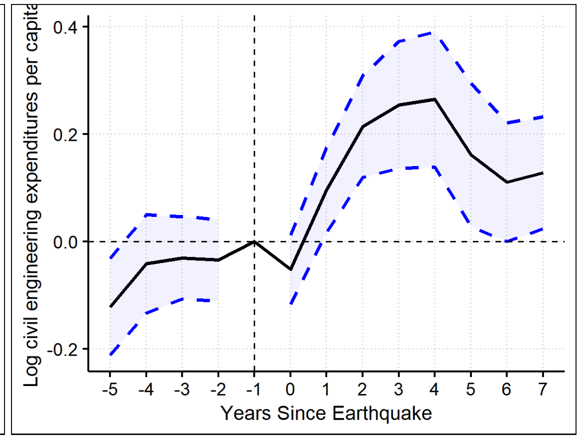
Similar to the results from the main analysis, the positive significant effect of 5^+ or higher earthquakes on per capita civil engineering expenditures and dwelling expenditures is not immediate, but only starts delayed. Similar to the rest of the results, the magnitude of the positive effect on per capita civil engineering expenditure is lower in robustness check speci-

Figure 7: Municipality expenditure components 5^+

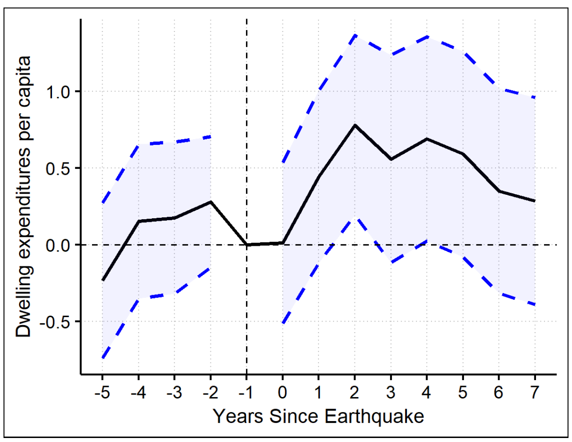
(a) Disaster relief expenditure 5^+ (log)



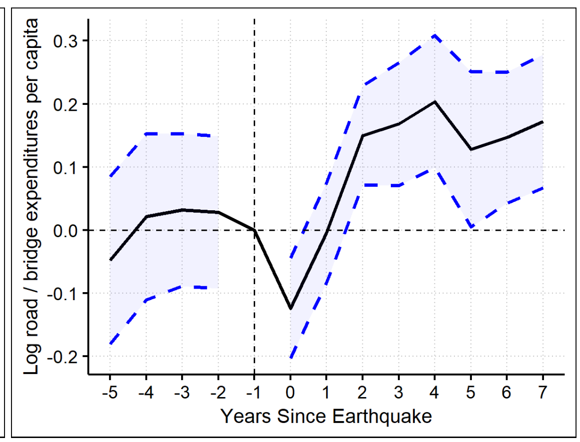
(b) Civil engineering expenditure 5^+ (log)



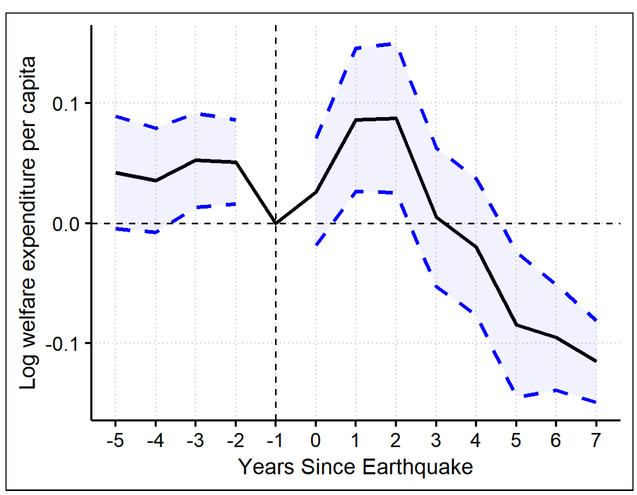
(c) Dwelling expenditure 5^+ (log)



(d) Road and bridges expenditure 5^+ (log)



(e) Welfare expenditure 5^+ (log)



fication as it varies between 9.6 percent and 26.5 percent starting a year after the event. The effect of 5^+ or higher earthquakes persists for a shorter period relative to the main specification and is only significant in years 2 and 4 relative to the event year after which it loses its significance.

Road and bridge expenditures also follow a similar path in robustness check compared to the main analysis of the paper, as earthquakes with an intensity equal to or higher than 5^+ have a negative-significant effect in the year of the event, and starting 2 years after the event, the effect changes its direction and persists throughout the rest of the period. The effect is also lower in magnitude in robustness check as the percent per capita decrease in the first period due to the event is -12.3 percent and the per capita increase in road and bridge expenditures peaks at 20.4 percent in year 4. Figure 7e, resembles Figure 4e as well, however, the different pre-earthquake trends become even more visible.

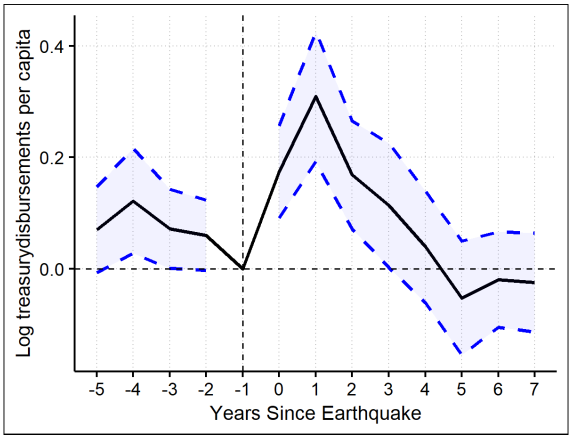
Figure 8 shows similar results to Figure 5 in regards to the direction of the effect and the path that the coefficient follows. 5^+ or higher earthquakes have an immediate positive significant effect on both per capita treasury and prefecture disbursements. The magnitudes of the effects are relatively lower for both compared to the main specification. Per capita treasury disbursements increase by 17.4 percent in the event period and peak a year later with a 30.9 percent increase. Similarly, per capita prefecture disbursements increase by 18.5 percent immediately after the event and by 26.2 percent a year later.

