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Natural disasters as stress-tests for housing systems. Vulnerability and local resistance to the 2012 earthquake in Italy*

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Abstract. Earthquakes often occur in Italy: for built-up areas, they represent exogenous stress tests, acting as catalysts for long-term socio-economic processes and testing local resilience and resistance. This work considers damages to residential buildings after the 2012 earthquake in Emilia, at census tract level. First, cluster analysis points out which are the most vulnerable census tracts in the affected area, according to their socio-economic characteristics; second, quantitative data about reconstruction (released as open data) are adopted to compute a sensitivity index. It emerges that clusters with poorer socio-economic and building conditions have been damaged more than others.

JEL classification: O18, Q54

Key words: Natural disasters, vulnerability, geocoding, housing system

1 Introduction

Natural disasters represent exogenous shocks for the local communities they hit, exerting a deep and long-lasting pressure on them. In the short term, they cause mortality and a general loss of physical infrastructures (e.g., residential housing, roads, telecommunications); in the long term, they may lead to a significant reduction of economic growth and to major disruptions on social communities and on their relationships (Noy 2012; DuPont and Noy 2015). Thus, a large part of the economic literature now focuses on the issue of building safer and more resilient communities (UNISDR 2005, 2015) rather than on the relief effort in itself (Ainuddin et al. 2015).

To this respect, local resilience and vulnerability (UNISDR 2005, 2015) represent key policy concepts, despite the ambiguity that comes from the fact that different theoretical and methodological orientations occur (Martin 2012; Ainuddin et al. 2015; Martin and Sunley 2015).

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However, both concepts can be applied to the case of the earthquake that hit Emilia-Romagna (in Northern Italy) in 2012. That earthquake was characterized by two major events, with a maximum magnitude of 6.1 M_w and a death toll hitting 27. It has not been the most devastating ones in recent Italian history: both the 2009 L'Aquila earthquake (6.3 M_w) and the 2016 Norcia-Amatrice long series of earthquakes (6.6 M_w at a maximum) were more powerful than it, with a death toll of 309 and 299 people, respectively. However, the Emilia earthquake caused severe damage, in a wealthy and industrialized area. The affected area accounts for about 2 per cent of Italian GDP, with the presence of important industrial and agricultural districts, significantly contributing to exports (Banca d'Italia 2013; Barone et al. 2013). Moreover, it has experienced a special governance, combining public and private action (Brusco 1982). As far as seismic hazard is concerned, that region was not classified among the most seismic ones in Italy, thus preparation to earthquakes was not a priority of local and regional government authorities. Therefore, large damages occurred to both private and public buildings, industrial facilities, rural farms, offices and retail shops, historical and cultural heritage sites (Russo and Silvestri 2016).

Nevertheless, it would be misleading to consider the whole area as showing the same high level of vulnerability to the earthquake, hence of risks: in fact, damages were scattered throughout this area, with wide differences across buildings, even within a same block.

To this respect, social, demographic and structural weaknesses that affect both the architectural heritage and local communities play a role (Giovannetti et al. 2015) highlighting the importance of the community level when considering both vulnerability (and, more in general, preparation to disasters) and resilience (Barton 1969; Murphy 2007).

In particular, at a sub-municipality level, it is also possible to link together damages and place-specific structural and socio-economic weaknesses, which enhance vulnerability. In fact, vulnerability also depends on local-specific processes of socio-economic decay (Fuchs 2009; Cavallo and Noy 2011): for instance, an inadequate level of building maintenance could lead over decades to a reduction of houses quality levels. Accordingly, even local resilience is expected to vary across the same neighbourhood. Because of long-lasting socio-economic challenges (e.g., out-migration flows, ageing, surge of presence of foreigners, the economic crisis), the area affected by the earthquake has displaced from its initial equilibrium to a different one, with an alteration of overall long-term paths of growth (Georgescu-Rogen 1967; Martin 2012). As a result, when the earthquake occurred in 2012, some places were 'located' on a better position than others. Such a working hypothesis is tested here, by explicitly focusing on housing resistance.

From an empirical perspective, considering housing safety as the output of a socio-ecological system (Anderies et al. 2004) is interesting but challenging, as selection of indicators suffers from a lack of available data (Cutter et al. 2010; Ainuddin et al. 2015). Here, the amount of the registered damages to private buildings is adopted as a proxy for system's lack of resistance, although some possible biases may occur. Damage can be geocoded to get sub-municipality data. Among alternative sub-municipality territorial units, here census tracts (*sezioni di censimento*) are adopted, as they single out major differences at a tiny territorial scale, both in terms of vulnerability and resistance.

The rest of the paper is organized as follows. Section 2 provides the theoretical background for the analysis, commenting adopted concepts, with an overview of the effects of the Emilia-Romagna 2012 earthquake on damages to private buildings. Section 3 introduces the empirical part of this work (cluster analysis) discussing main results. Section 4 focuses on the distribution of damages. First, data are analysed at sub-municipality level. Then, cluster types are considered and a sensitivity index is provided, in order to assess resistance at cluster level. Section 5 focuses on main policy implications for the ongoing reconstruction process, while Section 6 concludes the work.

2 Theoretical background

2.1 Assessing the effects of a natural disaster: some evidences from the literature

As natural disasters often occur, a long strand of literature has been devoted to it. However, the literature on extreme events has largely evolved over time. As far as earthquakes are considered, before the middle 1970s, the problem of their effects was studied only from a geological and/or engineering perspective (White and Haas 1975; Kahn 2005; Juntunen 2006). Later scholars have singled out the fact that also social and economic vulnerability matters in affecting earthquake risk (Bolin and Stanford 1991; Blaikie et al. 1994; Cannon 1994; Mitchell 1998; Uitto 1998; Wisner 1998; Fothergill et al. 1999; Mileti 1999; Morrow 1999; Steinberg 2000; Cavallo and Noy 2011; Lim et al. 2017). According to this strand of literature, while 'the occurrence of a natural hazard could be considered exogenous, its transformation into a disaster is not' (Rodriquez-Oreggia et al. 2013, p. 442), as also endogenous social and political issues matter (Chubb 2002). Indeed, vulnerability is grounded on multiple disciplinary theories (Fuchs 2009).

However, although attention to this problem has increased over time, it seems to have been much more concerned with sociological rather than economic studies. As far as economics is concerned, the concepts of 'vulnerability' and 'resilience' have been stressed.

