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Abstract

Even though the correct assessment of risks is a key aspect of the risk management analysis, we argue that limited effort has been devoted in the assessment of full measures of economic exposure at very low scale. For this reason, we aim at providing a complete and detailed map of the exposure of economic activities to natural disasters in the Italian context. We use Input-Output model and spatial autocorrelation (Moran's I) to provide information about several socio-economic variables, such as population density, employment density, firms' turnover and capital stock, that can be seen as direct and indirect socio-economic exposure to natural disasters. These measures can be easily incorporated into risk assessment models to provide a clear picture of the disaster risk for Italian local areas.

Keywords: Economic exposure, Disaster impact; Risk assessment; Risk management

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1 Introduction

The perception about the relevance of economic and social damage generated by natural disasters has grown substantially in recent decades (Blaikie et al., 2014). This greater awareness about natural disasters triggered the demand, from both the public and the private sectors, of actions aimed at preventing the occurrence of natural disasters (when possible), at mitigating the damages and at adapting to increasing risks. On these regards, a stronger collaboration of private and public sectors has gained on importance through Public-Private Partnerships (PPPs) (Mysiak and Pérez-Blanco, 2015) due to several reasons. First, climate change suggests that extreme events are likely to happen in a more harsh way that in the past (DEFRA, 2013; Warner et al. 2013). Second, the role of the governments in managing natural disasters implies a large and direct financial burden because of the emergency relief, recovery, and reconstruction (GFDRR, 2014). However, after the 2008 financial crises, the ability of governments to finance interventions for disaster protection, recovery and reconstruction is in doubt (Mysiak and Pérez-Blanco, 2015). Finally, the private insurance sector will not be able to cover all the claims for damages in case of natural disasters (Botzen and Van Den Bergh, 2012; Munich Re, 2009), especially so if they are due to global phenomena like climate change. In the PPP context, information about risk and exposure to damages is fundamental both in an *ex-ante* perspective (e.g. risk reduction, risk assessment) and in the *ex-post* perspective (e.g. risk management, assessment of damage, reconstruction) to allow for the correct definition of the role in the public and private partnership.

Even though the correct risk assessment is without any doubt a key aspect of the risk management analysis, and for this reason the academic literature contains a large variety of sophisticated models for risk assessment, we argue that less effort has been devoted in the assessment of full measures of socio-economic exposure at very low scale. For this reason, we aim at providing a complete and detailed map of exposure of socio-economic activities to natural disasters in the Italian context. We provide detailed information on several socio-economic variables that can be easily added to risk assessment models to provide a clear picture of the disaster risk for any Italian local areas. These variables are population density, employment density, firms' turnover and capital stock (divided also in its main component: buildings ad machineries).

In this respect, given the difficulties to address all the exposed goods, the existing literature employs different proxies of the socio-economic exposure (Chen et al., 1997) that depend on the features of the disaster that is analyzed. For instance, the density of the built environment is a common proxy used in the case of flood risk assessment, (e.g. Jongman et al., 2012; Koks et al., 2014, 2015: Sterlacchini et al., 2016). The Gross Domestic Product, (GDP), or the population density are commonly used in earthquake risk assessment (Chen et al., 1997), as well as the value of real estate assets (Field et al, 2005; Meroni et al., 2016). A similar proxy can be used in the case of drought (land value, Simelton et al., 2009) while for landslides an interesting measure is the mix between social (population), physical (buildings and infrastructures), economic (land value) and environmental (site of community importance) indicators (Bloechl and Braun, 2005; Pellicani et al., 2014).

The different choice of the proxy used in the evaluation of the economic losses due to natural disasters mostly depends on the sequence of effects which are expected to occur when different natural disasters affect a given area (Modica and Zoboli, 2016; Pelling, 2003). On these regards, there is extensive literature focusing on the definition of losses caused by extreme events (see ECLAC, 2003; FEMA, 1992; and Pelling et al., 2002, for more details). Even though definitions are not always coherent among each other, for simplicity we discriminate between direct and indirect losses.

Direct losses refer to direct damages to people (injuries and fatalities) and objects (goods, buildings, infrastructures, etc.), ECLAC (2003). For instance, earthquakes destroy buildings and infrastructure, which in turns, generate damages to other goods and people. Floods may generate minor damages to buildings if compared to damages to other goods (e.g. vehicles) and people (FFEMA 2003; Luino et al., 2009). Damages arising from the interruption of economic activities due to the natural disaster are also considered to be direct losses (see Rose and Lim, 2002; Rose et al, 2007). Interruption may occur for several reasons: damages to critical infrastructures such as energy and water supply and transport network; damages to people involved in production processes, destruction of production capital, etc. The interruption of economic activities in a region reduces the firms' turnover for a certain amount of time, which in turn reduces region's GDP.

A second category of losses includes indirect losses. This category is broad and borderless. Limiting the discussion to the indirect consequences of business interruption, foregone production and turnover also influences the whole (local and global) supply chain of the production activities that experience the interruption (e.g. Van Der Veen and Logtmeijer, 2005). Suppliers of intermediate goods will have a reduction in the demand for their products and consequently a reduction in turnover. On the other hand, customers will experience potential shortage of inputs needed for their production process and may be forced to find alternative suppliers, thus increasing production costs and potentially reducing production. Foregone wages will also influence region's GDP as consumption will be reduced. Finally, if the interruption lasts for a long period, producers may lose their customers permanently, limiting the possibility of economic recovery even once the cause of interruption is removed. For all these reasons indirect losses need to be evaluated looking at general equilibrium effects by means of specific economic models, however this is not an east task (see Okuyama, 2007).

Given these premise it turns out that policy makers and private actors have the vital need to know both the direct and indirect components of economic exposure for the elaboration and implementation of correct and effective risk management strategies. Direct components refer to those that might produce direct losses as a consequence of the disaster, from now on 'direct socio-economic exposure'. Indirect components refer to the losses due to the disruption of local and global supply chains of the production activities as a consequence of the disaster ('indirect socio-economic exposure'). Indeed, policy makers need to know clearly what is the socio-economic value of the area under analysis, as well as the possible interconnections between neighboring areas, to define for instance optimal mitigation policies in selected risky prone areas or to estimate the likely (or potential) maximum cost suffered by a region affected by a disaster. Private actors, such as insurance companies, can instead uses this information to provide a more accurate risk analysis and to provide better insurance plans.

However, measuring the costs and the economic impacts of extreme events is a difficult task due to the unpredictability of the different types of natural events (Hallegatte and Przylusky, 2010), both in the *ex-ante* and in the *ex-post* perspective, also for the scarcity of information about economic activities for small geographical units. To overrule this issue we create a set of maps of several socio-economic measures that can be used in different contexts and in relation to several natural disasters at a very detailed scale, providing in this way a full map of the potential exposure of socio-economic activities to natural disasters in the Italian municipalities.

Using administrative and statistical data we estimate a set of socio-economic information that can be used to map the socio-economic exposure of geographical unit in terms of direct economic exposure. The complete set of measures that we provide are the following: population density (proxy for potential life loss), employee density (indirect measure of how exposed is a municipality during its ‘working hours’), turnover (direct costs due to business interruption) and capital stock (direct costs due to the destruction of capital goods). These measures provide interesting information on the direct exposure since they are all proxy for the ‘local’ loss of the area due to natural disasters.

In order to consider the indirect socio-economic exposure, we also provide relevant information on the spatial clustering of the socio-economic characteristics underlined above, by means of local indicator of spatial autocorrelation (LISA), (for details see Anselin, 1995 and for an application see Cutter and Finch, 2008). This analysis is useful to identify areas where high values are spatially concentrated at municipality level, indicating in this way a greater economic exposure to risk and potentially high indirect losses. Finally, we also provide more explicit evidence about local linkages and possible diffusion of economic damages by means of input-output inter-sectoral linkages across neighboring municipalities.

These maps can inform risk assessment models to provide a robust tool for the risk management at different administrative levels (municipalities, regions, national government) or to provide important information on local exposure *per se*.

The work is organised as follows. Section 2 describes data sources. Section 3 explains the methodology used to attribute turnover and capital stock measures to local units.

Section 4 provides some descriptive evidence on the exposure to natural disasters of socio-economic activities in Italian municipalities. Section 5 concludes.

2 Data sources

The main source of information that is employed to evaluate the exposure to natural disasters of socio-economic activities in Italian municipalities is the ASIA database of Istat (Archivio Statistico delle Imprese Attive). "ASIA - Imprese" includes detailed information on the population of Italian companies from 1996 to 2012. This information includes the address of the headquarter of the firm, the number of employees, the class of turnover, the main sector of the firm (5-digit NACE) and its unique identifier. The total number of firms in 2011 was 4,515,691 firms and they were distributed across different classes of turnover as described in Table 1.

