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Disaster Risk Management: Building the 'Disaster Risk Assessment Tool' for Italy*

Giovanni Marin† Marco Modica‡ Susanna Paleari§ Roberto Zoboli**

Abstract

The paper provides a comprehensive assessment of hazard, exposure, vulnerability and resilience related to natural disasters in Italian municipalities. Indicators of the various components of risk assessment are built according to state-of-the-art methods. The combination of these dimensions is especially useful to identify hot spots that are characterized by high hazard, exposure and vulnerability and by low resilience. We also discuss the extent to which the institutional framework in place in Italy is able to deal with natural disasters.

The Disaster Risk Assessment tool (DRAT) developed by our paper may help policy makers in prioritising areas for intervention and it is particularly valuable when effective choices about mitigation and prevention strategies are to be taken in presence of tight public budgets.

Keywords: natural disasters, hazard, exposure, vulnerability, resilience

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1 Introduction

Hazard, exposure, vulnerability, risk and resilience are recurrent concepts in the analysis of natural and man-made disasters. However, when the socio-economic impacts of natural disasters are assessed, these concepts are typically considered in isolation or, in a few cases, in pairs.

Hazard, which is the natural event that may affect different areas and people, also in combination with other events (Wisner et al., 2004), is usually evaluated through models that measure the probability of its occurrence. For instance, the seismic maps, provided by the Italian National Institute of Geophysics and Volcanology (INGV) or the so-called hydrogeological plans are useful tools for assessing, respectively, the seismic and hydrogeological hazards (see e.g. Floris and Veneri, 2004 and Rossi et al., 2016).

Exposure, that may be considered as all the objects that potentially can suffer a harm from a natural disaster, and it encompasses physical and socio-economic components but also and direct and indirect aspects (Marin and Modica, 2017). For example, buildings and infrastructures are considered as physical exposure, population can be included in the socio-economic exposure (as the potential of human losses). At the same time exposure is direct when it refers to direct losses imputed to a disaster and indirect when it considers potential losses due to disruption of local and global supply chains of the production activities. The concepts of vulnerability and resilience, on the other hand, are more multi-faceted and address several different aspects related to the impact assessment of natural disasters. In principle, vulnerability may be defined as all '*inherent characteristics of the exposed objects/areas that create the potential for harm. However, it should be noted that this potential has to be thought independent of the probabilistic risk of occurrence of any hazard*' (Sarewitz et al., 2003 p. 805).[1] In practice, the vulnerability of a socio-economic system is generally measured through composite indicators. Most of the variables of the vulnerability indexes are selected by researchers based on ad hoc choices, depending on the topic

[1] For a complete review of vulnerability, readers may refer to Adger (2006) and Cutter et al. (2003).

under investigation. Some examples are provided by UNDP (2015), which analyses the social vulnerability to climate change and by Ding et al. (2017), who focus on the economic vulnerability to climate change of marine areas. These works mostly address emerging and least developed countries.

Finally, resilience is the ability of a system to recover or to adapt to a shock (Pimm, 1984; Martin, 2012), so that the impact of the disturbances affecting the system is reduced. As in the case of vulnerability, resilience is often measured through composite indicators covering several issues whose selection depends on the type of shock under consideration (e.g. financial crises, natural disasters, etc.) and on the object of the analysis.[2] Resilience to natural disasters is, for instance, assessed by Cardona et al. (2008); Cutter et al. (2008) and Mayunga (2007), based on composite indicators addressing several dimensions (e.g. demographic, economic, institutional characteristics). Other papers, such as Chan et al. (2014), Foster (2007) and Hallegatte (2014), instead, analyse the economic impact of natural disasters and the capacity of regions to recover after their occurrence, by defining composite indicators that mainly focus on the socio-economic and institutional dimensions.

Disaster risk, in a restrictive interpretation, is the result of the interaction between the hazard of a natural event (in particular, its frequency and the severity), the elements exposed to the hazard and their vulnerability (Birkmann, 2007). More formally, the risk consists of the potential likely level of loss, given the severity of the hazard and the vulnerability (Alexander, 2000). However, if we enlarge the concept of the disaster risk to a wider post-event time horizon (since we also deal with the long-term economic effects of disasters), resilience enters the analysis as a factor that can reduce or amplify them. Then resilience is an important aspect to be included in a disaster risk assessment tool, even though it cannot be directly considered a component of risk.

The aim of this paper is to assess the map the socio-economic dimensions of natural disasters by developing a tool that is able to provide information on the hazard, exposure, vulnerability and

[2] See Modica and Reggiani (2015) for a review.

resilience of the area under investigation. The tool is tested on the Italian case (at the municipal level), since Italy is one of the EU countries suffering from the highest natural disaster costs. In particular, after setting our framework for the analysis of natural disasters (Section 2), we assign a synthetic score to each municipality, representing its economic exposure, potentiality to suffer a harm (vulnerability), capacity to recover/adapt after a shock (resilience), weighted by the likelihood to suffer a damage (hazard; Sections 3 and 4). The tool is, then, complemented by a cluster analysis which may support policy makers, public authorities and first responders in identifying hot spots, as well as in shaping and implementing appropriate risk management policies and measures (Section 5). This quantitative assessment is enhanced by a synthetic overview/evaluation of the Italian governance of natural disasters, covering issues that significantly affect the different components addressed by the tool, but which cannot be translated into indicators (Section 6).

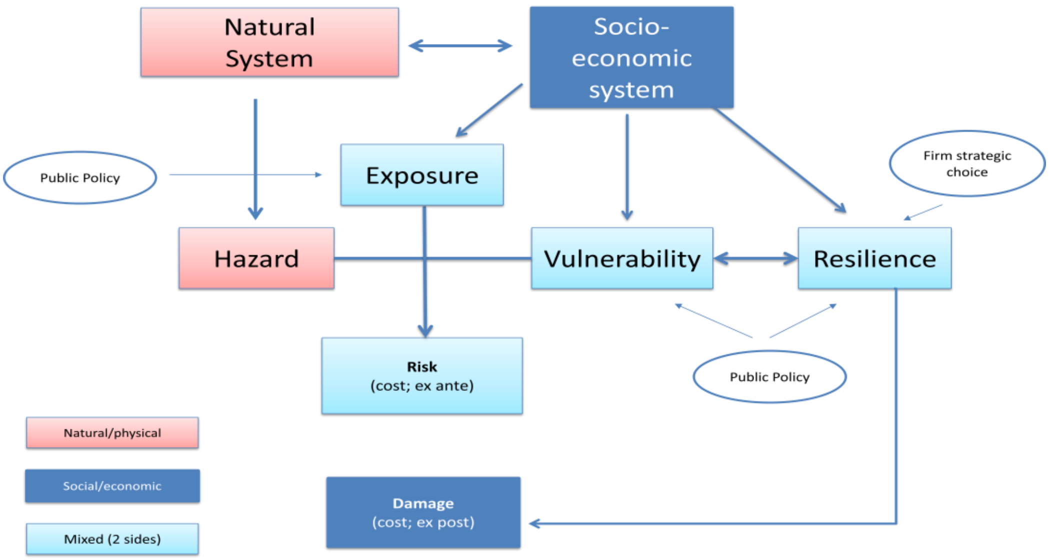
2 The framework for natural disaster analysis

This paper builds on Modica and Zoboli (2016) for what concerns the socio-ecological framework for natural disaster analysis. Nonetheless, to improve the assessment of natural disasters, we adapt and implement this framework, by taking into consideration all the factors that play a key role in the disaster chain of (re)actions.

According to Modica and Zoboli (2016) and in the light of the ecological literature, the socio-economic system may be thought as integral to nature, in the sense that human activity is contingent on the natural system (i.e. on all the factors that influence human beings and that are spontaneously regulated by the course of nature). At the same time, a socio-economic system consists of the amount of goods, services and resources that are produced, exchanged and allocated through the markets.

Figure 1 illustrates the relationship between the different aspects under analysis. In general, we relate hazard to the natural system, since the former can be only indirectly affected by the socio-economic system (think, for instance, about the effects of the global warming, which increase the frequency and the severity of extreme natural events; NASEM, 2016; Stott, 2016). Instead, all the other concepts (exposure, vulnerability, resilience and risk) derive from the relationship between the natural and the socio-economic systems.

Figure 1 - Socio-ecological framework for natural disaster analysis (based on Modica and Zoboli, 2016)



Exposure is mainly affected by the socio-economic system, as natural systems do not always play a key direct role in the supply of goods and services. For instance, as illustrated in Figure 1, exposure is affected by public policies. Land planning, which is a typical responsibility of policy makers, may prohibit building in high-risk areas (e.g. in flood-prone areas). These bans will result in the absence (or reduction) of exposed goods in those areas.

