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04/2016

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SEEDS Working Paper 04/2016
April 2016
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Housing Market Response to 2012 Northern Italy Earthquake: The role of house quality and changing risk perception

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Abstract

This paper examines the housing market response to Northern Italy earthquake in May 2012. Available literature provides evidence of a drop in the average price of houses after a disaster mainly due to i) underestimation by households of disaster risk in area where its occurrence is low or ii) overreaction because of a higher risk perception triggered by the unforeseen extreme event. Here, we provide evidence that overreaction can play a significant role. We use the Northern Italy earthquake as an experiment that permits to estimate the response of housing value to the extreme event by means of a diff-in-diff models. Differently from other papers, we directly carry out the assessment of the damage earthquake scenario, by using macroseismic methods to evaluate the physical damage level of the Northern Italy earthquake. In this way we are able to compare different damage scenarios and providing information on subjective perception of risk. Moreover, to our knowledge, this is the first work providing evidence that the quality of the houses in relation to the 'resistance to the tremor' might also play a relevant role for subjective risk assessment.

Keywords: Earthquake risk; Housing market; Risk perception
JEL Code: R21; R32; Q52

1 Introduction

On May 20, 2012 an earthquake of magnitude M_L = 5.9 (Scognamiglio et al., 2012) occurred on a wide portion of the Po Valley between the regions of Emilia-Romagna, Veneto and Lombardy affecting in particular the provinces of Ferrara, Modena, Mantua, Bologna and Rovigo (Fig. 1a).[1] The epicenter was located near the town of Finale Emilia (MO), about 30 km west of the city of Ferrara (Fig. 1b). Afterwards an important and long seismic sequence began, which continued in the following weeks with more than 2,200 aftershocks, six of them with a magnitude > 5. A second big event occurred on 29 May (M_L = 5.8) and showed a shift to the west of the epicenter (Scognamiglio et al., 2012). The distribution of the epicenters covers an area of about 50 km towards WNW-ESE.

The series of seismic events, despite their moderate magnitude, has generated extensive damage on a densely inhabited area. Overall, the sequence has caused 27 victims, significant damages to public and private infrastructures and to the historical monuments (Mucciarelli and Liberatore, 2014). The direct losses, according to Emilia-Romagna region, reached 2 billion Euros, and further 3 billion Euros, due to the interruption of industrial production, have been accounted (Ronchetti, 2012). The structures that have suffered most from this crisis are the monumental buildings (churches, towers, castles, palaces) and the industrial buildings. Given these premises, the importance in studying the impact of disasters in urban areas lies in the number of information on urban dynamics and in the households behavior (Siodla, 2015)

In this paper, the Emilia earthquake of 2012 is used for developing a quasi-random experiment that combines the macro-seismic approach to physical damages assessment with housing market data to evaluate housing market responses to seismic events. The proposed approach differs from those prevailing in other works with similar research aims and allows to investigate, inter alia, the role of both the subjective risk perception and the quality of the houses.

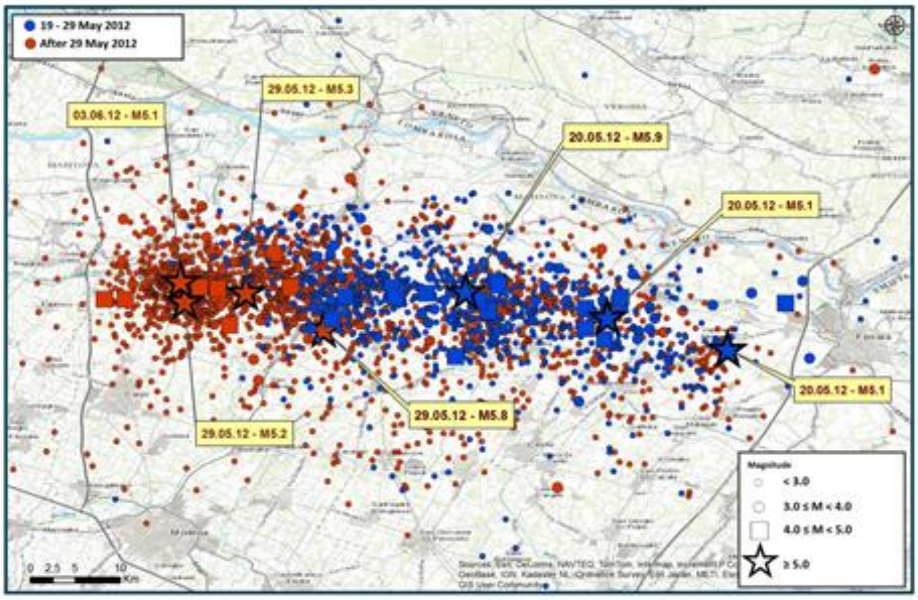
The paper is organized as follow: Section 2 provides a review of the literature on housing market effects of natural disasters and the outline of the approach proposed in this paper. Section 3 presents the macroseismic methodologies used to evaluate the physical damage to residential building due to earthquakes. Section 4 shows the data and the empirical strategies, providing also information on the identification strategy. Section 5 provides the results of the estimates. Finally Section 6 concludes.

[1] The event is known as 2012 Northern Italy earthquake.

Figure 1 - (a) List of locations under analysis, broken down by region, province and municipality. (b) Seismic events of the crisis in Emilia Romagna in 2012 (source: http://ingvterremoti.wordpress.com/2013/05/20/un-anno-dopo-il-terremoto-in-emilia/

Region	Prov.	n° municipalities	n° localities
Emilia-Romagna	MO	18	56
Lombardia	MN	29	53
Emilia-Romagna	FR	7	35
Emilia-Romagna	BO	13	27
Emilia-Romagna	RE	10	14
Veneto	RO	11	11
		88	196

(a)



(b)

2 Available studies and proposed approach

Available studies generally recognise that the effect of extreme natural events on housing market is to reduce the housing prices (see for instance Beron et al., 1997; Brookshire et al., 1985; Deng et al., 2015; Naoi et al., 2009; Willis and Asgary, 1997 for earthquake hazard; Bin et al. 2008 and Luechinger and Raschky, 2009 for flood hazard; Hallstrom and Smith, 2005 for hurricane hazard). The theoretical reason of this effect is rooted in the seminal works of Ehrlich and Becker (1972) and Brookshire et al. (1985). The former provides the framework of the general self-protection model (i.e. households will provide self-protection until the marginal benefits are higher than marginal costs); the latter shows that households will pay more for location with less chance of loss.

Although all these studies reach consensus on the fact that households will pay less for property houses in risky prone areas (*ceteris paribus*) the mechanism that produces price reductions *after* an extreme event is still unclear and it is consistent with several possible behavioral scenarios (Beron et al., 1997, Kellenberg and Mobarak, 2008).

First, the event brings new knowledge allowing a more precise risk assessment. This improvement in the risk judgment might produce a more accurate estimate of the objective probability of occurrence of an extreme event (Beron et al., 1997). Second, the event changes the subjective risk assessment without changing the objective probability. For instance, households might have underestimated the objective probability of an extreme event when there has not been a recent occurrence (Hallstrom and Smith, 2005; Naoi et al., 2009). According to that, housing price is not able to incorporate the real objective risk, which thus results higher than it should be if the risk perception was correct. After the natural disaster occurs, the price will align back to the correct price by means of a more or less drastic drop. Along the same line, overreaction due to higher risk perception triggered by the fear felt during the extreme event produces the same effects (i.e. a drop in the housing prices) of the previous example (Deng et al., 2015). However, in this case the situation is the opposite because households are expected to overestimate the subjective probability of an extreme event with respect to the objective probability. Finally, both subjective and objective risk assessment might change during time and the differences in the housing prices will follow the feeling of people according to the relationship between the perception of risk and the objective probability.