Figure 8c matches the results from the main analysis fairly well, as 5^+ or higher earthquakes have a positive-significant effect starting from the event period and persist throughout the following 7 years. Once again, the magnitude is lower in the robustness check compared to the main specification. Local allocation tax, on the other hand, loses its significance altogether and has no effect whatsoever in any period, in contrast to the main analysis.

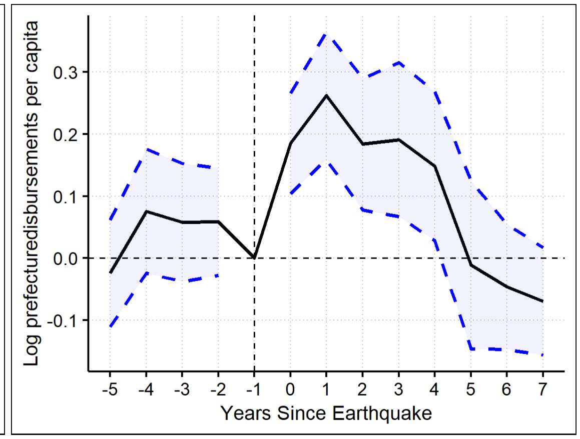
Earthquakes with an intensity equal to or higher than 5^+ have a negative effect on both per capita property income and rent and fee revenues, just as shown in the main analysis. Even the magnitudes are quite similar, as 5^+ or higher intensity earthquakes decrease per capita property income by 30.3 percent in the year of the event. Then it decreases gradually except for the peak 5 years later the event with a 33.9 percent decrease, while 5^+ or higher earthquakes decrease rent and fee revenue by 20.6 percent after the earthquake and stay rather

Figure 8: Municipality revenue components 5^+

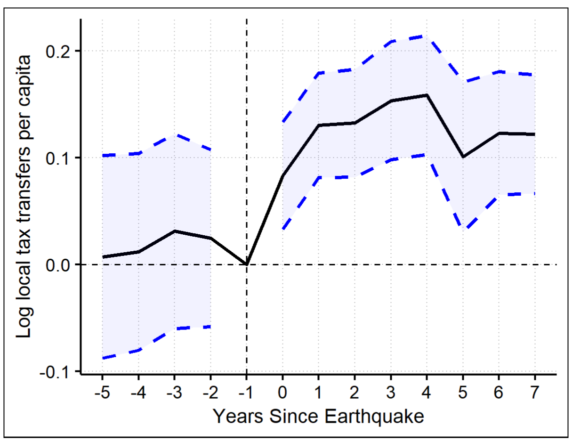
(a) Treasury disbursements 5^+ (log)



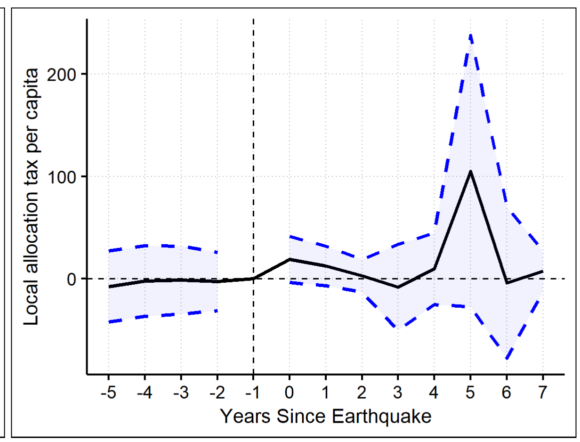
(b) Prefecture disbursements 5^+ (log)



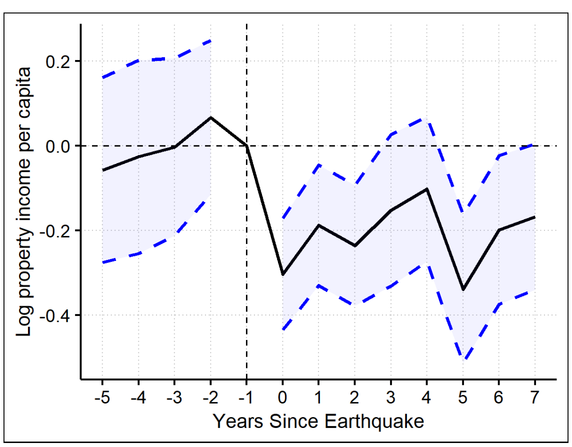
(c) Local transfer tax revenue 5^+ (log)



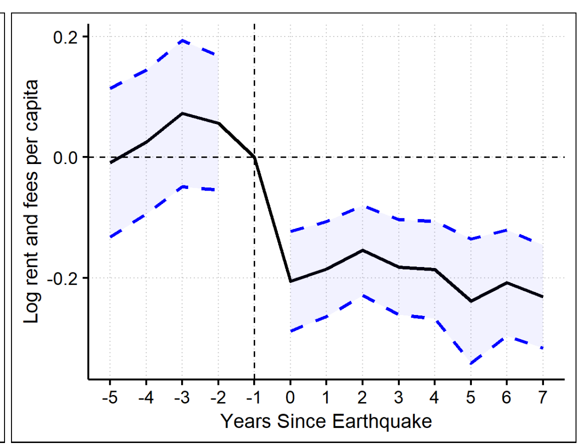
(d) Local allocation tax revenue 5^+



(e) Property income 5^+ (log)



(f) Rent and fee revenues 5^+ (log)



flat during the 7-year period after the event. Finally, contrary to the general trend of the comparison between robustness check results and the results of the main analysis, the effect persists even longer compared to the main specification for these two components.

Overall, the robustness check results validate the results of the main specification regarding the directions and the followed paths of the effects, as they match most of them. The general trend is that the magnitudes of the effects are higher in absolute values and the persistence of the effects is longer for the main analysis, which implies the effects of earthquakes with higher intensity have greater and longer effects in comparison with earthquakes that have lower intensity.