Table 1 – Distribution of firms by turnover class (in euro)

Class	Min	Max	# firms
1	0	19,999	1,042,223
2	20,000	49,999	1,161,047
3	50,000	99,999	788,529
4	100,000	199,999	603,462
5	200,000	499,999	464,785
6	500,000	999,999	198,311
7	1,000,000	1,999,999	120,353
8	2,000,000	3,999,999	66,543
9	4,000,000	4,999,999	13,791
10	5,000,000	9,999,999	28,355
11	10,000,000	19,999,999	14,312
12	20,000,000	49,999,999	8,487
13	50,000,000	199,999,999	4,230
14	200,000,000		1,263

This detailed information is very relevant but it is still characterized by two main limitations for the aim of providing an appropriate estimate of 'local' turnover. First, the 'true' value of turnover for each firm is unknown as we only know the turnover class of the firm. While for some classes the range is rather narrow, in some other cases (especially so for classes with greater turnover) the range is very wide. To illustrate, the upper bound estimate (the true value of turnover of all firms within a class equals the maximum of the class) is about 2.42 times greater than the lower bound estimate (the true value of turnover of all firms within a class equals the minimum of the class), even excluding the top class (turnover greater than 200 million euro),. Moreover, the highest class accounts for as much as 20 percent of total turnover, in the lower bound estimate. This is particularly worrisome as no upper limit exists for this class.

A second reason of concern refers to the fact that many firms, especially the larger ones, produce great part of their turnover in establishments other than the headquarter. In fact, in single-unit firms all production occurs in the headquarter, while for multi-unit firms (e.g. multi-plant) large share of production occurs in units other than the headquarter. However, it is important to know where the production actually occurs for measuring the exposure of a firm's production (and, consequently, turnover) to natural disasters. In order to attribute the total turnover of the firm to its various branches (local units) we combine "ASIA - Imprese" with "ASIA - Unità Locali" (local units). This latter database contains information on the population of local units of Italian firms from 2004 to 2012. Similarly to "ASIA - Imprese", it contains the address of the local unit, the number of employee, the main sector of the local unit (NACE 5-digit) and the unique identifier of the firm. The total number of local units of Italian firms is 4,826,882 in 2011. Table 2 shows some descriptive statistics on the number of local units per firm, split by turnover class. While small (in terms of turnover) firms have a very small number of local units (around 1), larger firms have higher number of local units. Proportionally distributing total firm production across different local units of the firms, may result in a substantial over-estimation of the turnover generated in the municipality of the headquarter and in a underestimation of the turnover generated in the municipalities of the local units, especially so for large firms. Indeed, headquarters are more likely to locate in big urban areas (e.g. Milan, Rome), therefore, the use of firm-level data only would result in a systematic over-estimation of turnover (but also employment and capital stock) in big urban areas.

To overrule these issues, the two sources of information described above have been complemented with data on ‘true’ turnover at firm-level from the AIDA database (Bureau van Dijk). This information is available only for 733,458 firms (16.24% of total). However, these firms are responsible for 41.77% of total employees as AIDA over-represents large firms. This is particularly important as big firms account for a large share of turnover and having detailed (and ‘true’) information on these large players limits the risk of systematically over-estimating or under-estimating turnover. This over-representation of large firms is also apparent when looking at the share of firms available in AIDA (over the total number of firms) by turnover class (

Table 3). While for small turnover classes the share of firms available in AIDA is very small, the coverage of AIDA increases substantially for medium-large firms (up to 76.45% for firms in class 11).

Table 2 – Number of local units per firm by turnover class

Class	Mean	Q1	Median	Q3	Max
1	1.02	1	1	1	239
2	1.01	1	1	1	28
3	1.02	1	1	1	21
4	1.05	1	1	1	37
5	1.11	1	1	1	65
6	1.19	1	1	1	146
7	1.29	1	1	1	173
8	1.43	1	1	2	190
9	1.59	1	1	2	133
10	1.84	1	1	2	380
11	2.42	1	1	2	838
12	3.41	1	2	3	546
13	7.71	1	2	5	1,599
14	42.42	2	5	14	12,392
Total	1.09	1	1	1	12,392

Table 3 – Distribution of firms available in AIDA by turnover class

Class	Firms in AIDA (share of total)
1	3.70%
2	3.78%
3	6.73%
4	12.38%
5	25.47%
6	40.75%
7	51.78%
8	62.08%
9	59.34%
10	73.48%
11	76.45%
12	72.33%
13	62.98%
14	55.50%

To estimate the value of the capital stock owned by economic activities, we retrieve information on net stock of capital by sector at the national level (*Investimenti fissi lordi, stock di capitale e ammortamenti per branca proprietaria* by Istat). This is available for 37 sectors (sub-section, Ateco 2007 / NACE rev 2) until 2012. We retrieve information on net capital stock (which is already partialled out from the depreciation of capital) at the aggregate level as well as its various components: buildings, machinery, intangibles. This information will be useful to estimate the expected stock of capital at the municipality level given its local sectoral composition and the national average capital stock per employee for each sector (see section 3.2). Finally, population density has been provided by 2011 Italian Census of Istat.

3 Methodology

3.1 Estimates of turnover

A first step to estimate total turnover at the municipality level consists in estimating firm-level turnover. As discussed in the previous section, actual turnover (from AIDA) is available for a small number of firms while for the rest of firms we only have information on the turnover class. To estimate firm-level turnover we fit an interval regression model on the population of firms in which the log of turnover (in class or, when available in AIDA, actual turnover) is function of the log of the number of employees of the firm. The interval regression model is a generalisation of the Tobit model in which both interval data and point data are allowed. After estimating the model, we predict the turnover (given the level of employment). We substitute the predicted turnover with the 'true' turnover from AIDA (when available) and we set to the upper bound of the interval the predicted turnover whenever it exceeds the upper bound. Similarly, we set the predicted turnover to the lower bound whenever it is smaller than the lower bound.

The model is estimated separately for each industry (NACE Subsection) separately to account for industry-specific relationship between employment and turnover.

Table 4 – Estimated turnover by turnover class (in billion euro)

Class	Total turnover	Share of total	Total turnover (firms in AIDA)	Share of turnover in firms in AIDA
1	18.53	0.58%	0.32	1.74%
2	40.40	1.26%	1.48	3.66%
3	49.80	1.55%	3.87	7.77%
4	73.96	2.30%	10.85	14.67%
5	124.68	3.88%	38.85	31.16%
6	124.24	3.87%	57.77	46.50%
7	151.75	4.73%	88.19	58.12%
8	170.69	5.31%	116.21	68.08%
9	59.46	1.85%	36.47	61.34%
10	186.71	5.81%	145.18	77.76%
11	190.28	5.92%	152.43	80.11%
12	243.32	7.58%	184.87	75.98%
13	355.65	11.07%	237.03	66.65%
14	1,422.13	44.28%	602.79	42.39%

Table 4 reports the estimated turnover by turnover class as well as the total turnover of firms for which actual turnover was available in the AIDA database. A large share of total turnover is estimated to be generated by large firms: firms belonging to the two top classes of turnover account for more than 55% of total turnover. Moreover, the share of turnover retrieved from AIDA (i.e. 'true' turnover) is greater in big turnover classes.

A final step of the analysis consists in attributing the total turnover of the firm to its local units. We assume that the ratio between turnover and employees is constant within each firm (y_i/L_i) and consequently attribute firm-level turnover (y_i) to local units (*j*) according the share of employment of the local unit (L_j) over the total employment of the firm (L_i).

$$y_j = y_i \times \frac{L_j}{L_i} \tag{1}$$

Total turnover at the municipality level (m) is finally computed as the sum of estimated turnover of local units operating in the municipality.

$$y_m = \sum_{j \in m} y_j \tag{2}$$

While total turnover by municipality is already useful as an indicator of exposure, it is important to scale it by the total land size of the municipality, thus obtaining the average turnover per square kilometre. This scaling factor is required as natural disasters (earthquakes, floods, landslides) hit specific areas of land.

The indicator measures the average expected loss of turnover if economic activity is completely interrupted for a year in a square kilometre of the municipality. The indicator can be further refined to reflect the expected loss of turnover due to partial interruption (e.g. 50%) or temporary (e.g. 7 days) interruption.

A final consideration is needed as forgone production and turnover in a specific local unit may be compensated, at least partly, by greater production and turnover in other local units in areas not affected by the potential natural disaster. This may occur within the same multi-units firm or in units belonging to other firms. For this reason, the indicator of turnover per square kilometre is a good indicator of the 'local' loss of turnover due to the interruption of economic activity but it is an upper bound of overall loss.

3.2 Estimates of capital stock

To estimate the net stock of capital of economic activities at municipality level we assume that the ratio between capital stock and number of employees is homogeneous in all Italian firms that belong to a specific sector (*k*). Table 5 shows the average national capital intensity (net capital stock per employee in 2011) by industry. We observe very large heterogeneity across industries in terms of capital intensity both for total capital stock and for the different categories of capital goods. Real estate activities (L) have a very high capital intensity which is mainly driven by its large stock of capital in buildings. Its value is about 34 times the average value of all sectors. Capital stock in machinery is less concentrated but still rather heterogeneous across sectors. Machinery per employees in the two top industries (C19 and D) is about 13 times the average value of all sectors. This great systematic heterogeneity across sectors in terms of capital intensity is likely to explain a large part of the difference in capital intensity across local units belonging to different sectors.