Although to take into account all the possible scenarios described above might be very complex, previous studies, related both to extreme event risk assessment in general and earthquake in particular, focus their attention on two situations: i) underestimation of the effective objective probability or ii) overreaction. For instance, Beron et al. (1997) show that information about earthquake hazard is imperfect and, after the event occurs, households align with the objective probability. Naoi et al. (2009) show that households tend to underestimate the earthquake risk and a new event produces latest information able to align with the objective probability. Willis and Asgary (1997) similarly show that increased information on earthquakes might increase the price differential between earthquake resistant and non-resistant houses. Hallstrom and Smith (2005) show that Andrew hurricane in 1992 produced a reduction in property value also for the area next to those directly affected. In the authors view, this is due to ‘near miss’ hypothesis (i.e. the event has shown the consequences of the catastrophe in similar areas). Finally, Deng et al. (2015) show that low floor units have higher relative price in the months after the Wenchuan earthquake occurred, indicating overreaction of households to earthquake.

All these studies might suffer of several shortcomings. First, almost all studies use the hedonic price model. This model needs to control for damages due to the event. However measure for damage are typically proxy (e.g. location in special zone, simulation of earthquake scenarios, distance from the fault, occurrence probability). These simple proxies of the possible damage scenario do not properly consider the real damage produced by an extreme event. Second, this model does not consider the possible fluctuations of the market due to exogenous (e.g. market volatility) and endogenous (e.g. impact of the earthquake) factors. Then the hedonic price model cannot isolate the effects of new information before and after the event of interest (Bin and Polansky, 2004; Hallstrom and Smith, 2005).

In this paper instead, we provide measures of damage directly calculated through a method for assessing the physical damage to residential buildings. The model is based on theEMS-98 macroseismic scale (European Macroseismic Scale; Grünthal, 1998) and exploits the to the census data of ISTAT (Italian Institute of Statistics) together with the value of macro-seismic recorded intensity. The damage is expressed in number of damaged buildings and volume. The macro-seismic approach is based on the definition of five levels of damage of the EMS-98 scale, given the vulnerability of the structures. These are grouped into classes of increasing vulnerability (A to F) on the basis of structural characteristics. Thanks to the availability of data on housing census ISTAT, we match typological and morphological information and age of the buildings and give them the class of vulnerability. The data are provided by ISTAT in aggregate for each census section and, at the end of the procedure, they are re-aggregated to municipality level.

Immediately after the earthquake the intensity values are collected for many of the damaged localities, both in terms of EMS-98 scale and MCS scale(Mercalli-Cancani-Sieberg; Sieberg, 1930). We integrated and homogenized the recorded macroseismic data to produce shaking scenarios that are at the basis of the damage calculation model. It is also possible to interpret the damage levels of the EMS-98 scale in terms of functionality (total or partial), use (as a result of remedial actions), and collapse (partial or total) to associate economic values that allow quantifying the loss.

The phisical damage quantification is used as input into a diff-in-diff model to test whether the 2012 Northern Italy earthquake changed housing price in relation to the event and in relation to the perception of the earthquake based on the damage levels. In our quasi-random experiment we use the 2012 Northern Italy earthquake as an external shock to distinguish the effect of the event over a large area that has experimented different levels of damage. In this way we are able to recognize different behavior of individuals according to the actual damage produced by the earthquake. The advantages of a diff-in-diff model have been recognized by Hallstrom and Smith (2005). First, it allows to take into account the possible fluctuations of the market. Second, it is able to isolate the effects of new information brought by the earthquakes.

The results show that the average level of the housing prices in the area affected by the earthquake is significantly lower than that of the area next to the epicentral area (i.e. the control group). By means of several controls (type of houses, state of conservation of buildings, and level of damage) we are able to provide evidence that the overreaction is due to the level of damage produced even though the objective probability of damage is the same as before the shock.

3 Physical damage assessment

3.1 The macroseimsic method

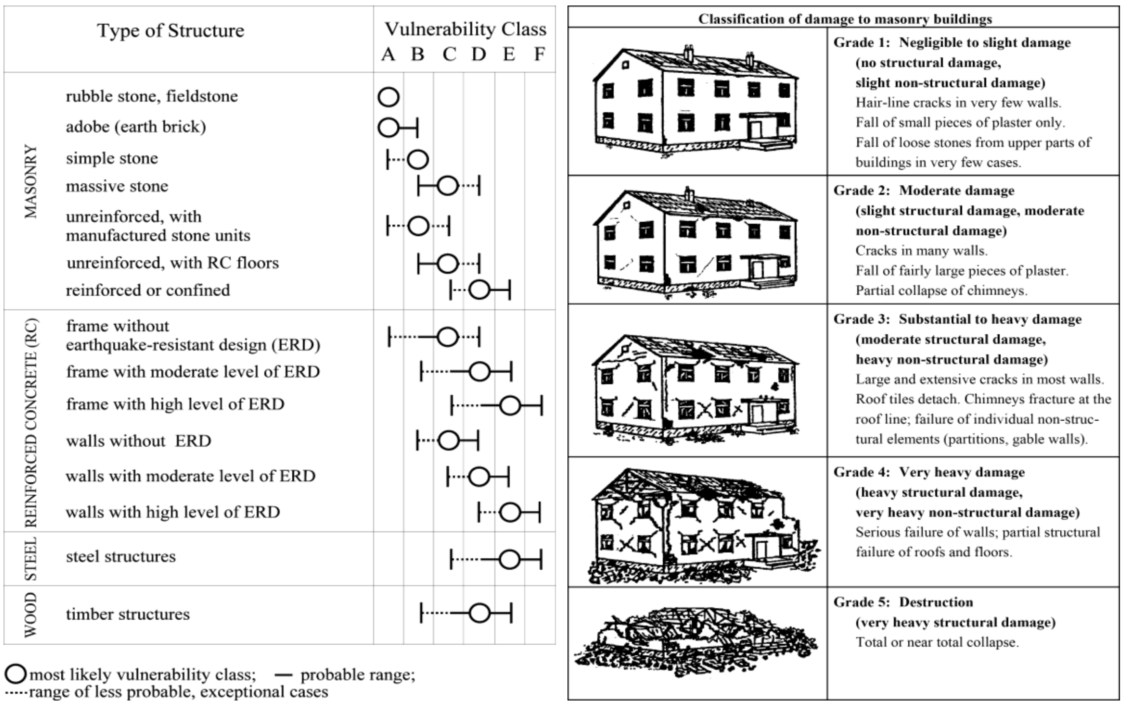
The macroseismic methods are extensively used to evaluate the physical damage level of residential buildings because of their robustness, flexibility, and easiness of use (Mouroux e Le Brun, 2006; Spence, 2007; Lantada et al., 2010; UPStrat-MAFA, 2012, Syner-G, 2012).

In the case of the Northern Italy earthquake in 2012, a macroseismic survey has been performed immediately after the event with the aim to coordinate the first-emergency activity. The macroseismic survey, is able to provide a fast and preliminary estimation of the damage distribution. Indeed, in the survey, the assigned intensity value is the percentage of the damaged buildings in each locality considered jointly with their proper vulnerability and damage level. For instance, a locality is classified with VIII grade when many buildings with high vulnerability level (class A) show very heavy damage (D4) and few of the same buildings (class A) are completely collapsed.

The method is based on the EMS-98 intensity definition: it classifies the buildings into 6 classes of decreasing vulnerability, from A to F (Fig. 2a); then it defines the damage distribution depending on the intensity level. The damage levels are 5 (from D1 to D5) and are based on the structural and not-structural features of the buildings (Fig. 2b). The level D0 means the lack of any damage.

