‘Near Miss’ Housing Market Response to the 2012 Northern Italy Earthquake: The role of housing quality and risk perception

Abstract

This paper examines the housing market response to the earthquake that hit northern Italy in May 2012. The available literature shows that the average price of houses decreases after a disaster because of the potential underestimation of disaster risk by households, or because of a higher risk perception in reaction to the unforeseen emergency. The physical assessment of the earthquake damage scenario provided in this paper (the so-called macro-seismic approach), combined with a difference-in-difference model with a multi-valued treatment, is able to extrapolate indirect information on the subjective perception of risk. We provide evidence that differences in costs and risk perceptions of the earthquake arise at high levels of damage. Furthermore, we also provide evidence that building characteristics, as well as houses’ states of maintenance, play a relevant role for subjective risk assessment, even though this assessment may be not related to the effective capacity of the buildings to resist earthquakes.

Keywords: Earthquake risk; housing market; risk perception; economics of natural disasters; diff-in-diff.

JEL Code: R21; R32; Q52

1 Introduction

On 20 May 2012, an earthquake with magnitude M_L 5.9 (Scognamiglio et al., 2012) occurred on a large part of the Po river plain (Northern Italy). The seismic sequence, with six events of magnitude Mw ≥ 5, generated extensive damage on a densely inhabited area causing significant affecting public and private infrastructures (Mucciarelli and Liberatore, 2014). Overall losses have been estimated at 5 billion euros (Ronchetti, 2012). Available studies generally recognize that the effect of extreme natural events on the housing market is to reduce housing prices (see for instance Baade et al., 2007; Beron et al., 1997 and Willis and Asgary, 1997). The theoretical reason for this effect is rooted in the seminal works of Brookshire et al. (1985) and Ehrlich and Becker (1972). The former shows that households will be ready to pay more for a location with a lower possibility of loss; the latter provides the framework for the general self-protection model (i.e. households will provide self-protection until the marginal benefits are higher than marginal costs). In these studies, an implicit assumption is that the final housing price is affected by the risk assessment of individuals on the intrinsic and extrinsic characteristics of the buildings in relation to the capacity of resisting to a seismic event. In this way, the individuals' willingness to pay is driven by the buyer risk aversion (Votsis and Perrel, 2016). However, a new event is able to, temporarily or permanently, affect the subjective and objective individuals' risk. According to that, after the natural disaster occurs, the price will align to the buyer risk aversion optimal price according to the "new" risk assessment.

However, the mechanism that produces price reductions after an extreme event is still unclear and it might mainly refer to the individuals' risk perception. In fact, as noted by Crescimbene et al. (2013), the psychological mechanisms that drive people to judge risks derive from the social and cultural learnings that are especially affected, among the others, by the content of information and the potential bias in the communication process. Similarly, Logan (2017) identifies different important aspects that might affect the seismic risk perception. For instance, people who have experienced the hazard before, have a better understanding of the real risk. However, risk perceptions depend on individual characteristics (e.g. gender, level of education, religion, age and so on) thus affecting the trade-offs for risk and the local housing property values. Armaş (2006), for instance, found that female, young people and non-highly educated people perceive higher seismic risk, and similar analyses have been provided since Slovic et al. (1977). Yet, a theory of 'integral' risk perception is still missing even though as denoted in Lindell and Perry (2000) the risk perception depends on the individual expected damage that is related to the probability and cost to suffer a damage.

It should be noted that a key point of this kind of analyses is the assessment of the damage caused by the natural extreme events. However, the measures used to evaluate the (potential of) damage are typically proxies (e.g. location in a particular area, simulation of earthquake scenarios, distance from the fault, occurrence probability). A proxy of the possible damage scenario may not properly consider the real damage produced by an extreme event. This paper overcomes this shortcoming by using the Northern Italy earthquake of 2012 as a natural experiment combining the physical damage of buildings with housing market data in order to evaluate housing market responses to a seismic event.

In this paper, the assessment of the physical damage of buildings is made according the so-called macro-seismic approach, an engineering method that assesses the residential-buildings damage according to a scale that goes from D1 (almost no damage) to D5 (collapse). The method is based on the EMS-98 intensity scale (European Macroseismic scale, Grünthal 1998) that '*depicts the effects of an earthquake on built-up areas in terms of observed intensities*' (Meroni et al., 2017, p. 326), allowing for a more appropriate definition of the damage scenario.

Therefore, we can recognize the different behaviour of households according to the actual damage produced by the earthquake. Moreover, we also use housing characteristics such as housing types and the current state of maintenance that may have in principle different capacities to resist earthquakes and that may give different individuals perceptions of the buildings' seismic resistance (Deng et al., 2015).

2 Literature review

Although many studies agree that (*ceteris paribus*) households will pay less for houses in risk-prone areas, the mechanism that produces price reductions after an extreme event is still unclear and it is consistent with several possible behavioural scenarios (Beron et al., 1997, Booth and Tranter, 2018).

