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NATURAL DISASTERS AS A STRESS-TEST FOR A SOCIO-ECOLOGICAL SYSTEM. ASSESSING RESILIENCE THROUGH THE DISTRIBUTION OF DAMAGES TO RESIDENTIAL BUILDINGS

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ABSTRACT

Natural disasters – but earthquakes in particular – occur quite often in Italy. With regard to built-up areas, they can be considered as exogenous stress tests: they act as a catalyst for socio-economic processes, lasting for longer time-spans. Eventually, they single out specific social, demographic and structural weaknesses that usually affect part of the architectural heritage of a given area. Indeed, some areas have experienced an ongoing reduction in the levels of their resilience, when referring to housing as a common good, according to a social-ecological system framework. In particular, this work focuses on the 2012 earthquake in Emilia, whose reconstruction process is still underway. In general terms, that process has been particularly effective, although some pitfalls and bottlenecks have affected private buildings' reconstruction. We mostly refer to damages to private buildings and their territorial distribution: the latter follows clear urban-decline geography. To this respect, the earthquake could have just anticipated the outcomes of longer term socio-economic processes. To test this hypothesis, data at census tract level have been retrieved. Firstly, a cluster analysis has been performed to point out the main features of the affected area, and its weakest portions. Secondly, data on each specific reconstruction intervention (released as open data by the regional government) have been grouped by census tract: this allows us to return robust results about the entity of damages at a very local level. The analysis confirms that those tracts showing poorer socio-economic conditions actually experienced more severe damages.

Keywords: natural disaster, resilience, housing

JEL Classification codes: O18, Q58

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1. Introduction

In May 2012, two major earthquakes hit Northern Italy and in particular Emilia-Romagna. The affected area is characterized by the presence of important industrial and agricultural districts, generating more than 1% of Italian GDP. A large part of it just comprises small municipalities, which are characterised by good practices of local governance, internationally renowned. By converse, larger cities (e.g., cities with more than 100,000 inhabitants) just occur on the edge of the affected area (Pagliacci and Russo, 2016).

Material damages have been severe: private and public buildings, factories, farms, offices and retail shops, historical and cultural heritage sites have all been damaged. Given the peculiar features of the affected area, both the recovery and the reconstruction of local economic systems (the latter being still underway) have been unique, involving agents and local stakeholders, acting at different levels (Pagliacci and Russo, 2016). To this respect, analysing the reconstruction of private and residential buildings is particularly insightful, but before any analysis on the reconstruction process and its evolution over time, a proper recognition of damages is necessary to better comprehend existing weaknesses that occur at local level.

Indeed, earthquakes may act locally as exogenous shocks. They produce dramatic challenges, but they can also provide unprecedented opportunities (e.g., new strategic decisions, taken by economic and political agents; newly available financial resources; coordination or lack of coordination among stakeholders...). Housing is obviously affected. Here, we consider this sector as a common good (Anderies *et al.*, 2004; Ostrom, 1990), as it represents a system of relationships that regulate the way people use both material (e.g., private buildings and other material public infrastructures) and immaterial resources (e.g., the living together in urban areas). Such a system of relationships is also intended to assure its own sustainability (and re-generation over time). Within this theoretical framework, the earthquake acts as a catalyst, prompting and anticipating the outcomes related to longer historical processes (Giovannetti *et al.*, 2015).

By assuming that, analysing both the way buildings have been hit and the overall distribution of damages may help in pointing out a specific geography of local decline. Damages may be expected to be greater where some given socio-economic characteristics occur: a larger presence of ancient buildings (built at the beginning of the 20th century or before), lack of building maintenance, according to latest earthquake regulations, the effects of the economic crisis (e.g. an above-the-average share of poor people or unemployed ones). More in general, the overall degree of socio-economic resilience of a given area is expected to play a role. A lower extent of local resilience may also affect the reconstruction process that follows a natural disaster, in terms of either temporal delays or lower quality of the final outcome. Again, the analysis of local decline processes may suggest which locations could experience additional difficulties, during the reconstruction phase. In particular, all these characteristics actually affect the decision-making process and the way the local reconstruction process is expected to be organised.

This paper mostly aims to validate the aforementioned hypotheses. Hence, the paper begins with a socio-economic analysis of the area affected by the earthquake. In particular, a cluster analysis is performed: it is crucial to point out those major weaknesses that may occur at local level. Although being a rather standard analysis, this analysis shows some major innovations: actually, it returns a detailed picture, as it is based on data at sub-municipality level (census tract). The aim of this analysis is to single out the existence of specific portions of the area affected by the earthquake which are characterised, for instance, by poor socio-economic conditions or by a degradation of the urban fabric. Obviously, such an analysis performed at municipality level would not be as insightful as the one performed at census tract level.

Eventually, the existence of the aforementioned weaknesses (that may result in a lack of local resilience, thus widening the effects of an exogenous natural disaster) is tested, by focusing on the amount of damages to private buildings in the area affected by the 2012 earthquake. Thanks to an electronic process for managing the reconstruction process (i.e. the digital infrastructure ‘Mude’), detailed information have been published as open data by Regione Emilia-Romagna. In particular, each intervention can be linked to a given census tract, hence to some specific socio-economic characteristics of the territory, on a disaggregated level. Eventually, from the joint analysis of both elements, insightful policy recommendations for the overall reconstruction process are returned and discussed.

The rest of the paper is organised as follows. Section 2 provides both an overview of the damages to the private buildings in the affected areas and a brief description of the reconstruction process: four years after the earthquake, some major pitfalls and economic bottlenecks in the reconstruction process can be enhanced. Section 3 provides a detailed description of those municipalities being largely affected by the 2012 earthquake. In particular, a cluster analysis is performed, according to a multidimensional perspective. As already stressed, the most innovative aspect of this analysis refers to the fact that data at sub-municipality level (i.e., census tract level) have been considered. Cluster analysis' major results are returned and discussed. Section 4 focuses on damages: the amount of damages is analysed by taking into account different cluster typologies, in order to highlight major divides occurring at sub-municipality level. Eventually, section 5 concludes the work, suggesting some insightful policy implications for the ongoing reconstruction process.