The 'Hyogo Framework for Action' (UNISDR 2005) defines vulnerability as the set of conditions that may increase the susceptibility of a community to the impact of hazards. Among others, physical, social, economic and environmental factors affect vulnerability, which eventually is a crucial dimension to develop plans for risk reduction (Pagliacci et al. 2017). Resilience is related to vulnerability, although it refers to the specific post-shock reaction of a system, in terms of ways of recovery (Martin 2012). Despite its popularity, the adoption of this concept poses both conceptual and methodological questions here. From a conceptual perspective, resilience is ambiguous (Markusen 1999), as at least three different interpretations of this concept co-exist: engineering resilience, ecological resilience and adaptive resilience (Martin 2012; Martin and Sunley 2015). In particular, and from a methodological perspective, resilience can only be assessed *ex post*, by taking into account medium-to-long time-series data, which involve the reconfiguration of the system.

Because of these issues, this work focuses on a more specific concept: the system's resistance to an exogenous shock. Within an engineering resilience perspective, resistance represents a proxy for resilience. It singles out the extent of coping with an exogenous shock (Martin 2012), although it says nothing on the speed of recovery after it. In particular, resistance is assessed here, by considering buildings damage, in relation to socio-economic *ex ante* vulnerability. As a matter of fact, a strong relationship between *ex ante* vulnerability and the amount of damages can be observed (Albala-Bertrand 1993): vulnerability, which depends on a wide range of community-level socio-economic variables, in addition to location, is a driver for defining local resistance (Blaikie et al. 1994; Lim et al. 2017).

2.2 Housing system's vulnerability and the damage caused by earthquakes

When considering the effects of the 2012 earthquake in Emilia, housing deserves specific attention. Compared to industrial facilities, which were quickly rebuilt after having been hardly hit, residential buildings reconstruction has been definitely slower, with heterogeneous outcomes, because of the existence of different paths of interventions and of non-homogenous levels of local resilience (and resistance). Earthquake damage was unevenly scattered, with perfectly usable houses standing up beside completely destroyed buildings.

However, earthquakes do not just produce random (hence, unpredictable) damage. As far as damage distribution is concerned, happenstances, driven by the unpredictable localization of epicentres and hypocentres and by the way of propagation of seismic waves, couple with other more predictable drivers that represent local vulnerability: (*i*) buildings' structural weaknesses; (*ii*) adoption of poor anti-seismic techniques[1]; and (*iii*) other socio-economic and demographic issues (e.g., population ageing, shrinkage and out-migration flows, ethnical segregation), which have delayed building ordinary maintenance and seismic improvement (Giovannetti et al. 2015). To this respect, the 2012 earthquake acted as an exogenous stress test for buildings, with three main building types that have failed to pass it:

1. Old buildings in the rural countryside, left empty and unimproved, because of the urbanization process, begun in the 1950s;
2. Buildings across city centres, dating back to the early 20th century (or before), being aggregated into disjoined blocks, after major structural alterations; and
3. Poor modern buildings, not following any anti-seismic legislation.

Moving from this concept of local vulnerability, within a given urban area, the safety and security of the housing system may represent an example of common good (Ostrom 1990), involving both material resources (buildings) and a codified system of relationships,[2] which assure system sustainability (and re-generation) over time (Ostrom 1990). The main idea behind this work is that a greater vulnerability, which reduces resistance, couples with decay processes. Decay is both structural (lack in ordinary and extra-ordinary maintenance) and socio-economic (because of ethnic segregation, spatial concentration of elderly people and other weaker social groups). Because of hysteresis, buildings keep memory of long-term processes of decay, affecting their vulnerability.[3]

2.3 Assessing resistance and sensitivity in the 2012 earthquake

In this work, the empirical assessment of resistance follows the methodology proposed by Martin (2012). Here, the ratio of damages per building at a sub-municipality level is considered to the respective ratio in the affected area as a whole, namely:

$$D_i = \beta_i D_t, \tag{1}$$

where $\mathrm{D_i}$ refers to damages per building in the *i*th census tract and D_t refers to damages per building in the overall affected area. From (1), it follows that:

$$\beta_i = \frac{D_i}{D_t}, \tag{2}$$

hence, β_i represents the 'sensitivity index' to the earthquake that allows a measurement of local resistance. In analogy to the suggestion by Martin (2012), an area with high 'sensitivity index' can be deemed less resistant to the natural disaster than a region with a lower index. Indeed, if $\beta_i > 1$, the *i*th census tract shows high sensitivity/low resistance, while the opposite holds true when $\beta_i < 1$.

Despite its mathematical plainness, territorially disaggregated data are needed to compute β_i. To this respect, two issues jointly occur: (*i*) properly defining the affected area and (*ii*) quantifying the local amount of damages. With regard to the former issue, this work focuses on the same set of municipalities that Pagliacci and Russo (2016) acknowledge as the most damaged ones (32 municipalities, with the exclusion of any NUTS 3 level capital cities – *capoluoghi*

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[1] According to Italian legislation, just in 2008, the affected area was included into a higher-seismic group. However, those buildings whose construction had followed proper anti-seismic regulations have not reported heavy damage.

[2] They regulate the way people use buildings and carry out essential maintenance (Anderies et al. 2004). Thus, also immaterial resources (e.g., public-private interactions and living together) play a role.

[3] Such a general condition tends to hinder also public interventions. Poor neighbourhoods are meant to be targets for large urban regeneration processes, but, because of their costs, they seldom occur. Conversely, most of small-scale urban-planning interventions are targeted to lively and growing neighbourhoods, able to attract private investment.

di provincia). Assessing the amount of damage at census tract level poses major problems. Nevertheless, the publication of detailed open data by Regione Emilia-Romagna allows it. In particular, full computerization of the management of both applications for grants and payments for repairing damaged dwellings using the MUDE (*Modello Unico Digitale per l'Edilizia* – Single Digital Form for Building). Such a technological innovation (Russo and Silvestri 2016) returns detailed information on the reconstruction process, disentangling each intervention on residential buildings. Available data (this work considers data up to February 2016) comprise 6,468 interventions funded, which account for €1,949 million of accepted costs and €1,778 million of grants.[4] Eligible funds cover reconstruction costs as well as seismic-related improvements and the energy efficiency enhancement. MUDE also includes additional information such as: address of the beneficiary and damage entity, as defined according to the AeDES (*Agibilità e Danno nell'Emergenza Sismica*) sheets. In this respect, each building is classified as: (A) usable[5]; (B) temporarily unusable, but usable after short-term countermeasures; (C) partially unusable; and (E) unusable. While levels B and C both refer to the least severe damages, level E (i.e., the most severe damages) has been disentangled into sub-types E_0, E_1, E_2 and E_3. In the latter case, demolition and rebuilding are allowed.