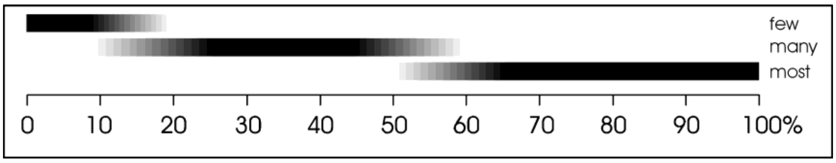
The definition of the damaged quantities, for each level of vulnerability and for each intensity grade, are expressed in a fuzzy way ("few", "many", "most". Fig. 3). It is possible to quantify these linguistic expressions into numerical values and create damage probability matrices, one for each vulnerability class. (Giovinazzi e Lagomarsino, 2001; Bernardini et al., 2007).

Figure 2 - (a) Vulnerability classes of buildings according to the EMS-98; (b) scale Damage level for masonry buildings, according to the EMS-98 scale



(a) (b)

Figure 3 - Definition of “few”, “many” e “most”, according to the EMS-98 scale



3.2 The damage assessment of the 2012 Emilia earthquake

To characterize the residential buildings of 196 localities (in 88 municipalities) affected by the earthquake, we used the national census data of dwelling and population (ISTAT, 1991). From the ISTAT data, it is possible to estimate the number of buildings (and volume) located in each census tract and obtaining information on the type of structure, the structural context (whether isolated or aggregated), the maintenance status, the age of construction or retrofitting and the number of floors.

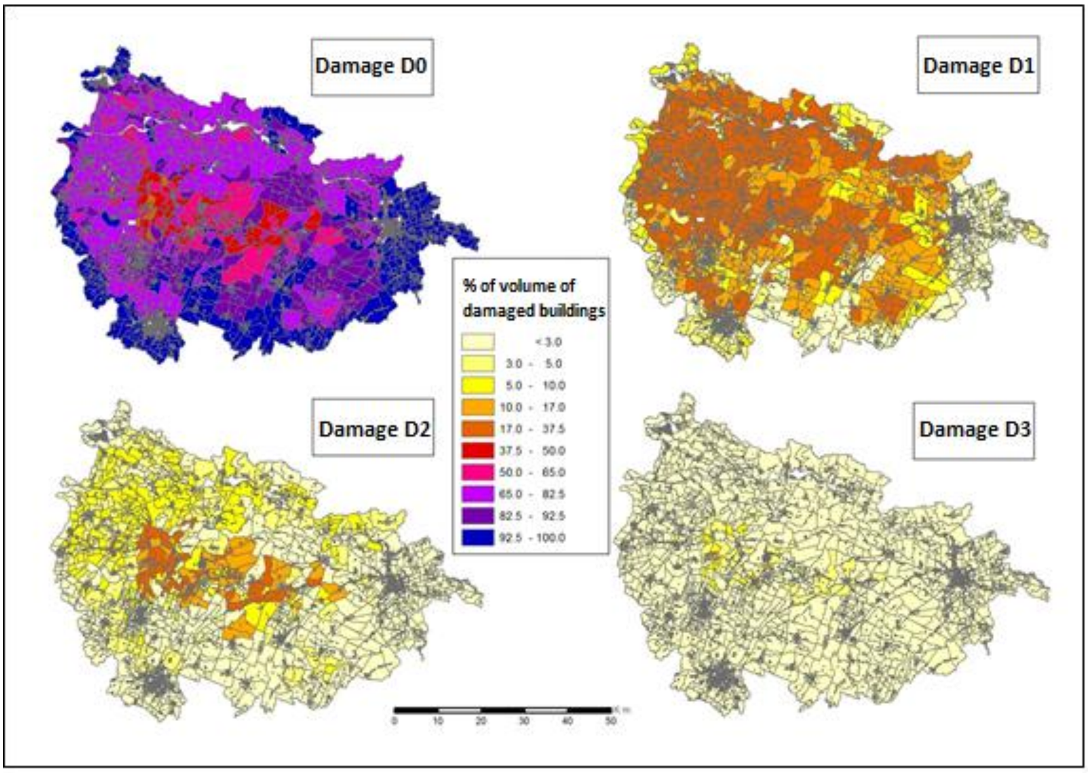
The most recent surveys (ISTAT surveys of 2001 and 2011) cannot be used for the vulnerability assessment because the most recent data are made available in an aggregate version and at the municipality scale only. Moreover, the municipality-level resolution cannot be matched with the OMI (Observatory of the housing market) information on housing prices having a more detailed resolution (see below). Herein, we preferred calibrate the methodological aspects of the analysis performing the evaluation as detailed as possible rather than use more updated data, able to better depict the effective real quantities, but requiring a rougher management. Recent studies on seismic risk made on the entire national territory prove that this apparent limitation is acceptable (see, for instance Crowley et al., 2009).

We evaluate the vulnerability classification of the buildings, from A to F, by combining the ISTAT data and by assigning a vulnerability index (Bernardini et al., 2008). The index varies according to building characteristics and to the year of seismic classification of the municipality.

The intensity value together with the vulnerability level of buildings are known in each census tract, so it is possible to calculate the damage grade (D0 –D5) for each structure according to the EMS-98 damage probability matrices (Bernardini et al., 2007).

Because of the relatively moderate magnitude of the events, the building features, and the characteristics of the territory, most of the buildings has no damage (D0) or light damage D1. Moderate damage are restricted only in the epicentral areas while the other damage quantities are negligible (Fig. 4).

Figure 4 - Percentage distribution of the buildings for the 88 municipalities, for classes of damage D0, D1, D2 and D3. Damage maps of the D4 and D5 classes show very small percentage values (not illustrated)



4 Housing market data and evaluation model

4.1 Housing market data

The data on housing values derive from the Observatory of the housing market (OMI – *Osservatorio del Mercato Immobiliare*) a branch of 'Agenzia delle Entrate', the Italian Tax and Revenue Service. The OMI database provides average prices of houses by type, quality of the house, OMI micro-area and macro-area at sub-municipal level, derived from the actual transactions taking place in the housing market.

The database provides information on different types of building units. For the aim of this work, we select only those types classified as residential buildings. All types included in the analysis are listed in Tab. 1 with a brief description.

Table 1 - Description of building types in the database OMI

Type of house	Description
'Civil' housing	residential unit part of a building with good general characteristics and value
'Economic' housing	residential unit part of a building with low general characteristics and value
Villa	residential unit that is a part of a villa

Source: Glossary of technical definitions (AdT – Tecnoborsa, 2008).

The quality of the house takes three different values: good, normal and poor.[2] OMI micro-areas are instead defined as homogeneous segments of the local real estate market, in which there is uniform conditions both in economic (price of houses) and socio-environmental characteristics (amenities of the area). In any of these areas the difference between maximum and minimum price of the prevalent type cannot be higher than 50% (Area Osservatorio del Mercato Immobiliare, 2009).

Finally, OMI macro-areas result from the aggregation of contiguous and homogeneous OMI micro-areas with a precise geographical location within a municipality. They range from the center to the boundary of any municipality. In details, the municipality is divided into the following OMI macro-areas: central (identified by the letter B), semi-central (letter C), peripheral (letter D), suburban (identified by the letter E) and rural (letter R) (Area Osservatorio del Mercato Immobiliare, 2009).

The OMI data cover the period 2005 - 2013 and are semi-annual. The first half of 2012 is the last observation before the 2012 Northern Italy earthquake has occurred. In Tab. 2 we report data on sample size in reference to the treated municipalities (i.e. the municipalities affected by the 2012 Northern Italy) and non-treated municipalities (i.e. the control group). The resident population of the total area in 2011 is over one million and a half, according to the Italian Census. The 137 municipalities are divided into 663 OMI micro-areas, with an average of about 5 OMI micro-areas for municipality. Most of these areas are peripheral (D) and suburban (E) zones. Typically, each municipality is composed by a central core surrounded by more peripheral areas and suburban areas. Furthermore, rural area is generally very extensive.[3] Descriptive statistics are reported in Tab. 3 for the total area under analysis with a detail for treated and control group municipalities, type of housing (e.g. ‘civil’ housing, ‘economic’ housing and ‘villa’) and quality of the buildings (e.g. normal or good).