2. The reconstruction process: Data and major assumptions

2.1 Material damages to residential buildings

The 2012 earthquake hit a vast wide area across Northern Italy. Its epicentres were both located in Emilia-Romagna, whose municipalities accounted for most of the damages. Broadest definitions of the affected area refer to 58 municipalities, which are home for about 1.5 million inhabitants and which represent one of the country's most productive areas (about 1% of Italian GDP, with a significant contribution to exports) (Banca d'Italia, 2013; Barone *et al.*, 2013; Russo and Silvestri, 2016). Moreover, the area has been the object of study, because of the presence of important - industrial and agricultural – districts, its governance and a special balance between public and private action: the so-called "Emilia model" (Brusco, 1982).

Although the cost of the earthquake in terms of human life has been enormous, also material damages have been extremely severe. They refer to private buildings (around 31,000 homes were left uninhabitable), public ones (such as historical and cultural buildings, buildings for health and social services) as well as to commercial and industrial structures, the reconstruction of which is a necessary condition for ensuring the recovery of economic and social activities (Russo and Silvestri, 2016).

In this paper, we mostly focus on housing, as no reliable data are available for damages on those buildings related to economic activities yet[3]. When focusing on residential buildings, a detailed analysis on damages is not easy task, given the co-existence of different issues. Firstly, when studying the effects of an earthquake, definition of the affected area represents a preliminary – but challenging – task. It is not trivial to detect its boundaries, although policymakers have tried to strictly define them, in order to implement policies and to define beneficiaries to be admitted to funding schemes (Pagliacci and Russo, 2016). Existing classifications just refer to municipality level[4]: given the purpose of this work, we have decided to refer to the classification provided by the Decree Law (D.L.) no. 74 of 6 June 2012. It singles out just 33 municipalities as the most affected municipalities. Actually, although funds for the reconstruction have been assigned to beneficiaries in about 60 municipalities across Emilia-Romagna, the list of 32 municipalities refers to the closest ones to the epicentres. Nevertheless, from that narrower set of municipalities, we have also excluded the city of Ferrara: indeed, it is the only NUTS 3 level capital city in that list. Hence, it shows major socio-economic differences, compared to the other municipalities. Accordingly, in this work we refer to a set of 32 municipalities.

Secondly, assessing the proper amount of damages is even more difficult (Ranuzzini *et al.*, 2015; Reverberi and Russo, 2015). This is true, although data on the reconstruction of public buildings have been published as open data by Regione Emilia-Romagna. Publication of data has been possible thanks to the fact that, after the 2012 earthquake, both management of applications and payment of grants for repairing damaged dwellings have been fully computerised. MUDE (*Modello Unico Digitale per l'Edilizia* - Single Digital Form for Building) is the computer platform used for this purpose (Russo and Silvestri, 2016). Nevertheless, despite such a major innovation, Ranuzzini *et al.* (2015) have already pointed out some illogical elements that seem

[3] We are aware that housing just represents part of the story: rebuilding economic activities and their facilities is a key part of the recovery process after a natural disaster.
[4] To this respect, Piazzi *et al.* (2015) provide a wide analysis on the alternative classifications of the affected area.

characterising open data publication by means of the MUDE platform: among other issues, they point out the presence of mistakes in data transcription and other major difficulties in merging data about accepted costs, grants and payments.

Nevertheless, most of the aforementioned issues have been partially tackled. In their latest release, open data update figures up to February 2016. To that date, 6,468 interventions have been funded in the municipalities under study here. Total accepted costs amount to 1,949 million €, whereas the amount of grants is equal to 1,778 million €. The funds widely cover the costs of reconstruction: they also support seismic-related improvements as well as the enhancement of energy efficiency. Furthermore, a large set of additional information for each single grant has been published as well. Both the place of the intervention (i.e. the address of the beneficiary) and the typology of damage are available as open data. Those pieces of information allow us to analyse in greater detail the effects of the earthquake at census tract level. To this respect, definitions of the level of damages deserve proper explanation. Damages are defined according to the AeDES (*Agibilità e Danno nell'Emergenza Sismica*) sheets, which classify each building as:

- Usable[5] (A);
- Temporarily unusable (totally or partially), but usable after short term countermeasures (B);
- Partially unusable (C);
- Unusable (E)

Although levels B and C refer to least severe damages, unusable buildings have been eventually disentangled in further typologies (E_0, E_1, E_2, E_3) according to the entity of observable damages: in the latter case, both demolition and rebuilding are allowed.

Clearly, both the amount of the accepted costs for the reconstruction and damages' typologies represent useful information to assess the level each census tract has been damages, hence its capacity to cope with an earthquake.

2.2 The "unpredictable" of earthquake's damages: hypothesis for an alternative explication

Assessing the amount of damages at census tract level represents a useful effort. Synthetic and aggregated data can only suggest the overall entity of the disaster. Nevertheless, damages are unevenly scattered throughout the affected area: for instance, perfectly usable houses usually stand up beside completely destroyed buildings. Thus, a more local analysis may help in detecting specific patterns in the distribution of damages as well as in identifying socio-economic drivers that might have produced observed effects.

In particular, despite apparent randomness, some local stakeholders, interviewed in 2015, have suggested the existence of possible drivers in damages' spatial distribution[6]. Each of the following drivers appears to be particularly critical (Giovannetti *et al.*, 2015):

- Buildings' structural weaknesses and the adoption of poor anti-seismic techniques. Moreover, it has to be recalled that just in 2008 the affected area was included into a higher-seismic area, according to the Italian legislation;
- Socio-economic and demographic issues, such as the ageing of local population, out-migration flows from historical city centres, ethnical segregation. In most cases, these features have led to major delays in buildings maintenance and in seismic improvement;
- Other happenstances (elements and/or conditions) that could not had been predicted in advance.