Finally, both natural and socio-economic systems influence vulnerability and resilience. Suppose that, as stated in Modica and Zoboli (2015, p. 61), '*a given region has an endemic shortage of drinking water. This area is more vulnerable to natural disasters than other areas having a greater supply of water. […] Similarly, a lack of drinking water might also reduce the ability of the area to recover after a natural disaster strikes, thus reducing the resilience of the territory*'. At the same time, the socio-economic system also affects vulnerability and resilience. For instance, wealthier areas have a lower degree of vulnerability (e.g. because of a better quality of buildings) and a higher capacity to recover and adapt to a shock (e.g. since they can quickly invest in reconstruction by using savings). Moreover, public and private behaviours may also reduce vulnerability or enhance resilience. Think, e.g., of the public measures aimed at providing financial support for reducing vulnerability (e.g. the fiscal incentives, introduced by the 2017 Italian Stability Law, for the anti-seismic improvement of buildings, so-called 'Sisma Bonus'). Similarly, different strategic choices that can be adopted by entrepreneurs, after a natural disaster has affected their firms (e.g. the penetration of new markets or product innovation), may increase the resilience of the firms themselves and, in general, of the related socio-economic system.

Nonetheless, the relationship between vulnerability and resilience needs to be further clarified, since, in the literature, there is no agreement on how the two concepts interact (Cutter et al., 2008). Three different links may be recognized: i) resilience as an outcome of vulnerability (e.g. a low vulnerability is associated with a high recovery capacity, Manyena, 2006); ii) vulnerability and resilience as two different concepts (Cutter et al., 2008); iii) vulnerability and resilience as separate (though likely correlated) concepts that share common characteristics (Modica et al., 2018).

In our paper, we adopt the last approach and we assume that the characteristics that are relevant for defining the level of vulnerability of a given system may also be considered for the analysis of resilience. For example, poverty is important for measuring vulnerability (e.g. poor people are more vulnerable to natural disasters than rich people, as the former are likely to live in more risky-prone areas). At the same time, poverty is generally associated to the lack of resilience, since rich people are more able to recover from a shock because of higher savings.

In the next sections we describe the methodology that has been used to build our composite indicators.

3 Building the Disaster Risk Assessment Tool (DRAT): hazard, exposure, vulnerability and resilience

In this section, we create a composite indicator that integrates all the dimensions playing a role in the management and assessment of disaster risks, namely, hazard, exposure, vulnerability and resilience. DRAT is proposed as a *Decision Support Tool* for both ex-ante and ex-post disaster risk management. Ex-ante, because, since the indicator can be applied at a very narrowly defined geographical level (at the municipality level, in our case study), it can provide relevant information to shape mitigation strategies or to identify high-risk areas (hot spots) that deserve priority in the implementation of risk reduction measures. Ex-post, because the tool highlights the weaknesses of the socio-economic systems affected by natural disasters and it can, therefore, contribute to fostering their reconstruction/recovery to previous conditions or, even better, to adapting to the new situation and using natural disasters as an opportunity for future development.

However, it is important to note that, although DRAT is rather general tool that builds several composite indicators for hazard, exposure, vulnerability and resilience and provides a synthetic general score, it is still able to capture only quantifiable aspects of risk assessment/management, while more qualitative, though important, aspects are left behind. These further aspects we will be discussed in Section 6. In this section we focus instead on quantitative aspects.

3.1 Hazard

Hazard is typically measured by institutional sources. Based on ISTAT (Italian National Statistical Office) data, we calculate, for each municipality:[3] a) a specific measure of the four main hazards affecting Italy (i.e. landslides, floods, earthquakes and volcanic eruptions); b) a synthetic measure of the different above-mentioned hazards (multi-hazard risk index).

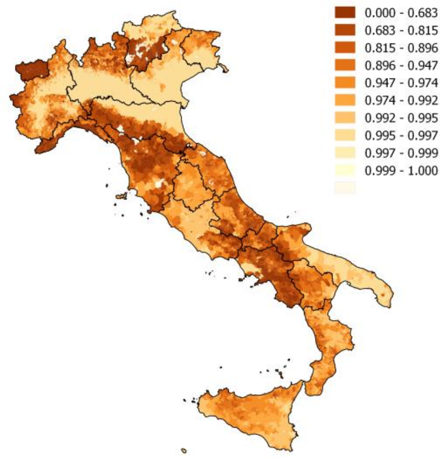
With regard to landslides, ISTAT provides information on the area (km^2) of the municipalities that are at risk of landslides, according to 5 different degrees of probability, from high to low. The data are scaled between 0 and 1 for all the degrees of probability and, then, the simple average is calculated to obtain a proxy of the landslide hazard of the whole municipality (Figure 2a) that is again scaled between 0 and 1.

A similar process has been used for mapping flood hazard (Figure 2b). Also in this case, ISTAT provides information on the area (km^2) of the municipalities that are at risk of floods, according to 3

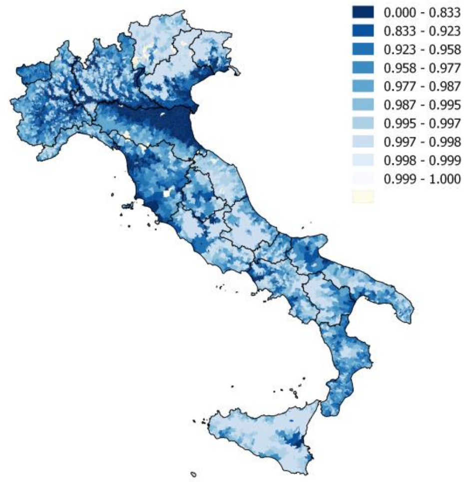
[3] Due to changing borders of provinces and municipalities, we decided to withdraw from the analysis the Sardinia region.

different degrees of probability of hazard occurrence. The data are again scaled between 0 and 1 for all degrees of probability and, then, we calculate the simple average.

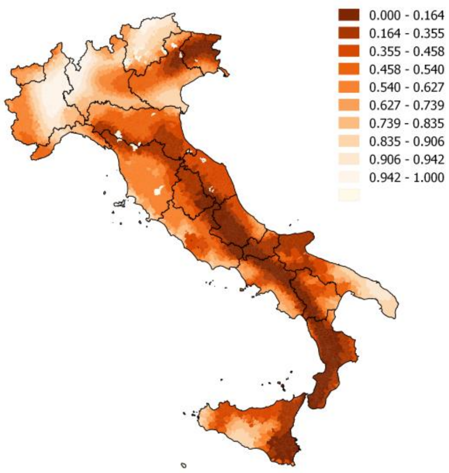
Figure 2 - Hazard of natural disasters for Italian municipalities