According to this assumption, the estimated capital stock for municipality *m* is given by:

$$Capital_m = \sum_k \frac{Capital_k}{L_k} \times \frac{L_k^m}{L^m} \tag{3}$$

where L_k^m is the total employment in local units in municipality *m* and sector *k* while $L^m = \sum_k L_k^m$. This means that the only source of variation across municipalities is the industry composition of economic activities of the municipalities. As discussed for turnover, we scale the capital stock by the land size of the municipality.

The indicator reflects the average expected loss in capital stock if all productive capital is destroyed in a square kilometre of land. As discussed for turnover, this can be refined to reflect partial destruction.

Table 5 – Capital per employee by sector for Italy (source: Istat, year 2011)

Ateco	Ateco (description)	Net capital stock per employee				Employees
		Total	Buildings	Machinery	Intangibles	
C10T12	Manufacture of food products; beverages and tobacco products	0.1307	0.0423	0.0839	0.0046	425,548
C13T15	Manufacture of textiles, wearing apparel, leather and related products	0.0578	0.0189	0.0327	0.0063	484,529
C16T18	Manufacture of wood, paper, printing and reproduction	0.0988	0.0321	0.0634	0.0033	292,733
C19	Manufacture of coke and refined petroleum products	1.6376	1.1378	0.4913	0.0084	18,947
C20	Manufacture of chemicals and chemical products	0.3121	0.1159	0.1663	0.0300	109,262
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.2613	0.0499	0.1518	0.0596	61,075
C22_23	Manufacture of rubber and plastic products and other non-metallic mineral products	0.1411	0.0480	0.0876	0.0055	371,893
C24_25	Manufacture of basic metals and fabricated metal products, except machinery and equipment	0.1182	0.0391	0.0752	0.0039	658,675
C26	Manufacture of computer, electronic and optical products	0.1807	0.0439	0.0784	0.0584	107,595
C27	Manufacture of electrical equipment	0.1301	0.0365	0.0746	0.0189	161,329
C28	Manufacture of machinery and equipment n.e.c.	0.1022	0.0381	0.0482	0.0158	452,592
C29_30	Manufacture of motor vehicles, trailers, semi-trailers and of other transport equipment	0.1646	0.0261	0.0903	0.0482	259,434
C31T33	Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment	0.0836	0.0455	0.0316	0.0065	436,062
D	Electricity, gas, steam and air conditioning supply	2.4922	1.9940	0.4773	0.0209	87,915
E	Water supply; sewerage, waste management and remediation activities	0.3306	0.2105	0.1171	0.0030	182,310
F	Construction	0.0549	0.0369	0.0173	0.0007	1,549,374
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	0.0604	0.0425	0.0161	0.0018	3,446,704
H	Transportation and storage	0.2972	0.2161	0.0785	0.0025	1,078,439
I	Accommodation and food service activities	0.0905	0.0773	0.0129	0.0003	1,323,844
J58T60	Publishing, motion picture, video, television programme production; sound recording, programming and broadcasting activities	0.2280	0.1059	0.0390	0.0831	93,817
J61	Telecommunications	0.4205	0.2496	0.1025	0.0683	94,234
J62_63	Computer programming, consultancy, and information service activities	0.0666	0.0147	0.0148	0.0371	354,460
K	Financial and insurance activities	0.1495	0.1317	0.0090	0.0088	589,682
L	Real estate activities	9.7985	9.7822	0.0140	0.0023	289,175
M69T71	Legal and accounting activities; activities of head offices; management consultancy activities; architectural and engineering activities; technical	0.0324	0.0207	0.0071	0.0046	912,709
M72	Scientific research and development	0.5844	0.3931	0.0814	0.1099	23,227
M73T75	Advertising and market research; other professional, scientific and technical activities; veterinary activities	0.0499	0.0335	0.0116	0.0048	257,690
N	Administrative and support service activities	0.0743	0.0431	0.0293	0.0018	1,114,627
P	Education	0.4183	0.3411	0.0295	0.0477	90,519
Q86	Human health activities	0.1827	0.1460	0.0270	0.0098	483,403
Q87_88	Residential care activities and social work activities without accommodation	0.0522	0.0439	0.0066	0.0018	272,135
R	Arts, entertainment and recreation	0.2383	0.1699	0.0377	0.0274	173,595
S	Other service activities	0.0641	0.0497	0.0120	0.0023	449,108
	Total	**0.2908**	**0.2466**	**0.0370**	**0.0072**	**16,706,641**

4 Descriptive evidence

In this section we provide some descriptive evidence on the exposure to natural disasters of socio-economic activities in 8,056 Italian municipalities for year 2011. The variables that we have selected as proxy for socio-economic exposure to natural disasters are population density, employment density, turnover and capital stock (divided also for its components: capital on buildings ad machineries). Indeed, according to Dilley (2005, p.31) "*to understand the risks posed by a range of hazards, it is also essential to characterize the exposure of people and their economic activities to the different hazards. Ideally, we would have a complete probability density function for population exposure to specific types of events...such estimates might vary depending on the time of the day, day of the week or month of the year*".

Population density based on place of residence is a proxy for potential life loss across different types of hazards (Dilley, 2005). However, because of commuting for work reasons, we also use employment density as an indirect measure of how exposed is a municipality during its 'working hours'.

To capture the exposure of economic activities, we instead focus on turnover and capital stock of firms. Turnover provides a measure of the gross economic value produced by an area in one year and it might be considered as the potential direct cost suffered by the area due to business interruption. Instead, capital stock reflects the average expected loss in buildings and machinery if all productive capital is completely destroyed in a square kilometre of land.

All these measures *per se* are able to provide information on the components that are directly exposed to natural disasters and that could cause direct losses. In order to account for the indirect effects induced by natural disasters in a given area, we have to account also for the dependency of each industry in a given municipality to all other industries in neighboring municipalities to retrieve intermediate inputs and as a market for final goods and service.

In the following of this section we first evaluate how the measures correlate each other. Then we look at the geographical distribution of proposed indicators and. we discuss the maps for the clustering of municipalities. Finally, we discuss our measures of indirect economic exposure.

4.1 Correlation across measures

Figure 1 and Table 6 report, respectively, the bivariate relationships and the correlation matrix between our measures of exposure to natural disasters. All measures are highly correlated. Correlation however is far from perfect between capital stock (and its components) and employment despite the former is estimated by using information of the latter. This means that heterogeneity in capital intensity across sectors and differences in sectoral composition across municipalities is substantial and results in rather heterogeneous estimates of exposure of productive capital stock. The greatest correlation is between total capital stock and capital stock in buildings (which represents a large share of the total capital stock), while the smallest correlation is between population and turnover.

Figure 1 – Relationship between variables (per square kilometre, year 2011)

