Earthquakes and house prices: a meta-analysis

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Abstract
A meta-analysis of international literature shows that the risk of earthquakes has a negative impact on house prices. This effect is related to the intensity of the expected earthquakes. The earthquake risk effect does not differ significantly in peer-reviewed studies from other papers. Whether there actually has been a recent earthquake has no significant impact on the effect of earthquake risk. Some studies show that risk perception may change over time and that it can be influenced by communication from media and governments. Risk reducing measures (reinforcing houses) may lower the price effect. Studies using (owner or realtor) estimated house values report a wider range of price effects than studies using transaction data.

1 Introduction

Several regions in the world suffer from the risk of earthquakes. Earthquake effects have a regional scale, being concentrated in specific locations (e.g. near fault lines). In some regions earthquakes are man-made, e.g. as a consequence of gas or oil production. An example is the Groningen region in the Netherlands, in which natural gas production led to a large number of earthquakes. Many houses were damaged and widespread unrest occurred, leading to court cases and extension of compensation measures.

One important consequence of earthquake risks may be a negative effect on house prices. Several studies try to estimate earthquake effects on house prices, e.g. Koster & Van Ommeren (2015b) and Deng et al. (2015). To identify the effects of earthquake risk, these studies use differences in earthquake risk between locations, or compare prices before and after earthquakes. This paper presents a meta-analysis of estimates of the effects of earthquake risk on house prices in the literature. In doing so this paper integrates and summarizes the scientific knowledge on these effects.

We will show that there is publication bias in the literature, causing estimates of positive effects to be largely missing. Corrected for this bias, we estimate the average effect of earthquake risk on house prices at minus 1.3% for 'light' earthquakes and minus 2.9% for strong earthquakes.

In section 2 we present the regression model we estimated and the data used. The results are described in Section 3. Section 4 contains conclusions. In the Appendix, each study is summarized briefly.

2 Data and meta-regression

2.1 Data

In the literature, a large number of studies on effects of earthquakes, other natural disasters and risk of natural disasters on house prices can be found (see Appendix). Studies were collected by searching for the following terms in Google Scholar: earthquake, house prices, housing prices, gas wells, natural disasters. Dutch-language studies were searched using 'aardbeving' (earthquake) and 'huizenprijzen' (house prices). Also included are Dutch-language studies known to the authors and studies referenced in the selected studies.

We restricted the scope of the analysis to empirical results with respect to effects on house prices. Effects on land prices are not included, as effects on land prices cannot be compared to effects on house prices without knowledge on the share of land prices in house prices. The number of studies into land prices was too low to perform a separate analysis. Second, we only consider (the risk) of earthquakes, as the intensity of other types of disasters cannot be measured in comparable ways. For instance the Richter (1935) scale cannot be applies to flooding.

Studies published until March 31, 2017, are included. This provides a selection of 20 studies containing 401 estimates of earthquake effects on house prices. Summary statistics are presented in table 1.