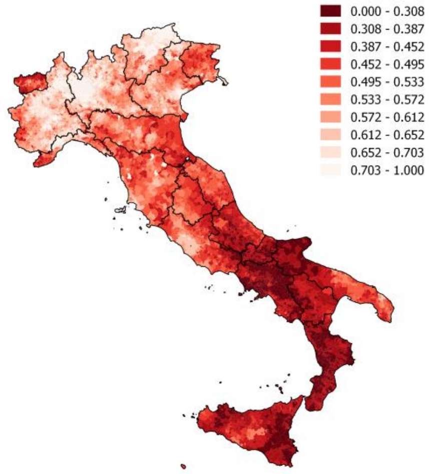
(a) landslide hazard



(b) hydrological hazard



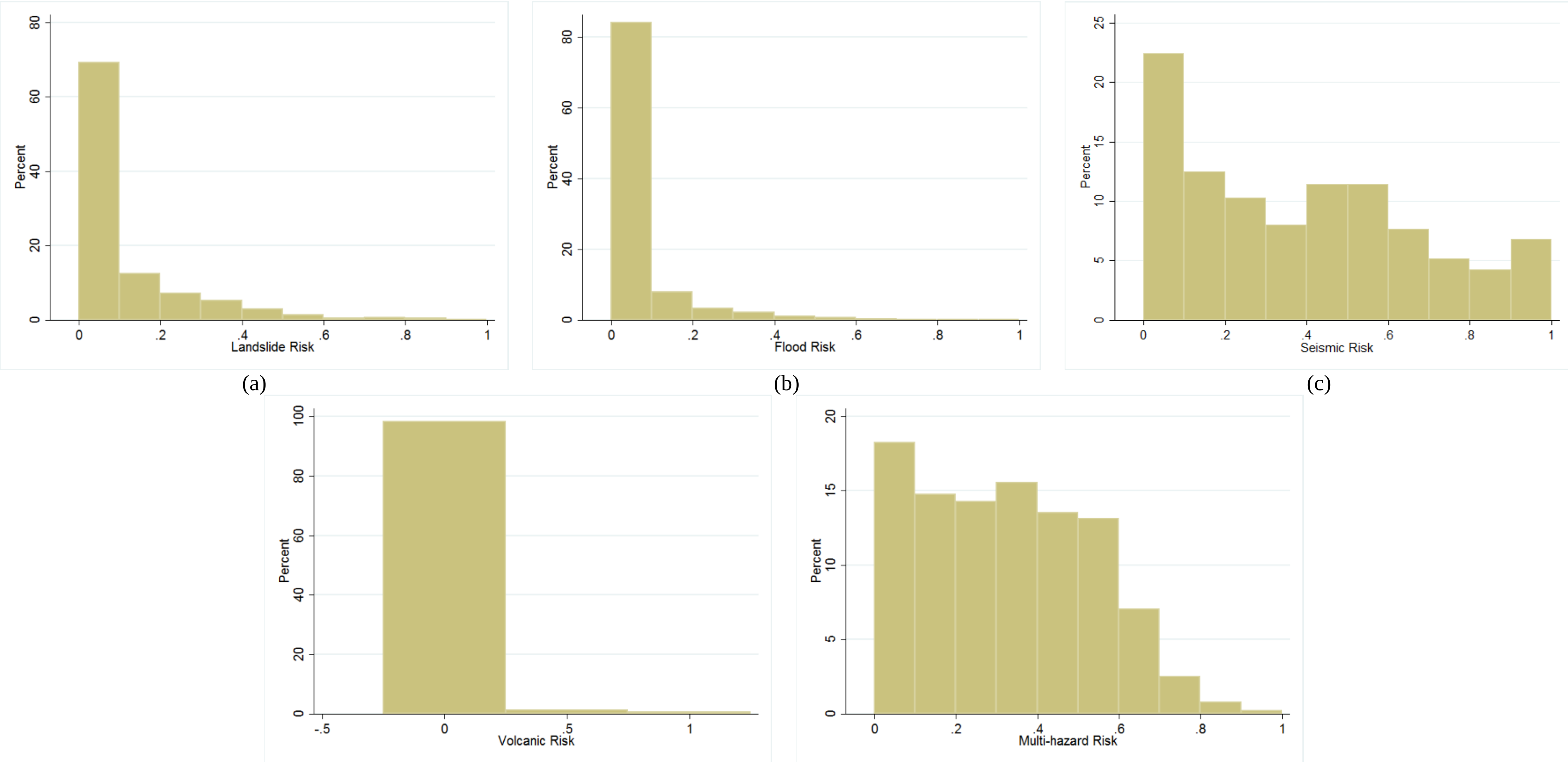
(c) seismic hazard



(d) multi-hazard

Based on the studies of the National Institute of Geophysics and Volcanology, ISTAT publishes seismic risk data. We calculate the seismic risk as a scaled value between 0 and 1 of the maximum municipal value of the peak ground acceleration (Figure 2c).

Figure 3 – Distribution of hazards



(a) (b) (c)

(d) (e)

Finally, in Italy, there are also areas exposed to volcanic hazard (less than 150 municipalities). Since the related risk depends on the maximum distance that the pyroclastic emissions could reach, we make a distinction between areas that are potentially highly affected by volcanic eruptions (e.g. the *Red Zone* for the areas around Vesuvius) and areas that may be only incidentally affected (e.g. the *Yellow Zone* for the areas around Vesuvius). We assign the value of 1 to the municipalities of the former group and the value of 0.5 to the municipalities in the latter group.[9]

All these measures of hazard may be aggregated to obtain a multi-hazard map for all the Italian municipalities, as a simple average of the scaled values of the different hazards (Figure 2d). As it emerges from Figure 2, the different hazards have a heterogeneous geographical distribution and appear to be rather uncorrelated: the simple correlation coefficient between different hazards is always, in absolute terms, below 15%.

It is important to note that the distribution of hazards at the municipal level varies according to the type of hazard under consideration. Figure 3 shows that most of the Italian municipalities are characterised by a very low hydrogeological hazard, (Figures 3a and 3b for landslides and floods, respectively), while the seismic risk is more equally distributed in all the classes of hazard (Figure 3c). Finally, very few municipalities are exposed to volcanic hazard (Figure 3d). When looking at the distribution of the multi-hazard risk we observe a rather heavy tailed distribution, with about 5% of the Italian municipalities that show a high degree of multi-hazard (Figure 3e).

3.2 Exposure

The measurement of the socio-economic exposure is an important step in assessing the effects of natural disasters, even if, as argued by Marin and Modica (2017), it is typically under-represented in risk analysis and management.

[9] Please note that in Italy there are two main volcanos, Vesuvius and Etna, and other very small ones: for the latter cases (8 municipalities: Barano d'Ischia, Casamicciola Terme, Forio, Ischia, Lipari, Lacco Ameno, Pantelleria and Serrara Fontana) we assign the value of 0.5. As only few municipalities are affected by volcanic hazard, we do not report the map, that remains available upon request.

A further step is the decomposition of exposure in its direct and indirect components. The direct components of exposure may be described as all the physical, monetary and human assets that are potentially directly affected by natural or man-made disasters.[10] For instance, extreme events can hurt people and damage buildings. On the contrary, the indirect component of exposure include all the physical, monetary and human assets that are potentially indirectly affected by natural or man-made disasters. For instance, business interruption and foregone production due to extreme events may '*influence the whole (local and global) supply chain of the production activities that experience the interruption […] Suppliers of intermediate goods will experience a reduction in the demand for their products and consequently a reduction in sales.[…] customers will experience potential shortages of inputs needed for their production process and may be forced to find alternative suppliers*' (Marin and Modica, 2017, p. 58).

Marin and Modica (2017) estimate the indirect exposure in Italian municipalities based on data from Input-Output tables and by considering economic activities at potential risk within a radius of either 20km or 50km from the centroid of the municipality under scrutiny. In this paper, we improve the above-mentioned approach, since we adopt a 'more economic' concept of indirect exposure and we identify the relevant economic-geographical area for local shocks diffusion, i.e. the local labour market area.

According to the literature, we assess the direct components of exposure based on the following variables: sales and capital stock of firms and monetary values of residential buildings. Sales indicate the potential direct costs arising from business interruption because of natural disasters. Capital stock of firms is a measure of the potential destruction of capital goods. Furthermore, we also consider the exposure in terms of the monetary value of all residential units. In this way we are

[10] It is common practice to attribute to direct exposure also the potential losses in terms of foregone activity directly caused by the consequences of a disasters, such as the destruction of production plants and machinery, the impossibility to commute to work due to the interruption roads and public transportation, etc. We have chosen to measure these direct costs in terms of value of sales of local units.

able to capture potential damages to buildings, which represent an important part of people's wealth. Average housing values in 2015 are provided by OMI ('Osservatorio del Mercato Immobiliare'), a branch of Italian Fiscal Agency, while the residential surface is retrieved from the population census of ISTAT (see Meroni et al., 2017). For the estimation of firms' sales, aggregated at the municipal level, we use data from the Italian Business Registry (ASIA, by ISTAT).[11] Finally, capital stock is estimated, first, at the sectoral level, using national accounts and, then, it is attributed to municipalities, according to the share of municipal-level employees for each sector.[12]

With regard to the indirect components of exposure, building on Marin and Modica (2017), we provide for two different measures. The former (*Destination of final goods as intermediates*) is computed as the share of sales, produced in the municipality of reference, that can be absorbed by firms operating in other sectors but belonging to the same local labour market area and identified according to national input output tables.[13] The latter measure (*Source of intermediate inputs*) considers the extent to which firms within the same labour market area contribute to supplying intermediate inputs to firms in the municipality of reference. Also this indicator is calculated using input-output tables for Italy, to identify weights for supplying sectors. Both these measures are able to capture the propagation of the shock to municipalities that are not directly affected by the disaster, but that may suffer from an interruption of the production activity, due to the link between their supply chain and those of affected municipalities.