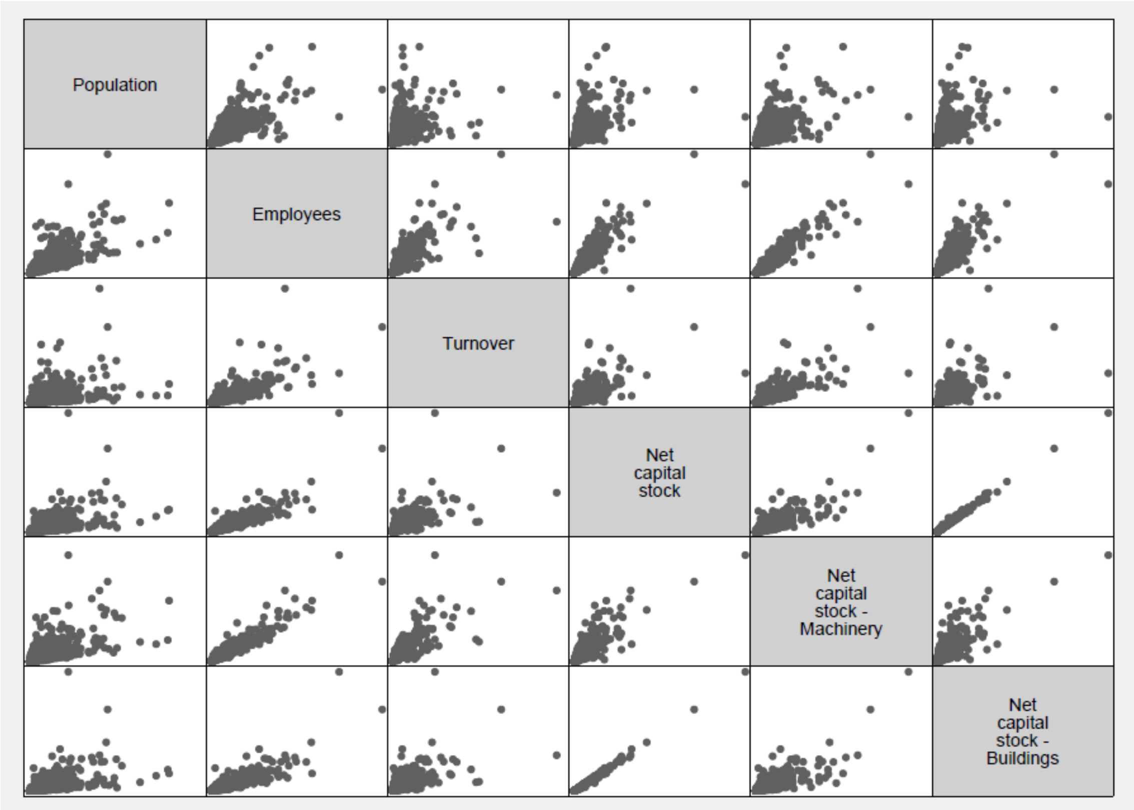


Table 6 – Correlation matrix

	Population	Employees	Turnover	Net capital stock	Net capital stock - Machinery	Net capital stock - Buildings
Population	1					
Employees	0.8367	1				
Turnover	0.6032	0.8269	1			
Net capital stock	0.7123	0.9222	0.7581	1		
Net capital stock - Machinery	0.7571	0.9612	0.8385	0.8906	1	
Net capital stock - Buildings	0.6895	0.8946	0.7273	0.9968	0.8522	1

Variables 'per square kilometre'. N=8056 municipalities.

4.2 Maps of direct exposure

In this section we map the measures of exposure for all 8,056 Italian municipalities. All measures are expressed in terms of average value per square kilometre. Besides maps, we also report top 10 and bottom 10 municipalities for each measure in Tables A1 and A2 in the Appendix.

Population density is reported in Figure 2 (panel a). As expected, population density is higher in urban areas (e.g. Napoli, Milano, Torino, Firenze, Palermo and the corresponding adjacent municipalities) and lower in mountainous areas. The first six municipalities in terms of population density all belong to the Napoli province (8 of the first 10 municipalities) while one belongs to the province of Milano (Bresso) and one to the province of Salerno (Atrani).

When considering employees per square kilometre (Figure 2,panel b) we observe some relevant difference. Employment seems to be more concentrated in large cities. At the same time, surrounding municipalities of large cities appear now less dense than when considering population. This reflects the fact that many people commutes from sub-urban municipalities to the urban centre to work. Looking at the first ten municipalities, we now observe a predominance of municipalities that belong to the province of Milano (5) followed by the province of Napoli (3).

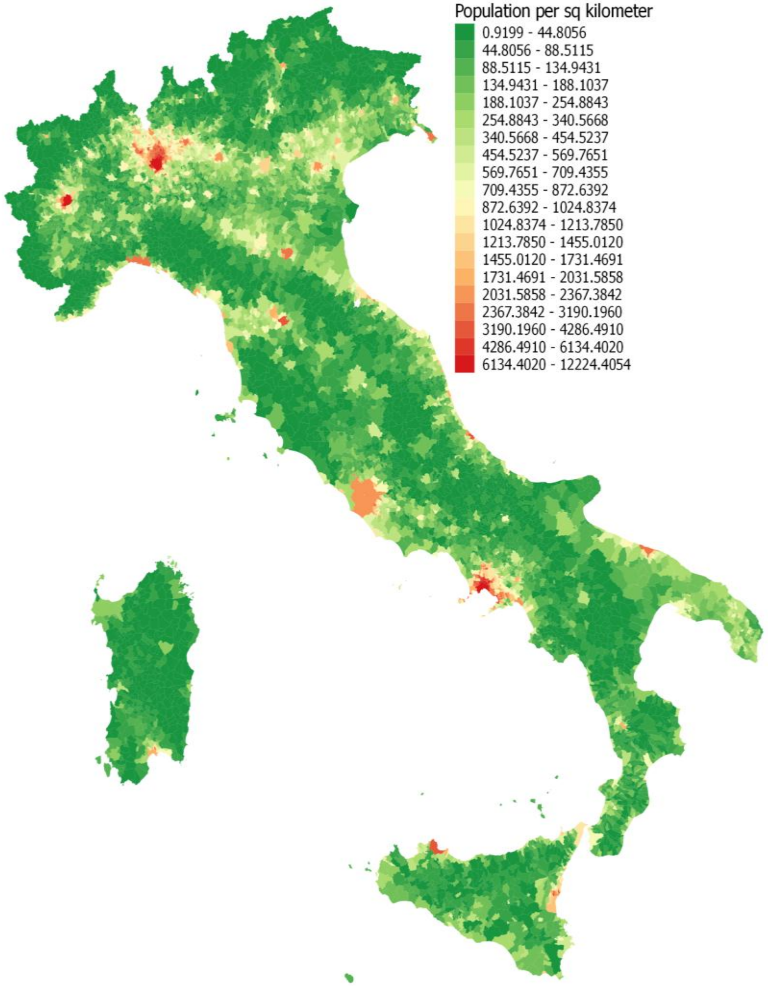
Turnover instead follows the common Italian pattern of economic growth being more concentrated in Northern Italy rather than in the Southern part of the country (Figure 3, panel a). The Lombardy, in general, and metropolitan area of Milan, in particular, look the more relevant areas. Indeed if we focus on the first ten municipalities ranked by turnover, eight over ten are in the metropolitan area of Milan, while the other two are in Lombardy.

Moving to total capital stock (Figure 3, panel b), we observe that its value is rather high also for medium-sized urban centres in the northern part of Italy (Padova, Bologna, Bergamo, Brescia, Genova) as well as municipalities in the northern part of the Adriatic coast. Among the top 10, municipalities in the province of Milano still lead (5).

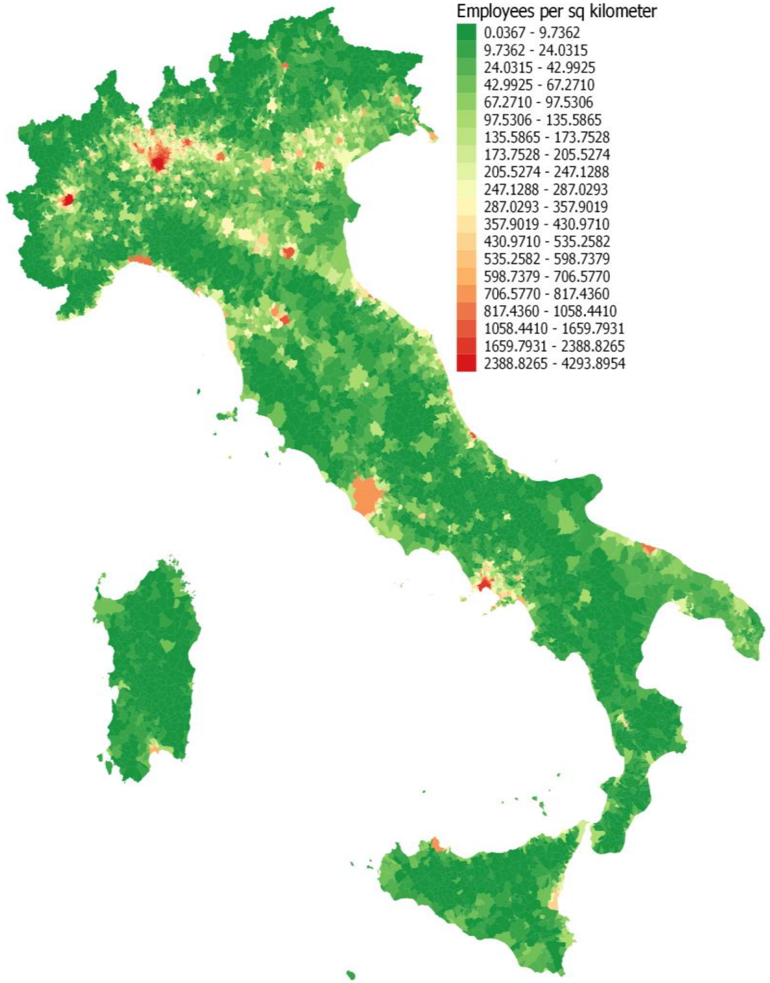
As a large share of the total capital stock is composed by buildings, the distribution of our measure of capital stock in building is very similar to the one of total capital (Figure 4, panel a).

The stock of capital in machinery is mostly concentrated in municipalities which are specialised in industrial production (Figure 4, panel b). Again, 6 municipalities of the top 10 are located in the province of Milano.

To sum up, descriptive evidence highlights a rather heterogeneous exposure of municipalities to natural disasters. However, the correlation between the various measures is very high and exposure according to different metrics tend to be overlapped to a great extent.