Table 2 - Treated and control group data

Group	# Municipalities	Population	# OMI micro-areas	Macro-Area B	Macro-Area C	Macro-Area D	Macro-Area E	Macro-Area R
Treated	73	901,416	338	77	18	142	81	53
Non-Treated	49	637,446	260	53	11	90	82	24
Heavy-damaged area	15	156,548	65	14	6	20	34	10
Total	137	1,695,410	663	144	35	252	197	87

[2] To determine the quality of the houses OMI analyzes 8 elements. If 6 of the them are good the state is good, poor when 4 elements are poor and normal in between the two situations (Area Osservatorio del Mercato Immobiliare, 2009).

[3] From this sample we discard 15 municipalities of epicentral area because the turbulences caused by the earthquake on the housing market are still persistent. However, this fact strength our work by excluding those municipalities that might bias the analysis due to the high impact of the most damaged municipalities can have on the treated area. In future works we will count to address this issue. The 15 municipalities are: Bomporto, Camposanto, Cavezzo, Concordia sulla Secchia, Finale Emilia, Medolla, Mirabello, Mirandola, Novi di Modena, Ravarino, San Felice sul Panaro, San Possidonio, San Prospero, Sant’Agostino, and Soliera (see also Fig. 5).

Table 3- Descriptive statistics

Type of house	Quality	No. Observations	Average log(price)	Standard deviation	Min	Max
			All			
All types	All	30,607	7.041	.398	5.521	8.117
All types	Normal	23,633	6.959	.368	5.521	7.972
All types	Good	6,966	7.320	.368	6.421	8.117
'Civil' house	All	11,556	7.045	.386	5.858	8.109
'Civil' house	Normal	8,787	6.960	.351	5.858	7.930
'Civil' house	Good	2,769	7.315	.364	6.600	8.110
'Economic' house	All	9,118	6.892	.439	5.521	7.990
'Economic' house	Normal	7,183	6.809	.406	5.521	7.844
'Economic' house	Good	1,927	7.203	.411	6.422	7.990
Villa	All	9,933	7.173	.319	6.346	8.117
Villa	Normal	7,663	7.098	.284	6.346	7.972
Villa	Good	2,270	7.424	.296	6.786	8.117
			Treated Area			
All types	All	17,469	7.033	0.380	5.521	8.109
All types	Normal	13,329	6.967	0.367	5.521	7.930
All types	Good	4,135	7.245	0.340	6.422	8.109
'Civil' house	All	6,595	7.045	0.370	5.858	8.109
'Civil' house	Normal	4,943	6.973	0.351	5.858	7.930
'Civil' house	Good	1,652	7.258	0.341	6.600	8.109
'Economic' house	All	5,477	6.884	0.431	5.521	7.919
'Economic' house	Normal	4,256	6.816	0.420	5.521	7.832
'Economic' house	Good	1,216	7.127	0.379	6.422	7.919
Villa	All	5,397	7.169	0.264	6.397	7.946
Villa	Normal	4,130	7.117	0.243	6.397	7.892
Villa	Good	1,267	7.341	0.257	6.786	7.946
			Control group			
All types	All	13,138	7.051	0.421	5.704	8.117
All types	Normal	10,304	6.947	0.369	5.704	7.972
All types	Good	2,831	7.429	0.380	6.477	8.117
'Civil' house	All	4,961	7.044	0.406	6.052	8.055
'Civil' house	Normal	3,844	6.941	0.351	6.052	7.882
'Civil' house	Good	1,117	7.400	0.381	6.600	8.055
'Economic' house	All	3,641	6.903	0.449	5.704	7.990
'Economic' house	Normal	2,927	6.799	0.386	5.704	7.844
'Economic' house	Good	711	7.333	0.433	6.477	7.990
Villa	All	4,536	7.177	0.372	6.346	8.117
Villa	Normal	3,533	7.077	0.324	6.346	7.972
Villa	Good	1,003	7.528	0.310	6.877	8.117

4.2 Model and identification strategy

To evaluate the market response to 2012 Northern Italy earthquake we use a standard diff-in-diff model as follow:

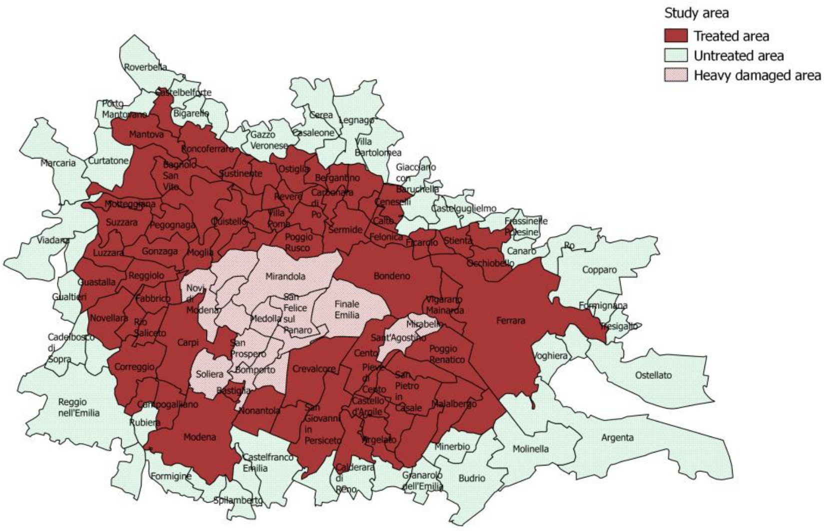
$$\log\left(Price_{i,j,t}\right) = \alpha_{i,j} + \beta_1 Post_t + \beta_2 D_j * Post_t + u_{i,j,t} \qquad (1)$$

where the dependent variable is the log of the average price of the housing units, i, in the OMI micro-area, j, at time t. D is a dummy variable equal to 1 if the observation is in the treatment groups (i.e. in the area affected by the earthquake) or 0 otherwise, $Post$ is a dummy variable taking value 1 if the treatment occurs and 0 otherwise. β_2 is the parameter of interest indicating the difference in average of the changes in prices between control and treated groups. We use a time fixed effect model. As underlined by Bertrand et al. (2004), to avoid serial correlation resulting with inconsistent standard errors, we run block bootstrap with 500 replications by keeping all the observations that belong to the same municipality, maintaining in this way the same autocorrelation structure (Efron and Tibshirani, 1994).

With the aim of selecting a suitable control group (i.e. the municipalities not affected by the Emilia earthquake that show similar characteristics of the 'treated' ones) we use the following strategy: we focus on all the neighboring municipalities to those of the treated area (See Fig 5); our control group is then composed of 49 municipalities; the total population of the control area is slightly lower of that of the treated area but the distributional characteristics between macro-areas is very similar (see Tab. 2 and Tab. 3).

The model's fixed effects in equation (1) is able to control for regional-specific shocks that occur in a particular year. However, for β_2 to identify the causal effect of the earthquake, housing prices in the regions affected by the earthquake must have similar trends to their counterparts in the non-affected areas prior to the earthquake.

Figure 5 - Treated and control group data



Then, identification of causal estimates for this class of differences-in-differences models rests on controlling for common trend assumption meaning that "*under common trends, in the absence of treatment the average outcome change from any pre-treatment period to any post-treatment period for the treated is equal to the equivalent average outcome change for the controls*" (p. 2, Mora and Reggio, 2014).