5 Conclusion

fThere are three main questions that this paper tries to answer. First is how individuals react after a high-magnitude earthquake regarding the way they value the implicit price of earthquake risk, second the condominium and building characteristics in real estate market change after a high-magnitude earthquake and third is how municipalities react to a high-magnitude earthquake regarding their level of economic activity.

To answer the first question, I employ a simple hedonic regression model with municipality and quarter-year fixed effects and use real transaction data with detailed house characteristics between the years 2008 and 2020. I first show there is a positive relationship between 5^+ or higher earthquakes and both condominium and building prices. I then continue contributing to the literature by showing evidence of the negative implicit price of earthquake risk, which is an ambiguous topic in the literature. Finally, I show that the implicit price of earthquake risk decreases even more for both condominiums and buildings after a 5^+ or higher earthquake. The most probable explanation for the additional decrease in the implicit price of earthquake risk is that people underestimate the earthquake risk in the pre-earthquake periods, and they adjust their risk perception after receiving an information shock in the form of a massive seismic event. I then present additional evidence on the results by both running a robustness check by changing the research period to 2010-2014 and using 2SLS regression setup to address the difference between objective earthquake risk measures and subjective risk perception of individuals. Both specifications validate the results from the main analysis for both condominiums and buildings.

To answer the second question of the paper, I use DID framework with municipality and quarter-year fixed effects. I first show how the numbers of condominium and building sales are affected by a high-magnitude earthquake event. Then I continue by observing how the age, number of rooms, and area of the properties in the real estate market change in reaction to 5^+ or higher earthquakes. I show that the effects of high-magnitude earthquakes on the number of rooms and age of sold properties are ambiguous and depend on the earthquake risk of the region. Massive seismic events have an increasing effect on building age and a decreasing effect on the number of rooms in condominiums in regions with low earthquake risk, while they have a decreasing effect on building age and an increasing effect on the number of rooms in condominiums in regions with high earthquake risk. I also show an increasing overall effect of high-magnitude earthquakes on the area of condominiums, an increasing effect on property sales volume in low earthquake-risk regions, and a decreasing effect on property sales volume in high earthquake-risk regions. However, while the results of the effects on the number of rooms and the age of properties are robust, effects on the property sales volume and area are not robust to different specifications, which implies the results are not generalizable.

Finally, I attempt to answer the third question by using event study specifications and municipality financial data between the financial years of 2010 and 2020. I use interaction-weighted event study setting to avoid contamination of event study coefficients under treatment effect heterogeneity. I show municipalities react to 6^- or higher earthquakes by increasing their economic activity as they increase both per capita expenditure and revenue in the year of the earthquake and the following 5 years. I continue by examining the components of municipal expenditures and revenues. I show that municipalities first react by increasing disaster relief expenditures starting from the financial year of the earthquake. Starting the year after the earthquake, municipalities start increasing per capita civil engineering and dwelling expenditures, and finally, they increase per capita road and bridge expenditures starting 2 years after the earthquake. On the revenue side, most of the increase comes either from the national government level or from the prefecture level as all treasury disbursements, prefecture disbursements, and local allocation tax revenues increase starting from the year of the earthquake. In contrast with the increase in revenue, per capita property income and rent and fee revenues decrease significantly following a 6^- or higher earthquake.

I run the same analysis for earthquakes with an intensity of 5^+ or higher as a robustness check. For the most part, the results of the robustness check validate the main specifications. The results from the robustness check also imply that municipalities respond with a higher increase in economic activity for earthquakes of greater magnitude.

A Data

Table 13
Yearly residential real estate transactions statistics

Year	Condominiums				Buildings			
		Price (Million ¥)				Price (Million ¥)		
	Sold	Mean	Median	Std. Dev.	Sold	Mean	Median	Std. Dev.
2008	32,393	20.062	18.000	12.219	67,066	27.088	25.000	17.344
2009	36,343	19.971	18.000	12.102	67,640	26.009	24.000	16.618
2010	40,814	20.281	18.000	12.325	74,020	26.213	24.000	16.402
2011	37,654	19.933	18.000	12.269	71,472	26.176	24.000	16.563
2012	38,334	19.457	17.000	11.971	77,817	25.953	24.000	16.501
2013	41,987	19.856	18.000	12.240	82,749	26.239	24.000	16.716
2014	40,201	20.408	18.000	12.429	80,340	26.206	24.000	17.287
2015	42,190	21.173	19.000	12.752	85,030	26.653	24.000	17.602
2016	42,351	21.935	20.000	13.079	83,069	27.131	25.000	18.006
2017	33,667	22.308	20.000	13.121	82,654	27.393	25.000	18.146
2018	25,200	23.479	21.000	13.336	79,638	27.508	25.000	18.382
2019	27,873	24.354	22.000	13.733	78,291	27.530	25.000	18.287
2020	32,054	24.764	23.000	13.669	90,781	28.200	26.000	17.954
Total	472,925	21.211	19.000	12.780	1,020,567	26.822	25.000	17.430

Notes: This table presents the descriptive statistics of the yearly residential condominium and building transactions of this paper's sample obtained from Real Estate Transaction-price Information (RETI).