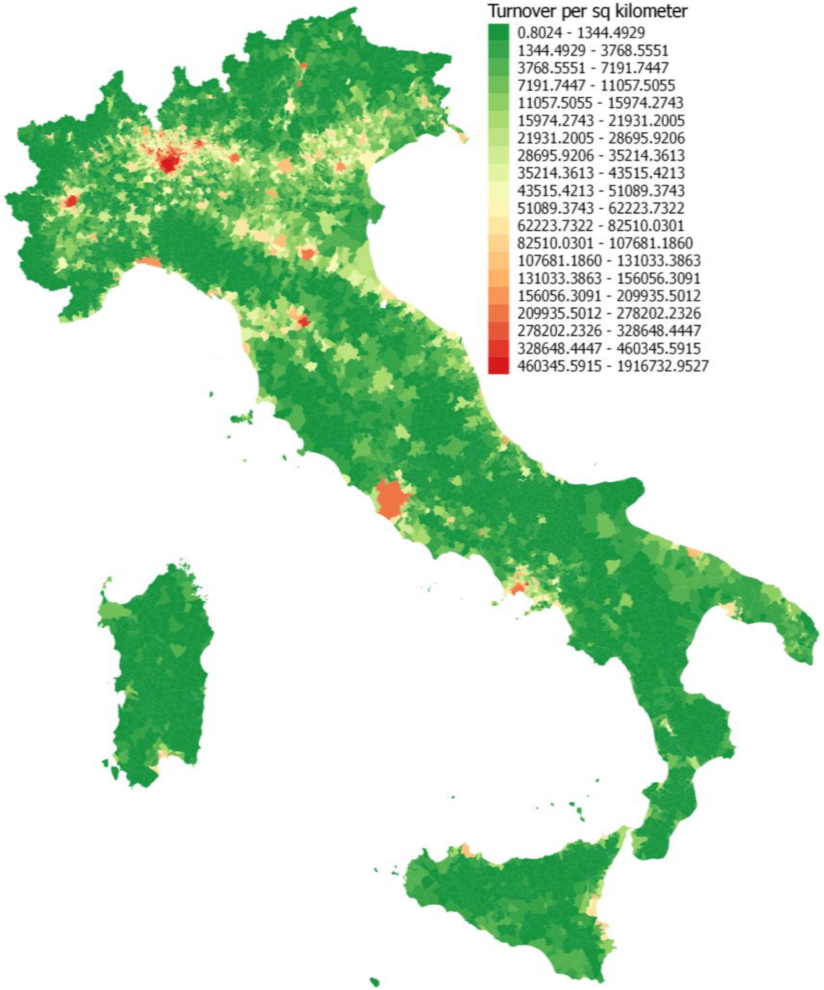


(a) Population density (per square kilometre, year 2011)

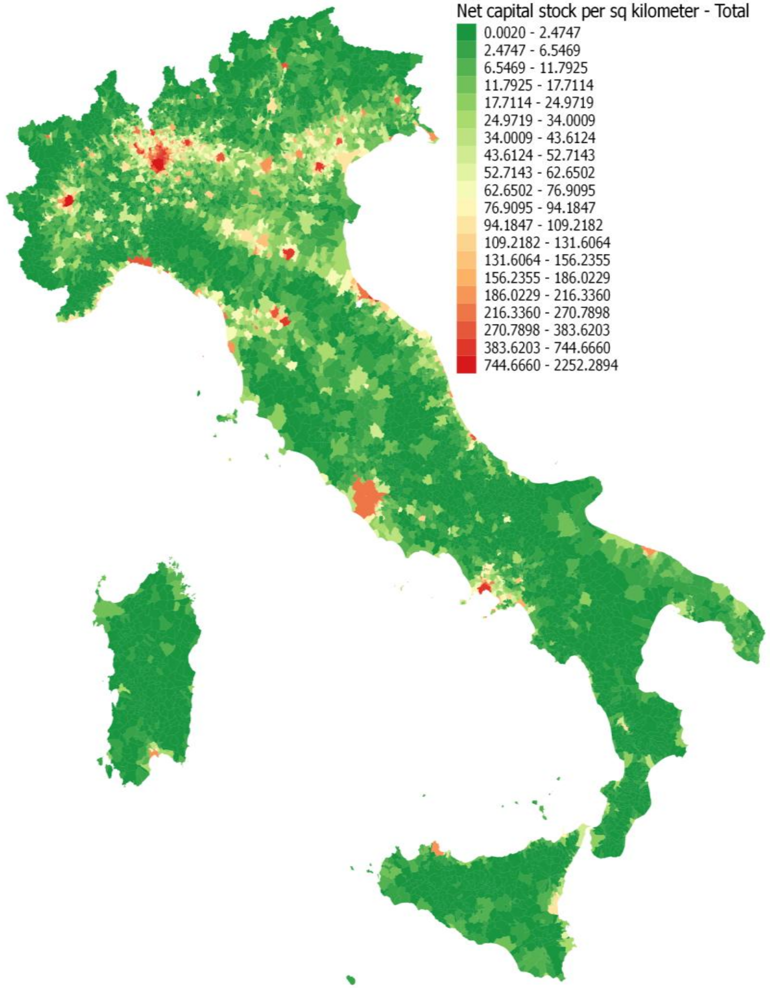


(b) Employees (per square kilometre, year 2011)

Figure 2 – Direct exposure of population and employees

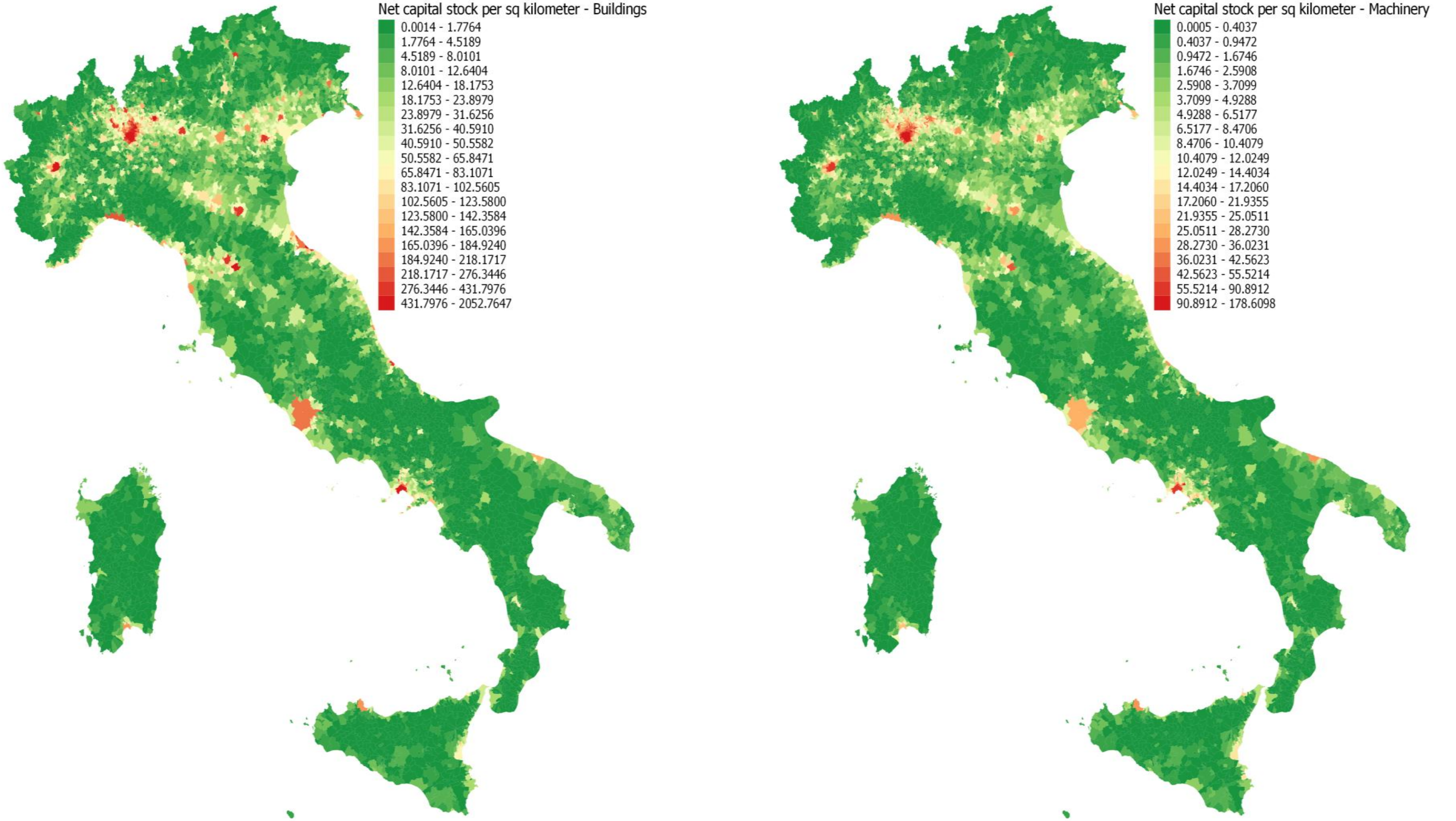


(a) Turnover (per square kilometre, year 2011)



(b) Net capital stock - Total (per square kilometre, year 2011)

Figure 3 – Direct exposure of turnover and total capital stock



(a) Net capital stock - Buildings (per square kilometre, year 2011)

(b) Net capital stock - Machinery (per square kilometre, year 2011)

Figure 4 – Direct exposure of capital stock in buildings and machinery

4.3 Maps of indirect exposure

4.3.1 Spatial statistics

As a last step of descriptive evidence, we evaluate some geographical features of our measures of exposure. For all variables of interest we estimate the spatial autocorrelation (Moran's I, Moran, 1950) using as geographical weights either the contiguity matrix which considers only direct neighbours (first column) or the contiguity matrix that considers up to the fifth group of neighbours. The Moran’s I is computed as:

$$I = \frac{\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \frac{N}{\sum_i \sum_j w_{ij}} \tag{4}$$

Results are reported in Table 7. Spatial autocorrelation is rather high for population density, employee density and capital stock (total and its various components) per square kilometre, while it is rather low for turnover. Spatial correlation is much greater when using one-neighbours spatial weights than when using five-neighbours spatial weights.