[5] It can be noticed that even usable buildings might have suffered some kind of damages. Nevertheless, their repair is not a necessary condition for the usage of the whole building.
[6] Interviews have taken place, within the "Energie Sisma Emilia" project. Information is available at the website:http://www.energie.unimore.it.

The idea earthquakes produce random (and unpredictable) damages sounds reasonable, but it would be misleading to consider it as a major justification of observed damages. Rather, this work just aims to point out that happenstances play a minor role. Indeed, the earthquake has represented an exogenous stress test for each building standing in the affected area. In fact, those buildings, whose construction had followed proper anti-seismic regulations, have not been severely damaged. Hence, the hypothesis of happenstances playing a major role does not hold. On the opposite side, socio-economic weakness may undermine local resilience. In particular, a more comprehensive and long-lasting process of local depletion had occurred in the area affected by the earthquake, well before 2012. Indeed, three typologies of buildings seem to have particularly suffered from such a stress test:

1. Buildings in the rural countryside, most of them being ancient and left empty and unimproved, because of the dramatic urbanisation process, which has taken place since the 1950s;
2. Buildings in the city centres, whose construction dates back to the beginning of the 20th century, or before, being aggregated into not coherent blocks or having experienced structural interventions that had altered their own structural characteristics;
3. Modern buildings (both residential ones and factories/production facilities), being characterised by poor building choices and not following anti-seismic legislation.

Moving from these observed regularities, this works just aims to test the following hypothesis: far from being completely unpredictable, earthquake's damages can actually represent the outcome of a longer term socio-economic process of local depletion. As a natural event, earthquakes are unpredictable: it is not possible to forecast the localisation of epicentres and hypocentres or the way of propagation of the seismic waves. All these elements may either amplify or reduce earthquakes' effect, randomly. Nevertheless, other characteristics of the affected area are not analogously unpredictable: socio-economic features of a given place as well as buildings' structures partially influence the amount of damages and their distribution. These features are somehow predictable, as they mostly stem from broader social processes, such as housing, living together, public-private interactions, in order to manage both public and private space (Ostrom, 1990). Thus, we can expect that the damages produced by the 2012 earthquake as well as those produced by other natural disasters in the past cannot represent a mere happenstance. Rather, earthquakes hit cities and buildings, according to given patterns: heavy damages usually couple with degradation processes that have occurred over time. Degradation can be both structural (involving, for instance, a lack in ordinary and extra-ordinary maintenance) and socio-economic (e.g. the one produced by ethnic segregation, spatial concentration of elderly people and other weak social groups). Buildings and infrastructures keep memory of such a long-term depletion process. Hence, it is possible to observe partial overlapping between the spatial distribution of damages and socio-economic criticalities (Giovannetti *et al.*, 2015), the latter playing a role in setting the final outcome of a natural disaster.

To some extent, earthquakes act as a trigger for those processes (Giovannetti *et al.*, 2015), making socio-economic weaknesses clear. More in general, living together has an effect on housing, in terms of the quality of public and private buildings and their level of maintenance. Moreover, both these elements represent a proxy for the quality of life in urban areas, meant as a socio-ecological process whose resilience may be endangered under some circumstances (Ostrom, 1990; Anderies *et al.*, 2004).

But such a broad theoretical framework allows us to enrich general analyses on earthquakes and their effects. Indeed, it may also drive the analysis of the emergency phase and the recovery one. If we claim the existence of a relationship between local socio-economic characteristics and a natural disaster, we can easily notice that even the latter may dramatically change the former: local industries (e.g. the construction industry) may change; local practitioners (e.g. engineers, architects and urban planners) may adopt new urban planning tools; policy-makers' activity dramatically evolves. Thus, even the reconstruction process after a natural disaster is expected to be influenced by the joint relationship among all these features. To this respect, the reconstruction of damaged city centres represents an interesting case study, which can be compared across different experiences (Giovannetti *et al.*, 2015).

2.3 Bottlenecks in the reconstruction process

Furthermore, damages' analysis sheds new light on the reconstruction process, following the earthquake. So far, the reconstruction process after the 2012 earthquake has been usually acknowledged as representing a case of best practice in terms of building recovery. Four years later, the reconstruction process is underway, no critical constraints being posed on available budget. Despite undoubted successes, which mostly refer to industrial facilities and their machineries, some critical issues may be stressed as well. Some stakeholders, being interviewed last year, have underlined issues that could challenge, at least in perspective, the reconstruction process. Firstly, they observe a lack of shared urban and land management laws: urban plans are implemented by municipalities, thus they differ even among neighbouring ones. Secondly, the reconstruction process has been more than necessary segmented. The combination of both *laissez-faire* policy and the fragmentation of the real estate market across the affected municipality have atomised construction sites. Lastly, the affected area shows some additional weaknesses, in terms of number of highly-skilled practitioners, whose presence would have been crucial for the implementation of more comprehensive interventions (especially in historical city centres), and in terms of construction industry, which had been suffering from the effects of the economic crisis since 2008. All these issues confirm the hypothesis of a reduced level of local resilience, which has contributed to further difficulties and delays in the re-building process. For instance, defining some common guidelines in the rebuilding of the city centres or sharing some best practices would have surely helped. Nevertheless, any analysis on reconstruction and its major issues should move from a proper analysis of local damages. Thus, this work will largely contribute to this purpose.

3. The characteristics of the affected area: A cluster analysis by census tract

3.1 Cluster analysis: Methodological issues

Distribution of damages throughout the affected area cannot be properly assessed at municipality level. In fact, it does not provide enough disaggregation. Rather, the latest General Census round (Istat, 2011a; 2011b) may help in more properly analysing the area affected by the 2012 earthquake: for the first time, many variables have been disaggregated up to the census tract level. In particular, the 15th General Census of Population and Housing (Istat, 2011a) returns socio-demographic information about resident population, families, dwellings and buildings. Moreover, the 9th General Census of Industry and Services (Istat, 2011b) returns information on local units and number of employees, by economic sectors. Reference year is 2011, namely the year before the earthquake. Thus, an updated picture about the affected area can be drawn. When moving from the municipality level to the census tract level, the amount of available information largely increases, making the picture of the built-up area affected by the earthquake much more accurate. With regard to Emilia-Romagna, its 348 municipalities comprise 38,603 census tracts (110.93 census tracts per municipality, on average). Given the large amount of available information, some statistical techniques have to be implemented in order to analyse the relevant dimensions of the problem. Here, a conventional Cluster Analysis (CA) has been performed, here. Among alternative multivariate statistical techniques, CA makes possible a classification of all the observations in mutually exclusive groups, based on similarities according to the set of original variables (Tryon, 1939; Johnson, 1967; Kaufman and Rousseeuw, 1990).