First, the event brings new knowledge allowing a more precise risk assessment and, therefore, a more accurate estimate of the objective probability of occurrence of an 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). Thus, housing price is not able to incorporate the real higher objective risk. After the natural disaster occurs, the price will align back to the correct price by means of a more or less drastic drop. Similarly, Gu et al (2018) find a switch in the households' behaviour in the land pricing before and after an earthquake – in fact, prices were not related to the proximity to the fault line before an earthquake, while they were negatively correlated with the geographic proximity after the event.

Along the same line, overreaction due to higher risk perception triggered by the fear felt during the extreme event produces a similar drop in the housing prices (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 it may be very complex to take into account all the possible scenarios described above, previous studies mainly 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 an earthquake, indicating overreaction of households to earthquake.

According to previous studies, we argue that, prices of houses that are not directly damaged by an earthquake might react to a change in risk perception when there has not been a recent recurrence of the disaster (Hallstrom and Smith, 2005; Naoi et al., 2009). In this case, housing prices are not able to incorporate the perceived risk of future earthquakes, which results in higher housing values before the event and a quick price reduction following the disaster.

3 Data and model

3.1 Damage data

In this paper, we provide measures of the damage to residential buildings directly calculated through a method for assessing physical damage. The model is based on the EMS-98 macro-seismic scale, which groups buildings into six classes of increasing vulnerability (A to F) based on the peculiar structural characteristics of the constructions, where vulnerability is understood as the capacity of the residential units to suffer a given level of damage according to the intensity of the shock. In more details, we use the 2011 housing census ISTAT data in order to match typological and morphological information and the age of the buildings to assign them to a class of vulnerability. ISTAT provides data aggregated for each census sections and, at the end of the procedure, they are aggregated at municipality level.

The damage is defined by matching the observed macro-seismic intensities of the earthquake to the vulnerability classes of the buildings expressed in the number and volume of damaged buildings, according to five degrees of harm, from ‘almost no damage’ to ‘collapse’ (D1–D5).[1]

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[1] For a complete description of the method, see Meroni et al. (2017).

3.2 Housing market data

Data on housing values are provided by the Observatory of the Housing Market (OMI – *Osservatorio del Mercato Immobiliare*), a branch of the Italian Revenue Agency. OMI defines, for each Italian municipality, homogeneous areas of the local real estate market in which there are uniform economic (house prices) and socio-environmental (local amenities) characteristics. In any of these areas, the difference between maximum and minimum price of the prevalent housing type cannot be higher than 50% differentiated for a precise topological classification. In details, the municipality is divided into the following areas: central (identified by the letter B), semicentral (letter C), peripheral (letter D), suburban (letter E) and rural (letter R).

The rationale to establish a territorial segmentation ex ante derive from the presence of territorial clusters: in fact, i) in urban areas the topology represents the main driving factor in explaining unit prices and ii) income aggregations do not follow a full proportionality hypothesis because they strongly depends by the interactions of e.g. cohorts, trend, regions and education level (Blundell and Stoker, 2005). Therefore, a sub-urban differentiation that proxy this evidence through the use of the OMI areas might result in a sort of "corrected aggregated series" (Blundell and Stoker, 2005).

In fact, OMI aims at define homogeneity of the socio-environmental and economic characteristics according to accessibility to public and private services; level of urban and extra-urban transport services and connections roads; presence of school, health, sports and commercial buildings. Therefore, the pricing values of the areas are synthetic values that are defined from all the actual transactions in the local housing market as known by the Italian Revenue Agency. Then it provides and updates every six months, the average prices of residential units that are grouped by type and current state of maintenance for any of these homogenous areas.

For the purposes of this study, we select only those units classified as residential buildings. It is possible to discriminate according to the type of quality of the materials used to builds the dwelling and these are described as 'high-quality houses' and 'low-quality houses'.[2] We can also differentiate for a peculiar building type defined as 'villa'.[3]

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[2] Characteristics evaluated for high-quality houses: flooring of common parts; facades of buildings and internal cladding of buildings.

[3] Large house with more or less extended backyard, typically no higher than two floors.

A further characteristic provided by the OMI database is the state of maintenance of the residential units, which may take three different values: 'good', 'normal' and 'poor'.[4] Finally, for any homogenous area, the OMI database provides average prices for each classification, for instance for high-quality houses in a good state of maintenance, for high-quality houses in normal state of maintenance and so on.

The housing values data cover the period 2005–2013 and the average prices provided by the OMI database are semi-annual. The first half of 2012 is the last observation before the earthquake, which occurred in May. We therefore have average housing prices for 14 periods before the event (leads) and three after (lags).