Table 7 – Spatial autocorrelation (Moran’s I)

Variable	Moran’s I 1 neighbour	Moran’s I 5 neighbours
Population	0.728	0.266
Employees	0.695	0.236
Turnover	0.087	0.040
Net capital stock – Total	0.540	0.169
Net capital stock – Buildings	0.505	0.152
Net capital stock – Machinery	0.638	0.245
Net capital stock - Intangible	0.571	0.170

4.3.2 Clustering

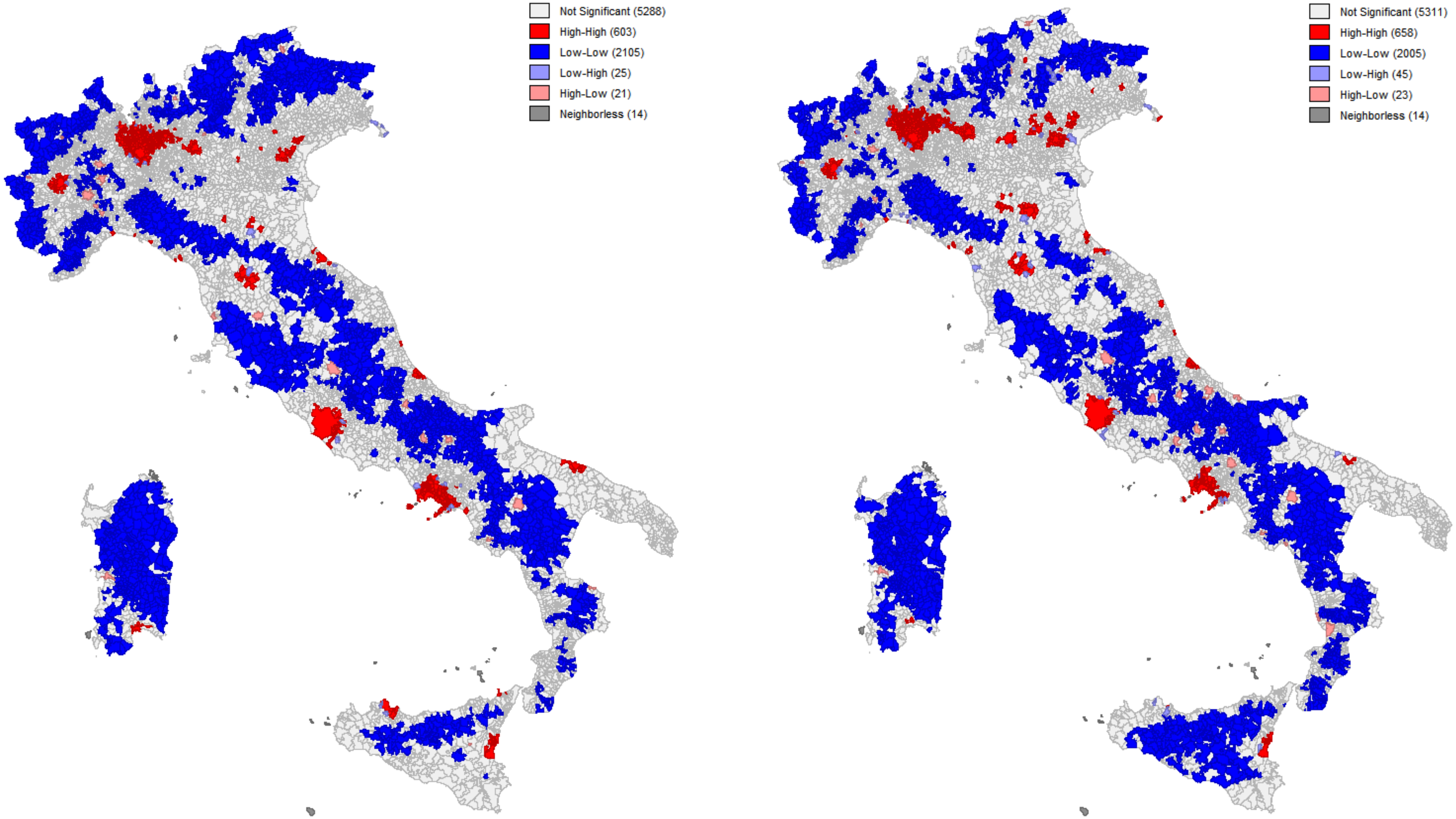
We compute Local Indicators of Spatial Associations (LISA, see Anselin, 1995). For each municipality we compute the local Moran’s I (based on the 5-neighbours weighting matrix) and identify clusters of municipalities and outliers. Whenever the local Moran’s I is not statistically different from zero the municipality does not belong to a cluster and it is not an outlier (light grey area). On the other hand, four possible outcomes are possible when the local Moran’s I is statistically significant:

- the municipality belongs to a clusters with high values (HH, red area);
- the municipality belongs to a cluster with low values (LL, blue area);
- the municipality is an outlier with high value surrounded by municipalities with low value (HL, pink area);

- the municipality is an outlier with low value surrounded by municipalities with high value (LH, light blue area).

This approach is particularly useful as it allows to easily identify possible hot-spots or critical areas in terms of exposure to natural disasters. If a cluster ‘HH’ belongs to a region characterized by high probability of experiencing a natural disaster, that will generate large damages no matter the specific municipality (or municipalities) is directly affected as most municipalities in the region have high values of exposure. On the contrary, ‘LL’ clusters in regions with high probability of experiencing a natural disaster will experience rather low average expected damages as economic activities are not concentrated in any of the municipalities of the clusters. Finally, ‘HL’ municipalities belonging to areas with high risk of natural disasters will be characterized by a very high expected damage which is combined, however, to a rather low probability of being the municipality that is hit among the ones belonging to the larger region.

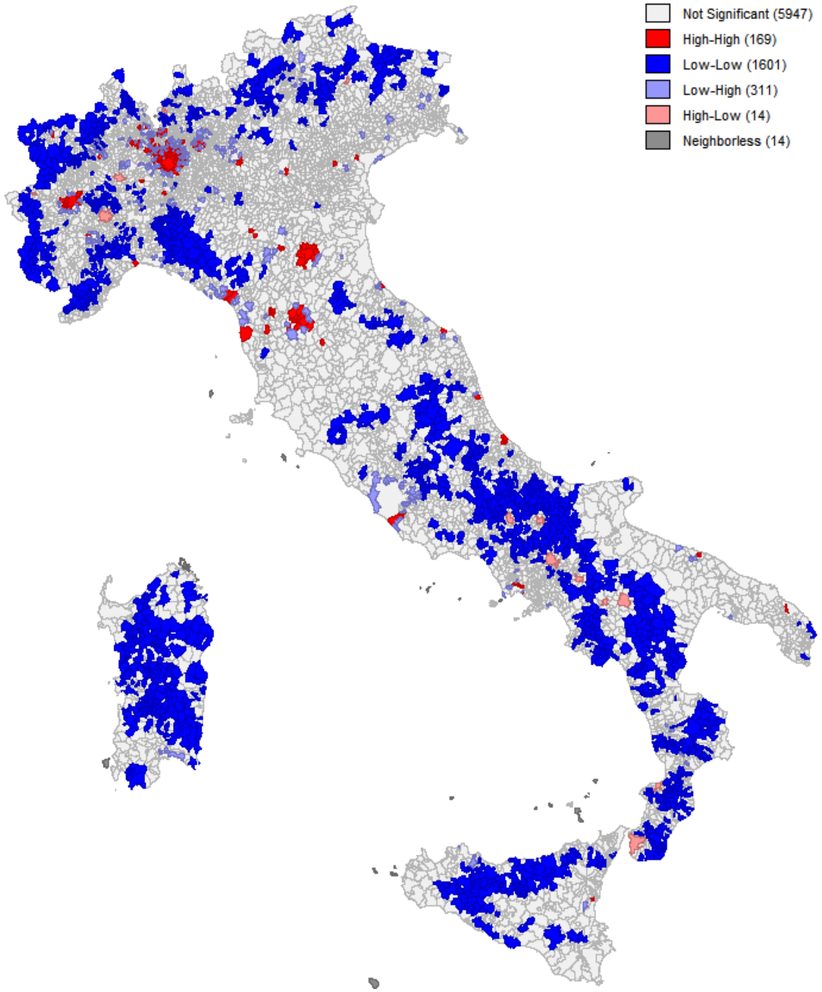
Results for population, employment, turnover, total capital stock, capital stock in buildings and capital stock in machinery are shown in Figure 5, Figure 6 and Figure 7. For what concerns population (Figure 5, panel a), we observe HH clusters in medium-large urban areas (Milano, Torino, Genova, Bergamo, Padova, Firenze, Prato, Rimini, Roma, Pescara, Napoli, Bari, Palermo and Cagliari, among others) while LL clusters emerge in the mountains of Alps and Appennini. Few HL outliers also exists in correspondence of medium towns while LH outliers are very uncommon. Evidence for employment density (Figure 5, panel b) is very similar to what is found for population while for turnover (Figure 6, panel a) we observe a much smaller number of (smaller) HH clusters. Finally, the various measure of capital stock (Figure 6, panel b, and Figure 7) tend to reflect to a great extent what we found for employment.