This works refers to MUDE information about accepted costs for the reconstruction, damage type and beneficiaries' addresses in order to assess local resistance.[6] By means of geocoding, addresses are turned into couples of geographical coordinates, being assigned to a census tract (geospatial data). This methodology points out both resistance to the earthquake and local vulnerability, linking damages to the presence of given socio-economic features.[7]

3 Describing the affected area at a sub-municipality level

3.1 Methodological issues

According to the Italian National Institute of Statistics (ISTAT), census tracts represent the basic units for collecting demographic and economic variables during census rounds. For the purpose of this work, there are two ways to describe the affected area at census tract level.

First, census tracts' types of locality are considered. According to ISTAT (2011a), four types occur: urban areas, small-inhabited areas, production/special sites, scattered sites. This classification disentangles urbanized city centres from the rural countryside, but is still too rough to analyse sub-municipality areas.

Thus, a richer characterization can be obtained, thanks to a wider set of socio-economic features. Here, the same methodology originally implemented by CAIRE[8] for the socio-economic analysis of

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[4] Data are available at the following website: http://trasparenza.regione.emilia-romagna.it/sovvenzioni-contributi-sussidi-vantaggi-economici/contributi-assegnati-comuni/contributi-patrimonio-privato.

[5] Even usable buildings might have suffered some kind of damages, but their repair is not necessary condition for using them.

[6] According to the funding mechanism, every building classified as unusable (AEDES sheets) is eligible for reconstruction funds. Thus, any owner can apply for funding and there are no reasons to hypothesize differences in behaviours between high-income owners and low-income owners. Moreover, any distinction between eligible and non-eligible costs is made at administrative level. Eligible costs cover all structural interventions to make damaged buildings usable and safe again; non-eligible costs include, for instances, high-quality dwellings' finishes. Given that, it is possible to take eligible costs as a proxy for buildings low resistance.

[7] Ranuzzini et al. (2015) have singled out the presence of illogical elements in the first release of MUDE open data (e.g. mistakes in data transcription and difficulties in merging accepted costs to grants and payments). Latest releases seem to have fixed most of them.

[8] CAIRE (*Cooperativa Architetti e Ingegneri Reggio Emilia*) is an Italian cooperative that has worked on the issues of territorial and urban planning, local development and urban design, for over 30 years.

the city of Reggio Emilia is adopted. In particular, CAIRE (2016) performed a cluster analysis on a list of variables available at census tract level, covering socio-demographic information about resident population, families, dwellings and buildings (CAIRE 2016). In this work, the same set of input variables have been adopted, but additional information on firms' local establishments and employees are considered, for a total number of 20 variables under consideration (Table 1). Data source is the latest census round, in 2011 (Istat 2011a, 2011b).

However, in this case, study, in order to return a more general classification, cluster analysis (CA) has been performed on a broader set of observations. Besides the census tracts in the 32

Table 1. List of variables for the CA

	Variable	Definition	Source
Population	Old Age people	Ratio of older dependents (people aged 65+) to the total population	15th Census Population Housing
	Young Age people	Ratio of younger dependents (persons under age 15) to the total population	
	Foreigners	Ratio of the foreign population to the total population	
	Single-person households	Ratio of the single-person households to the total number of households	
Education & jobs	Higher education	Ratio of the people with higher education attainment to the total population	15th Census Population Housing
	Unemployment rate	Unemployed persons (aged 15+) over the number of persons (aged 15+) in the labour force (%)	
	Commuters	People commuting out of their own municipality over total population	
Built-up areas & buildings	Residential buildings	Residential buildings over the number of total buildings	15th Census Population Housing
	Owned dwellings	Ratio of the families owning their own dwelling to the total number of families living in dwellings	
	Empty dwellings	Share of unoccupied dwellings over the total number of dwellings	
	Pre-1919 buildings	Buildings built before 1919 over the total number of buildings	
	1949–1960 buildings	Buildings built between 1949 and 1960 over the total number of buildings	
	Single-family detached homes	Share of single-family detached homes over the total number of buildings	
	High-rise buildings	Share of buildings with at least three storeys out of the total	
	Dwelling surface	Average dwelling area (in m^2)	
	Buildings' state of maintenance	Share of buildings in bad maintenance state over the total number of buildings	
	Density	Resident people per km^2 (computed on the area of each census tract)	
Employment	Employment (density)	Number of employees (all economic activities) per km^2	9th Census Industry Services
	Size of local establishments	Ratio of the number of employees (all economic activities) to the number of local establishments	
	Manufacturing	Ratio of the employees in manufacturing local establishments (Nace Rev.2) to the total number of employees	

Source: Authors' elaborations.

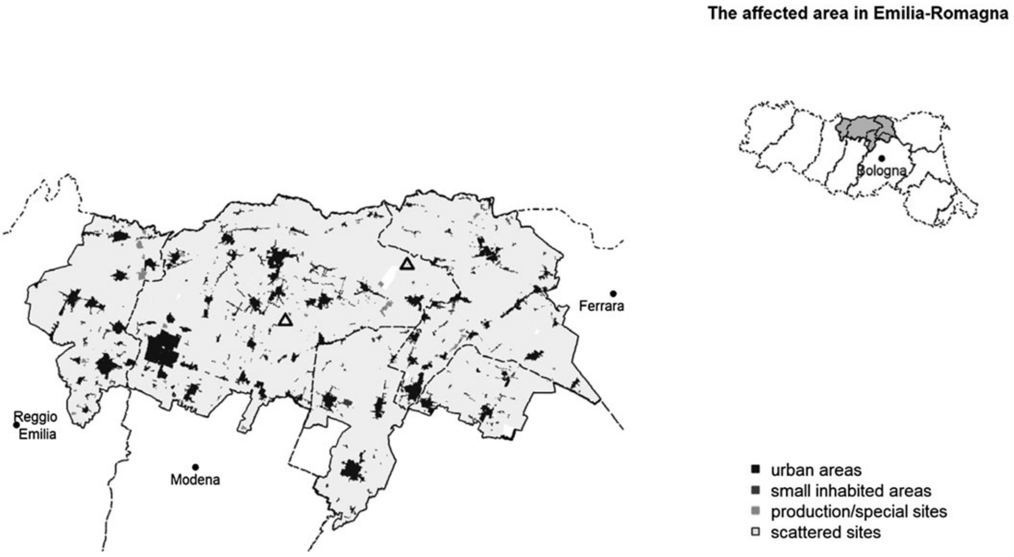

Fig. 1. The area affected by the 2012 earthquake: census tracts, by type
Notes: Triangles: two major epicentres of the 2012 earthquake. Dashed lines: NUTS 3 regions boundaries.
Source: Authors' elaborations on Istat (2011a) data.

most affected municipalities, this analysis also considers those belonging to the other municipalities located in the four NUTS 3 regions (*province*) affected by the 2012 earthquake (i.e., the provinces of Reggio Emilia, Modena, Bologna and Ferrara). Thus 20,658 census tracts are firstly considered.[9] A preliminary, data homogenization and data cleaning was needed. Because of the presence of missing values, non-complete observations have been dropped out from the analysis. Thus, for CA, just 19,795 census tracts are considered (they cover 10,602 hectares of land and host 2.5 million inhabitants). Within the boundaries of the most affected municipalities, just 2,912 census tracts are included into the analysis.