We analyse the OMI data by dividing them into two groups: those for municipalities damaged by the earthquake (the treated municipalities) and those for not-affected municipalities. According to the macro-seismic assessment, 88 municipalities (defined as the treated ones) have experimented at least damage D1. The control group is composed of 49 municipalities bordering the treated area. It should be noted that from the entire sample we discarded 15 municipalities at the epicentre since the turbulence caused by the earthquake on the housing market is persisting because of the widespread building damage (i.e. this is an area of heavy damage), see Figure 1.[5]

<Figure 1 about here>

In Table 1, we compare the sample size of the treated municipalities (i.e. the municipalities affected by earthquake) and the non-treated municipalities (the control group). The resident population of the total area in 2011 is over one and a half million, according to the Italian census. The 137 municipalities are divided into 663 homogenous housing market areas, with an average of about five areas per municipality. Most of these areas are peripheral (D) and suburban (E) zones.

Descriptive statistics of the housing prices are reported in Table 2 for the entire area under analysis, with a focus on: i) the municipalities of the treated and control group, ii) the type of housing (e.g. 'high-quality' housing, 'low-quality' housing and 'villa') and iii) state of

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[4] OMI analyses 8 quality-elements. If 6 of them are good the state is good, poor when 4 elements are poor.

[5] 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.

maintenance of the buildings (e.g. normal or good).[6] Overall, the total population of the control area is slightly lower of that of the treated area but the distributional characteristics between macro-areas (B, C and so on) is very similar, even differentiating for the housing characteristics (see Table 1 and Table 2).

<Table 1 about here>

<Table 2 about here>

3.3 Empirical strategy

To evaluate the market response to the earthquake we use a difference-in-difference model with a multi-valued treatment, which has the following general form:

$$log\ (Price_{i,j,t}) = \alpha_{i,j} + \tau_t + \beta Treat._j * Post_t + \sum_{d\ =\{medium,\ hig\ h\}} \gamma_d Treat._j * Damage_j^d * Post_t + u_{i,j,t}, \qquad (1)$$

where the dependent variable is the log of the average price for any category of residential unit, i, in the homogenous housing market area, j, at time *t*. $Treat$ is a dummy variable equal to 1 if the observation is in the treatment group (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 and γ_d are the parameters of interest: γ_d captures the different damage costs of the earthquake, while β indicates the difference in the average of the changes in prices between the control and treated groups after controlling for the damages; this latter coefficient can be seen as an estimate of the overall earthquake risk perception in the treated areas. τ_t are the time dummies. We aggregate the damage in three categories: *low*, which is given by the nearly non-damage class D1; *medium*, which is given by the damage class D2; and *high*, characterized by classes D3 and D4. We use a time fixed effects 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). It should be noted here that we consider damage as a dummy variable. This means that a homogenous housing market area will suffer of damage D*X* if there is at least one building

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[6] Poor state of repair owns very few observations: we dismissed this category.

that has suffered *X* level of damage. The number of homogenous housing market areas that have reported at most the damage of level D*X* are shown in Table 3. Only 17 areas reported a maximum damage level of D1. D2 and D3 are the more represented damage classes, with 295 and 83 areas, respectively

<Table 3 about here>

However, in the context of this simple diff-in-diff setting, we would not be able to recognize changes in risk perception, because we are implicitly assuming that all the areas in the treatment group share the same change in risk perception regardless of the level of damage. In fact, the diff-in-diff model just estimates the overall effect of the damages produced by the earthquake in the treated area with respect to the control area, without isolating the change in risk perception.

Nonetheless, our identification strategy allows the possibility to recognize non-damaged areas among those of the treatment group. Indeed, we recall that our strategy identifies treated municipalities if they have experimented no less than damage D1 in at least one of the homogenous areas of their local real estate market. However, this does not prevent the possibility of no damage (D0) in the other homogenous areas of the municipalities. Thus, given the peculiarity of the sample, we could argue that the higher the level of damage suffered by a single area, the higher the additional loss of value suffered by the homeowners. Therefore, after considering the additional loss related to the damage, what remains is the potential price reduction caused by the increased risk perceived by the households of the treated area in comparison with those of the control group.

These latter considerations give the possibility of implementing a difference-in-difference model with a multi-valued treatment. In this model the multi-valued treatment *post*treat*damage* identified by the coefficient γ of Equation (1) estimates the different damage costs of the earthquake within the treated areas, while the double interaction *post*treat* (which is, in this way, ‘purified’ of the different damage costs), identified by the coefficient β, estimates the overall earthquake risk perception in the treated areas. The model’s fixed effects in Equation (1) are able to control for regional-specific shocks that occur in a particular year.