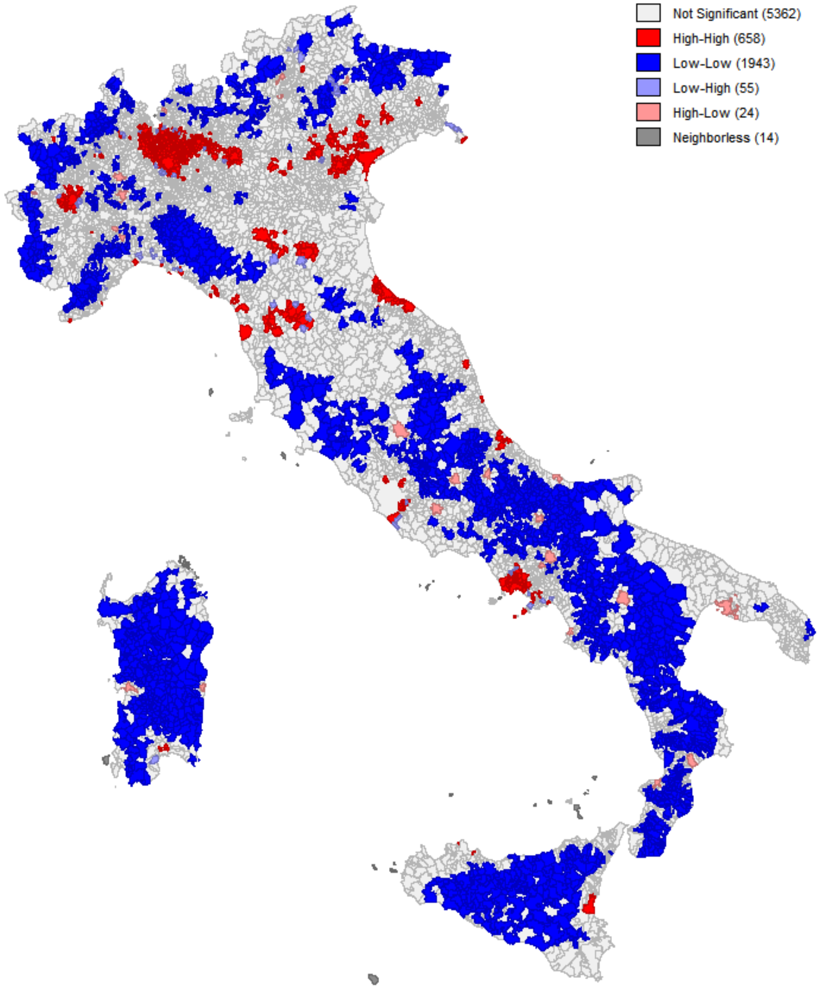
(a) Local Moran's I for population density (year 2011)

(b) Local Moran's I for employees density (year 2011)

Figure 5 – Clustering for population and employees

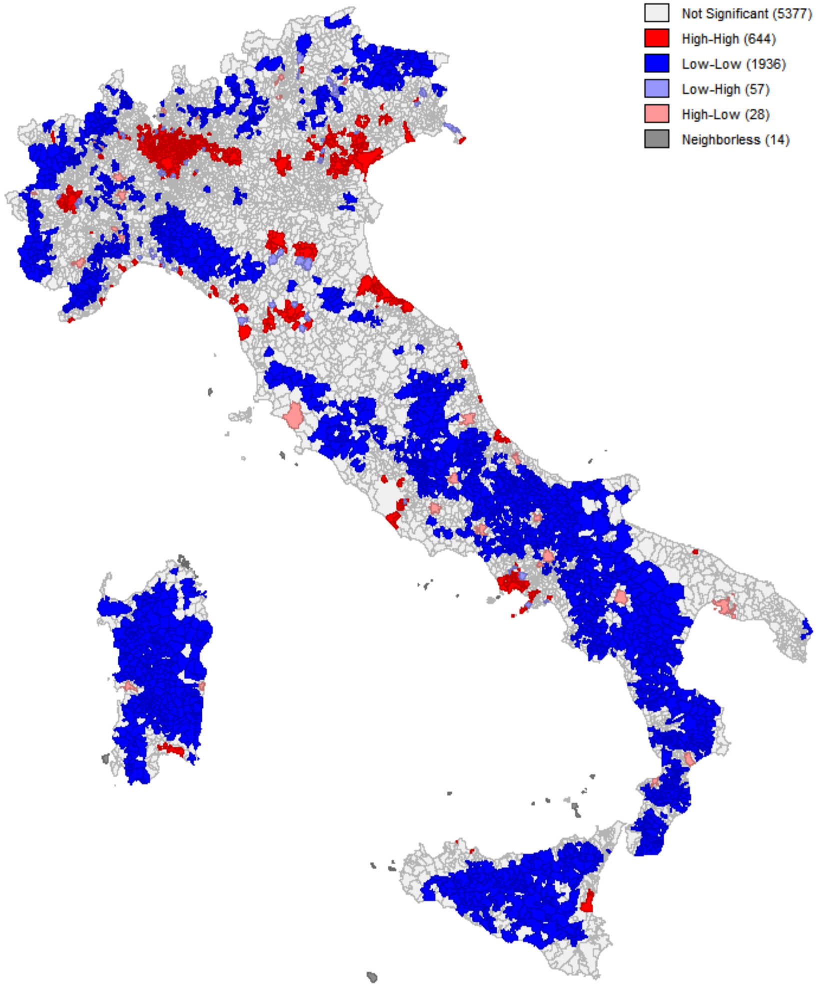


(a) Local Moran's I for turnover density (year 2011)

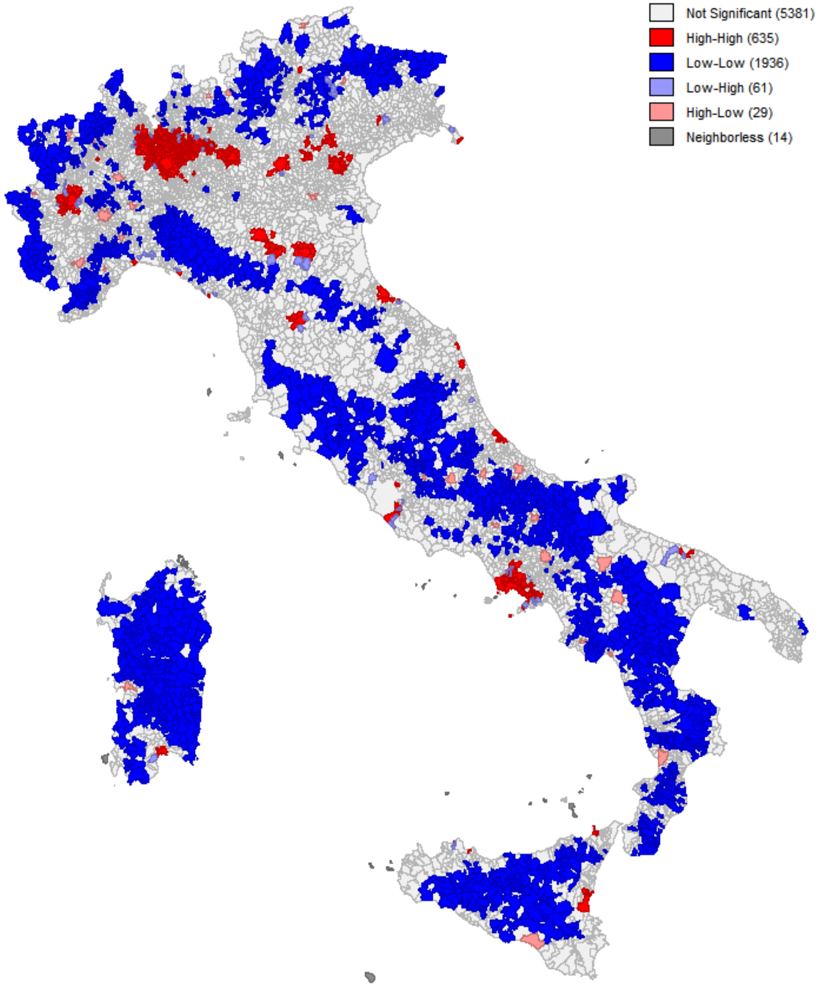


(b) Local Moran's I for net total capital stock density (year 2011)