As far as CA methodology is concerned, the *hclust* algorithm in the R software (R Core Team 2015) is applied. Here, a hierarchical approach – which does not require a preliminary definition of the number of cluster to be extracted (Kaufman and Rousseeuw 1990) – is preferred, albeit the seminal work by CAIRE (2016) adopted a k-means clustering. In particular, this agglomerative approach uses a set of dissimilarities, according to the Euclidean distance: before computing them, variables have been standardized. The Ward minimum variance method has been adopted in order to compute distances between pairs of clusters (Ward 1963; Lance and Williams 1966).

3.2 Results: a general overview of the area under study

The 32 municipalities hit by the 2012 earthquake – in the Northern part of Emilia-Romagna – are largely rural (Figure 1). According to census tract types, scattered sites cover 90.7 per cent of the total area, although they represent 16 per cent of the total number of tracts and 10.4 per cent of total population. Conversely, urban areas just cover 8.2 per cent of the land area, hosting 86.8 per cent of the population (Table 2). Accordingly, the latter group shows the highest population density (2,400 people per square kilometre), while in scattered sites there are just 26 people per square kilometre.

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[9] In alternative, CA could have taken into account all census tracts in the region, but this hypothesis was discarded, to limit the computational (and interpretation) burden.

Table 2. The area under study by census tract type

	Urban areas	Small inhabited areas	Production/ special sites	Scattered sites	Total
Number of census tracts	2,126	282	36	468	2,912
Population	352,714	10,885	506	42,240	406,345
Land area (square km)	145.46	12.53	7.09	1601.51	1766.59

Note: Just census tracts with no missing values are considered.
Source: Authors' elaborations on ISTAT (2011) data.

Furthermore, CA returns nine different clusters. Table 3 shows clusters' features according to input variables (upper part) and the number of census tracts, total population and total area within each cluster (lower part). As CA has been performed on all census tracts within the four affected NUTS 3 regions as a whole, even labels refer to this wider area. Conversely, Figure 2 (as well as Figure 1) just focuses on the 32 most affected municipalities.[10] Accordingly, clusters are defined as follows:

High-density census tracts:

- historical sites (at the urban heart of the largest cities), with high population and employment density,[11] old buildings (built before 1919) and a large presence of foreigners and highly educated people;
- high-density tracts built between 1949 and 1960 (just outside historical city centres), with the highest population density but a lower employment density and with the largest proportion of high-rise buildings (86.5% of the total);
- urban neighbourhoods, with post-1960 high-rise buildings, with a low number of foreigners and a large number of families with more than one component.

Low-density census tracts:

- suburbs for commuting families, comprising just residential buildings, but with a medium-to-low population density (although being the most populous cluster) and a large presence of commuters' families (33.5% of the total);
- rural areas with detached houses (>6,000 census tracts, 1,880 of them classified as scattered sites, covering more than 4,830 km^2), characterized by detached houses (50% of the total) with a large average size of dwellings (> 120 m^2);
- areas facing socio-economic changes, with a concentration of foreigners (24.3% of the total population), poor socio-economic conditions (33% of buildings with bad maintenance conditions, and unemployment rate above 11%), and covering both urban census tracts and scattered sites;
- shrinking areas, mostly located across the mountains, with dramatic population ageing and out-migration flows (more than 60% of dwellings are empty);

Productive areas:

- areas with manufacturing activities, where residential buildings and manufacturing activities co-exist (about 1,000 employees per km^2, largely employed in manufacturing);
- areas providing services, with no resident population, but hosting a large number of employees, with no economic specialization in manufacturing.

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[10] In particular, the most affected municipalities cover a rural flatland, lacking any NUTS 3 level capital city. Carpi, with 70,000 inhabitants, is the largest city.

[11] Since the Middle Ages, European cities have gathered together people and economic activities (Bairoch 1988).

Table 3. Cluster profiles and their importance

Cluster Description	1 Historical sites	2 High-density tracts (1949–1960)	3 Urban neighbourhoods	4 Suburbs for commuting families	5 Areas with detached houses	6 Areas under socio-economic changes	7 Shrinking areas	8 Areas with manufacturing activities	9 Areas providing services
Old people	0.194	0.272	0.254	0.192	0.231	0.210	**0.325**	0.222	0.000
Young people	0.111	0.111	0.125	0.149	0.122	0.141	**0.061**	0.135	0.000
Foreigners	0.159	0.156	0.089	0.074	0.053	**0.243**	0.038	0.096	0.000
Single-person households	0.479	0.456	**0.351**	**0.288**	**0.292**	0.333	0.405	0.271	0.000
Higher education	**0.555**	0.466	0.472	0.399	0.395	0.358	0.288	0.353	0.000
Unemployment rate	0.061	0.065	0.051	0.044	0.040	**0.110**	0.023	0.045	0.000
Commuters	0.106	0.098	0.117	**0.335**	0.215	0.172	0.152	0.229	0.000
Residential buildings	0.800	0.825	0.861	**0.908**	**0.857**	0.783	0.862	**0.772**	0.000
Owned dwellings	0.474	0.620	0.715	0.768	0.752	0.577	0.719	0.727	0.000
Empty dwellings	0.256	0.107	0.114	0.112	0.198	0.230	**0.604**	0.215	0.000
Pre-1919 buildings	**0.684**	0.015	**0.038**	**0.060**	0.198	0.176	0.225	0.153	0.000
1949–1960 buildings	0.084	**0.711**	**0.124**	**0.071**	0.195	0.227	0.148	0.152	0.000
Single-family detached homes	0.118	0.082	0.147	0.207	**0.503**	0.385	0.544	0.470	0.000
High-rise buildings	**0.792**	**0.865**	**0.783**	**0.551**	0.262	0.436	0.401	0.311	0.000
Dwelling surface	94.108	86.115	102.044	101.899	**122.721**	104.819	95.478	119.610	0.000
Buildings' state of maintenance	0.087	0.040	0.035	0.062	0.121	**0.333**	**0.166**	0.141	0.000
Density	**11417.5**	**15319.3**	**8839.3**	4550.6	**1640.5**	3615.7	**673.6**	1190.8	0.0
Employment (density)	3894.8	2759.0	1484.2	689.4	408.7	1069.8	375.5	**920.7**	**1697.2**
Size of local establishments	12.365	2.099	2.168	2.091	1.982	2.832	1.736	**6.175**	**4.295**
Manufacturing	0.076	0.048	0.069	0.090	0.028	0.070	0.035	**0.662**	0.102
# census tracts	942	756	3635	2038	6110	1992	1603	1906	813
Population	105,526	137,694	604,927	672,017	498,257	184,811	74,650	251,836	0
Area (square km)	43.37	15.75	143.27	495.73	4831.50	939.22	1626.54	2271.18	235.21