However, in order to identify the causal effect of the earthquake, housing prices in the regions affected by the earthquake must have parallel trends to their counterparts in the non-affected areas prior to the earthquake. Then, the identification of causal estimates for this class of model 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*' (Mora and Reggio, 2014, p. 2). To examine potential pre-existing trends we run the following model:

$$log\ \ (Price_{i,j,t}) = \alpha_{i,j} + \tau_t + \eta_t Treat_j + u_{i,j,t}, \tag{2}$$

where η_t are the coefficients of the interaction between the treatment and the time dummies. More precisely, we include the interactions of the time dummies and the treatment indicator where the last period before the earthquake (the first period of 2012) is the omitted category. In this way, we express all the other interactions in relation to our baseline. If the outcome trends between treatment and control group are the same, then all the coefficients of the leads (e.g. 14 periods) should be insignificant. Figure 2 provides evidence for the acceptability of the common trend assumption: the trends of the treatment and control groups are not significantly different in the pre-treatment period.

<Figure 2 about here>

Another important aspect to consider is the possible presence of compositional differences between the treatment and control areas that may play an important role in determining lower or higher damage. In fact, this means that differences in the socio-economic characteristics of the areas under analysis could affect the vulnerability of the buildings (e.g. poorer areas might show lower housing quality, which leads to more damage) and the capacity to recover from the damage (e.g. richer areas might have a better housing quality, requiring higher costs of repair).

To control for this possibility we run balancing tests with socio-economic characteristics for treatment and control regions. We focus on the following socio-economic variables: total population, dependency ratio, percentage of graduates, employment rate, percentage of in- and out-commuters, percentage of buildings constructed after the Italian seismic laws of 2008, and percentage of buildings with no more than two storeys. All the information is from the 2011-census (ISTAT). Table 4 shows the descriptive statistics of the selected variables for the municipalities in the treatment and control groups. Overall, the variables have similar distributional characteristics in the two groups.[7]

<Table 4 about here>

We also control for the fact that individuals' different perceptions of the capacity of the buildings to resist an earthquake may be linked to a series of specific construction features. To this purpose, we focus on two building characteristics: the quality of the materials used to build the residential units and the buildings' state of maintenance.

'High-quality' houses are structurally and qualitatively superior to 'low-quality' houses, mainly owing to the construction materials used. Villas, instead, are subtly different from these two types: they are buildings with a lower number of storeys (commonly one or two) of very good quality. We suppose that each type of house, because of its structural characteristics, will have its own different capacity to 'resist' an earthquake.[8]

Villas instead, are peculiar type of houses that are different from the others and therefore they deserve some attention. In fact, we might expect no effect, or even positive effects, of the earthquake on the average price of the treated villas compared to those of the control group, if the overall perception of this kind of houses with their capacity to resist to an earthquake it thought to be higher. At the same time, we can argue that higher-quality houses would show lower price reduction after an earthquake because they may be considered potentially more able to resist the seismic event.

Similarly, the buildings' state of maintenance may be another important signal for the capacity of the residential units to resist the tremors produced by the earthquake. We consider two different states of maintenance: good and normal.

To investigate the relationship between earthquake effects and characteristics of the houses, we have split the sample of buildings according to the different types of housing

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[7] Balancing tests are available upon request. No significant compositional differences between the two groups.

[8] Unfortunately we do not have enough information to determine the damage suffered by these types of buildings individually.

and states of maintenance (i.e. actual conditions). Formally, we estimate a difference-in-difference with a multi-valued treatment equation where, instead of the damage, we consider the type of housing:

$$log\ (Price_{i,j,t}) = \alpha_{i,j} + \tau_t + \beta Treat_{.j} * Post_t + \sum\nolimits_{h\,=\,\{high,\ villa\}} \gamma_h Type_j^h * Post_t + \sum\nolimits_{h\,=\,\{high,\ villa\}} \gamma_h Treat_{.j} * Type_j^h * Post_t + u_{i,j,t}, \qquad (3)$$

where again $Treat$ is a dummy variable equal to 1 if the observation is in the treatment groups (i.e. in the area affected by the earthquake) and 0 otherwise, $Post$ is a dummy variable taking value 1 if the treatment occurs and 0 otherwise. β and γ_h are the parameters of interest, indicating the difference in average of the changes in prices between the control and treated groups, β, and according to the different building characteristics, *high* and *low*-quality houses and *villas*; τ_t are the time dummies.

In the same way, the state of maintenance of the buildings (e.g. good vs normal status of the building) also plays an important role in the perception of the buildings' resistance to a shock and the model is the following:

$$log\ (Price_{i,j,t}) = \alpha_{i,j} + \tau_t + \beta Treat_{.j} * Post_t + \gamma_{good} Status_j^{good} * Post_t + \gamma_s Treat_{.j} * Status_j^{good} * Post_t + u_{i,j,t} \qquad (4)$$

4 Results

4.1 Damage costs and risk perception

We run several models that take into consideration the different types of housing and the current state of maintenance of the housing units.