Table 1 Summary statistics

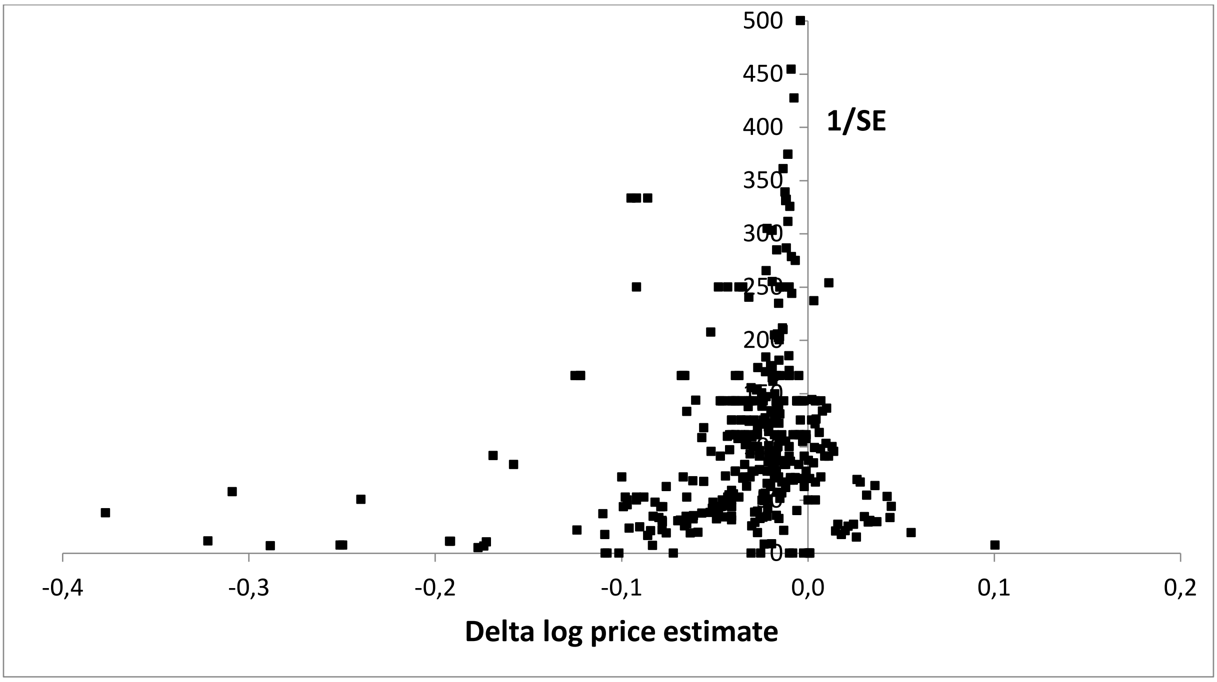
Variable	Mean	Standard deviation	Minimum	Maximum	N
Price effect (delta log)	-0,042	0,079	-0,68	0,106	401
Standard error of price effect*	0,021	0,033	0,0005	0,246	392
Earthquake intensity (0 to 4)	1,176	1,555	0	4	401
Risk without actual earthquake (dummy)	0,232	0,422	0	1	401
Non-advanced economy (dummy)	0,122	0,0328	0	1	401
Price estimate (dummy)	0,049	0,0218	0	1	401
Non-peer reviewed study (dummy)	0,818	0,0386	0	1	401

* For four estimates of price effects, the studies reported a (rounded) standard error of 0.0000. In the metaregression, we use the inverse of the standard error as weights. Using 0.0000 would imply that these estimates would be missing, leading to a loss of information (the low standard error implies that these are high-precision estimates). To prevent this, we gave the standard error of these estimates a value of 0.00005 (i.e. the highest standard error consistent with the rounded value of 0.0000).

2.2 Publication bias: funnel plots

To correct for publication bias, we follow the 'FAT-PET-PEESE' approach (Stanley & Doucougliagos, 2012). A first impression is given by a funnel asymmetry test (FAT). Figure 1 shows a funnel plot of the size of the estimates of house price effects in the studies versus the precision (inverse of the standard error) of the estimates. In the absence of publication bias, the graph should show an (inverted) symmetric funnel shape (Stanley & Doucougliagos, 2012). We see, however, that the funnel is asymmetric, with many estimates of strong negative effects to the left and relatively few estimates of positive effects on the right side. The asymmetry may reflect publication bias (positive effects underreported) or overestimation (many strong negative effects). Separate funnel plots for each level of earthquake intensity show a similar asymmetry.

Figure 1 Funnel plot



2.3 Meta-regressions

We estimate the following meta-regression:

$$\Delta \ln(E_{si}) = \alpha SE_{si}{}^2 + \beta_0 + \sum_{k=1}^{K} \beta_i x_{sik} + u_{si} \quad (1)$$

Where E_{si} = Effect estimate i (=1.. N_S) in study s (=1..S) of the effect of earthquake (risk) on house prices
SE_{si} = Standard error of estimate si
x_{si1} .. x_{siK} = Characteristics of estimate si
u_{si} = Error term
α, β_0 ... β_K = parameters

The standard error is included to correct for publication bias (Stanley & Doucougliagos, 2012). The characteristics which may moderate the size of the earthquake (risk) effect (x_{si1} .. x_{siK}) are:

- The (expected) maximum intensity of the earthquake(s). 0 (zero) represents earthquakes up to and including magnitude 3.9 (Richter scale); magnitude 4.0-4.9 was coded as 1; magnitude 5.0-5.9 as 2; magnitude 6.0-6.9 as 3; and magnitude 7.0-7.9 as 4[1].
- Earthquake risk only (without an actual earthquake) (dummy). Our hypothesis is that actual earthquakes induce people to increase their risk estimates, leading to stronger price effects.
- Non-advanced economy (dummy)[2]. Housing construction quality may be lower in non-advanced economies, causing more (expected) earthquake damage.
- Price estimate (dummy). Some studies use estimates of house prices (by e.g. house owners, see Bernkopf et al., 1990) instead of transaction data.
- Non-peer reviewed study (dummy).