Notes: The table considers all the census tracts that belong to the four NUTS 3 regions. In bold, characterizing values are highlighted.
Source: Authors' elaborations on ISTAT (2011a, 2011b) data.

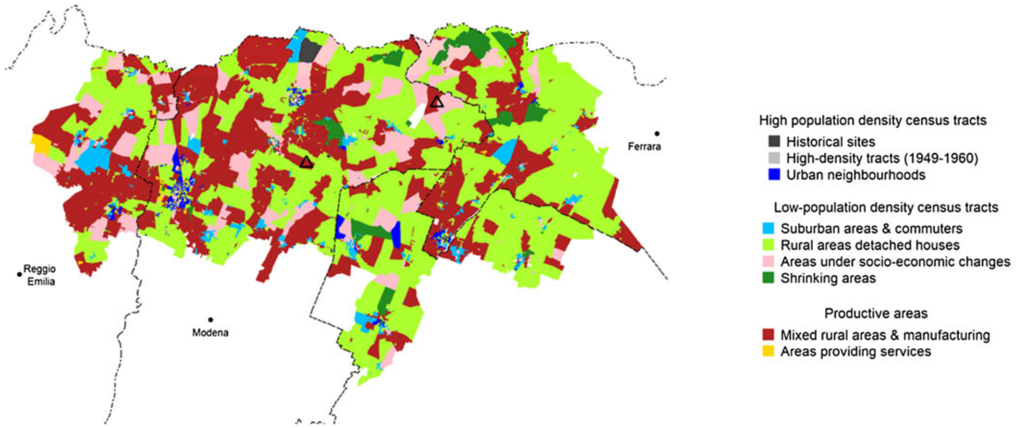

Fig. 2. The nine clusters in the most affected area
Notes: Triangles: two major epicentres of the 2012 earthquake. Dashed lines: NUTS 3 regions boundaries.
Source: Authors' elaborations on Istat (2011a, 2011b) data.

According to this classification, when considering buildings' structural features, low-population density clusters, together with areas with manufacturing activities, seem to share the poorest levels of building maintenance quality. They also share poorer economic conditions together with a large presence of foreigners, elderly and unemployed people. These features clearly suggest a greater vulnerability to earthquakes.

When just focusing on the 32 municipalities, CA output confirms the rural trait of this area. Clusters 4 to 7 account for about 60 per cent of the total number of census tracts, while areas with manufacturing activities account for an additional 18.5 per cent. By converse, most of population still lives in the cluster of suburbs for commuting families (Table 4).

Additional considerations refer to the heterogeneity of this area (Figure 2), as its westernmost portion tends to be more urbanized and industrialized than the easternmost one (Pagliacci and Russo 2016).

4 Estimating damages to assess local sensitivity

The aforementioned analysis has highlighted the structural features of the area affected by the 2012 earthquake. Moreover, this analysis sheds new light on the assessment and the understanding of local resistance. Here, buildings' sensitivity is a proxy for resistance: to this respect, this work considers the amount of damages, in terms of registered accepted cost for reconstruction (according to the open data, published by Regione Emilia-Romagna).

Referring to available data (up to February 2016), the 32 municipalities under study account for 5,800 out of 6,468 single interventions for repairing and reconstructing private buildings. Accepted costs equal to €1.77 billion out of 1.95 € billion, whereas total grants equal to €1.61 billion out of €1.78 billion.[12] These municipalities share severe damages (39.9% of interventions classified as extremely damaged) and a great number of buildings was classified as unusable (Table 5): these figures are larger than the ones assessed by Ranuzzini et al. (2015) on the overall set of municipalities.[13]

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[12] Data may partially differ from the ones published by other publications from Regione Emilia-Romagna.

[13] When explicitly referring to damage entity figures, some illogical elements may occur. For some beneficiaries, dataset provides this piece of information twice: in particular, the variable 'additional information' sometimes returns the damage type in a non-coherent way. Thus, under the idea that 'additional information' would represent a sort of updated information, 8 interventions have been switched from B/C to E_0 level, whereas 25 interventions have been switched from B/C to E_1, E_2 and E_3 levels.

Table 4. Importance of the clusters in the affected area

Cluster	Cluster name	No. census tracts		Population		Area	
		No.	%	Inhab.	%	Km2	%
1	Historical sites	79	2.71	9,868	2.43	7.71	0.44
2	High-density tracts, built in 1949–1960r	26	0.89	1,950	0.48	0.24	0.01
3	Urban neighbourhoods	453	15.56	60,375	14.86	18.59	1.05
4	Suburbs for commuting families	348	11.95	110,654	27.23	58.06	3.29
5	Rural areas with detached houses	1,000	34.34	95,521	23.51	832.56	47.13
6	Areas facing socio-economic changes	322	11.06	39,302	9.67	197.81	11.20
7	Shrinking areas	67	2.30	1,547	0.38	51.35	2.91
8	Areas with manufacturing activities	538	18.48	87,128	21.44	591.73	33.50
9	Areas providing services	79	2.71	0	0.00	8.52	0.48
Total in the affected area		2,912	100.00	406,345	100.00	1766.59	100.00

Source: Authors' elaborations.