In Table 5 we provide the results of the estimations. We run five different models, which account for different uses of the damage variables. The first model (model (1) in Table 5) uses a simple diff-in-diff approach that can be considered the baseline model and the damage is considered as a dummy that assumes value 1 if the level of damage is D1 or higher and 0 if the level of damage is D0 (i.e. no damage). Overall, the estimated interaction dummy (β) in the first model shows that the average level of the housing prices in the area affected by the earthquake is significantly lower than that of the area away from the epicentre (i.e. the control group). The difference accounts for a lower price of about 4.9%. This indicates a significant effect of the earthquake in reducing the value of the houses affected by it.

<Table 5 about here>

Instead, the second and third models use a difference-in-difference model with a multi-valued treatment. In the second model (model (2) in Table 5), we use a damage dummy that assumes value 1 if the area has suffered at least D2 damage and 0 otherwise. In the model (3) in Table 5, we account for the different degrees of damage aggregated in the following three categories: *low*, as given by the damage class D1; *medium*, as given by the damage class D2; and *high*, as given by the classes D3 and D4.

Model (2) in Table 5 provides the results of a difference-in-difference model with a multi-valued treatment. The estimate of risk perception (β) is not significantly different from zero, indicating that all the reduction of housing values has to be imputed to the damage effect. In fact, the coefficient γ, which is an estimate of the damage costs of the earthquake, remains negative and equates to a drop of 8.7% in the prices of the houses in damaged areas in comparison with those areas without damaged.

Finally, when we split the different damage classes into three categories, the risk perception parameter, β, is again not significantly different from zero, while most of the price differential as a result of the earthquake has to be assigned to medium damage (-0.0832).[9]

As a result, we find that changes in risk perception in treated municipalities are not driven by the earthquake damage other than those associated with higher levels of damage (D3 and D4). The reason may be twofold: first, as explained by Meroni et al. (2017), the intensity of the earthquake has to be considered moderate and this has returned in a huge number of residential units with almost no damage. Second, we had not considered, until now, differences in housing characteristics.

Nonetheless, it is possible to calculate the overall decrease of the housing value for residential units in the area under analysis, by assuming an average drop of the housing values of the 8.7% for all of the residential buildings of the treated area. This value

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[9] In fact, comparing models (2) and (3) we can see that the estimated parameter γ of model (2) is closer to the estimated parameter γ_{md} than γ_{hd}.

accounts for about 4.3 billion euros, equivalent to an average discount in selling prices of 118 euro/m^2 and may be seen as a sort of indirect damage of the earthquake.

By looking at previous studies, we can see that our results are in line with the typical reduction observed in housing prices after an earthquake. For instance, Beron et al. (1997) found evidence of a drop of about 3.5% in housing prices after the Loma Prieta earthquake (in the San Francisco Bay Area); Deng et al. (2015) found evidence of a reduction of the prices after the Wenchuan earthquake, of between 2% and 6% depending on the methodology used. Finally, Naoi et al. (2009) show a 13% reduction in Japan after a massive earthquake. Overall, however, the results shown have not until now provided evidence of statistically significant changes in households' risk perception other than for higher levels of damage.

In the next subsection, we explore the housing characteristics that might affect property values after an earthquake as a result of different perceptions of their capacity to resist seismic disturbances.

4.2 Housing characteristics and risk perception

The main aim of this subsection is to disentangle the potential effect of the earthquake on housing values according to type and state of maintenance of the residential units. Indeed, we argue that the construction characteristics of the buildings and the type of residential unit are important features for determining the different levels of vulnerability of the residential units (Inzulza-Contardo and Gatica-Araya, 2018). However, in principle, these characteristics would not play a role as amenities for the determination of housing values because seismic vulnerability is not considered a relevant aspect unless an earthquake had occurred in the recent past (Naoi et al., 2009). Nonetheless, these characteristics may turn out in a potential signal for the capacity of the buildings to 'resist' the ground shaking when an earthquake actually occurs. The results are shown in Table 5 (models 4 and 5).

The results in Table 5 (model 4) still show an overall reduction in the average housing values in the area affected by the earthquake compared to the area next to the epicentre (β). When looking at the housing types instead, only the building type 'villa' (i.e. the *Treat*villa*post* coefficient, γ_{villa}), shows higher prices in the affected areas with respect to the reference building characteristics (e.g. low-quality units) of 3.9%. Instead, high-quality residential units show no significant differences (i.e. the *Treat*high*post* coefficient,γ_{high}). This result provides the first evidence that the construction characteristics of the building may influence individuals in their perception of the capacity of particular type of buildings to resist earthquakes.