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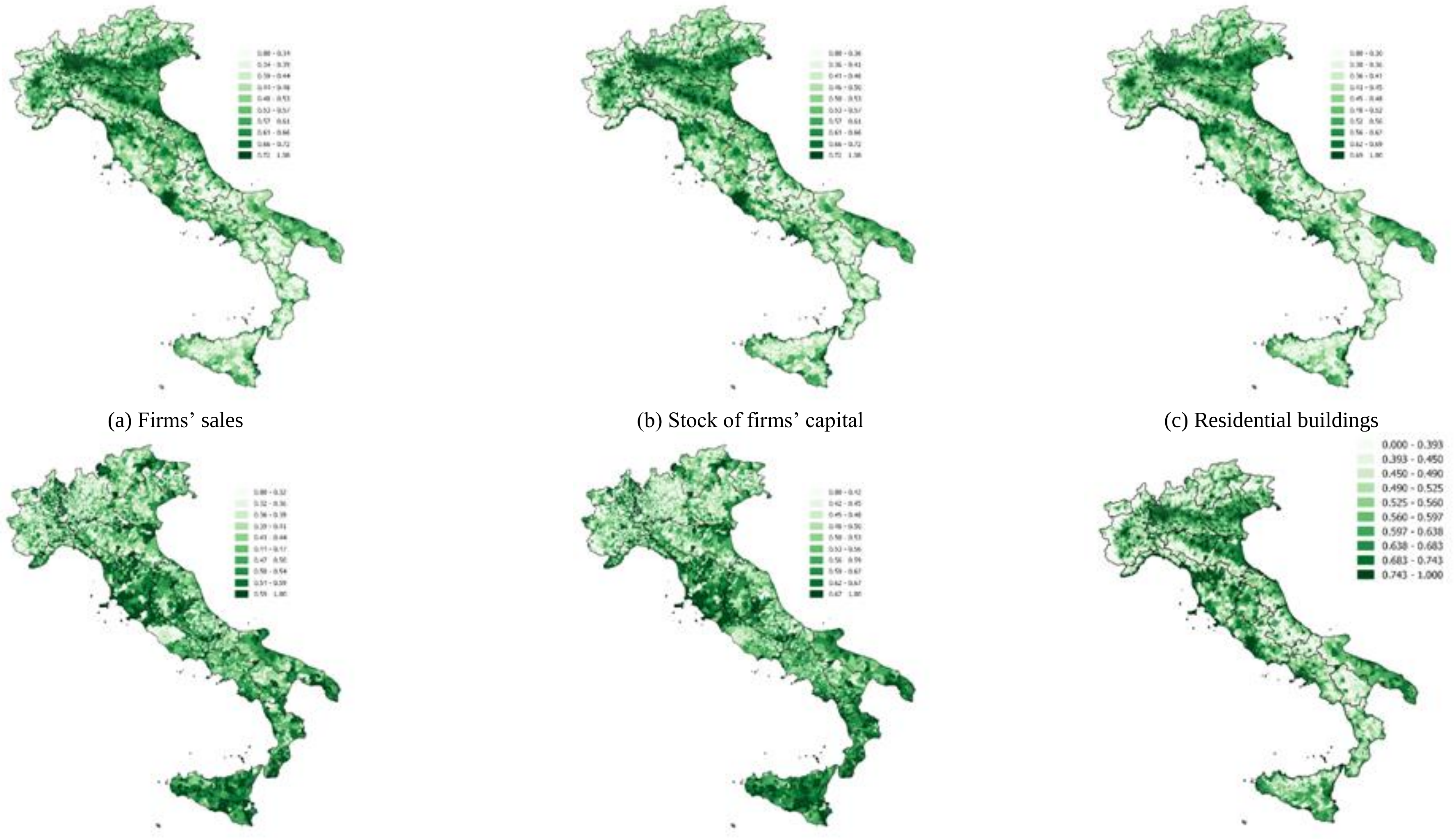
[11] The Italian Business Registry contains information on the number of employees and sales (in bands), to predict the level of sales produced by establishments located in the municipality of interest by using an interval regression model that estimates the sales as a function of the number of employees of the firm, separately for each industry. Firm-level sales is then attributed to establishments (eventually located in different municipalities), proportional to their employment within the firm.

[12] Refer to Marin and Modica (2017) for further details regarding the estimation of municipality-level sales and capital stock.

[13] The main difference here with respect to Marin and Modica (2017) is that we consider the economic entity 'local labour market area', rather than a cruder measure of distance (e.g. municipalities within the radius of 20km or 50km).

Figure 4 – Measures of exposure



(a) Firms' sales

(b) Stock of firms' capital

(c) Residential buildings

(d) Source of intermediate goods

(e) Destination of final goods as intermediates

(f) Exposure index

All the components of exposure are scaled between 0 and 1 and they are, then, aggregated into a composite indicator, as the simple average of all the components, which is again rescaled to range between 0 and 1 (Figure 4).

Figure 4 (a, b and c) highlights that the most exposed value with reference to direct components (i.e. sales, capital stock and value of residential buildings), is localized in the Northern regions. When considering, instead, indirect exposure, it emerges that some Central and insular regions (e.g. Tuscany, Lazio and Sicily) have municipalities that heavily depend on firms within their local labour market (Figures 4d and 4e). Overall, however, the synthetic index of exposure (Figure 4f) shows higher values in the Northern regions.

3.3 Vulnerability and resilience

Previous literature reviews have explored how scholars have analysed vulnerability and resilience. However, very few works address the two issues in a systematic and comprehensive way. For instance, the concept of vulnerability is explored by Adger (2006) and the one of resilience by Modica and Reggiani (2015).

Modica et al. (2018) provide for a systematic review of the indicators of vulnerability and resilience. The authors list all the indicators that have been used to measure vulnerability and resilience in the existing literature, with the aim of defining a taxonomy of the main features that could be considered part of the two concepts. At the same time, they also highlight the common characteristics shared by the two concepts. In this paper, we exploit the knowledge gathered by Modica et al. (2018) to build our composite indicators of vulnerability and resilience.

In their literature review, the authors list the attributes that are typically used in the construction of indicators of vulnerability and resilience to natural disasters. In this way, we rely on the existing literature to select the relevant indicators, limiting the arbitrariness of the process, by selecting the variables that appear in the literature at least 15% of the times. According to this rule, 17 variables have been selected for the vulnerability index and 13 for the resilience index.

Table 1 - The components of the vulnerability index

	Vulnerability	Appearance	Data source	Note	Weights	
1	Extension of agriculture	34.4	Agricultural Census 2010	Percentage of agricultural land	7.1473	+
2	Dependency on agriculture	15.6	Agricultural Census 2010	Number of cattle per person	3.2412	+
3	Age	43.8	Population Census 2011	Dependency ratio	9.1004	+
4	Wealth	56.3	Ministry of Economy and Finance.	Average income per household	11.697	-
5	Poverty	40.6	Population Census 2011	Households with potential economic discomfort	8.4355	+
6	Inequality	21.9	Atlante Prin-Postmetropoli	Gini Index	4.5502	+
7	Unemployment	25	Population Census 2011	Unemployment rate	5.1943	+
8	Institutional capacity	18.8	Atlante Prin-Postmetropoli	Synthetic index defined as the simple average of Z-scores of the three following indicators: - Employees in the Public administration over total population - Employees in state education over total population - Employees in public health	3.9061	-
9	Political rights	15.6	Ministry of Interior	Turnover of 2014 EU Parliament election	3.2412	-
10	Population pressure	40.6	Population Census 2011	Population density	8.4355	+
11	Urbanisation	15.6	ISPRA	Land use per capita	3.2412	+
12	Building characteristics	25	Atlante Prin-Postmetropoli	Herfindahl-Hirschman index for residential, non-residential buildings (functional mix)	5.1943	+
13	Ecosystem conversion	15.6	Agricultural Census 2010	% of agricultural area actually used (SAU) on total agricultural area	3.2412	+
14	Education	43.8	Population Census 2011	Ratio between people in the age 15-24 who does not attend a regular course of study and population of 15-24 years	9.1004	+
15	Family structure	15.6	Population Census 2011	Ratio between the number of single-parent households over total number of households	3.2412	+
16	Female condition	15.6	Population Census 2011	Male employment rate over females employment rate	3.2412	+
17	Health	37.5	Ministry of Health	Hospital beds for 10,000 inhabitants	7.7914	-

Table 2 - The components of the resilience index

	Resilience	Appearance	Data source	Note	Weights	
1	Density of business	19.4	DB	Number of local units per km2	5.2277	+
2	Wealth	71	Ministry of Economy and Finance.	Average income per household	19.132	+
3	Debt	22.6	AIDA - PA	Debt of the public administration per capita	6.0900	-
4	Poverty	29	Population Census 2011	Households with potential economic discomfort	7.8146	-
5	Homeownership	19.4	OMI - Fiscal Agency	Affordability index	5.2277	+
6	Unemployment	51.6	Population Census 2011	Unemployment rate	13.905	-
7	Productivity	22.6	Asia - Istat	Sales per employee	6.0900	+
8	Sectorial dependence	16.1	DB	Herfindahl-Hirschman concentration index of employees in the economic sectors	4.3385	-
9	Government effectiveness	19.4	AIDA- PA	Paid expenditure / Committed expenditure of municipal governments	5.2277	+
10	Institutional capacity	25.8	Atlante Prin-Postmetropoli	Synthetic index defined as the simple average of Z-scores of the 3 following indicators: - Employees in the Public administration over total population - Employees in state education over total population - Employees in public health	6.9523	+
11	Education	25.8	Population Census 2011	Ratio between resident in the age 15-24 who does not attend a regular course of study and resident population of 15-24 years	6.9523	+
12	Health	22.6	Ministry of Health	Hospital beds for 10,000 inhabitants	6.0900	+
13	Social capital	25.8	Nannicini et al. (2013)	Synthetic index defined as the simple average of normalized scores of the following indicators: - No. of non-profit association - Employees in non-profit association - Blood donations - No. of non-sport newspapers sold/1000 person - Answer to 'tolerance' question in the WVS - Answer to 'trust' question in the WVS	6.9523	+