Given the problem under study, hierarchical approach is preferred. Although there are no objectively right clustering algorithms, a hierarchical CA does not require any *ex ante* definition of the number of clusters to be selected, which in fact cannot be known in advance. Moreover, such an approach shows additional qualities: it handles outliers properly and it returns a dendrogram as its final output (Kaufman and Rousseeuw, 1990). Nevertheless, major issues have to be tackled. We have already discussed about the existence of alternative definitions of the affected area. In this work, we focus on the set of 32 municipalities as suggested by Pagliacci and Russo (2016). Nevertheless, we decided to perform cluster analysis on a larger area: thus, we have included all the census tracts belonging to the four affected NUTS 3 regions (i.e., the provinces of Reggio Emilia,

Modena, Bologna and Ferrara). Thus, a more robust classification is returned at census tract level: indeed, total number of census tracts under study is equal to 20,658[7].

Before performing CA, data cleaning and data homogenisation have been performed, as both data sources refer to slightly different census tracts sets. The Census of Population and Housing (Istat, 2011a) refers to those tracts that host people and/or residential buildings (namely 37,013 census tracts in Emilia-Romagna); by converse, the Census of Industry and Services (Istat, 2011b) focuses on census tracts hosting local units and their employees (just 29,732 census tracts in Emilia-Romagna). Thus, when merging both datasets, we have assigned a value that equals to zero if a given variables is not reported for a given census tract. Table 1 returns the set of variables adopted as inputs for the CA. Data selection has been mostly driven by a previous analysis performed by CAIRE (2016) focusing on the city of Reggio Emilia, with a few minor improvements. We added number of younger people and some indicators on employment in local units. Hence, final set comprises 20 variables across four thematic areas (population; education/jobs; built-up areas/buildings; employment).

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 and 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 and jobs	Higher education	Ratio of the people with higher education attainment to the total population	15th Census Population and Housing
	Unemployment rate	Unemployed persons (aged 15+) over the number of persons (aged 15+) in the labour force (%)	
	Commuters	Ratio of the people commuting out of their own municipality to the total population	
Built-up areas and buildings	Residential buildings	Residential buildings over the number of total buildings	15th Census Population and 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	Share of buildings built before 1919 over the total number of buildings	
	1949-1960 buildings	Share of 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 and Services
	Size of local units	Ratio of the number of employees (all economic activities) to the number of local units	
	Manufacturing	Ratio of the employees in manufacturing local units (Nace Rev.2) to the total number of employees	

Source: authors' elaborations

CA has been performed by means of the *hclust* algorithm in the R software (R Core Team, 2015). It is an agglomerative approach, which uses a set of dissimilarities for the *n* objects being clustered (here, computed

[7] Pagliacci and Russo (2016) have performed a cluster analysis on the area affected by the 2012 earthquake. They aim to identify a counterfactual sample of municipalities, hence they focus on administrative boundaries, including all municipalities in Emilia-Romagna. Here, we just analyse four affected provinces, to reduce the computational burden of such an analysis at census tract level.

according to the Euclidean distance). Before computing dissimilarities, variables have been standardised. Eventually, the *Ward's* minimum variance method has been adopted in computing distances between pairs of groups (or clusters): it aims to find compact and spherical clusters (Lance and Williams, 1966; Ward, 1963).

Because of the presence of missing values across the dataset, we have decided to drop out non-complete observations: accordingly, just 19,795 observations have been included into the analysis.

3.2 Results: A general overview of the area under study

Figure 1 returns the dendrogram, which shows overall clustering structure. The dendrogram can be eventually truncated to select a specific number of disentangled clusters. A trade-off occurs: if selecting just a few clusters, they will comprise too many observations and they will be characterised by large within-cluster heterogeneity. On the opposite case, clusters will be homogeneous, although being not too much representative of the sample under study. Given this trade-off, we have truncated the dendrogram at the height of 1100, disentangling 9 different clusters[8].

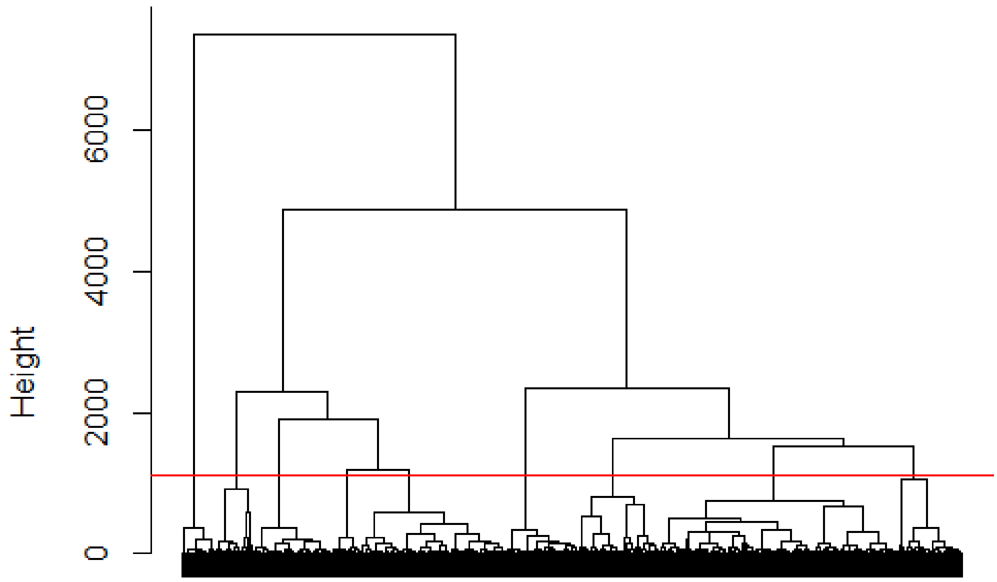
Table 2 provides a description of each cluster's features, according to the input variables. Furthermore, in the lower part of the table the number of census tracts that occur within each typology as well as total population and total area are returned. Eventually, the spatial distribution of each cluster is shown in Figure 2. The black thick line in the figure shows the borders of the affected area (32 municipalities).