Given these choices, β_0 estimates the effect of the risk of relatively light earthquakes, where actual earthquakes occur, in advanced economies, based on transaction prices, and reported in peer reviewed studies.

We weighed all regresssions by $1/N^{0.5}$, unless otherwise mentioned. Not using such weights would imply that a study containing e.g. 20 estimates would have 20 times as much impact on the metaregression as a study with only one estimate. If we would use weights 1/N, each study would have an equal impact, irrespective of the number of estimates in the study. The weights $1/N^{0.5}$ are in between these two situations.

We tested for publication bias using a Precision Effect Test (PET) (Stanley & Doucougliagos, 2012). This amounts to estimating eq. (1) replacing the squared standard error with the standard error, and using weights 1/SE. The estimated coefficient of the squared standard error is -0.987 with a standard error of 0.273 (p=0.000). This confirms the impression, derived from funnel plots in the previous section, that there is publication bias in the metadata.

[1] Some estimates by Cheung et al (2016) were coded as 4.5, as it was not clear whether these estimates pertained to magnitude 4 or 5.
[2] We used the IMF list of advanced economies:
https://www.imf.org/external/pubs/ft/weo/2017/01/weodata/groups.htm.

Next, we performed a Precision Effect Estimate with Standard Error (PEESE), to estimate the size of the effect β_0 and its moderators $\beta_1 \dots \beta_K$. Results are shown in columns (1) - (5) of Table 1. In column (1), R^2 is reasonably high. None of the parameters is significant at 5%. A possible cause is multicollinearity. Indeed, the correlation between Earthquake intensity and Non-advanced economy is high (0.6784). All earthquakes in non-advanced economies in the data are of the highest magnitude (Richter scale 7 or higher). Removing the Non-advanced economy moderator reduces the standard error of Earthquake intensity (see column (2)). For the other moderators, the standard errors do not change much.

In column (3), we leave out the 8 effect estimates of Önder et al. (2004). In this study, advertised prices are used (not transaction prices), the price effects are relatively large and the set of control variables is limited. This may cause bias in the metaregression. In column (3), R^2 is much lower than in columns (1) and (2), but most standard errors are lower. Compared to column (2), only the coefficient of the Price estimate dummy changes considerably. The other results, including the estimated constant, seem to be fairly robust. Apparently, the Price estimate dummy - in columns (1) and (2) - 'explains' the variation caused by the relatively large price effects in Önder et al. (2004).

In column (4), we discard not only the estimates of Önder et al. (2004), but also other price measurements not based on transaction prices. This implies leaving out 10 more estimates. The coefficients and standard errors are similar to column (3), but R^2 is lower.

Finally, we perform a sensitivity analysis using weights 1/N instead of $1/N^{0.5}$. This does not affect the parameters and standard errors much, except for the standard error of the publication bias variable coefficient (α). Column (3) is our preferred specification, as it has the highest explanatory power (R^2) among the variants which avoid the possibly biased Price estimate coefficient caused by Önder et al. (2014) (columns (3)-(5)).