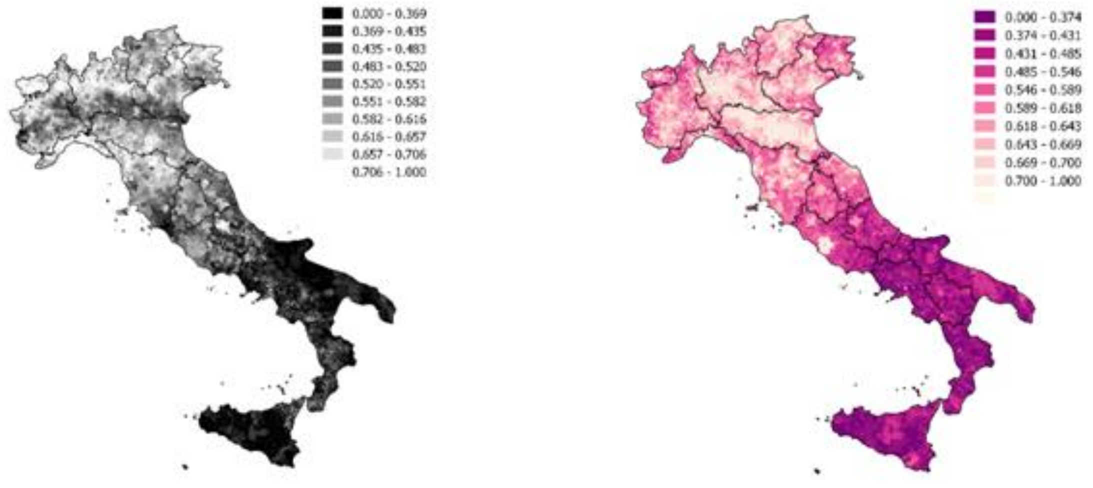
Moreover, the number of occurrences of each attribute, reported by Modica et al. (2018), allows us to calculate a weighted synthetic indicator based on how many times an attribute appears in the literature. In both the indicators, the role of economic variables is remarkable (i.e. wealth measures appear in half of the papers on vulnerability and in 71% of the papers on resilience), while some specific characteristics are peculiar for the two concepts. For instance, for the vulnerability indicators, agricultural (34%), demographic (44%) and building characteristics (25%) variables appear more frequently than for the resilience indicators. On the contrary, variables related to education (26%), institutions (26%) and business density (19%) appear more frequent for resilience indicators.

All the indicators composing the vulnerability and resilience indexes are rescaled to range between 0 and 1 and the final indicators consist of the weighted averages of the different components. The final indicators are, again, rescaled to range between 0 and 1 (Tables 1 and 2).

It is important to note that our index of resilience is more suitable to capture the recovery capacity (medium / long term) of a territory rather than the first response capacity, as often the emergency is managed at the national level (see Section 6 for a detailed discussion of this issue).

Figure 5 provides the maps for vulnerability (a) and resilience (b). The darker is the colour, the higher is the vulnerability of the area and the lower is the resilience.

Figure 5 – Vulnerability and resilience index in Italy



(a) Vulnerability index

(b) Resilience index

Based on Figure 5, the regions of the South are characterised by a more critical situation due to the higher socio-economic vulnerability associated with the low capacity to absorb and adapt after a shock.

4 Discussing the Disaster risk assessment tool DRAT

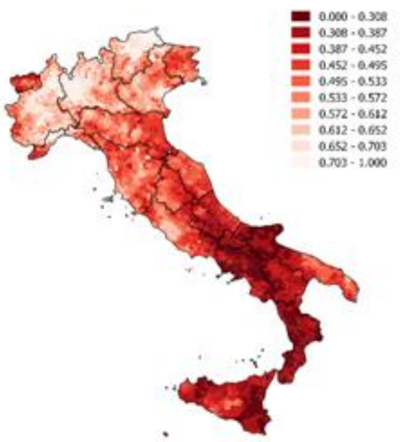
In this section, we discuss the (DRAT), as defined in the previous section, by by aggregating all the components defined in the previous sections in a synthetic indicator, which summarizes the overall risk of the Italian municipalities.

Figures 2, 4 and 5 described the single components of the DRAT. As a next step, we define a synthetic index that includes hazard, vulnerability and resilience, while exposure is incorporated into the index at a later stage.

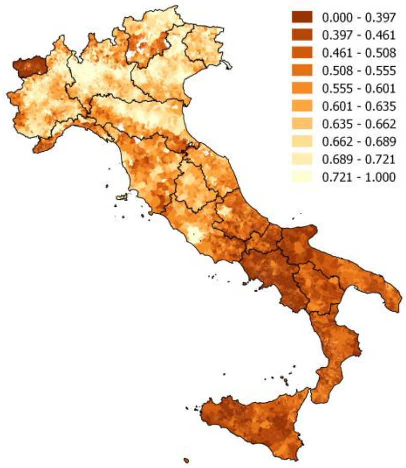
Figure 6 represents the different hazards, weighted for the vulnerability and resilience of Italian municipalities. This index measures not only the potential risk due to the probability to be affected by a natural disaster, but also to what extent municipalities are prepared to mitigate the damage and to react quickly once the damage occurs. The darker areas identify those municipalities with high potential damage that are also expected to experience difficulties in recovering from the shock. In Italy, most of these critical areas, as highlighted by Figure 6a, are in the South, particularly in the following regions: Campania, Abruzzo, Apulia (particularly in the North), Calabria and Sicily. The scenario changes according to the type of hazard considered. For instance, when focusing on the landslide and hydrogeological hazards, also other regions show some criticalities (Valle d'Aosta with regard to landslides and the Northern part of Emilia Romagna with regard to the hydrogeological hazard). Instead, the seismic hazard shows some similarities with the multi-hazard index.

Finally, we add exposure to the previous indicator, to get a complete synthetic indicator for disaster risk assessment. Taking into account of the exposed goods and economic activities is relevant, since there may be situations where the high probability of hazard occurrence is combined with the low economic value of the area. Figure 7 shows the results for the aggregate hazard (a), as well as for the single types of hazard (b, c and d). When adding the exposure to the analysis we note that the potential to suffer an economic damage is relatively low for some municipalities that are characterised by very high hazard, vulnerability and lack of resilience (see Figure 6). This is particularly true for some municipalities in Central and Southern Italian regions such as Abruzzi, Campania and Molise, where the exposure is low. On the contrary, some municipalities in Northern Tuscany, that show moderate high level of hazard, vulnerability and lack of resilience but with high values of exposure, might potentially suffer severe economic damages.

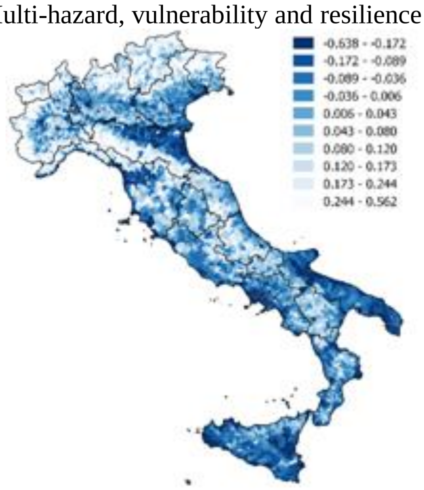
Figure 6 – Composite index of hazard, vulnerability and resilience in Italy



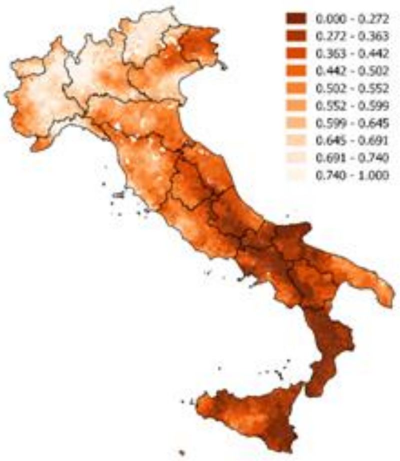
(a) Multi-hazard, vulnerability and resilience index