Moving from the joint analysis of clusters' average profile and their spatial distribution across the area under study here, we can label them, providing an in-depth analysis. In particular, nine returned clusters seem belonging to three major (and more comprehensive) groups of clusters:

- High-population density census tracts:
  1. Historical sites (942 observations): census tracts within this cluster mostly occur across urban city centres. They are characterised by a large presence high-rise buildings (i.e., buildings with three storeys or more), built before 1919. Both foreigners and highly educated people are over-represented in this cluster (15.9% and 55.5%, respectively). Lying at the heart of major cities, these census tracts share large values for both population density and employment density: indeed, across Europe, cities have always seen large concentration of both people and activities, since the Middle Ages (Bairoch, 1988; Acemoglu *et al*., 2005);
  2. High-density tracts, built in 1949-1960 (756 obs.): these census tracts lie just outside historical city centres, being characterised by the highest levels of population density and the largest share of buildings with three storeys or more (86.5% of the total). Compared to cluster 1, these census tracts show much more residential traits: employment is definitely less here than in city centres;
  3. Urban neighbourhoods (3,635 obs.): this cluster mostly includes cities' modern neighbourhoods, built after 1960. Within these tracts, the share of foreigners is definitely low, whereas the share of families with more than one component out of the total is larger. Despite these differences, high-rise buildings characterise also these census tracts. Furthermore, it can be noticed that this cluster is much more populated than the previous ones: indeed, it hosts more than 600,000 inhabitants;

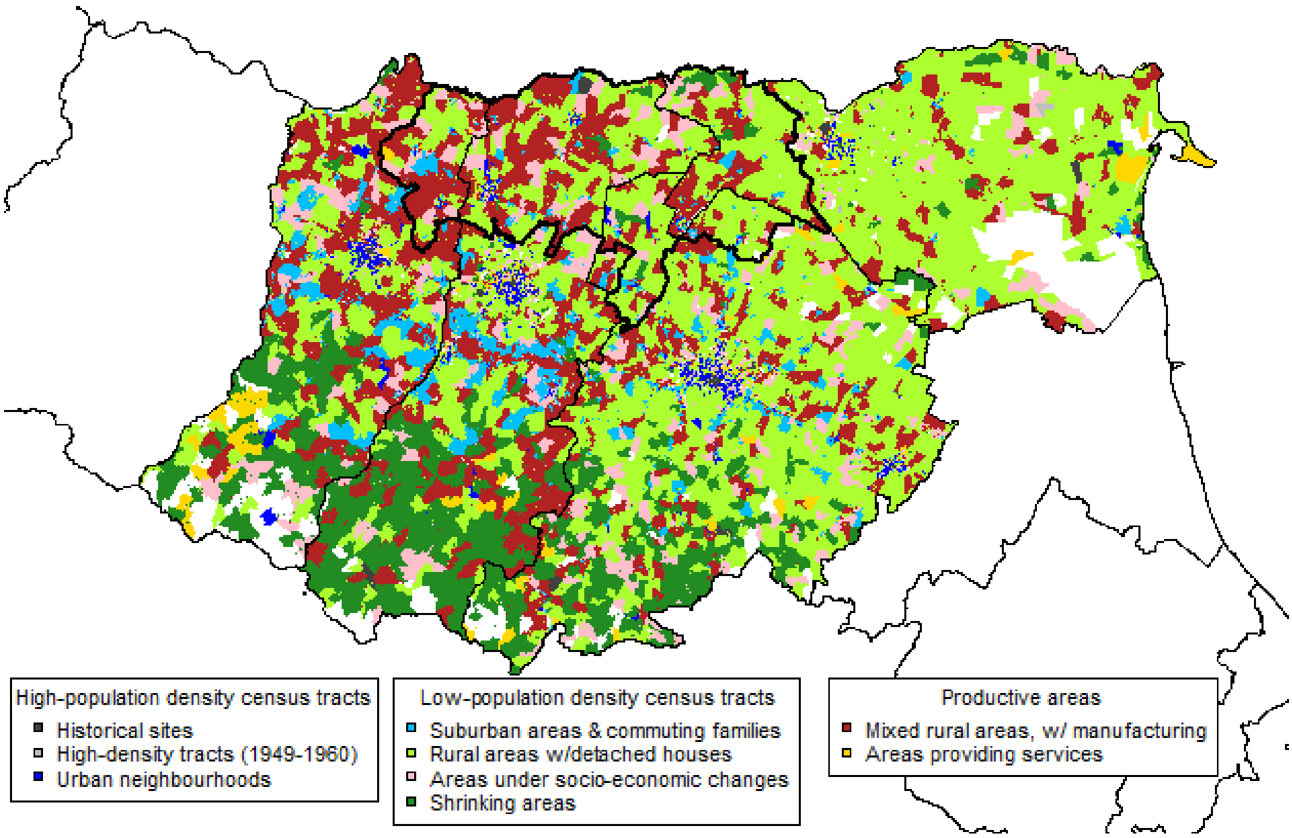
[8] A classification into 10 clusters would not have really improved the analysis. It would have just split into two the group of production areas.