Table 2 Meta-regressions

Model	(1)	(2)	(3)	(4)	(5)
Weight	$(1/SE)(1/N_s^{0.5})$	$(1/SE)(1/N_s^{0.5})$	$(1/SE)(1/N_s^{0.5})$	$(1/SE)(1/N_s^{0.5})$	$(1/SE)(1/N_s)$
			Without Önder et al. (2004)	Without Price estimates	Without Price estimates
Constant (β_0)	-0,010 (0,009)	-0,011 (0,007)	-0,013 (0,005)**	-0,012 (0,005)**	-0,011 (0,006)
Standard error squared (α)	-1,548 (1,513)	-0,692 (1,734)	-3,415 (0,496)***	-3,927 (0,591)***	-3,750 (0,399)***
Earthquake intensity (0 to 4)	0,005 (0,008)	-0,005 (0,002)**	-0,004 (0,002)**	-0,004 (0,002)**	-0,003 (0,002)
Risk without actual earthquake (dummy)	-0,004 (0,007)	-0,002 (0,006)	-0,003 (0,005)	-0,002 (0,005)	-0,002 (0,005)
Non-advanced economy (dummy)	-0,058 (0,042)	- (-)	- (-)	- (-)	- (-)
Price estimate (dummy)	-0,254 (0,121)*	-0,252 (0,135)*	-0,005 (0,013)	- (-)	- (-)
Non-peer reviewed study (dummy)	-0,009 (0,009)	-0,008 (0,007)	-0,006 (0,006)	-0,006 (0,006)	-0,007 (0,006)
Observations	392	392	384	384	374
R^2	0,407	0,381	0,099	0,068	0,082

Dependent variable: delta log average house price
Cluster-robust standard errors between brackets
* significant at 10%, ** 5%, *** 1%

The constant in column (5) implies that the estimated impact on transaction prices of the risk of relatively light earthquakes in the presence of actual earthquakes, in peer reviewed studies, is minus 1.3%, with a 95% confidence interval [-0.3%; -2.3%]. An increase in the intensity of the earthquake (1 level higher on the Richter scale) increases this effect by 0.4%, leading to an effect estimate of minus 2.9% for the strongest earthquakes (Richter scale 7 or higher). The other moderators are not significant.

3 Other findings

Apart from the meta-regression, we see several other interesting findings in the literature:

- The effects on house prices are often determined by subjective perceptions of earthquake risks. Earthquakes that occur or have occurred recently may affect risk perception positively or negatively. Naoi et al. (2009) show that owners estimate the effect of earthquakes on house prices twice as high after a (heavy) earthquake in a nearby area. A similar effect occurred after an earthquake in eastern Turkey in 2011 (Keskin & Watkins, 2014). Beron et al. (1997) show that the perceived (subjective) risk declined after an earthquake occurred in California.
- The perceived risk of earthquakes and its impact on the development of land and house prices may fluctuate over time. The effects of the (heavy) Wenchuan earthquake in China on risk perception disappeared after a year (Deng et al., 2015).
- Risk-reducing measures may result in higher house prices. Nakagawa et al. (2009) show that measures against physical risks (collapse) reduce price differences between areas of high and low earthquake risk in Tokyo between 1980 and 2001. In Iran a survey among real estate brokers showed a 15% price difference between new homes with and without earthquake mitigation measures (Willis and Asgary, 1997).
- Government communication matters. In California the negative impact of earthquake risks on prices occurred only after active communication that the location of the property was in an earthquake risk area (Brookshire et al., 1985; Bernkopf et al., 1990). In the Netherlands Bosker et al. (2015) estimate a negative impact of 3% on house prices of earthquakes after a relatively large earthquake. However, after government pledges to compensate the region, no significant effect could be found any more.
- Media attention can affect the perceived risk of earthquakes and (therefore) house prices. Beron et al. (1997) show that both the (heavy) Loma Prieta earthquake in California in 1989 and media coverage that followed had implications for risk perception. People were initially inclined to overestimate the risk, but over time they adapted their views on the basis of new information. In Istanbul, risk perception increased as the media reported about an earthquake (Önder et al., 2004).
- Studies using survey data or other estimated house values report a wider range of price effects than studies using transaction data. The effect of risks of strong earthquakes on house prices in Japan was estimated in surveys among owners to be -17.5% to +10.6% (Naoi et al., 2009). Effects on advertised prices in Istanbul varied between -68.0% and -1.9% (Önder et al., 2004).

4 Conclusions

A meta-analysis shows that the risk of relatively light earthquakes (<=3 on the Richter scale) lower house prices by an estimated 1.3%. For strong earthquakes (>=7), this effect is minus 2.9%. Whether there actually has been a recent earthquake has no significant impact on the effect of earthquake risk. Estimates from peer reviewed studies and non-peer reviewed studies do not differ significantly.

Observations from individual studies used are that risk perception may change over time, and that it can be influenced by communication from media and governments. Risk reducing measures (reinforcing houses) may lower the price effect. Studies using estimated house values report a wider range of price effects than studies using transaction data.