(b) Landslide hazard, vulnerability and resilience index

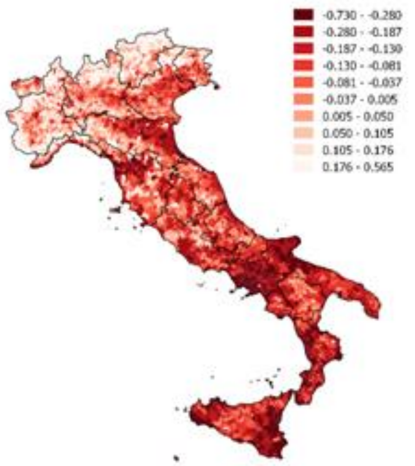


(c) Hydrological hazard, vulnerability and resilience index

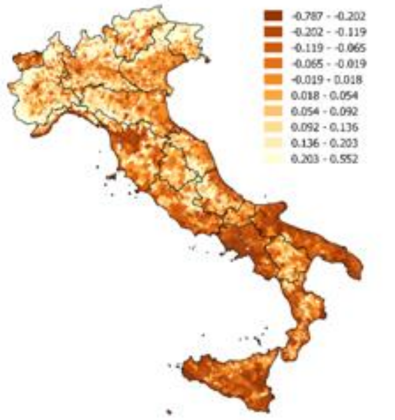


(d) Seismic, vulnerability and resilience index

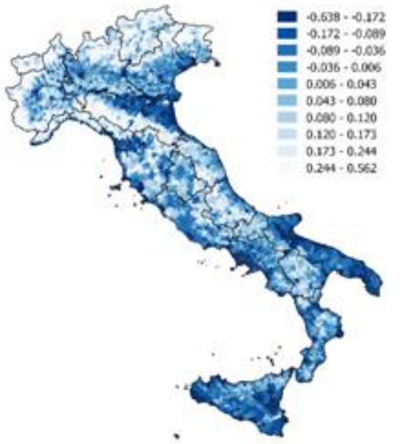
Figure 7 – Disaster risk assessment index



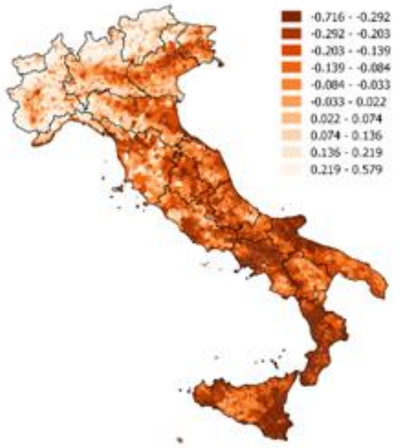
(a) Multi-hazard, vulnerability, resilience and exposure index



(b) Landslide hazard, vulnerability, resilience and exposure index



(c) Hydrological hazard, vulnerability, resilience and exposure index



(d) Seismic, vulnerability, resilience and exposure index

5 A taxonomy of disaster risk

Results reported in Figures 6 and 7, which provide for a synthesis of all the different dimensions of disaster risk assessment, may hide relevant interactions between these dimensions. In order to evaluate such interactions in a more accurate way, we combine resilience, vulnerability and exposure (direct and indirect exposure, separately) with cluster analysis, so that common patterns across different municipalities, in terms of susceptibility to disasters, are described. We, then, integrate this taxonomy with the actual hazard of municipalities, with the aim of identifying hot spots.

This cluster analysis is based on our measures of resilience, vulnerability, direct and indirect exposure, all transformed in percentile ranks, to limit the influence of outliers. We adopt a two-step procedure to define the optimal composition of clusters, as suggested by Hair et al. (2009). First, we perform hierarchical clustering to establish the "optimal" number of clusters (Milligan and Cooper, 1985) by assessing how distinct the clusters are. As a second step, we use the resulting clusters (and corresponding centroids) as a starting point for the optimal re-attribution of municipalities into clusters, by means of non-hierarchical clustering.[14] We use as clustering algorithm the average linkage algorithm, which computes the squared Euclidean distance in clustering variables across all possible pairs of individuals across different clusters and which aims to minimize distances within the clusters while, at the same time, maximizing distances across the clusters. Based on this process, six main clusters have been identified. Table 3 reports the average percentile rank for the clustering variables, across the six different clusters of municipalities, together with the total surface and population of the municipalities within each cluster.[15]

Table 3 – Profiling of cluster (average percentile)

Cluster	Direct exposure	Indirect exposure	Resilience	Vulnerability	Surface (km2)	Population (in 1000)
1 Low values exposed and resilient	24	38	54	23	45394	1469
2 Only directly exposed but ready to react	78	26	81	30	30924	16211
3 High exposure but ready to react	73	76	73	33	53210	17162
4 Low values exposed and vulnerable	38	24	43	68	34656	2773
5 Fragile but only indirectly exposed	21	75	20	78	69411	3712
6 Hot spots	70	70	20	80	39990	16055
Total	50	50	50	50	273587	57382

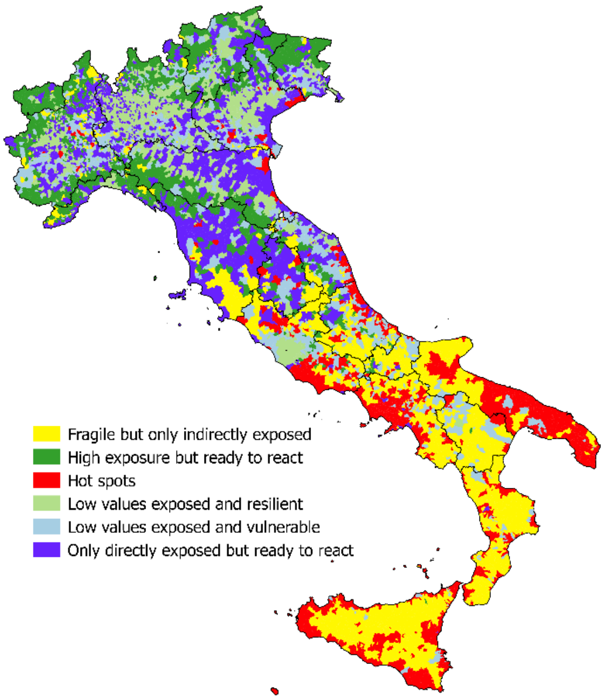
[14] Hierarchical clustering techniques sequentially split clusters and do not allow for the re-allocation of observations across different branches of the clustering tree. Non-hierarchical clustering techniques are more flexible and allow for re-allocation of observations to render clusters more homogeneous and distinct.

[15] To ease the interpretation, we now inverte the scale of resilience, with larger values indicating higher levels of resilience.

The different clusters are, then, synthetically described by labels, reflecting their characteristics in terms of exposure, resilience and vulnerability. The first cluster "*Low values exposed and resilient*" groups together municipalities with relatively low direct and indirect exposure (well below the median) and with the lowest vulnerability across all the clusters. These municipalities are also quite resilient, with a score that is, on average, right above the median. Therefore, the municipalities belonging to this cluster are not particularly sensitive to natural disasters, as the economic exposure and vulnerability are very low and resilience is medium-high. The second cluster "O*nly directly exposed but ready to react*" has the highest level of direct exposure, but it is also the cluster with the highest resilience and it has low vulnerability and indirect exposure. Municipalities in this cluster may be sensitive to disasters directly affecting them (high direct exposure), but they appear prepared to reduce the losses (low vulnerability) and recover after the shock (high resilience). The third cluster "*High exposure but ready to react*" is very similar to the second one, with the exception that municipalities in this cluster are also characterized by high indirect exposure: this means that these municipalities need to consider also the hazards of neighbouring municipalities. The fourth cluster "*Low values exposed and vulnerable*" groups together municipalities that, despite the relatively small value of direct and indirect exposure, are particularly vulnerable to disasters. The fifth cluster "*Fragile but only indirectly exposed*" is also particularly vulnerable and weak in terms of resilience, but it includes municipalities that are just indirectly exposed, while direct exposure is the lowest on average. Finally, the sixth cluster "*Hot spots*" is the most interesting one, as it includes those municipalities with the highest average vulnerability, the lowest average resilience and with very high values of both direct and indirect exposure. For this reason, natural disasters occurring in these municipalities are likely to generate substantial direct and indirect losses and a recovery is expected to be very problematic due to the low degree of resilience.

Figure 8 illustrates the geographical distribution of municipalities across different clusters. "Hot spots" and "Fragile but only indirectly exposed" municipalities are almost exclusively located in the Centre-South of Italy. Municipalities belonging to "Low values exposed and resilient" and "Low value exposed and vulnerable" are more evenly distributed across different regions, while those included in "High exposure but ready to react" and "Only directly exposed but ready to react" are concentrated in the Northern regions, Toscana and Umbria. The cluster analysis confirms the North-South divide that was identified in the previous section, with regions in the North that are better equipped to cope with natural disasters and regions in the South being less resilient and more vulnerable to natural disasters.