Table 14
Yearly residential condominium and building attributes statistics

Variables	2008-2020		2009-2010		2011-2012	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Condominiumns						
House Sales Price	21.211	12.780	20.135	12.222	19.693	12.122
Age of House	18.11	11.57	14.46	10.72	16.59	10.78
Area (m^2)	58.74	22.60	60.74	21.64	60.29	22.25
Nearest Station 0-5 min (=1)	0.227	0.419	0.212	0.409	0.219	0.413
Nearest Station 5-10 min (=1)	0.345	0.475	0.329	0.470	0.341	0.474
Nearest Station 10-15 min (=1)	0.198	0.398	0.202	0.402	0.196	0.397
Nearest Station 15-30 min (=1)	0.171	0.376	0.189	0.392	0.181	0.385
Nearest Station 30-60 min (=1)	0.052	0.221	0.059	0.236	0.055	0.227
Nearest Station 1-1.5 h (=1)	0.005	0.073	0.006	0.076	0.006	0.079
Nearest Station 1.5-2 h (=1)	0.001	0.031	0.001	0.028	0.001	0.035
Nearest Station 2+ h (=1)	0.001	0.032	0.001	0.029	0.001	0.035
Number of Rooms	3.45	0.98	3.55	0.96	3.52	0.96
Reinforced Concrete (=1)	0.703	0.457	0.699	0.459	0.698	0.459
Steel Frame Reinforced Concrete (=1)	0.292	0.455	0.297	0.457	0.296	0.457
Steel Frame (=1)	0.006	0.076	0.006	0.074	0.006	0.078
Buildings						
House Sales Price (Million ¥)	26.822	17.430	26.116	16.506	26.060	16.531
Age of House	15.56	16.68	13.72	14.59	14.32	15.40
Area (m^2)	195.17	163.29	189.93	153.17	191.11	159.37
Nearest Station 0-5 min (=1)	0.052	0.221	0.050	0.219	0.052	0.223
Nearest Station 5-10 min (=1)	0.174	0.379	0.170	0.376	0.170	0.376
Nearest Station 10-15 min (=1)	0.186	0.389	0.183	0.387	0.185	0.389
Nearest Station 15-30 min (=1)	0.329	0.470	0.329	0.470	0.330	0.470
Nearest Station 30-60 min (=1)	0.182	0.386	0.187	0.390	0.184	0.387
Nearest Station 1-1.5 h (=1)	0.048	0.214	0.051	0.220	0.049	0.215
Nearest Station 1.5-2 h (=1)	0.016	0.126	0.016	0.127	0.016	0.127
Nearest Station 2+ h (=1)	0.013	0.114	0.013	0.112	0.013	0.113
Reinforced Concrete (=1)	0.028	0.165	0.029	0.167	0.029	0.167
Steel Frame Reinforced Concrete (=1)	0.002	0.040	0.002	0.043	0.002	0.042
Steel Frame (=1)	0.049	0.216	0.071	0.258	0.044	0.204
Light Steel Structure (=1)	0.063	0.242	0.044	0.205	0.071	0.258
Concrete Block (=1)	0.002	0.045	0.002	0.043	0.002	0.044
Wooden (=1)	0.863	0.344	0.860	0.347	0.859	0.348

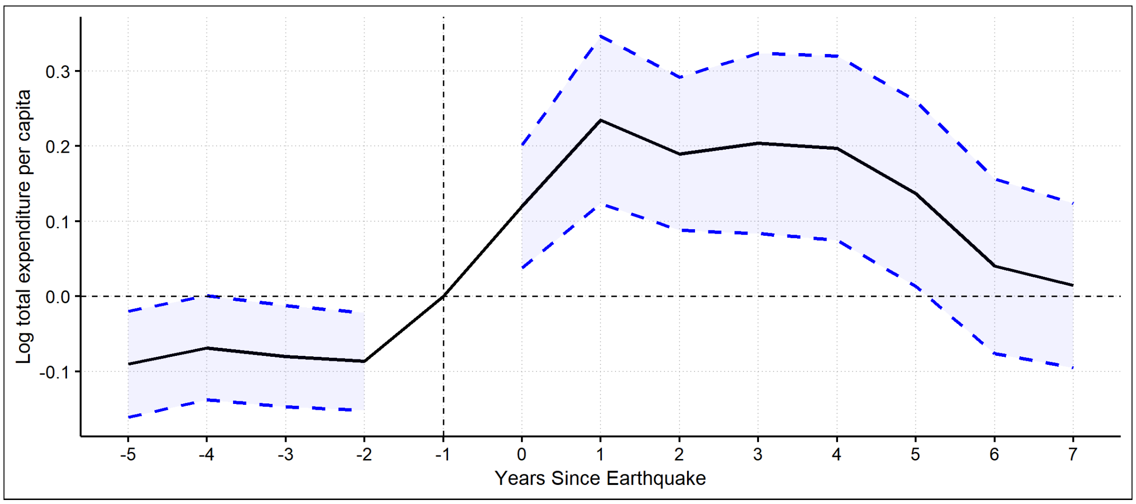
Notes: This table presents the descriptive statistics of various residential real estate characteristics of the paper's sample for three different time periods. 2008-2020 is the full period of the paper. The second column shows the 2-year period prior to the Great East Japan Earthquake, and the last column shows the following 2-year period.

B Quantitative Analysis

B.1 Municipal level response to earthquakes with prefecture fixed effects

Figure 9: Municipality per capita expenditures and revenues

(a) Total expenditure (log)



(b) Total revenue (log)