Table 5. Damage and interventions in the 32 municipalities, by level of damage

	Total	B and C(light damages)	E_0(severe damages)	E_1, E_2, E_3(extremely severe damages)	Other
Number of interventions	5,800	2,892	587	2,316	5
Accepted costs – total in million €	1,769.22	326.32	184.73	1,257.28	0.89
Grants – total in million €	1,613.50	294.51	171.00	1,147.17	0.82
Accepted costs – per beneficiary in thousand €	305.04	112.84	314.70	542.87	177.42
Grants – per beneficiary in thousand €	278.19	101.84	291.31	495.32	163.95

Source: Authors' elaborations.

Overall data are disaggregated at census tract level, thanks to information provided as open data about beneficiary addresses. Single interventions have been geocoded through the software QGIS and its plug-in MMQGIS (QGIS Development Team 2016). After having converted addresses into couples of geographical coordinates, geospatial data are obtained by superimposing census tract boundaries onto the set of couples of coordinates. Thus, the outcome comprises number of interventions, accepted costs and grants, by considering damage levels: each piece of information refers to one single census tract.

Geocoding is not a trivial process: errors or misspellings often occur. In this study, 142 observations (2.4% of the total) were not automatically geocoded because of address misspellings, while 407 additional observations, although being properly processed, were geocoded beyond municipality boundaries.[14] Hence, location of these interventions was manually changed. Then, additional controls were performed randomly: as a result, 10 per cent of miscoded addresses were manually assigned to their most appropriate census tract.[15]

Then, by summing up geospatial data about interventions at census tract level, it emerges that just 39.7 per cent of census tracts have reported at least one reconstruction intervention. At a disaggregated level, results are even more scattered. When considering types of locality (Table 6, upper part), the largest part of damages refers to urban areas (66% of the total). Nevertheless, scattered sites are proved to be much less resistant: with a population of just 10.4 per cent of the total, they account for 29 per cent of damages. Cluster analysis returns similar findings

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[14] Geocoding was performed municipality by municipality, in order to check for errors.

[15] The authors are aware that a negligible share of observations could be still assigned to the wrong census tract.

(Table 6, lower part). Two clusters (rural areas with detached houses and areas with manufacturing activities) account for about 30 per cent of damages each. In both cases, this share is larger than the respective share of population. Furthermore, even those areas facing socio-economic changes have been severely hit (14.4% of total damages and less than 10% of population). Conversely, urban neighbourhoods and suburbs for commuting families have been definitely less affected.

Table 6 also returns statistics about alternative indicators of damage intensity. Indeed, raw data (i.e., total number of interventions, or total amount of damages) change according to the large variability in width of census tracts: on average, urban tracts are 6.84 hectare (with 166 people, each), while scattered sites are 342.20 hectare (with 90 people, each). Thus, damages per intervention, per hectare of land area, per inhabitant and per building are more reliable. On average, the largest damages per affected hectare occur across more urbanized areas (historical and high-density tracts), while they are smaller across shrinking and productive areas. When considering damages per inhabitant, shrinking areas are the most affected ones (more than €20,000 of accepted costs per inhabitant), together with those areas under socio-economic changes and areas with detached houses. Conversely, high-density tracts show a lower amount of damages per inhabitant.

Although each indicator provides insightful information about damage distribution, they lead to inconclusive results. Rather, the most reliable indicator to assess local resistance seems to be the one that returns the amount of damages per building. Referring to types of locality, scattered sites show larger damages per building (€40,000/building) than urban areas (€18,450/building), with the largest damage affecting buildings across shrinking areas, areas under socio-economic changes and historical city centres. These findings confirm that those census tracts with a poor quality of maintenance (higher vulnerability) have been hit harder by the 2012 earthquake (Table 6).

Figure 3 strengthens this idea from a spatial perspective. The largest damage intensity occurs in the area that is the closest to the epicentre. However, other socio-economic elements play a role, when considering the differences at a sub-municipality scale. Figure 3 also shows the city of Mirandola (i.e., one of the mostly damaged ones). Damage is higher in the historical city centre (the circular area, in the central part of the picture), than in other semi-peripheral tracts, including modern neighbourhoods. Lastly, damage per building becomes once again higher in the town's rural countryside (Figure 3).

Thus, quality of buildings is part of local vulnerability, influencing resilience (as proxied by local resistance). While differences are small when considering types of locality, they get sharper at cluster level. Light damage (i.e., B and C level interventions) characterizes the vast majority of high-density census tracts. Conversely, in low-density tracts, where quality of buildings has been proved to be lower, a larger number of interventions refer to extremely severe damage (E_1, E_2, and E_3). For instance, extremely severe damage represents more than 40 per cent of interventions across clusters 5, 6 and 8 (Table 6).

Moving from this descriptive picture, resistance to the earthquake is properly assessed through the sensitivity index β_i, as described in (2) and considering the amount of damages per building.

According to Table 7, there is considerable variation in sensitivity to the earthquake across different sub-municipalities areas. As far as types of localities are concerned, sensitivity is much larger across production sites and scattered sites (i.e., non-urban areas). Among the nine clusters, sensitivity is the largest (low resistance) across shrinking areas, areas facing socio-economic changes and historical sites. Although each of these clusters show specific features, they all share high vulnerability to the earthquake, because of an ongoing process of socio-economic decay, affecting buildings' maintenance.

A slightly different pattern affects rural areas with detached houses and manufacturing areas. Both clusters actually account for a large share of total damages, although their sensitivity index is 1.08 and 1.09 respectively. This means their resistance is close to the average resistance of the whole area. Conversely, the lowest sensitivity to the earthquake (well below the average)

Table 6. Number of interventions and damages, by type of locality and by cluster type