Figure 8 – Municipalities by cluster



As the final step of the analysis, we evaluate the hazard of municipalities belonging to different clusters. The underlying idea is that, while exposure, vulnerability and resilience are the results of human activities and historical roots, hazard is largely exogenous and related to the geomorphological features of each specific area. Therefore, exposure, vulnerability and resilience jointly allow to identify the short and long term losses due to the verification of an exogenous natural event (hazard).

Table 4 shows the average percentile of different hazards across different municipalities, while Table 5 reports the average percentile of hazard of other municipalities (other than the focal municipality) within the same local labour market area.[16] Overall, the highest within-municipality multi-hazard score is recorded in the fifth and sixth clusters, which are the least resilient and most vulnerable ones. When considering the different hazards separately, instead, evidence is more mixed, with floods and landslides hazards being rather evenly distributed across the clusters and earthquake hazard being very high in the fifth cluster. Moving to hazards in neighbouring municipalities, we observe a very similar distribution across different clusters, suggesting that the spatial correlation of hazard across municipalities within the same local labour market is high.

Overall, we have some preliminary evidence that the two most sensitive clusters (fifth and sixth) are also the ones with the highest levels of multi-hazard.

Table 4 – Hazards (average percentile) by cluster

Cluster	Multi-hazard	Landslides	Floods	Earthquakes
1 Low values exposed and resilient	38	64	42	45
2 Only directly exposed but ready to react	26	27	54	38
3 High exposure but ready to react	34	40	60	40
4 Low values exposed and vulnerable	58	45	45	51
5 Fragile but only indirectly exposed	80	62	38	71
6 Hot spots	77	48	44	61

Table 5 – Average hazard in other municipalities within the same local labour market area (average percentile) by cluster

Cluster	Multi-hazard	Landslides	Floods	Earthquakes
1 Low values exposed and resilient	39	62	46	44
2 Only directly exposed but ready to react	28	37	61	38
3 High exposure but ready to react	37	45	61	40
4 Low values exposed and vulnerable	52	48	54	51
5 Fragile but only indirectly exposed	78	58	37	72
6 Hot spots	79	53	39	62

[16] It is important to account for hazards of other municipalities within the same local labour market when considering indirect exposure, which responds to shocks in connected areas.

Looking at average, however, is not enough as, in presence of tight public budgets, it is important to set priorities for intervention, focusing on areas that are at highest risk. For illustrative purposes, Table 6 reports the distribution of municipalities across clusters and quartiles of multi-hazard score.[17] As discussed above, the cluster "Hot spots" includes those municipalities that are the most susceptible to disasters. Among the 936 municipalities that belong to this cluster, as much as 541 lie in the highest quartile of multi-hazard score, meaning that they are both extremely susceptible to disasters and, at the same time, located in high multi-hazard areas. Public authorities should, therefore, take immediate action to improve the resilience of these municipalities and reduce their vulnerability and, if possible, their exposure. Since each hazard requires substantially different measures to reduce the overall risk, it would be important to classify high-hazard susceptible municipalities according to the specific hazards they are exposed to.

Table 6 – Distribution of municipalities by cluster and quartile of multi-hazard score

Cluster	Q1 (low hazard)	Q2	Q3	Q4 (high hazard)	Total
1 Low values exposed and resilient	428	383	329	51	1191
2 Only directly exposed but ready to react	858	516	186	7	1567
3 High exposure but ready to react	502	426	307	24	1259
4 Low values exposed and vulnerable	83	406	423	290	1202
5 Fragile but only indirectly exposed	14	99	312	976	1401
6 Hot spots	4	59	332	541	936
Total	1889	1889	1889	1889	7556

As shown in Figure 9 and Table 7, these 541 municipalities, accounting for 18.19% of the Italian population, are mostly located in the regions of the South, with a few exceptions in Liguria, Emilia-Romagna, Tuscany and Marche. Campania is the NUTS2 region with the highest share of population (almost 80%) living in these very risky municipalities and the share of population in risky municipalities is above 50% also in Sicily and Calabria. When focusing on a more

[17] Results for the different hazards are not reported and remain available upon request.

disaggregated geographical level (provinces, NUTS3), it emerges that, in 13 provinces, more than half of the population lives in risky municipalities, with the extreme case of the province of Naples (with 97.73% of the population in risky municipalities).

Figure 9 – Municipalities in hot-spot cluster with high (fourth quartile) multi-hazard score

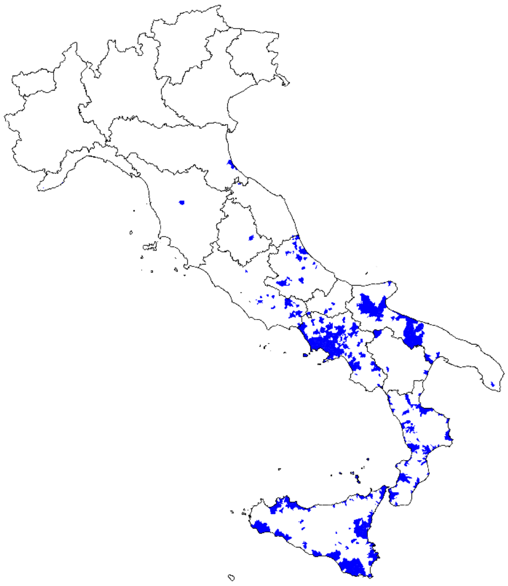


Table 7 – Share of population in municipalities in 'hot spot' cluster with high multi-hazard score (fourth quartile) – Average by region and top-20 provinces

Region (NUTS2)	Share of municipalities in 'danger' (weighted by population)	Province (NUTS3)	Region (NUTS2)	Share of municipalities in 'danger' (weighted by population)
Campania	0.7929	Napoli	Campania	0.9773
Sicilia	0.6486	Ragusa	Sicilia	0.8289
Calabria	0.5648	Catania	Sicilia	0.8213
Puglia	0.2355	Palermo	Sicilia	0.8116
Abruzzo	0.1737	Reggio di Calabria	Calabria	0.7069
Molise	0.0795	Siracusa	Sicilia	0.6987
Basilicata	0.0518	Benevento	Campania	0.6756
Lazio	0.0339	Catanzaro	Calabria	0.6661
Emilia-Romagna	0.0171	Caserta	Campania	0.6484
Umbria	0.0094	Messina	Sicilia	0.6343
Marche	0.0055	Barletta-Andria-Trani	Puglia	0.5892
Toscana	0.0044	Salerno	Campania	0.5430
Liguria	0.0032	Foggia	Puglia	0.5255
Friuli-Venezia Giulia	-	Avellino	Campania	0.4859
Lombardia	-	Cosenza	Calabria	0.4794
Piemonte	-	Crotone	Calabria	0.4330
Trentino-Alto Adige	-	Caltanissetta	Sicilia	0.3799
Valle d'Aosta	-	Vibo Valentia	Calabria	0.3730
Veneto	-	Teramo	Abruzzo	0.3553
Total	0.1819	Trapani	Sicilia	0.3410

6 Disaster management policy

The ‘disaster risk assessment tool’ developed in the previous sections highlights the importance of evaluating all the relevant dimensions related to natural disasters, to get a comprehensive overview of their economic effects. The governance of natural risks and disasters, consisting of both ex ante (prediction, prevention, mitigation and preparedness) and ex post (emergency response and recovery) policies, affects most of these dimensions. Indeed, all the above policies are aimed at decreasing natural risks (by preventing hazard and reducing exposure and vulnerability) and increasing resilience.

Governance-related indicators are already taken into account, to a certain extent, by the literature assessing disaster risks and their components. For instance, the review of 36 community resilience assessment tools by Sharifi (2016) shows that, on average, the majority of the examined tools pay primarily attention to the institutional dimension, followed by other dimensions (social, built environment, economic and environmental characteristics). Similarly, the literature review on the indicators used in vulnerability assessments by De Ruiter et al. (2017) highlights that flood vulnerability assessments usually include indicators related to zoning and land-use planning (while for earthquakes, it appears that fewer models use governance-related indicators). Also in our work, the institutional capacity appears as a component of both the vulnerability and resilience indexes, while the variable of Government effectiveness is only included in the latter.

However, evaluating the extent to which disaster governance affects natural risks and resilience entails considering issues (related e.g. to policy adoption, implementation and effectiveness; learning, adaptive and innovation capacity of institutions; institutional interaction; etc.), which are difficult to transpose into quantitative indicators. Moreover, relevant policies and institutions often belong to supra-municipal government levels, while our tool is applied at the municipal level. For this reason, this section provides a short overview and evaluation of the governance for disaster management in Italy, with the aim of complementing the quantitative analysis developed in Sections 2-5.