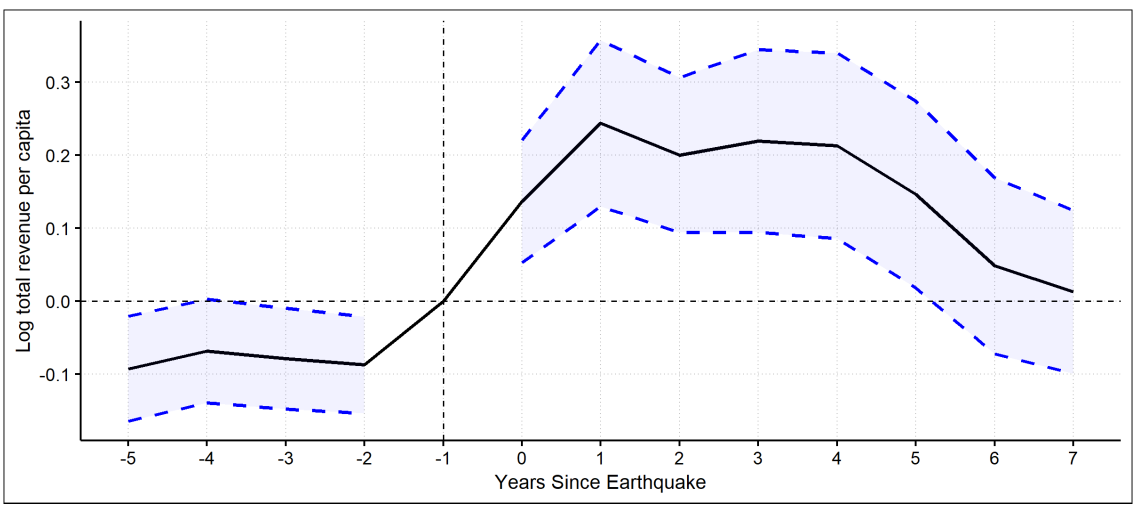
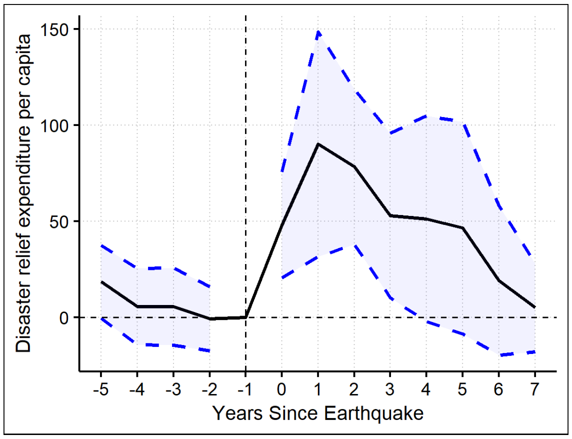
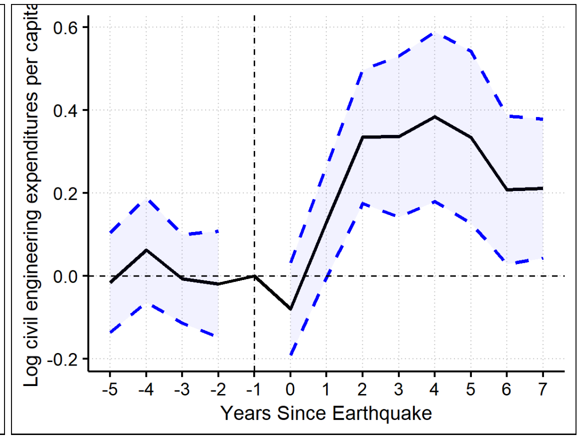


Figure 10: Municipality expenditure components

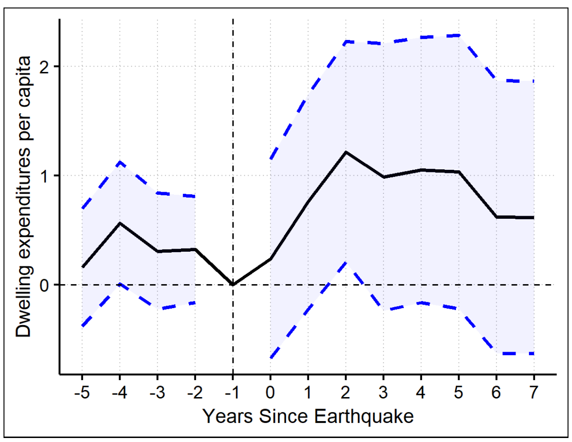
(a) Disaster relief expenditure (log)



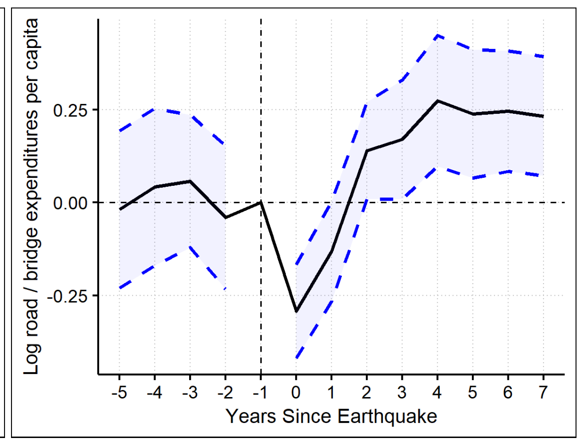
(b) Civil engineering expenditure (log)



(c) Dwelling expenditure (log)



(d) Road and bridges expenditure (log)



(e) Welfare expenditure (log)

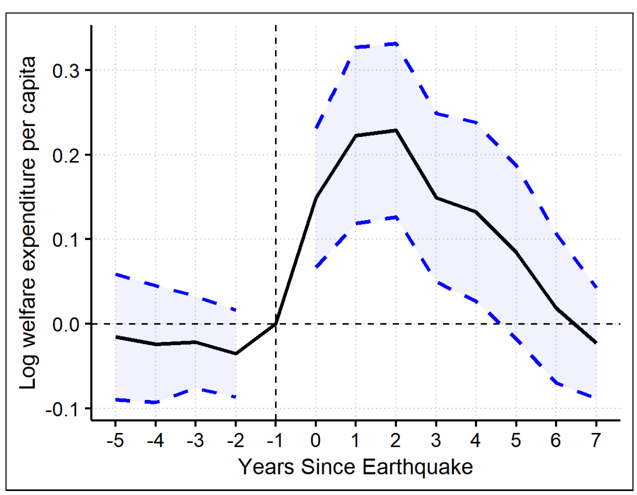
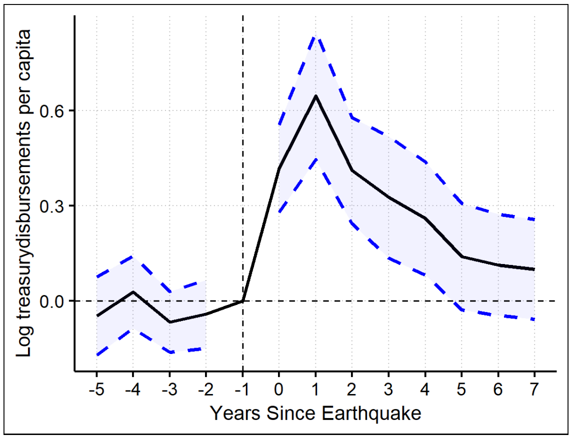
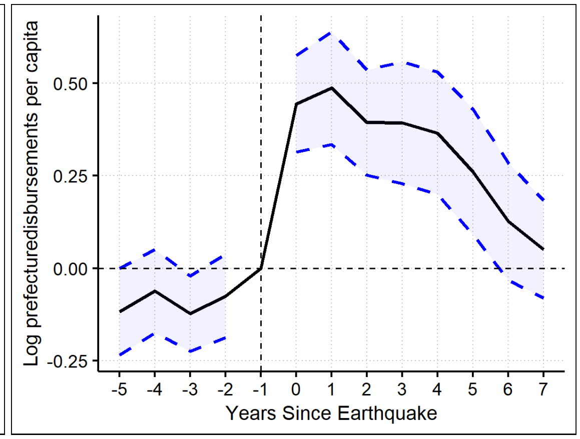