To examine potential pre-existing trends we run the following model:

$$\log(Price_{i,j,t}) = \alpha_{i,j} + \sum_{t<2012} \tau_t D_j T_t + u_{i,j,t} \qquad (2)$$

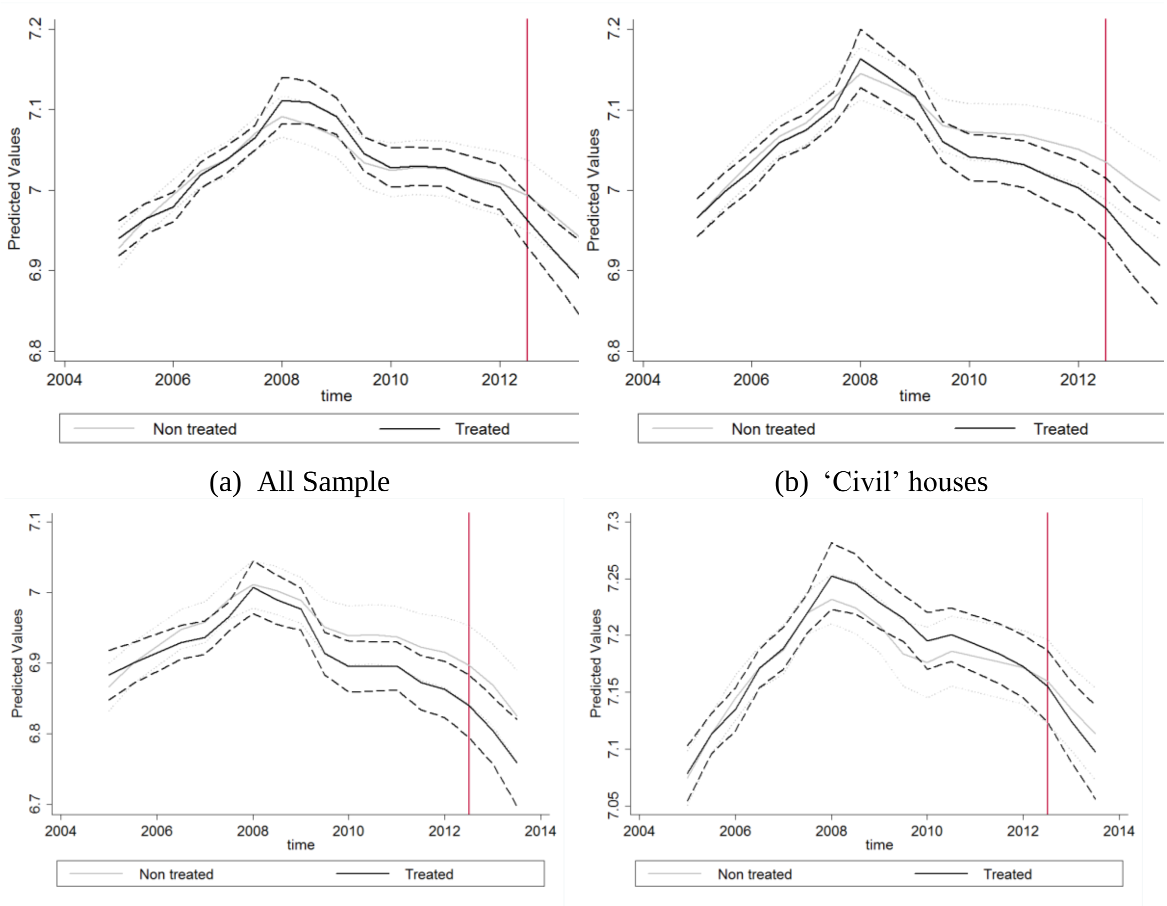
where τ_t are the coefficients on time dummies T_t. We then test the jointly significance of the estimated τ_t coefficients before the earthquake has occurred. If the test does not reject the H_0 we can affirm that the two samples satisfy the common trend assumption. Tab. 4 and Fig. 6 provide evidence for the acceptability of the common trend assumption: trends of the treatment and the control group are the same; then, the difference-in-differences is not significantly different between the two groups in the pre-treatment period.

Another issue to be addressed is the stable unit treatment value assumption (SUTVA). One concern is the presence of geographic spillover, namely the earthquake might have played a role in the perturbation of the housing prices even in the area not directly affected by the disaster. One plausible reason would be that the earthquake might have caused reallocation of evacuated people in safer areas (e.g. the control group area). This fact might have played a role in the increases of housing value of the units in the control group area. While it is impossible to fully test for this effect, several reasons can be provided to support SUTVA. First, as shown in Fig. 4 in Section 3, the percentage distribution of buildings indicating a damage higher than D2 is very low in the 88 municipalities initially considered. Damage maps of the D4 and D5 are not shown because of the very small percentage share of these damage classes. As we said above, however most of the heavy damaged buildings are in the epicentral area that we have excluded from the rest of the analysis because of the higher level of perturbation produced in the housing market, a factor that induced OMI to do not provide housing data on that particular area. Tab. 5 provides a detail of the distribution of damages for all the classes in the treated area of Fig. 5. Less than 1% of buildings have reported a damage of class 3 or higher. It is then possible to suppose that the number of evacuated people is then very low.

Table 4 - Pre-treatment common test

Sample	F test	p-value
All observations	1.40	0.16
Civil housing	0.97	0.49
Economic housing	1.55	0.11
Villa	1.79*	0.06

Figure 6 - Pre-treatment common test. Predicted values for treated and non-treated group



(a) All Sample (b) 'Civil' houses

(c) 'Economic' houses (d) Villa

Table 5 - Distribution of the buildings volume in damage classes

	D1	**D2**	**D3**	**D4**	**D5**
Vol. [m^3]	21,870,080	6,194,033	1,077,071	153,432	6,340
% (*)	16.73	4.74	0.82	0.12	0.005
Number of OMI micro-areas	17	295	83	28	-

(*) Notice that the total volume of residential housing in the treated area is 130,749,792 m^3,this includes also the non-damaged buildings (class D0).

Second, the northern part of the area considered in Fig. 5 is a border area between the three administrative regions of the analysis (Emilia-Romagna, Lombardy and Veneto). Reallocation of people, if any, between regions was difficulty because of different reasons, from the typical Italian parochialism to the regional-level management of the post-disaster phase. In addition, reallocations of people were publicly supported and not left to the free housing market and then should have not caused specific perturbations in the housing market of the control area. Finally, as Fig. 5 shows, heavy damaged area lies entirely in central part of the area under analysis (and totally included in the Emilia-Romagna administrative region). It is reasonable to think that reallocation might play indifferently trough north and south areas that are next to the heavy damaged areas but not will interest more distant areas (e.g. those of the control area). Ideally, if we run the model (1) taking into account north and south differences (the 'south' sample is composed only by units of Emilia-Romagna region, while the north includes Lombardy and Veneto), we do not find evidence of a different behavior in the two sub-samples.[4]

5 Results

5.1 Results without considering the damage degree

In this section, we present the results of the analysis. We have run several models that take into consideration the different typologies of housing and the qualitative state of the housing units. In Tab. 6 we report the results for all the residential units without any distinction for housing type. The model (1) provides the estimate for all the residential housing without any distinction of quality of the houses, while models (2) and (3) take into consideration, respectively, a normal state of conservation and a good state of conservation.

Three considerations are worth mentioning. First, the parameter that indicates the post earthquake period is significantly lower than zero, indicating an overall reduction of housing price for all the sample taken into account (both in the control and treated groups). This is in line with the overall trend of the real estate market that shows an overall price reduction – a trend that is in line with the after 2008 crisis of the housing market. Second, the interaction dummy in model (1) shows that the average level of the housing prices in the area affected by the earthquake is significantly lower than that of the area next to the epicentral area (i.e. the control group). The difference is 4.6%. This indicates a significant effect of the earthquake in the reduction of the value of the houses affected by the earthquake. The same effect is confirmed in model (2) but not in the model (3). The two models take into consideration different quality of the units, respectively normal and good. We interpret this different behavior as a signal given by the condition of the houses with respect to capacity to 'resist' to the tremor. Good quality buildings might be recognized to resist more to an earthquake and this could explain the results. To further investigate the relationship between earthquake effects and characteristics of the houses we have split the sample according to the different types of housing and state of conservation of the buildings. Results are shown in Tab. 7.