	Population	Total costs (damage)						Damage type: no. of interventions (%)			
Territorial area	%	000€	%	000 € per intervention	000 € per hectare	000 € per inhab.	000 € per building	B and C (light damages)	E_0 (severe damages)	E_1, E_2, E_3 (extremely severe damages)	Other
Type of locality											
Urban areas	86.80	1,163,461.18	65.76	319.72	79.98	3.30	18.45	54.5	11.5	33.9	0.1
Small inhabited areas	2.68	85,226.38	4.82	274.92	68.01	7.83	27.73	42.3	6.1	51.6	0.0
Production/ special sites	0.12	6,181.62	0.35	247.26	8.72	12.22	51.95	44.0	16.0	36.0	4.0
Scattered sites	10.40	514,347.54	29.07	281.68	3.21	12.18	40.92	41.9	7.9	50.1	0.0
Cluster											
1 Historical sites	2.43	52,638.92	2.98	290.82	68.25	5.33	28.25	69.1	11.0	19.9	0.0
2 High-density tracts, built 1949–1960	0.48	1,494.71	0.08	373.68	62.98	0.77	6.58	75.0	0.0	25.0	0.0
3 Urban neighbourhoods	14.86	78,982.64	4.46	349.48	42.48	1.31	10.86	69.0	11.1	19.9	0.0
4 Suburbs for commuting families	27.23	231,818.63	13.10	321.08	39.93	2.09	14.92	51.2	13.4	35.3	0.0
5 Areas with detached houses	23.51	595,748.82	33.67	306.30	7.16	6.24	24.18	47.9	8.9	43.0	0.1
6 Areas facing socio-economic changes	9.67	255,187.13	14.42	333.14	12.90	6.49	34.80	53.7	11.6	34.6	0.1
7 Shrinking areas	0.38	31,400.33	1.77	365.12	6.11	20.30	46.59	44.2	8.1	47.7	0.0
8 Areas with manuf. Activities	21.44	519,701.16	29.37	278.81	8.78	5.96	24.45	45.8	9.4	44.7	0.1
9 Areas providing services	0.00	2,244.40	0.13	374.07	2.63	NA	NA	50.0	0.0	50.0	0.0
Total in the 32 affected municipalities	100.00	1,769,216.73	100.00	305.04	10.01	4.35	22.44	49.9	10.1	39.9	0.1

Source: Authors' elaborations.

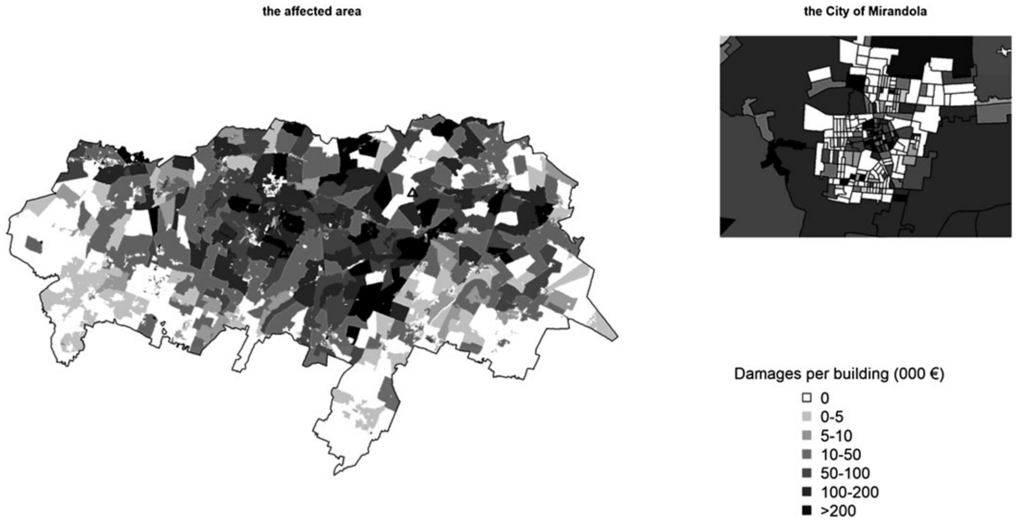

Fig. 3. Damages (000€) per building, by census tract: an overview on the whole area and a focus on the city centre of Mirandola
Source: Authors' elaborations on Regione Emilia-Romagna open data.

Table 7. Sensitivity index to the earthquake

Territorial area		Sensitivity Index - βci
Type of locality		
Urban areas		0.82
Small inhabited areas		1.24
Production/ special sites		2.31
Scattered sites		1.82
Cluster		
1	Historical sites	1.26
2	High-density tracts, built 1949–1960	0.29
3	Urban neighbourhoods	0.48
4	Suburbs for commuting families	0.66
5	Areas with detached houses	1.08
6	Areas facing socio-economic changes	1.55
7	Shrinking areas	2.08
8	Areas with manuf. Activities	1.09
9	Areas providing services	NA

Note: Data refer to 2,912 census tracts, across the 32 affected municipalities.
Source: Authors' elaborations.

characterizes suburbs for commuting families, urban neighbourhoods and high-density tracts, built in 1949–1960.

Lastly, data disentangled at the census tract level confirm the same result. Table 8 returns Pearson correlation coefficients between sensitivity index and the previous set of CA input variables, computed at census tract level. A positive and significant correlation occurs between β_i and foreigners, dwellings left empty, buildings built before 1919, average dwellings' surface and buildings in bad state of maintenance. Even employment density is positively correlated to earthquake sensitivity. Conversely, a negative and significant correlation occurs between β_i and young people, owned dwellings, high-rise buildings and population density.

Table 8. Correlation coefficients

	Pearson Correlation coefficients	*p*-value
Old Age people	0.021	0.260
Young Age people	–0.053*	0.005
Foreigners	0.067*	0.000
Single-person households	–0.032	0.092
Higher education	–0.025	0.183
Unemployment rate	0.004	0.837
Commuters	–0.021	0.270
Residential buildings	–0.021	0.260
Owned dwellings	–0.075*	0.000
Empty dwellings	0.095*	0.000
Pre-1919 buildings	0.097*	0.000
1949–1960 buildings	0.024	0.208
Single-family detached homes	0.010	0.583
High-rise buildings	–0.046*	0.015
Dwelling surface	0.101*	0.000
Buildings' state of maintenance	0.091*	0.000
Density	–0.091*	0.000
Employment (density)	0.048*	0.011
Size of local establishments	–0.012	0.526
Manufacturing	–0.002	0.904

Notes: Data refer to 2,912 census tracts, across the 32 affected municipalities. Tracts with missing values have been excluded. *Statistically significant at 5%.
Source: Authors' elaborations.

5 Policy implications

Assessing resistance of local communities to earthquakes (and linking it to local vulnerability) represents a key policy issue, which is particularly important to manage natural hazard risk and to reduce losses and material damages (Fuchs 2009). Actually, a low level of resilience (resistance) is also expected to affect the recovery phase (Kahn 2005). This is the reason why the 'Building Back Better' principle (UNISDR 2015) now devotes a greater importance to building safer and more resilient communities (Ainuddin et al. 2015). In Italy, this has become even more important under the light of the latest devastating series of 2016 earthquakes in Central Italy. With regard to the 2012 Emilia-Romagna earthquake, the hypothesis that earthquakes explicitly represent exogenous stress tests for buildings' level of maintenance is validated.

The empirical analysis performed here confirms the inverse relationship between local vulnerability and resistance (Fuchs 2009), even with regards to earthquakes, and the fact that the lack of maintenance couples with external socio-economic weakness (e.g., population ageing, spatial concentration of foreigners and unemployed persons). Thus, not only specific processes of local decay emerge as geographically bounded; geography also drives distribution of damages to residential buildings and then the overall reconstruction (and the recovery) process.