Figure 11: Municipality revenue components

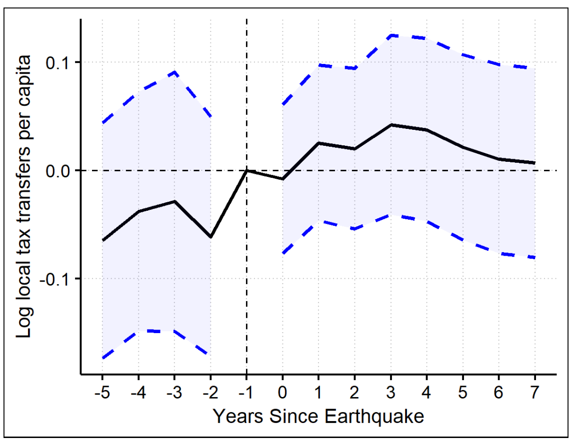
(a) Treasury disbursements (log)



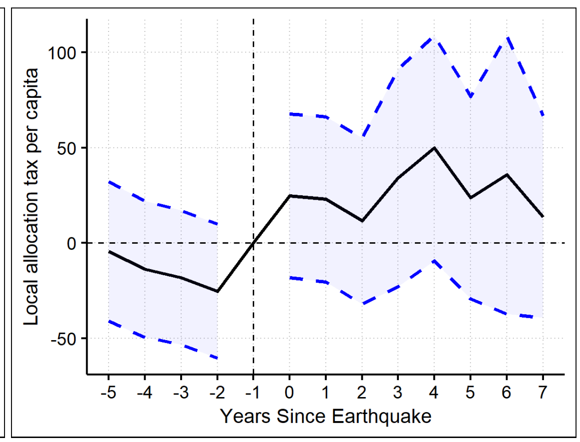
(b) Prefecture disbursements (log)



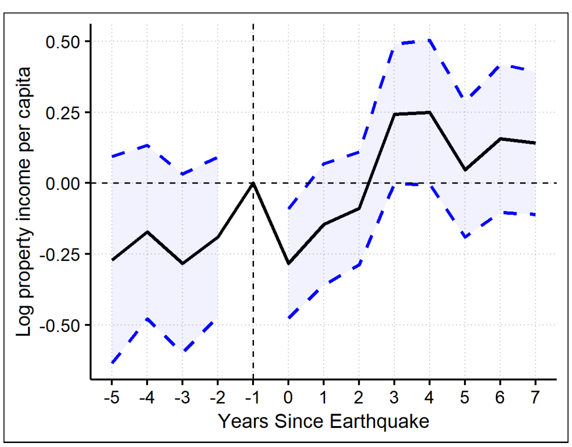
(c) Local transfer tax revenue (log)



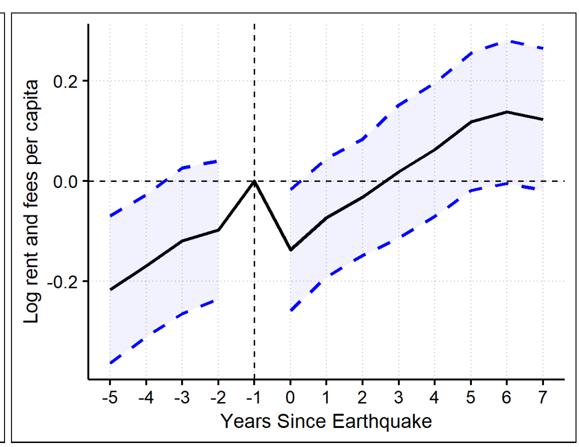
(d) Local allocation tax revenue



(e) Property income (log)



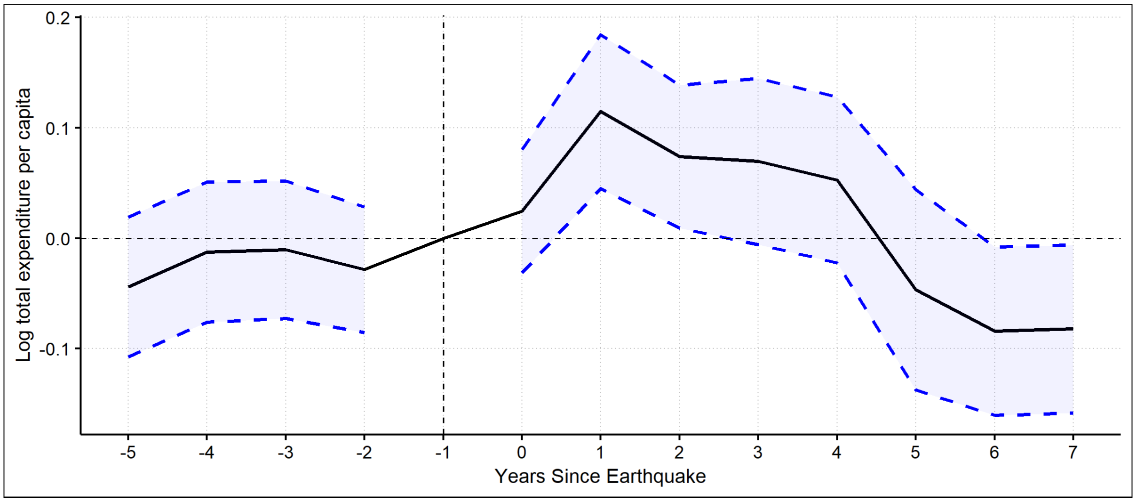
(f) Rent and fee revenues (log)



B.2 Robustness check with prefecture fixed effecs

Figure 12: Municipality per capita expenditures and revenues 5^{+}

(a) Total expenditure 5^{+} (log)