According to the description reported in Tab. 1 'civil' houses are structurally and qualitatively superior to 'economic' houses mainly due to the materials used. Villas instead, are quietly different from the previous two types: they are mainly buildings with a lower number of floors (commonly one or two). Then, we can suppose that each type of house, because of it structural characteristics, might own different capacity to 'resist' to an earthquake. In particular, we suppose that villas are better than civil houses that are better than economic houses.[5]

For instance, Deng et al. (2015), p. 1, observe that '*the relative price of low to high floor units, particularly units located in the first and second floor, considerably*

[4] Considering all the housing types, we estimate an interaction coefficient equal to -0.03* and block bootstrapped s.e equal to 0.015 for south sub sample, and -0.06** and block bootstrapped s.e 0.03 in the north sub-sample.

[5] It should be noted that we do not have enough information to determine the damage suffered by these types of buildings singularly.

increased for several months after the earthquake. This relative pricing pattern is in line with a higher risk perception and fear, triggered after the tremor'. Then, according to them, we might expect no effect, or even positive, of the earthquake on the average price of the treated villas with respect to those of the control group. At the same time, we can argue that, as in model (3) a higher quality of the house might have a positive impact on the reduction of prices after an earthquake occurs. So that we might expect a differential of price between civil and economic houses.

All these remarks are considered in models (4)-(12). For any type of house, we report the result of the diff-in-diff model for the average price of all type of houses (civil, economic, villa), normal quality, and good quality.[6]

As mentioned before, average price of villas in the treated area do not show significant differences with respect to that of the control group (models (10)-(12)), meaning that the earthquake does not have any significant effect on the prices of this type of building. This result is in line with previous literature (Deng et al., 2015). It is worth noting that this behavior does not change according to the quality of the villas (normal (11), good (12)).

Instead, the average prices of 'civil' and 'economic' houses show a different behavior (models (4)-(9)). The earthquake produces a reduction in the average prices of these types of building (respectively of 5% and 6%). Moreover, the reduction in price is greater for 'economic' buildings. So we can confirm that the quality of the houses in term of perception of resistance to the tremor plays an important role. This fact is strengthen by the results for good quality houses (models (6) and (9)), which display no effect for both 'economic' and 'civil' houses of good quality. This means that both the type and the quality of houses play a joint role in the effect of the earthquake on the average prices.

[6] Then, model (4) is related to all 'Civil' houses; model (8) to 'Economic' houses of normal quality and (12) villa of good quality.

Table 6 - Diff-in-diff for all residential units by quality (All (1), Normal (2), Good (3))

Independent variable	log of the average price		
	(1)	(2)	(3)
Post shock (β_1)	-0.0606***	-0.0709***	-0.0259***
	(0.0158)	(0.0205)	(0.00663)
Interaction (β_2)	-0.0470**	-0.0684**	0.00439
	(0.0229)	(0.0323)	(0.00795)
Constant	7.057***	6.978***	7.325***
	(0.0373)	(0.0341)	(0.0466)
r2	0.0960	0.122	0.0268
F	51.71	38.87	46.98
N	30607	23633	6966

* p<0.1, ** p<0.05, *** p<0.01 (block-bootstrapped standard errors in parentheses)

Table 7 - Diff-in-diff by type of buildings and quality (all (4), (7), (10), normal (5), (8), (11), good (5), (9), (12), respectively)

Independent variable	log of the average price								
	'Civil houses' by quality: all, normal, good			'Economic houses' by quality: all, normal, good			'Villas' by quality: all, normal, good		
	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
After shock (β_1)	-0.0610***	-0.0717***	-0.0282***	-0.0817***	-0.0999***	-0.00647	-0.0430***	-0.0453***	-0.0359***
	(0.0164)	(0.0217)	(0.00540)	(0.0205)	(0.0269)	(0.00862)	(0.0138)	(0.0165)	(0.0118)
Interaction (β_2)	-0.0513**	-0.0783**	0.0100	-0.0614**	-0.0903**	0.00354	-0.0216	-0.0270	-0.00787
	(0.0237)	(0.0328)	(0.00735)	(0.0285)	(0.0407)	(0.0101)	(0.0197)	(0.0255)	(0.0146)
Constant	7.061***	6.979***	7.320***	6.914***	6.789***	7.204***	7.183***	7.109***	7.432***
	(0.0382)	(0.0366)	(0.0444)	(0.0439)	(0.0588)	(0.0640)	(0.0334)	(0.0284)	(0.0449)
r2	0.102	0.134	0.0264	0.129	0.170	0.00162	0.0559	0.0575	0.0586
Wald chi2	51.60***	42.98***	42.43***	71.05***	62.48***	0.85	27.69***	19.39***	33.90***
N	11,556	8787	2769	9,118	7,183	1,927	9,933	7,663	2,270

* p<0.1, ** p<0.05, *** p<0.01 (block-bootstrapped standard errors in parentheses)

5.2 Type of housing, house quality and physical damage: moving through a different risk perception

Up to now we did not introduce any discussion on the actual damage produced by the earthquake and its possible consequence on the risk perception of individuals. To take into account the different physical damage produced by the earthquake we then add to our model the level of damage of the treated areas as estimated in Section 3. The damage, as reported in Section 3.2, varies between D1 and D4, where D1 means little damage and D4 means almost complete destruction of the house. It should be noted here that, although we have estimated the volume of the buildings that show a given level of damage, as reported in Tab. 5 in Section 4, we consider the damage as a dummy variable. This means that an OMI micro-area will suffer of damage *DX* if there is at least one building that has suffered the *X* level of damage. It should be noted that when we show results for a given level of damage, we have selected those areas that have experienced exactly that level of damage. For instance if we show the results for the *D3* level, this means that we have selected all the micro-areas that have experienced exactly *D3* level of damage and we discard all the other areas that have experienced at most lower or higher damage. The number of micro-areas that have reported at most the damage of level *DX* are shown in Tab. 5. Only 17 micro-areas have reported at most a damage level *D1*. The damage classes more represented instead are *D2* and *D3*, with 295 and 83 micro-areas respectively. The damage class then can be considered as other features of the sample units that must be accounted for. In this way, we are able to extrapolate the casual relationship between damage, housing characteristics and subjective perception of the risk, because we will be able to compare the different effects on the price reduction (if any) due to different damage classes jointly to the housing features. Formally, model (1) becomes:

$$\log\left(Price_{i,j,d,t}\right) = \alpha_{i,j} + \beta_1 Post_t + \beta_2 D_{j,d} * Post_t + u_{i,j,d,t} \qquad (3)$$

where the dependent variable is again the log of the average price of the housing units, *i*, in the OMI micro-area, j, that has experienced at most a given damage, *d*, at time *t*. Then, in this setting, D is a dummy variable equal to 1 if the observation is in the treatment groups and shows at most the given level of damage under analysis, *d* (i.e. in the area affected by the earthquake with at most a *D1* damage) or 0 otherwise. Moreover, we drop all the observations that are in the treated areas that show a higher level of damage, *d*, of that considered. Furthermore, we do not change the control group. $Post$ is a dummy variable taking value 1 if the treatment occurs and 0 otherwise. β_2 is again the parameter of interest indicating the difference in average of the changes in prices between control and treated groups.