In particular, even if the different building characteristics of villas are not very likely comparable with the other two types we can argue that buildings that have few storeys, such as villas, seem to enjoy a higher perceived resistance to an earthquake, at least in the opinion of homebuyers. Indeed, the results in Table 5 show that individuals were willing to pay a higher price differential with respect to the other types of houses in the aftermath of the northern Italy earthquake. On the other hand, the results do not show significant differences in the prices of high-quality and low-quality buildings (γ_{high}). A plausible reason is that externally the two types of buildings look quite similar and only experts would able to recognize differences in the building characteristics. It follows that households may not perceive dissimilarities in the capacity of the two types of buildings to resist the ground shaking and this will reflect no significant price differential.

On the same line, when looking at the state of maintenance of the buildings, the results in Table 5 (model 5) suggest that, in the treated areas, buildings with good states of maintenance show higher prices (of about 7.3%) compared to those with normal current status. This evidence underlines again that ‘external’ and recognizable building characteristics may influence individuals’ risk perception regarding the subjective understanding of the capacity of buildings to resist an earthquake. Indeed, residential units with good states of maintenance may be perceived to be more resistant to ground shaking because they may look well kept.

Overall, the results provided in this section can confirm that the building characteristics of the houses play an important role in terms of the perception of the buildings’ resistance to earthquakes, a result that is in line with previous findings of the literature (see e.g. Deng et al., 2015). However, we would like to underline that the building features that seem to affect different individuals’ perception of the residential units’ capacity to resist seismic events, such as the state of maintenance and the low number of storeys, are mainly external. Indeed, the link between the characteristics highlighted above (e.g. good state of maintenance; low number of floors) and the capacity to resist earthquakes does not consider other and more important structural characteristics of the residential units that may affect the real capacity of the building to resist to the ground shaking.

5 Discussion and Conclusion

This paper proposed an approach to the evaluation of housing market responses to earthquakes, using the 2012 northern Italy seismic event as a case study. We considered the results of a macro-seismic analysis of the area affected by the earthquake together with the housing market data at the sub-municipal level. Then, by means of a difference-in-difference model with a multi-valued treatment setting, we were able to identify price differentials in the average housing prices for the different levels of damage and also for the different building features of the residential units.

Departing from other works, we directly assessed the damage earthquake scenario, by using a method able to evaluate the physical damage level produced by the earthquake. The results provide evidence that the average level of the housing prices in the treated area is significantly lower than that of the control area. However, only higher levels of damage (i.e. D3 and D4) are able to produce significant damage costs. Furthermore, we underlined that building features such as houses with few storeys and good states of maintenance may be relevant for the emergence of the subjective risk assessment of the buildings' 'resistance to the ground shaking'. However, the different perception of resistance of the residential units seem to be more related to 'external' features of the residential units. Indeed, high-quality and low-quality buildings do not show significant differences in their housing prices in the treated area. On the other hand, non-structural characteristics, such as the good state of maintenance, seem to have positive and significant effects on the housing values. This latter fact highlights that subjective risk assessment may be unrelated to the effective capacity of the buildings to resist earthquakes.

This study arises relevant implications in relation to the post-earthquake recovery activities and in the change of households' wealth of near-missed household, namely those households not directly affected by the event but that are suffering a damage driven by a reduction of the housing values. In fact, from an economic point of view, the cost of restoration or re-construction, if realized (and for the part not covered by any compensation), represents for the owners a loss compared to the individual capacity of income and savings (liquid) and not a loss of real estate wealth, which constitutes the largest component of wealth of Italian households.

It therefore has a specific meaning with respect to a possible 'wealth effect' in the choices of the owners. Therefore, keeping into consideration the role of housing prices reduction due to a change in the households' subjective perception in the near missed areas is fundamental in order to analyse a stronger damage effect of not only directly involved people, but also near-missed households. For example, if the restoration does not allow to fully recover the pre-event real estate value as we show in the results section, the opportunity cost of giving up portions of income / savings to restore can be very high, leading to accept a permanent loss of real estate value but with consequent negative 'wealth effects' over time on the affected areas.

This also arises a concern in relation to the role of spatial inequalities with respect to the capacity to suffer a damage and more importantly on the capacity to recover from it. In fact, our results shown that low-quality houses and poor quality of the buildings are those that show a higher drop in the housing values. We therefore could infer that historical disparities in the socio-demographic structure within the area under analysis not only shaped the social vulnerability of local residents and their responses to recovery, but it also will perpetuate and increase spatial inequalities.

Therefore, further analysis has to be developed in order to analyse the long-run evolution of the housing market in the area affected by the earthquake, in particular in order to determine the persistency of the reduction of the housing prices.