In Italy, the fundamental tasks of risk prediction, prevention, mitigation and emergency response are undertaken by the National Civil Protection Service (NCPS). The NCPS involves a wide range of actors, including national, regional, provincial and local authorities, other public/private institutions, volunteer organizations, the scientific research community and all the Italian operative structures (National Fire Brigades, National Police, Carabinieri, Armed Forces, Italian Red Cross, etc.). Two NCPS central bodies (the National Committee for major risks prediction and prevention and the Operative Committee) ensure the connection between ex ante and ex post disaster management, while the National Coordination Centre ('Sistema') monitors emergency situations and, when needed, alerts the various components of the NCPS. The President of the Council of Ministers (PCM), through the Civil Protection Department (CPD), is responsible for coordinating and directing the NCPS, in accordance with the subsidiarity principle.

Natural disasters are classified by Legislative Decree 1/2018 into three categories, depending on the extent, intensity and responsiveness of civil protection: 'type a' (municipal level), 'type b' (provincial and regional) and 'type c' (national). When a disaster cannot be faced at the municipal level, the higher levels are activated. For 'type c' events, the PCM declares the state of emergency.

The role of the different administrative levels in the field of civil protection is also defined by Legislative Decree 112/1998, which has decentralized a set of functions traditionally performed by the State. This process, in turn, has been completed through the assignment of civil protection to the concurrent legislative competence of the national and regional governments by Constitutional Law 3/2001 (i.e. the legislative power is exercised by regions, while complying with the basic principles established by the State). Administrative authorities are responsible for the various civil protection functions (related to both ex ante and ex post disaster management), as described below.

- ✓ Municipalities shall implement risk prediction and prevention activities specified by the regional programmes and adopt local and inter-municipal emergency plans, on the basis of regional guidelines. As of October 2017, 86% of Italian municipalities, belonging to 19 Regions and the Autonomous Province of Trento,[18] had an emergency plan, ranging from 49% of Sicily to 100% of Friuli Venezia Giulia, Marche, Molise, Valle d'Aosta and the Autonomous Province of Trento. In case of natural disasters, the first response to the emergency has to be provided by the Mayor who shall manage and coordinate relief and assistance to population, through the municipal civil protection structures. When the event cannot be coped with at the municipal level, the Mayor activates the Prefect (i.e. the public authority representing the Government at the provincial level).

- ✓ Provinces shall adopt risk prediction and prevention programmes and implement risk prediction and prevention activities established by regional programmes.

  Prefects shall adopt provincial emergency plans, according to regional guidelines and direct emergency operations in the Provinces, through provincial civil protection structures, while coordinating their activities with those of the municipalities involved. They also inform the CPD and the regional Government about the occurrence of 'type b' or 'c' events.

- ✓ Regions shall adopt risk prediction and prevention programmes, based on national guidelines and define the guidelines for the adoption of provincial emergency plans by the Prefects. They may also set their own emergency plans, based on CPD guidelines.

  Moreover, pursuant to Directive 2007/60/EC (EU, 2007), Regions were required to establish, along with river basin authorities, flood-risk managements plans (FRMPs) for all river basin districts (RBDs) by 2015 (being mainly involved in the provision of early warning systems for civil protection purposes). In October 2016, the FRMPs were approved by the Council of Ministers for all the eight Italian RBDs, except for the one of Sicily. Moreover, apart from risk preparedness, there are several other regional planning instruments that play a relevant role in reducing the hydrogeological risk, primarily the flood and landslides management plans, the landscaping plans, the natural parks plans and the climate change adaptation strategies.

[18] No data has been provided by the Autonomous Province of Bozen.

When 'type b' events occur, Regions shall launch urgent interventions, also availing of the National Fire Brigades. If the natural disaster needs to be managed through extraordinary powers and means, Regions submit a request to the PCM for a declaration of the state of emergency.

- ✓ The central government is responsible for: 1) directing, promoting and coordinating civil protection activities; 2) deliberating and revoking the state of emergency for 'type c' events; 3) issuing ordinances; 4) drawing up national emergency plans concerning 'type c' events (e.g. the National Earthquakes Relief Programme was adopted in 2014) and 5) organizing drills. With regard to the hydrogeological risk, the DPC and Regions manage, through a network of ad hoc centres, the national early warning and monitoring system.

This complex system of natural disasters governance, consisting of several different functions performed by multiple interacting actors, cannot be easily evaluated. In a nutshell, we can argue that the progressive reform of civil protection has contributed to increasing the effectiveness of the NCPS in coping with the short-term effects of natural disasters (Del Federico, 2016, p. 23).

Further improvements need, instead, to be achieved with regard to both risk prevention/mitigation (RPM) and disaster recovery policies. Under the former respect, priorities to be addressed include: 1) strengthening the implementation of planning instruments and the application of land use restrictions and seismic codes and 2) providing, on a regular basis, adequate public funds to RPM and incentives to support private investments in RPM (Basilavecchia, 2016, p. 497; OECD, 2010; Paleari, 2018). Some positive signals about the Government commitment to ex ante disaster management are represented by the recent introduction of a tax deduction for the seismic retrofitting of buildings (so-called Sisma Bonus) and by the adoption, in 2017, of the National Program for reducing the hydrogeological risk (with a current budget of about 10 billion Euros for the 2015-2023 period).

Moving to recovery policies, it has to be underlined that, apart from emergency relief by the NCPS, there is not to date in Italy a stable and predictable legislative framework for ex post disaster management (Contrino, 2016, p. 237). Since the country has neither a compulsory nor a semi-mandatory insurance against natural disasters, compensation for damages is mainly provided by the Government, either through grants or in the form of tax benefits. Most of these financial measures are not regulated by the Italian legislation in force, but are specifically introduced after the occurrence of each natural disaster and only applied to single events. Some financial measures are recurrent, since they have been taken to address several natural disasters, but they are generally re-proposed with differences in terms, e.g., of scope, recipients and earmarked resources, which do not seem always justified by specific situations.[19] It has been argued that, in this 'fluid' recovery governance system, resilience is improved when regional authorities '*immediately take leadership to set up priorities and relevant actions*, [but that this] *«self-government» requires capacities that not all Regions and territories have*' (Bianchi and Labory, 2014, p. 13). Another relevant consequence of the Italian ad hoc recovery measures is that only in some cases they show a clear connection to the objective of risk prevention.[20]

7 Conclusions

The tool developed by this paper contributes to assessing disaster risks and the related economic impacts. The set of indicators we have created, and the related cluster analysis provide information, at the municipal level, on hazard, exposure, vulnerability and resilience. The tool proves to be innovative and versatile: on the one hand, it integrates all the above-mentioned dimensions of natural risks/disasters into a comprehensive assessment, to highlight their interactions and combined effects. On the other hand, it maintains its analytical foundation, since each component can be separately investigated. For this reason, the tool may be useful for all the actors involved in the (ex ante and ex post) governance of natural disasters. In particular, it may support the priority-setting

[19] Wide differences, for instance, can be observed in the financial contributions for the reconstruction of damaged buildings, provided after the earthquakes of Abruzzo, 2009; Emilia Romagna, 2012 and Central Italy, 2016.

[20] For instance, in the post-event scenario, compensation and fiscal incentives for building repairs have been sometimes provided only to buildings located outside the areas exposed to higher hydrogeological risk; Fichera, 2016, p. 63).

process with regard to the measures to be implemented to prevent/mitigate natural risks and to foster recovery after disasters occurrence, the allocation of the available financial resources, the identification of potential recipients, etc.

The set of indicators presented in the paper may be further refined and improved. For instance, exposure indicators could be extended to measure the value of the cultural heritage or the industrial composition of disadvantaged areas such as the so-called inner areas. Since our work is mainly built on the existing literature, these limitations turn out to be suggestions for new research. Moreover, we recognise that not all the aspects that are relevant for risks/disasters assessment can be translated into indicators. Indeed, a qualitative evaluation of the institutional framework for the governance of natural disasters is also provided.

The application of the tool to the Italian case study reveals that, based on a synthetic measure of different hazards, critical regions are localised both in the North and in the South of the country, but the Northern regions, although characterised by the highest values of exposure (especially of direct exposure), are affected by a lower socio-economic vulnerability, compared to the regions of the South and perform better in terms of resilience. The cluster analysis confirms this North-South divide, by showing that Southern regions host most hot spots (i.e. municipalities with the highest average vulnerability, the lowest average resilience and with very high values of both direct and indirect exposure). Overall, the picture that emerges from the application of the tool suggests that the governance of natural disasters should represent a national priority, while, in spite of some positive signals (such as the introduction of the Sisma Bonus and the adoption of the National Program for reducing the hydrogeological risk), there is not, to date, in Italy, a long-term, coherent and sound risk reduction strategy. When considering ex post measures, it has to be noted that, while the NCPS is quite effective in coping with the short-term effects of natural disasters, the Government financial assistance for recovery is not clearly predictable, as provided on an ad-hoc basis, so that, in the end, the resilience of local and regional authorities is crucial.

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