The reason to this choice is that we are more interested on the impact of the earthquake on the subjective perception of the risk and not in the objective risk itself. For instance, the average volume of buildings reporting a damage *D4* is lower than 0.5% of the total buildings. However, this low percentage has a huge impact in the reduction of prices as we see in Tabb. 8–11.

According to all the models the OMI micro-areas that have experienced at most a damage *D1*, do not show evidence of reduction in prices after the earthquake in comparison to the control group regardless of the type of housing. The quality instead is still a very important component; indeed, good houses do not show reduction in prices until a damage *D3*. Moreover, an increased maximum damage experimented in the treated areas results in a reduction of the prices, with a huge impact of the areas with a *D4*.

For a more clear picture results are summarized in Tab. 12. It is interesting to note that:

i) prices decreases when damage increases for ‘civil’ and ‘economic’ houses when the quality is ‘normal’;
ii) when the quality is ‘good’ often there is no reduction in the prices after the earthquake occurred until *D3* level of damage;
iii) villas do not show different behavior in the treated and control areas in *D1-D3* damage levels, whereas it seems that a reduction might arise in *D4* areas.

Tab.8 *Diff-in-diff by damages D1-D4 for all residential units by quality*

Independent variable log of the average price												
	All Residential by level of damage: D1-D4				All Residential: Normal, by level of damage: D1-D4				All Residential: Good, by level of damage: D1-D4			
	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
After shock (β_1)	-0.0606***	-0.0606***	-0.0606***	-0.0606**	-0.0709***	-0.0709***	-0.0709***	-0.0709***	-0.0259***	-0.0258***	-0.0258***	-0.0259***
	(0.0162)	(0.0162)	(0.0160)	(0.0251)	(0.0213)	(0.0208)	(0.0208)	(0.0261)	(0.00638)	(0.00680)	(0.00642)	(0.00696)
Interaction (β_2)	0.0303	-0.0488**	-0.0662*	-0.241***	0.0216	-0.0698**	-0.0844*	-0.322***	0.0263*	0.00383	-0.00674	-0.0602***
	(0.0292)	(0.0233)	(0.0391)	(0.0297)	(0.0398)	(0.0331)	(0.0474)	(0.0866)	(0.0145)	(0.00825)	(0.0141)	(0.00696)
Constant	7.088***	7.046***	7.028***	7.060***	6.978***	6.972***	6.929***	6.958***	7.455***	7.304***	7.422***	7.430***
	(0.0625)	(0.0385)	(0.0603)	(0.107)	(0.0494)	(0.0351)	(0.0446)	(0.0851)	(0.0672)	(0.0522)	(0.0715)	(0.0920)
r2	0.0574	0.0953	0.0690	0.0741	0.0675	0.119	0.0817	0.0873	0.0249	0.0296	0.0344	0.0354
F	15.59	49.26	22.92	1258.1	13.25	37.19	21.82	50.39	16.62	43.09	22.21	8.09
N	14,149	26,912	16,551	13,257	10,904	20,859	13,144	10,396	3,242	6,045	3,339	2,955

* p<0.1, ** p<0.05, *** p<0.01 (block-bootstrapped standard errors in parentheses)

Tab. 9 *Diff-in-diff by damages D1-D4 for civil housing by quality*

Independent variable log of the average price												
	'Civil housing', by level of damage: D1-D4				'Civil housing': Normal, by level of damage: D1-D4				'Civil housing': Good, by level of damage: D1-D4			
	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
									-			
After shock (β_1)	-0.0610***	-0.0610***	-0.0610***	-0.0610***	-0.0717**	-0.0717***	-0.0717***	-0.0717**	0.0282***	-0.0282***	-0.0282***	-0.0282***
	(0.0168)	(0.0162)	(0.0162)	(0.0173)	(0.0226)	(0.0217)	(0.0221)	(0.0254)	(0.0050)	(0.00554)	(0.00541)	(0.00483)
Interaction (β_2)	0.0324	-0.0525**	-0.0782*	-0.309***	0.0200	-0.0781**	-0.109*	-0.420***	0.0360**	0.00787	0.00962	-0.0521***
	(0.0345)	(0.0263)	(0.0453)	(0.0173)	(0.0477)	(0.0338)	(0.0571)	(0.0253)	(0.0158)	(0.00749)	(0.00971)	(0.00482)
Constant	7.081***	7.049***	7.025***	7.054***	6.972***	6.972***	6.953***	6.938***	7.429***	7.299***	7.400***	7.403***
	(0.0587)	(0.0397)	(0.0437)	(0.0580)	(0.0489)	(0.0378)	(0.0441)	(0.0461)	(0.0617)	(0.0467)	(0.0627)	(0.0686)
r2	0.0523	0.101	0.0721	0.0703	0.0609	0.129	0.0959	0.0829	0.0294	0.0332	0.0355	0.0410
F	14.13	48.33	22.08	31.51	11.57	40.25	22.93	58.81	30.79	44.78	35.79	22.15
N	5,345	10,111	6,256	5,000	4,071	7,705	4,345	3,874	1,274	2,406	1,284	1,126

* p<0.1, ** p<0.05, *** p<0.01 (block-bootstrapped standard errors in parentheses)

Tab.10 *Diff-in-diff by damages D1-D4 for economic housing by quality*

Independent variable log of the average price

	Economic housing', by level of damage: D1-D4				Economic housing': Normal, by level of damage: D1-D4				Economic housing': Good, by level of damage: D1-D4			
	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)
After shock (β_1)	-0.0817***	-0.0817***	-0.0817***	-0.0817***	-0.0995***	-0.0999***	-0.0995***	-0.0995***	-0.00647	-0.00671	-0.00647	-0.00647
	(0.0200)	(0.0209)	(0.0199)	(0.0199)	(0.0260)	(0.0274)	(0.0265)	(0.0264)	(0.00857)	(0.00892)	(0.00904)	(0.00959)
Interaction (β_2)	0.0244	-0.0654**	-0.0761	-0.240***	0.0148	-0.0960**	-0.0860	-0.377***	-0.00600	0.00674	-0.0246	0.0332
	(0.0369)	(0.0289)	(0.0526)	(0.0198)	(0.0484)	(0.0428)	(0.0608)	(0.0265)	(0.0251)	(0.0102)	(0.0202)	(0.0327)
Constant	6.958***	6.896***	6.914***	6.910***	6.845***	6.789***	6.813***	6.813***	7.374***	7.185***	7.327***	7.328***
	(0.0751)	(0.0471)	(0.0740)	(0.0914)	(0.0580)	(0.0565)	(0.0562)	(0.0691)	(0.0887)	(0.121)	(0.0917)	(0.129)
r2	0.0977	0.130	0.119	0.113	0.124	0.173	0.145	0.147	0.00394	0.00139	0.0127	0.00408
F	19.85	60.62	26.48	40.12	18.98	51.17	24.85	43.04	0.897	4.300	3.577	1.345
N	3,982	7,912	4,222	3,677	3,126	6,269	3,386	2,954	853	1,635	833	720

* p<0.1, ** p<0.05, *** p<0.01 (block-bootstrapped standard errors in parentheses)