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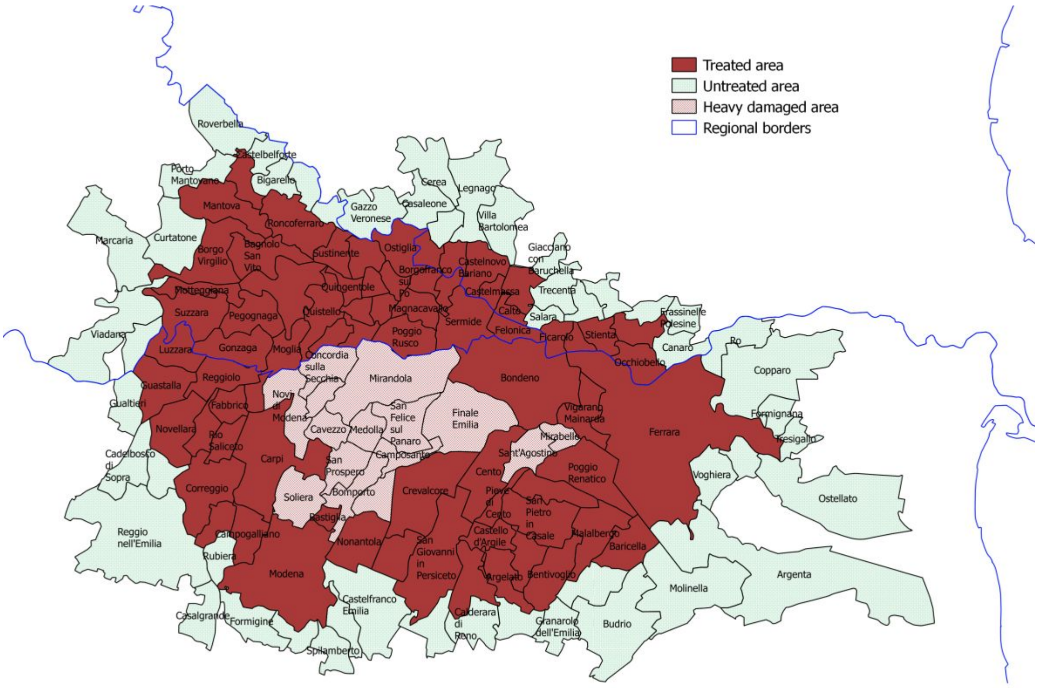

Figure 1 – Treated and control group data

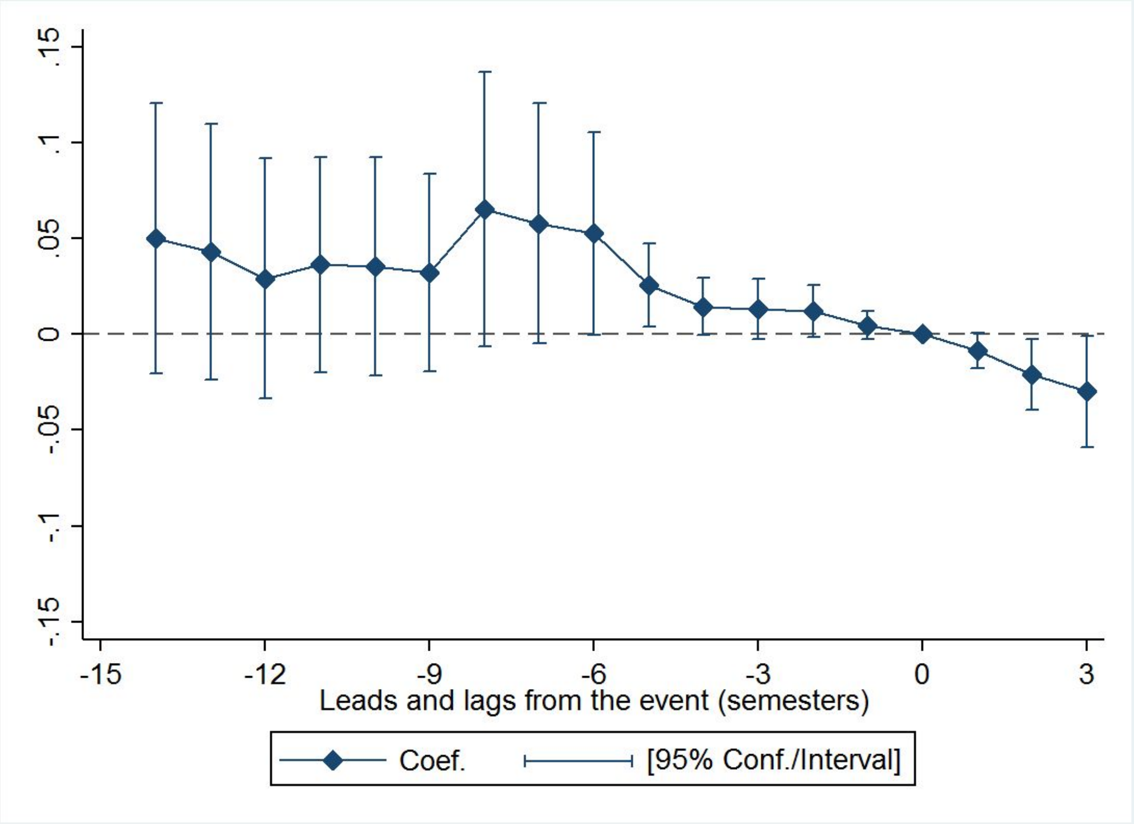

Figure 2 – Pre-treatment common test. Event-time indicators (*time dummies*treatment*), with the last period before the earthquake being the omitted category (*0 = first period of 2012, the last before the earthquake*)