Figure 1 –The dendrogram



Source: authors' elaborations

Figure 2 –Spatial distribution of the 9 clusters, in both affected and non affected municipalities (four NUTS 3 regions are considered)



Source: authors' elaborations

Table 2 - Defining typologies: cluster centres (in bold characterising values) and size in terms of number of census tracts, population, total area

Cluster	1	2	3	4	5	6	7	8	9
Description	Historical sites	High-density tracts, built in 1949-1960r	Urban neighbourhoods	Sub-urban areas for commuting families	Rural areas with detached houses	Areas facing socio-economic changes	Shrinking areas	Mixed rural areas, with manufacturing activities	Areas providing services
Old Age people	0.194	0.272	0.254	0.192	0.231	0.210	**0.325**	0.222	0.000
Young Age 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 units	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	43.37	15.75	143.27	495.73	4831.50	939.22	1626.54	2271.18	235.21

Source: authors' elaborations

- Low-population density census tracts:
    4. Sub-urban areas for commuting families (2,038 obs.): this cluster shows a lower population density, despite the presence of high-rise buildings (mostly built after 1960). It is a sub-urban cluster, where residential buildings represent 90.8% of the total and families are mostly composed by commuters (33.5% out of the total). Moreover, even the share of single-person households is quite low. In terms of total population, this cluster is the most populous one, hosting about 670,000 inhabitants;
    5. Rural areas with detached houses (6,110 obs.): this cluster covers the largest share of the land area under study here (4,830 km^2). It mostly refers to rural areas, where detached houses represent the peculiar typology of building (50% of total buildings). As a consequence, average size of dwellings is the largest one, amongst those observed across the nine clusters (122.72 m^2). Referring to socio-demographic features, the presence of foreigners is definitely low in this cluster (5% of total population) and unemployment rate is quite low (4%);
    6. Areas facing socio-economic changes (1,992 obs.): this group of census tracts shows some peculiar socio-economic features. Firstly, it is characterised by a large share of foreigners (24.3% of the total population). Secondly, it shows poor economic performance, with an average unemployment rate

above 11%. Moreover, even buildings' conditions are poor: 33% of buildings shows bad maintenance conditions. Being cluster's average density quite close to the total average (3,615 inhabitants per km^2), both urban and rural census tracts seem to co-exist within this typology.

7. Shrinking areas (1,603 obs.): they mostly cover the mountainous part of the area under study, where population ageing and out-migration flows are key policy issues (population aged 64+ is 32% of the total). Furthermore, empty dwellings are more than 60% of the total. These figures suggest ongoing shrinking trends, which affect buildings maintenance as well;

- Productive areas:
  8. Mixed rural areas, with manufacturing activities (1,906 obs.): this cluster is characterised by the co-existence of both residential buildings (77% of total buildings) and manufacturing activities. Indeed, this cluster, which is mostly rural – according to a low population density, on average – hosts about 1,000 employees per km^2: furthermore, about two thirds of them are employed in manufacturing;
  9. Areas providing services (813 obs.): this cluster comprises those census tracts where no resident population lives, but where a large presence of employees is hosted. No specialisation in manufacturing is actually observed in those tracts: actually, they rather host enterprises that provide both B2B services and services to local population.

Aforementioned description refers to the overall set of 19,795 census tracts under analysis. Given the aim of this work, we can now have a closer look to the area affected by the earthquake. In particular, here we focus on 32 municipalities, which represent the area most affected by the 2012 earthquake. Costs for the reconstruction have been accepted by a wider set of 60 municipalities within the region. Nevertheless, here we follow a previous work from Pagliacci and Russo (2016), which has already provided a general description of the area affected by the earthquake by focusing on the 32-set of municipalities. In particular, authors have stressed the existence of an East-West divide, across the affected area. Divides refer to both urban-rural features and economic specialisations. Moreover, the affected area lacks any NUTS 3 capital city: population in the largest municipality (the city of Carpi) is below 100,000 inhabitants (Pagliacci and Russo, 2016).

Despite peculiarities, each cluster is represented within the affected area, although each of them shows a different relevance (Table 3). As expected, low-population-density census tracts represent a vast majority of the affected area. In particular, rural areas with detached houses account for about 34% of the total number of census tracts. Even mixed rural areas, where manufacturing activities take place, are well-represented (18.5% of the total tracts). By converse, population is mostly concentrated in cluster 4: sub-urban areas for commuting families host 27% of total population. Furthermore, even the analysis at census tract level confirms the aforementioned East-West divide: mixed rural areas, with manufacturing activities mostly occur in the Western part, whereas rural areas with detached house mostly cover the Eastern portion of the area.

Table 3 – Importance of nine 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	Sub-urban areas 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	Mixed rural 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

4. Estimating damages and evaluating the rebuilding process

The cluster analysis discussed in section 3 does not only improve our knowledge about structural features across this portion of the Emilia-Romagna region (to our best knowledge, no similar analyses focusing on such wide area exist). In fact, it also helps us in analysing the distribution of damages produced by the earthquake in 2012. As already mentioned, most severe effects were reported just throughout those 32 municipalities. Regione Emilia-Romagna provides information about accepted cost and grants, given to each single beneficiary as open data on its official website. Data refer to all the grants that have been provided up to February 29th, 2016[9]. According to this dataset, aforementioned municipalities account for 5,800 single interventions for repairing and reconstructing private buildings out of 6,468 total interventions. Accepted costs are equal to 1.77 billion € (out of 1.95 billion €), whereas the total amount of grants is equal to 1.61 billion € out of 1.78 billion €[10]. These figures largely confirm the fact that 90% of damages concentrate within the 32 municipalities we are focusing on. Furthermore, having been mostly affected by the earthquake, these municipalities are also experiencing major difficulties in the reconstruction process. Firstly, in those municipalities, a larger portion of both private and public buildings have been affected. Secondly, the share of severe damages is expected to be larger: in fact, a larger presence of unusable buildings (namely those classified as level E_0 and as level E_1, E_2 and E_3) is expected to occur.