The sensitivity index, built on the amount of damages per building, suggests that some groups of census tracts are less resistant to earthquakes: shrinking areas (suffering from depopulation processes and empty houses; areas under socio-economic changes and historical sites (sharing poor levels of building maintenance); rural areas with old detached houses.

Within such a territorial analysis, policy implications are important, especially with regard to the role of institutions (Kahn 2005) in the framework of the reconstruction process, which five years later is still under its way. Such a process has been acknowledged as a best practice, in the national context. Local, regional and national authorities have taken effective measures to manage both the emergency and the recovery phases. Major priorities were the minimization of the period of temporary housing for population and a quick restarting of economic (industrial) activities and social life. Thus, local and national authorities quickly supported both firms' facilities and school rebuilding (schooling was acknowledged as a key element for social cohesion as, if children can go to school, their parents can go to work). Moreover, additional national plans (such as the 'Casa Italia' Plan, approved in 2016) will aim to foster the 'Building back better' principle, reducing local vulnerability, even in the area already affected by the 2012 earthquake (Pagliacci et al. 2017).

Both the recovery process and the Plan 'Casa Italia' income are expected to cause redistribution effects (favouring some owners more than others), but the most important target of all these interventions should be restoring the overall public safety of buildings. As stressed by Boyce (2000, p. 4): 'Vulnerability […] is to a large extent a public bad: such disasters typically strike communities, not isolated individuals. By the same token, measures to reduce vulnerability are to a large extent public goods'. Therefore, policy interventions should not only orientate individual behaviours. They should tackle the relationships among places and people, at a community-level. In particular, the ultimate goal of prevention policies should be enhancing common goods (i.e., the safety and security of the housing system, which have to be considered on the same terms as the public health), through the construction of public and club goods, which eventually gives new market values to all private goods.

When these principles are not followed, the reconstruction process itself may suffer from some specific criticalities, which have emerged also in the Emilia case. Giovannetti et al. (2015) stressed the following elements, among others:

- the lack of shared urban management laws, which were just implemented at municipality level;
- more-than-necessary atomized reconstruction process (produced by *laissez-faire* policies and heavy fragmentation of the real estate market); and
- lack of highly-skilled practitioners and large construction firms, whose presence would have been crucial for implementing more comprehensive interventions, across historical city centres.

These criticalities could delay the reconstruction (and the recovery) process, especially in the historical city centres that still concentrate large and costly interventions. This situation asks for an even stronger intervention from policymakers in the reconstruction of the public and common goods. To do that, the reconstruction process requires a different (i.e., larger) unit of analysis (hence, of intervention). Other works have already stressed the importance of a meso-unit of analysis, at territorial level. They converge in emphasizing how economic resilience is closely linked to a single community's social cohesion, stressing the importance of social and natural capital. Conversely, when such an attention is lost (for the breaking of the community's equilibria: extension of markets, migrations, economic decline) the geography of vulnerability (which amplifies risks) couples with the geography of local decay.

These policy implications go well beyond the boundaries of the Emilia-Romagna case study. First, same hypothesis could be tested across different geographical areas and under different earthquakes (e.g., the 2016 Central Italy earthquake). Second, a wider and more detailed mapping of the socio-economic conditions of built-up areas across Italy could single out the most vulnerable portions across cities or rural places. Actually, it is important to highlight those census tracts that deserve preliminary attention in order to reduce their vulnerability to future events. Because of budget constraints, when planning a large national recovery and seismic improvement plan, such as the 'Casa Italia' Plan, any intervention should just start from the most vulnerable areas. However, when considering community level, intervention to the most vulnerable areas would lead to a win-win solution, as in the case of the quick restoration of industrial facilities.

6 Conclusions

This study has considered the resistance of residential buildings to the 2012 earthquake in Emilia-Romagna, highlighting the existing relationships with local vulnerability features. As a major novelty, the paper considers census tracts as territorial units for the analysis. Firstly, a comprehensive and detailed analysis of the area affected by the earthquake is returned, by considering both types of locality and the outcome of a cluster analysis, grounded on 20 different variables. Second, earthquake damages are taken into account and through addresses geocoding, any intervention has been linked to the specific census tract it belongs to. Results confirm the idea that the most vulnerable tracts (because of socio-economic features) are among the least resistant ones (Fuchs 2009; Cavallo and Noy 2011).

Moving from this analysis, future works will update both the available set of data (including latest grants, approved in 2017) and the adopted methodology. In particular, through specific econometric techniques, it will be possible to model the extent to which marginal gains in specific socio-economic drivers at census tract level may improve building resilience. However, a broader set of information is needed to properly model these effects: most of them are also of a spatial nature (e.g., the spatial distribution of central and peripheral areas within each municipality, the real network of road communication systems). This is the reason why additional investigations to return a real model are needed. As stressed by Cavallo and Noy (2011), properly understanding the channels of causality will support both more informed ex-post policymaking and *ex ante* preparation and mitigation policies.

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Resumen. Los terremotos son un fenómeno que sucede a menudo en Italia y, para las áreas urbanizadas, representan un test exógeno de estrés, además de servir como catalizadores de los procesos socioeconómicos a largo plazo y de poner a prueba la resiliencia y la resistencia locales. Este trabajo examinó los daños a edificios residenciales después del terremoto de 2012 en Emilia, a nivel de distrito censal. Primero, el análisis de conglomerados señala cuáles son los distritos censales más vulnerables dentro del área afectada, de acuerdo con sus características socioeconómicas; segundo, se emplean datos cuantitativos sobre la reconstrucción (publicados como datos abiertos) para calcular un índice de sensibilidad. Los resultados muestran que los conglomerados con peores condiciones socioeconómicas y peor construcción fueron dañados más que otros.

抄録: 地震は、イタリアでは頻繁に起きているが、密集市街地においては外因性ストレステストとしての役割があり、長期的な社会経済的プロセスに大きな変化をもたらすものとして機能し、地域のレジリエンスと耐久性を試すものである。本稿では、2012年のエミリア地方における、地震による居住用建築物の被害を国勢統計区レベルで検討する。まず、クラスター分析を行い、その地区の社会経済的特性により、最も脆弱な国勢統計区を見極める。次に、復興に関する量的データ(オープンデータとして公表されている)を用いて感度指標を求める。結果から、社会経済的条件と建築的条件が劣るクラスターではその他のクラスターよりも被害が大きいことが示される。