Table 1 – Treated and control group data

Group	No. municipalities	Population	No. OMI 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
Heavily damaged	15	156,548	65	14	6	20	34	10
Total	137	1,695,410	663	144	35	252	197	87

Table 2 – 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	23,641	6.959	.368	5.521	7.972
All types	Good	6,966	7.320	.368	6.421	8.117
'High-quality' house	All	11,556	7.045	.386	5.858	8.109
'High-quality' house	Normal	8,787	6.960	.351	5.858	7.930
'High-quality' house	Good	2,769	7.315	.364	6.600	8.110
'Low-quality' house	All	9,118	6.892	.439	5.521	7.990
'Low-quality' house	Normal	7,183	6.809	.406	5.521	7.844
'Low-quality' 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
'High-quality' house	All	6,595	7.045	0.370	5.858	8.109
'High-quality' house	Normal	4,943	6.973	0.351	5.858	7.930
'High-quality' house	Good	1,652	7.258	0.341	6.600	8.109
'Low-quality' house	All	5,477	6.884	0.431	5.521	7.919
'Low-quality' house	Normal	4,256	6.816	0.420	5.521	7.832
'Low-quality' 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
'High-quality' house	All	4,961	7.044	0.406	6.052	8.055
'High-quality' house	Normal	3,844	6.941	0.351	6.052	7.882
'High-quality' house	Good	1,117	7.400	0.381	6.600	8.055
'Low-quality' house	All	3,641	6.903	0.449	5.704	7.990
'Low-quality' house	Normal	2,927	6.799	0.386	5.704	7.844
'Low-quality' 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

Table 3 – 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).*

Table 4 – Descriptive statistics of selected socio-economic characteristics in the treated and in the control area in 2011

	Treated area				*Control group*			
Socio-economic characteristic	Mean	Standard deviation	Min	Max	Mean	Standard deviation	Min	Max
Total population	12014.2	24821.22	790	179149	12743.67	23161.4	1214	162068
Dependency ratio	56.8896	4.493173	47.90	69.284	55.76833	4.34237	48.73	65.6022
Graduated	13.8656	4.274688	8.214	32.705	12.97612	3.69564	7.051	23.1556
Employment rate	68.9415	3.2767	58.27	75.422	69.08567	3.44328	60.578	75.2143
In-commuters	23.4232	6.925233	10.25	45.411	22.96689	6.30588	13.549	44.5017
Out-commuters	28.3174	6.939867	9.103	40.784	29.25587	6.1624	10.672	43.3029
Buildings after 2008	4.59556	3.271906	0	18.957	4.185879	2.38023	.798005	13.3654
One or two storeys	37.8431	17.23999	5.355	79.630	38.22528	19.1615	8.2107	78.5949

Table 5 – Diff-in-diff for all residential units, by types and quality of the houses

Independent variable	log of the average price				
	(1)	(2)	(3)	(4)	(5)
Interaction (β)	-0.0475**	0.0332	0.0332	-0.0613**	-0.0678**
	(0.0238)	(0.0280)	(0.0280)	(0.0292)	(0.0324)
Treat*damage*post (γ)	-	-0.086***	-	-	-
	-	(0.0252)	-	-	-
Medium damage (γ_{md})	-	-	-0.0832***	-	-
	-	-	(0.0248)	-	-
High damage (γ_{hd})	-	-	-0.109**	-	-
	-	-	(0.0521)	-	-
Villa*post	-	-	-	0.0384***	-
	-	-	-	(0.0123)	-
High*post	-	-	-	0.0202**	-
	-	-	-	(0.00901)	-
Treat*villa*post	-	-	-	0.0381**	-
	-	-	-	(0.0178)	-
Treat*high*post	-	-	-	0.00983	-
	-	-	-	(0.0121)	-
Good*post	-	-	-	-	0.0369**
	-	-	-	-	(0.0185)
Treat*good*post	-	-	-	-	0.0709**
	-	-	-	-	(0.00901)
Time fixed effects	YES	YES	YES	YES	YES
r2	0.224	0.227	0.228	0.232	0.241
Wald chi^2	1007.8	1035.8	1062.4	1070.0	1010.7
N	30607	30607	30607	30607	30607

** $p<0.1$, ** $p<0.05$, *** $p<0.01$ (block bootstrap standard errors in parentheses)*