Nevertheless, any specific analysis that would take into account location and typology of damages has to face major issues in the process of open data publication (Ranuzzini *et al.*, 2015). As an example, the online dataset provides twice information about the damage level for some beneficiaries. Indeed, additional variable, labelled "additional information", is populated with it. Often, both pieces of information do not match. Here, we made the following hypothesis: "additional information" represents some kind of updated information. Thus, we have considered 8 interventions as E_0 levels rather than as B and C levels; moreover, we have considered 25 interventions as E_1, E_2 and E_3 levels rather than as B and C levels. Accordingly, within the most affected 32 municipalities, 2,925 out of 5,800 interventions are classified as light damages (B and C levels), whereas 2,035 interventions are classified as extremely severe damages (E_1, E_2, E_3). In particular, share of extremely severe damages (i.e., 39.5% of the total) is greater than the same share measured by Ranuzzini *et al.* (2015) on the overall set of municipalities, and according to a previous round of published data. In addition, we can notice a large variability in the entity of the damages as proxied by both the accepted costs and the grants (Table 4).

Table 4 – Damages in the most affected 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

Moving from aggregated data, the main aim of this work is to define the amounts of damages at a more disaggregated level, namely the census tract level. Hence, we have made large use of information about beneficiaries and their addresses, as provided by Regione Emilia-Romagna as open data. Software QGIS – a cross-platform free and open-source desktop geographic information system (GIS) – has been used for

[9] Data are available at the following website: http://trasparenza.regione.emilia-romagna.it/sovvenzioni-contributi-sussidi-vantaggi-economici/contributi-assegnati-comuni/contributi-patrimonio-privato (last access: June 13th, 2016).
[10] Data may partially differ from those published on the Regione Emilia-Romagna website, because of differences in data collection and publication.

geocoding (QGIS Development Team, 2016). A specific plug-in (MMQGIS) makes possible the geocoding of objects from any street address: in particular, beneficiaries' addresses have been transformed into couples of geographical coordinates. Eventually, geospatial data referring to each administrative unit have been obtained by superimposing the census tracts boundaries onto the set of couples of geographical coordinates. The outcome is represented by a set of information (number of interventions, accepted costs and grants, disentangled by damage level) that refers to each single census tract.

Nevertheless, geocoding is not a trivial process: in fact, errors or misspellings may occur within the set of addresses. Here, it was not possible to automatically geocode about 150 observations (i.e., 2.6% of the total). Moreover, 173 observations, although being processed, have been approximated by the geographical centre of the municipality they belong to (being QGIS not able to properly identify their address). Last but not least, about 300 observations (approximately 5% of the total) were geocoded beyond municipality boundaries[11]. In all these cases, we had to manually check for specific errors, by assigning each of the miscoded addresses to its most appropriate census tract. Nevertheless, additional random controls were also performed, just to check for other cases of improper assignations[12].

Eventually, geospatial data have been analysed at census tract level. In particular, we have summed up following information: number of interventions; amount of damages (accepted costs); amount of grants. Moreover, we have disentangled each of these indicators by level of damage (level B and C; level E_0; level E_1, E_2, E_3). Furthermore, we also return some measures for damages' intensity. In particular, we have computed both the amount of damages per hectare and the amount damages per inhabitant. Lastly, even, the amount of damages per each intervention has been returned as well.

According to these indicators, distribution of damages is analysed in the light of the cluster analysis performed in Section 3. Indeed, we expect each cluster has experienced a different level of damages. Table 5 returns overall results by cluster typology. Most of damages have occurred within rural areas with detached houses (32.8%) and in mixed rural areas, with manufacturing activities (29.9%). These results confirm that buildings in rural areas have been amongst the most damaged ones. This finding is confirmed even when comparing the share of damages to the share of resident population. In both clusters, the former is larger than the latter (23.5% and 21.4%, respectively). Furthermore, even areas facing socio-economic changes have been particularly damaged (14.5% of damages, when they just account for less than 10% of total population). On the opposite, across urban neighbourhoods and sub-urban areas for commuting families the share of damages has been below the share of resident populationTable 5.

Indicators about the intensity of damages returns a partially different picture. The greatest damages per single intervention occur across urban neighbourhoods and shrinking areas. By converse, the lowest values occur in the high density tracts built in years 1949-1960. When observing damages per affected hectare, damages are large in the most urbanised areas (e.g. historical sites, high-density tracts...) while they are rather small in the shrinking areas and in the areas providing services (as expected, because of a few numbers of residential buildings). Nevertheless, those census tracts facing socio-economic changes, although they show a low population density, are characterised by a greater amount of damages (i.e., 12.94 € per hectare). Lastly, when considering damages per resident inhabitants, shrinking areas are the most damaged ones (20,000€ of accepted costs per inhabitant). They are followed by those areas facing socio-economic changes (6,500€ per inhabitant) and the rural areas with detached housed (6,000€ per inhabitant). Conversely, urban neighbourhoods and other high-density tracts, built in the latest decades, show a lower amount of damages per inhabitant (Table 5).

[11] We have checked for these errors, by geocoding interventions' addresses separately by municipality.

[12] The authors are aware that still some observations could be eventually assigned to a wrong census tract (e.g., when observations are assigned to the opposite side of the street). Nevertheless, those typologies of errors may represent a negligible share of the total, not affecting overall results.

Table 5 – Damages, by cluster typology

Cluster	Total costs					Population
	000 €	*%*	*000 € per intervention*	*000 € per ha.*	*000 € per inhab.*	*%*
1 Historical sites	49,685.02	2.81	290.56	64.42	5.03	2.43
2 High-density tracts, built in 1949-1960	1,544.64	0.09	257.44	65.09	0.79	0.48
3 Urban neighbourhoods	81,253.89	4.59	367.66	43.70	1.35	14.86
4 Sub-urban areas for commuting families	239,027.92	13.51	317.86	41.17	2.16	27.23
5 Rural areas with detached houses	579,729.08	32.77	303.05	6.96	6.07	23.51
6 Areas facing socio-economic changes	256,059.98	14.47	333.41	12.94	6.52	9.67
7 Shrinking areas	31,744.40	1.79	387.13	6.18	20.52	0.38
8 Mixed rural areas, with manuf. activities	528,523.14	29.87	280.98	8.93	6.07	21.44
9 Areas providing services	1,648.66	0.09	274.78	1.94	NA	0.00
Total in the 32 affected municipalities	1,769,216.73	100.00	305.04	10.01	4.35	100.00

Source: authors' elaborations

Although providing insightful information about the links between the effects of the earthquake and the characteristics of the built-up areas, such a distribution of the accepted costs per cluster typology may be also affected by the damage level. As discussed, light damages and extremely severe damages show a very different amount of accepted costs. Table 6 returns the share of each typology of damage level out of the total. Light damages characterise the vast majority of interventions in the historical sites and in the high-density tracts built in years 1949-1960. Nevertheless, light damages show a lower share in both the shrinking areas and the mixed rural areas with manufacturing activities. By converse, these areas share the largest amount of extremely severe damages (about 50% of the total) (Table 6).