A limitation of this study is that the number of observations is not very large (392 estimates in 20 studies). This also seems to limit the number of moderators that can be included in the metaregression. Moreover, there is much variation in the data which remains unexplained. Further research may focus on other causes of this variation.

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Appendix Studies of quantitative effects of earthquake risk on house prices

Study	Peer reviewed ?	Effect of	Richter scale	Country/ State	Effect size (Δ log)[a]	Type of house prices	Remarks and other findings
Bernknopf et al. (1990)	Yes	Warnings of earthquake risk	3	California	-0.041 to -0.057	Owner estimates	Warnings affect not only house prices, but risk perception as well
Beron et al. (1997)	Yes	Earthquake risk (before/after earthquake)	4	California	-0.072 to -0.108	Transactions	Smaller effect after earthquake. Not in the meta-analysis because no standard errors or t-values are given.
Bosker et al. (2015)	No	Earthquake risk (natural gas extraction)	0	Netherlands	-0.035 to +0.001	Transactions	Net effect after compensation by gas company.
Bosker et al. (2016)	No	Earthquake risk	0	Netherlands	-0.065 to +0.004	Transactions	Net effect after compensation by gas company.
Brookshire et al. (1985)	Yes	Local risk label	4	California	-0.065 to 0.000	Transactions	Effect occurs after active communication about the risk label
Cheung et al. (2016)	No	Earthquake risk	0 to 2	Oklahoma	-0.110 to +0.011	Transactions	Difference between before and after earthquake
Deng et al. (2013)	No	Earthquake risk before/after earthquake	4	China	-0.067 to -0.004	Transactions	Price difference between apartments on 1st/2nd floor and 7th floor and higher. Difference appears after earthquake, disappears after about 1 year.
Deng et al. (2015)	Yes	Earthquake risk before/after earthquake	4	China	-0.067 to -0.004	Transactions	Price difference between apartments on 1st/2nd floor and 7th floor and higher. Difference appears after earthquake, disappears after about 1 year.
Francke & Lee (2014)	No	Physical earthquake damage	0	Netherlands	-0.083 to 0.000	Transactions	-
Gibbons et al. (2016)	No	Earthquake risk in shale gas drilling areas	0	United Kingdom	-0.125 to +0.013	Transactions	-
Keskin (2008)	Yes	Earthquake risk	4	Turkey	-0.0060	Transactions	-
Keskin & Watkins (2014)	No	Earthquake risk	4	Turkey	-0.099 to -0.0082	Realtor listings	-
Koster (2016)	No	Earthquake risk before/after earthquake	0	Netherlands	-0.0442 to -0.0009	Transactions	Effect per earthquake. Net effect after compensation by gas company.

Koster &Van Ommeren (2015a)	No	Earthquake risk before/after earthquake	0	Netherlands	-0.0461 to +0.0061	Transactions	Effect per earthquake. Net effect after compensation by gas company. The effect increases over time.
Koster &Van Ommeren (2015b)	Yes	Earthquake risk before/after earthquake	0	Netherlands	-0.0423 to +0.0112	Transactions	Effect per earthquake. Net effect after compensation by gas company. The effect increases over time.
Modica et al. (2016)	No	Earthquake risk before/after earthquake	2	Italy	-0.4200 to +0.0448	Transactions	-
Murdoch et al. (1993)	Yes	Local risk label	4	California	-0.1088 to -0.0024	Transactions	Not in the meta-analysis because no standard errors or t-values are given.
Naoi et al. (2009)	Yes	Earthquake risk (after nearby earthquake)	4	Japan	-0.2885 to +0.1003	Owner estimates	The price effect is larger soon after earthquake events than beforehand.
Önder et al. (2004)	Yes	Distance to fault line	4	Turkey	-1.1395 to -0.0196	Advertised	Stronger effect of risk after an earthquake. Limited set of control variables.
Willis & Asgary (1997)	Yes	Measures to reduce earthquake risk	4	Iran	-0,1451	Survey of realtors	Not in the meta-analysis because no standard errors or t-values are given.

a In some papers, effects per percent probability of an earthquake or distance to a fault line were given. These effects were recomputed to reflect the effect of total existing risk.