(b) Total revenue 5^{+} (log)

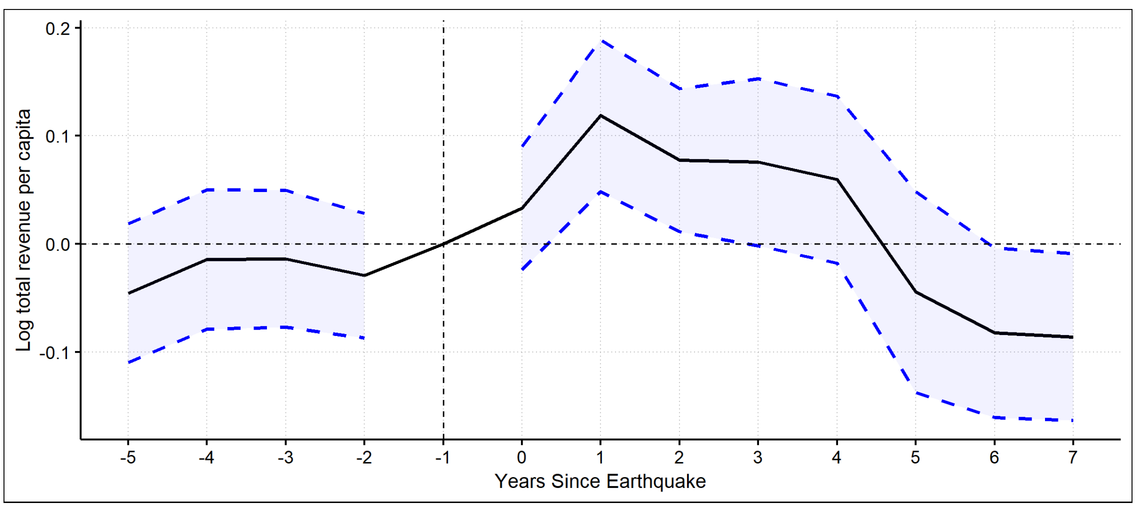
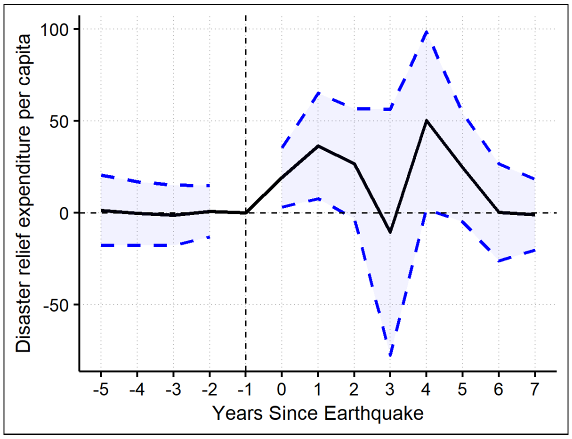
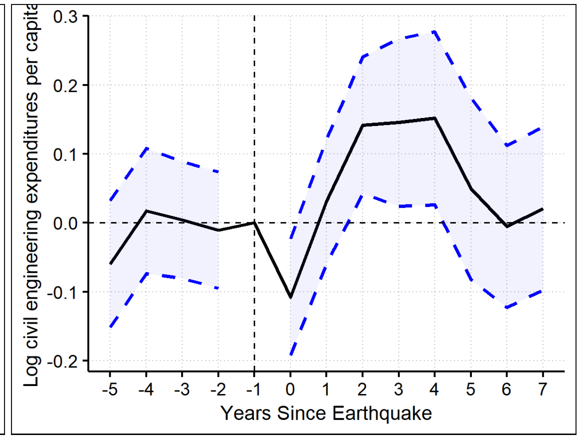


Figure 13: Municipality expenditure components 5^+

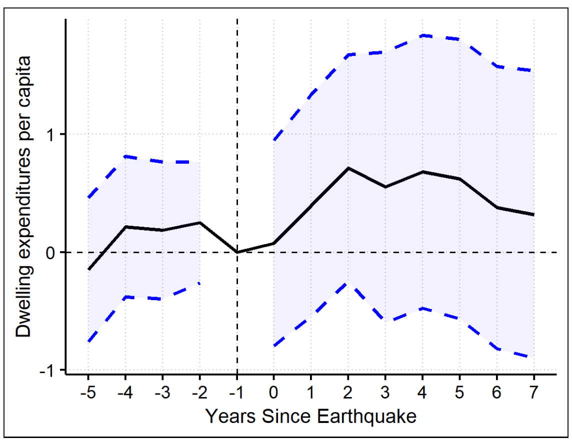
(a) Disaster relief expenditure 5^+ (log)



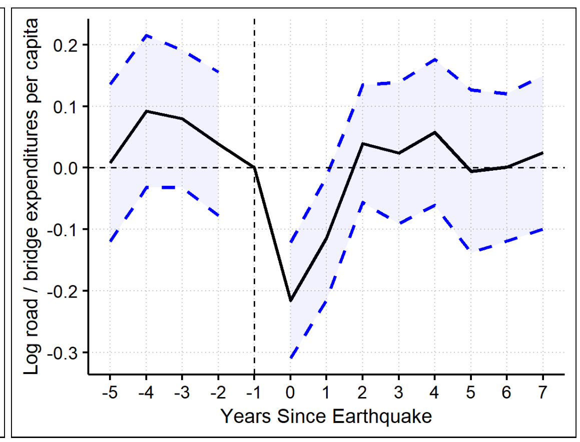
(b) Civil engineering expenditure 5^+ (log)



(c) Dwelling expenditure 5^+ (log)



(d) Road and bridges expenditure 5^+ (log)



(e) Welfare expenditure 5^+ (log)