Table 6 – Damages, by level and by cluster typology

Cluster	Level of the damage (%)			
	B and C (light damages)	*E_0 (severe damages)*	*E_1, E_2, E_3 (extremely severe damages)*	*Other*
1 Historical sites	70.18	11.70	18.13	0.00
2 High-density tracts, built in 1949-1960	83.33	0.00	16.67	0.00
3 Urban neighbourhoods	66.06	12.22	21.72	0.00
4 Sub-urban areas for commuting families	52.66	12.50	34.84	0.00
5 Rural areas with detached houses	48.56	9.25	42.08	0.10
6 Areas facing socio-economic changes	52.60	11.33	35.94	0.13
7 Shrinking areas	41.46	8.54	50.00	0.00
8 Mixed rural areas, with manuf. activities	45.40	9.25	45.24	0.11
9 Areas providing services	66.67	16.67	16.67	0.00
Total in the 32 affected municipalities	49.86	10.12	39.93	0.09

Source: authors' elaborations

Nevertheless, the distribution of the accepted costs by damage level is even more unbalanced. Actually, Figure 3 returns the average value of the accepted costs by jointly considering cluster classification and the level of damages. As expected, average cost per interventions rises as the level of damages rises. Nevertheless, a couple of exception occurs. In shrinking areas, interventions aimed at restoring light damages are more costly

than those aimed at restoring extremely severe damages: this might suggest the fact that some more valuable dwellings have been just lightly damaged within this cluster. Nevertheless, the highest costs per single intervention occur in historical sites and in the high-density tracts, built in years 1949-1960 (Figure 3a). Accepted costs per hectare follow the aforementioned pattern, declining when moving from high-population density tracts to lower-density ones (Figure 3b**Errore. L'origine riferimento non è stata trovata.**). Eventually, when considering accepted costs per inhabitant (Figure 3c), a slightly different picture emerges. Indeed, shrinking areas represent the most heavily affected cluster, in terms of both light damages and extremely severe ones. Moreover, mixed rural areas with manufacturing activities and the areas facing socio-economic changes are particularly affected, if considering extremely severe damages as well. To this respect, historical sites damages seem to show a total amount of damages that is close to the average.

Figure 3 –Accepted costs, by cluster and level of damage

a) costs per intervention

b) costs per hectare

c) costs per inhabitant

Source: authors' elaborations

5. Conclusions

This work has tried to quantify effects coming from a natural disaster, such as an earthquake, on a built-up area, according to the main hypothesis that it may represent a sort of exogenous stress tests for housing. To this respect, the 2012 Emilia earthquake and the damages to residential buildings have been considered as a case study. Results seem to validate such a theoretical hypothesis.

Firstly, the affected area has been carefully analysed, by retrieving data available at the census tract level. Such an analysis has improved any previous analysis of the characteristics of the affected area. Indeed, through a cluster analysis, we have been able to disentangle high-population density tracts (such as historical sites and other urban neighbourhoods) and low-population density tracts (rural areas). Nine different clusters have been returned.

Secondly, such a taxonomy has been adopted to analyse the distribution of the accepted costs for buildings reconstruction. In particular, number of interventions, accepted costs and grants, per typology of damages (as they are reported as open data) have been geocoded and assigned to each census tract. The picture that emerges is particularly insightful. Not all cluster typologies have been hit with the same intensity. For instance, when comparing the share of damages with the share of resident population, earthquake effects have been larger on historical sites, rural areas with detached houses, areas facing socio-economic changes, shrinking areas and mixed rural areas, with manufacturing activities. Moreover, the same clusters also comprise the largest part of extremely damaged buildings and dwellings. This means the both urban city centres, where most of socio-economic changes tend to concentrate (e.g., the concentration of foreigners) and rural areas, with their ancient buildings, lacking maintenance, share an ongoing reduction in resilience, which has widened the amount of damages. Such a reduction in local resilience levels has contributed to the spatial concentration of damages, as well.

In particular, a link between damages (i.e. the effects of a natural disaster) and a general decline geography is widely supported by the quantitative analysis provided in this work. Hence, it seems crucial for policy-makers to deal with the issues of the socio-economic changes at first. Demographic decline and other economic issues make built-up areas particularly weak in coping with natural disasters, their resilience being largely affected and hence structural maintenance of buildings being limited.

Further policy implications come from this analysis and they refer to the reconstruction process as a whole. Even though this work does not take into account the progresses in the reconstruction process (future works will do) and although we are still ignoring damages to industrial facilities and to other buildings, hosting economic activities, some preliminary lessons already emerge. Large interventions (i.e., the most costly ones) tend to concentrate within some given census tracts (namely, the historical city centres and other high-population density tracts). Spatial concentration of this process is also confirmed by average values of the accepted costs per hectare. Accordingly, we may expect that the overall pace of the reconstruction process can be slowed down. To this respect, even the low socio-economic resilience we have assessed across these census tracts may represent a negative element, yielding to even larger delays.

As a consequence, the pitfalls and bottlenecks that have already emerged as critical are expected to interact with such a distribution of damages. Actually, much more comprehensive interventions, being able to manage jointly larger reconstruction sites, could better fit with the current distribution of the damages.

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