Tab.11 *Diff-in-diff by damages D1-D4 for villa by quality*

Independent variable log of the average price

	Villa, by level of damage: D1-D4				Villa: Normal, by level of damage: D1-D4				Villa: Good, by level of damage: D1-D4			
	(49)	(50)	(51)	(52)	(53)	(54)	(55)	(56)	(57)	(58)	(59)	(60)
After shock (β_1)	-0.0430**	-0.0430***	-0.0430***	-0.0430**	-0.0453**	-0.0453***	-0.0453***	-0.0453**	-0.0359**	-0.0359***	-0.0359***	-0.0359***
	(0.0145)	(0.0144)	(0.0146)	(0.0157)	(0.0169)	(0.0167)	(0.0162)	(0.0187)	(0.0116)	(0.0118)	(0.0111)	(0.0109)
Interaction (β_2)	0.0448**	-0.0234	-0.0257	-0.174	0.0441	-0.0287	-0.0302	-0.177	0.0425**	-0.00945	-0.0156	-0.169***
	(0.0228)	(0.0203)	(0.0307)	(0.154)	(0.0300)	(0.0260)	(0.0390)	(0.200)	(0.0188)	(0.0146)	(0.0307)	(0.0109)
Constant	7.202***	7.174***	7.184***	7.146***	7.098***	7.101***	7.088***	7.048***	7.548***	7.426***	7.514***	7.526***
	(0.0593)	(0.0343)	(0.0581)	(0.0596)	(0.0476)	(0.0281)	(0.0442)	(0.0506)	(0.0615)	(0.0480)	(0.0654)	(0.0603)
r2	0.0354	0.0555	0.0443	0.0416	0.0350	0.0564	0.0434	0.0387	0.0403	0.0618	0.0542	0.0648
F	8.827	26.46	16.89	6.334	7.227	18.70	13.70	4.585	9.837	35.10	13.51	32.73
N	4,822	8,889	5,043	4,580	3,707	6,885	3,898	3,568	1,115	2,004	1,145	1,012

* p<0.1, ** p<0.05, *** p<0.01 (block-bootstrapped standard errors in parentheses)

Table 12 - Summary of results

Type of housing	Normal				Good			
	D1	D2	D3	D4	D1	D2	D3	D4
All	Null	-	-	-	+	Null	Null	-
Civil housing	Null	-	-	-	+	Null	Null	-
Economic housing	Null	-	Null	-	Null	Null	Null	Null
Villa	Null	Null	Null	Null	+	Null	Null	-

5.3 Further controls and damage perception

In the previous sub-section, we have shown how at different damage levels correspond to a drop in the housing price according to housing features, like type and quality of the buildings. However, a reasonable critique could be the following: the drop in the prices might arise not because of the change in the subjective perception of the risk (and in particular because of overreaction) but because of underestimation by households of disaster risk in a area where its occurrence is low. In this section we then want to control for another relevant aspect: damage perception in areas affected by different damage levels but that show the same objective risk probability. According to the Italian civil protection regulations, the seismic classification of the territory is assigned at the level of municipality. Then, within any municipality, the risk might be considered homogenous (at least for small municipalities as those of the selected area). This means that for any municipality a rank indicating the seismic risk has been assigned, and this can be taken to represent an objective probability of the area. This fact helps in finding a strategy able to keep into consideration differences in damage level given the same objective probability.

We then run the last diff-in-diff models using the following strategies: we select only the municipalities that experiment at least two OMI micro-areas with two different levels of damage. We then, focus on pairs of damage (i.e. *D4* vs *D3*) and we run a diff-in-diff model where the treated area is composed by the OMI micro-areas with the higher level of damage (i.e. *D4*), while the control group is given by the areas with the lower damage (i.e. *D3*). It should be noted that here the treatment and control groups look very different from the ones of the previous sections because the way in which we construct the empirical strategy is quite different. The aim of this section is then to control for changes in the perception of risk as represented by the different damages produced by the earthquake within the same municipality (meaning for the same objective probability). For all these reasons, we keep into consideration the change in the price ratio exclusively due to different damages within the same municipality. In this way, we are able to provide evidence of the different perception triggered by the same shock that however has produced different level of damage in areas that show in principle the same objective probability of being affected by the earthquake.

In Tab. 13 model (1) compares *D4* and *D3*; model (2) compares *D3* and *D2* and finally, model (3) compares *D2* and *D1*.[7] The result is that areas with same objective probability suffer a reduction in the average price of house of 18.8 % if the areas is affected by the damage *D4*, while there is no difference between *D3* and *D2*, and again different reduction in price between *D2* and *D1*. These results show that a first 'psychological' threshold in the perception of risky prone areas due to the damage produced by an

[7] Note that there are very few observations where the difference in term of damage level is higher than two classes.

earthquake might be recognized when the damage goes through negligible (*D1*) to moderate (*D2*). No statistical difference are recognized when the damage passes from *D2* (moderate) to *D3* (substantial) meaning that moderate damages produce a change of perception of the risk equal to the one produced by substantial damages. Finally, another threshold can be recognized when the damage goes through substantial to heavy, because the psychological effects of structural failure of roof and floors can have a huge impact in the subject perception of being in a risky prone area. We then can conclude by saying that the perception of higher risk plays a key role for housing prices when the scene of devastation is greater.

Table 13 - Diff-in-diff, damage comparison

Independent variable	log of the average price		
	(1) D4 vs D3	(2) D3 vs D2	(3) D2 vs D1
After shock (β_1)	-0.113	-0.0918***	-0.0303
	(0.0915)	(0.0312)	(0.0213)
Interaction (β_2)	-0.188***	-0.0112	-0.0376*
	(0.0307)	(0.0215)	(0.0194)
Constant	6.798***	7.029***	7.306***
	(0.00335)	(0.00468)	(0.00572)
r2	0.117	0.109	0.0642
F	11.73	5.772	2.293
N	1,884	5,183	4,330

* p<0.1, ** p<0.05, *** p<0.01 (block-bootstrapped standard errors in parentheses)

6 Conclusion

This paper proposes an approach to the evaluation of housing market responses to earthquakes using the Northern Italy earthquake of May 2012 as case study.

We have merged the results of a macro-seismic analysis of the area affected by the 2012 earthquake with the OMI housing market data at the sub-municipal level for the same area. Then we used a diff-in-diff model using the unaffected municipalities as a control sample - in which we are able to take into account the different degrees of actual damage and the type and quality of houses. Differently from other works, we proceeded directly to the assessment of a damage earthquake scenario., meaning that we use macroseismic methods to evaluate the physical damage level produced be the Northern Italy earthquake.

We first have provided a map of the damage produce by the 2012 Northern earthquake showing that most of the buildings has no damage (D0) or light damage D1 and that moderate damage are restricted only in the epicentral areas while quantities in the other damage classes are negligible.

Furthermore, the results provide evidence that the average level of the housing prices in the area affected by the earthquake is significantly lower than that of the area next to the epicentral area (i.e. the control group) but at the same time the quality of the houses in relation to the 'resistance to the tremor' might play a relevant role for the emergence of the subjective risk assessment. In addition, the actual damage can cause an overreaction of housing market prices: the higher risk perception triggered by the unforeseen extreme event reduces housing prices where the perception of damage itself is higher. More in details, prices decreases differently according to damage and housing characteristics: when damage increases for ‘civil’ and ‘economic’ houses and the quality is ‘normal’ the price decreases, while if the quality of the houses is good there is no significant evidence of reduction in the prices after the earthquake occurred until a substantial damage (typically *D3* or above) was suffered. Furthermore, villas do not show different behavior in the treated and control areas in *D1-D3* damage levels, whereas it seems that a reduction might arise in *D4* areas. All these facts are in line with previous research, in particular with Willis and Asgary (1997) that show how earthquakes might increase the price differential between earthquake resistant and non-resistant houses and with Deng et al. (2015) showing that low floor units have higher relative price in the months after the earthquake occurred, indicating overreaction.

Further analysis have to be developed to analyze the long-run evolution of the housing market in the area affected by the earthquake. In fact we expect that overreaction will not continue to be in operation after a certain period of time and the gap in the price ratios might be absorbed.

Acknowledgements. The authors wish to thank Caterina Andreussi and Gianni Guerrieri to make available the housing market data from “Agenzia delle Entrate – Territorio – Osservatorio del Mercato Immobiliare”. The authors also acknowledge the support received by the project “The Economic Evaluation of Natural Disasters in Italy” (sponsored by Fondazioni Generali).

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