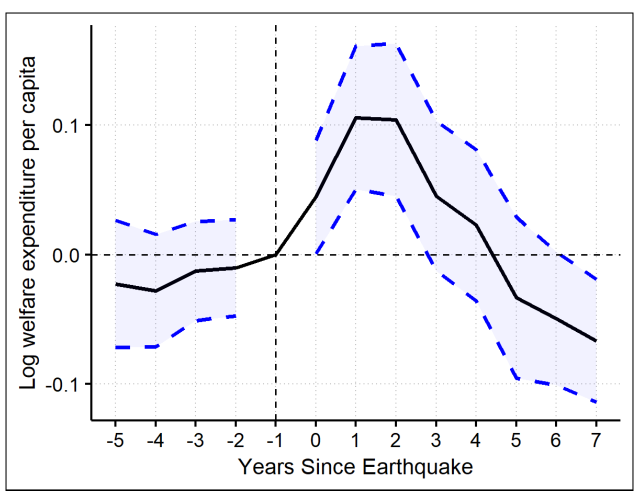
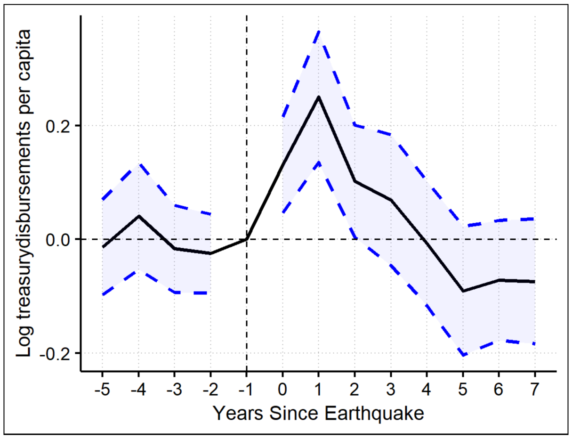
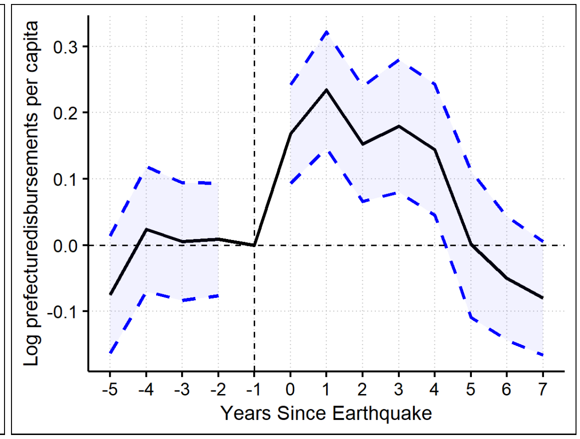


Figure 14: Municipality revenue components 5^{+}

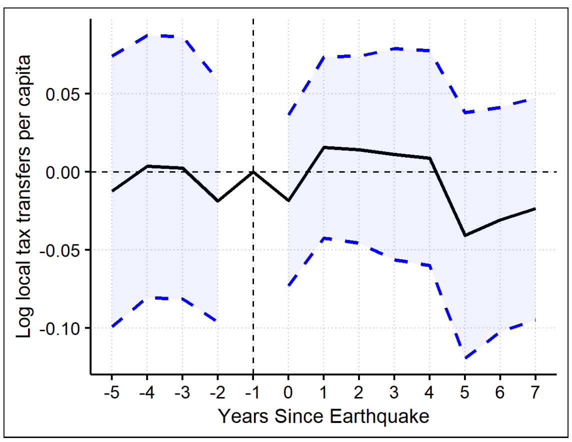
(a) Treasury disbursements 5^{+} (log)



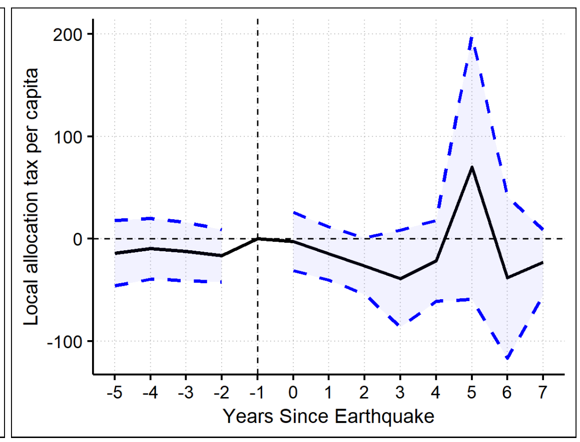
(b) Prefecture disbursements 5^{+} (log)



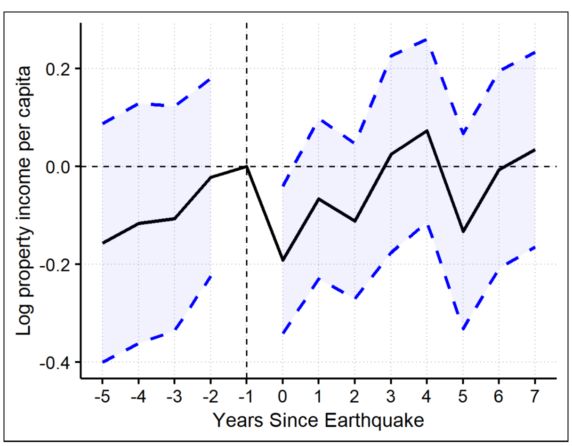
(c) Local transfer tax revenue 5^{+} (log)



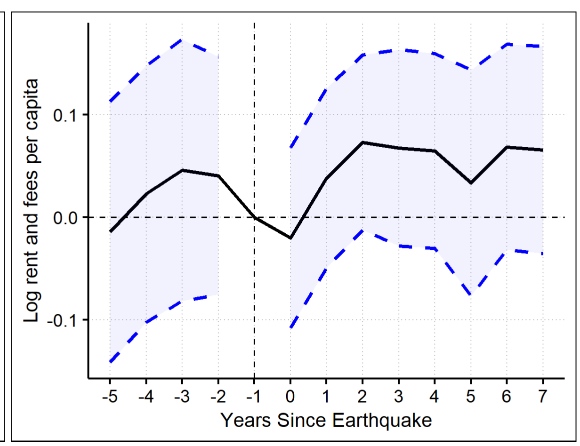
(d) Local allocation tax revenue 5^{+}



(e) Property income 5^{+} (log)



(f) Rent and fee revenues 5^{+} (log)



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