Figure 6 – Clustering for turnover and total capital stock



(a) Local Moran's I for net capital stock in buildings density (year 2011)



(b) Local Moran's I for net capital stock in machinery density (year 2011)

Figure 7 – Clustering for capital stock in buildings and machinery

4.3.3 Socio-economic exposure to the damage of the nearby municipalities

The evaluation of spatial clustering based on direct exposure to risk is an implicit way of assessing indirect exposure to risk. The link between neighbouring municipalities with similar (high or low) exposure may indicate some sort of economic linkage between the municipalities. Even though proximity is often endogenous and driven by agglomeration forces that enable to take advantage of geographically concentrated economic linkages, a more explicit measure of economic linkage is needed.

At a more aggregate level, the economic literature has focused on inter-sectoral (input output) relationships as a mechanism through which shocks diffuse throughout the economy (Acemoglu et al., 2012). The general idea is that, especially in the short run, the collapse of a sector (due to any reason, including natural disasters) has an impact on other sectors that are either upstream (suppliers) or downstream (customers) in the supply chain. If, for any reason, the output of a sector experiences an unexpected drop, firms in that sector will respond by reducing their demand for intermediate goods from upstream sectors. Suppliers, in turn, will also reduce their production as one of their customer sectors has reduced its demand. Moreover, a collapse in the production of a sector will also generate shortages (at least in the short run) of inputs for those sectors that need goods or services produced by the collapsed sector (i.e. downstream sectors). These shortages induce a slow down (or even an interruption) of the production activities of the downstream sectors.

Even though approaches based on input–output modeling have been criticized for some weaknesses (i.e. rigid structure and lack of responses to price changes, see Rose, 2004), they have been widely used in the assessment of disaster damages, mostly because of their attitude to capture the economic interdependencies within a regional economy (Okuyama, 2014). For instance Tan et al. (2015) use IO to estimate the maximum percentage of damage that an economic system is able to absorb. Rose and Wei (2013) simulate the impact of a seaport shutdown to the national economy through input-output while Van Der Veen and Logtmeijer (2005) simulate the impact of a large-scale flooding in one province of Netherlands.

To translate this approach to the local level (e.g. municipality), a number of assumptions need to be made. First, statistical agencies, with very few exceptions, only provide national input-output tables. This means that it is not possible to account for likely geographic heterogeneity in technical coefficients. Even though these coefficients generally reflect rather standard 'recipes' for producing final goods, heterogeneity exists and cannot be accounted for. More importantly, a second assumption refers to the share of inputs that a firm purchases from local suppliers and to the share of output that a firm sells to local customers. National input-output tables are split into a 'domestic' transaction table and a 'rest of the world' transaction table. In absence of any information about the relevance of local suppliers and customers, we use the national domestic input-output table that represents an upper-bound of the relevance of local suppliers. The implicit assumption, in fact, is that all 'national' inputs are completely purchased from firms in neighbouring municipalities. Even though this is a very strong assumption, the absence of information about cross-regional and cross-municipal trade flows limits the possibility of providing any better estimate of the share of 'local' sourcing of intermediates over total 'national' sourcing of intermediates. A third assumption relates to the definition of 'local' linkages, namely how far should be the municipality affected by natural disasters to influence other cities (Östh et al., 2016). To evaluate the sensitivity of our mapping to this assumption we report results for two different thresholds of distance (e.g. 20 km and 50 km). Finally, the diffusion of shocks influences, as a first step, only direct suppliers and customers. However, the shock also propagates to suppliers of suppliers and customers of customers. To simplify, in our analysis we only consider 'first order' effects and leave the evaluation of higher order effects (e.g. using the Leontief model for suppliers and the Ghoshian model for customers) for future research.

We therefore build two different measures. The first measures the share of output (turnover) created in a municipality that can be absorbed by firms that operate in neighbouring municipalities as intermediate inputs, within a certain distance (either 20km or 50km). We first compute the total output by sector in the municipalities within the radius of the reference municipality. These totals are then post-multiplied to the technical coefficient matrix of the input-output matrix (i.e. the matrix **A**, that describes the amount of euro of goods that are required from each sector *j* to produce one euro of goods for sector *i*). We obtain, in this way, the hypothetical demand of intermediate inputs from each sector in neighbouring municipalities. We then divide this hypothetical demand by the output (of each sector) produced in the municipality of reference and take the average across sectors (weighted by the turnover of each sector). This measure indicates the relative share of inputs that neighbouring municipalities may potentially purchase from companies in the municipality of reference. We define this measure as "*Destination of final output in neighbouring municipalities*". This measure captures the potential lack of goods in the neighbouring municipalities due to a shock in production (eventually driven by a natural disaster) that occurs in the municipality of reference. This may undermine production activities in neighbouring municipalities and determine an indirect loss also in case the disaster only affects the municipality of reference.

Results are reported in Figure 8. To ease the graphical representation, we rescaled the indicator to be in a range between 0 and 1. Figure 8 does not show a well defined pattern. What is interesting to note, however, is that at the top of the list we have both municipalities that host large industrial facilities (i.e. the steel districts of Piombino and Taranto) and large cities (e.g. Rome, Milan, Palermo, Turin).

Similarly, we compute the share of intermediate inputs that can be possibly retrieved locally (i.e. in neighbouring municipalities) by firms that operate in the municipality of reference. We post-multiply the vector of total turnover by sector of the municipality of reference by the technical coefficient matrix to obtain the potential demand for intermediate inputs from firms in the municipality. We then divide each element of this vector by the vector of total production (turnover) by sector in neighbouring municipalities and take averages across sector (weighted by the turnover of each sector). This measure proxies the potential share of inputs that can be retrieved by firms in the municipality of reference from firms that operate in neighbouring municipalities. We define this measure as "*Source of intermediate inputs in neighbouring municipalities*". The measure is useful to quantify the potential drop in demand (for intermediates) that could be experienced by neighbouring municipality in the case a disaster interrupts production in the municipality of reference.

Results are reported in Figure 9. Also in this case, to ease the graphical representation, we rescale the indicator to be in a range between 0 and 1. Even though the list of municipalities at the very top remain the same (i.e. industry-based municipalities and large cities), the correlation with the previously discussed measure (Figure 8) is positive but not very large (0.45), thus suggesting that these measures depict different dimensions of indirect exposure.

Results should be interpreted as follows: the overall density of activities (of any sector) in large cities generates a large demand for intermediate inputs, that usually is above the output produced in neighbouring municipalities. On the other hand, manufacturing sector (such as steel industries) are characterized, on average, by much larger 'upstream' multipliers (or, in our case, technical coefficients) than service sectors as they require a large amount of intermediate inputs to carry out production activities. This generates a large demand for intermediates that often cannot be completely met by neighbouring municipalities, leading to high values for our indicators.

Not all sectors are likely to be influenced (directly and indirectly) by natural disasters in the same way. On the one hand, manufacturing sectors are, on average, more capital intensive than service sectors. In case the natural disaster under evaluation has relevant consequences in terms of destruction of capital goods, capital intensive sectors are more likely to be forced to interrupt their production activities than less capital intensive sectors. On the other hand, given that manufacturing sectors are 'tradable' sectors (i.e. they are exposed to foreign competition). Tradability implies that there is the risk that temporary interruptions in production due to the disaster induce a permanent change in the structure of the supply chain in favour of manufacturing firms operating in other areas.

For these reasons, we also provide evidence for manufacturing-to-manufacturing linkages as well as manufacturing-to(from)-all sectors linkages. These measures are reported in Figure 10, Figure 11, Figure 12 and Figure 13. While providing a full discussion of the results for these alternative measures goes beyond the aim of the paper, it is interesting to observe that these measures positively correlate each other even though this correlations is usually far from perfect (see Table 8)

Table 8 – Correlation across measures of indirect exposure

Destination of final output in neighbouring municipalities (20 km radius)			
	Tot-Tot	Manuf-Tot	Manuf-Manuf
Tot-Tot	1		
Manuf-Tot	0.58	1	
Manuf-Manuf	0.59	0.98	1
Source of intermediate inputs in neighbouring municipalities (20 km radius)			
	Tot-Tot	Manuf-Tot	Manuf-Manuf
Tot-Tot	1		
Manuf-Tot	0.73	1	
Manuf-Manuf	0.68	0.88	1

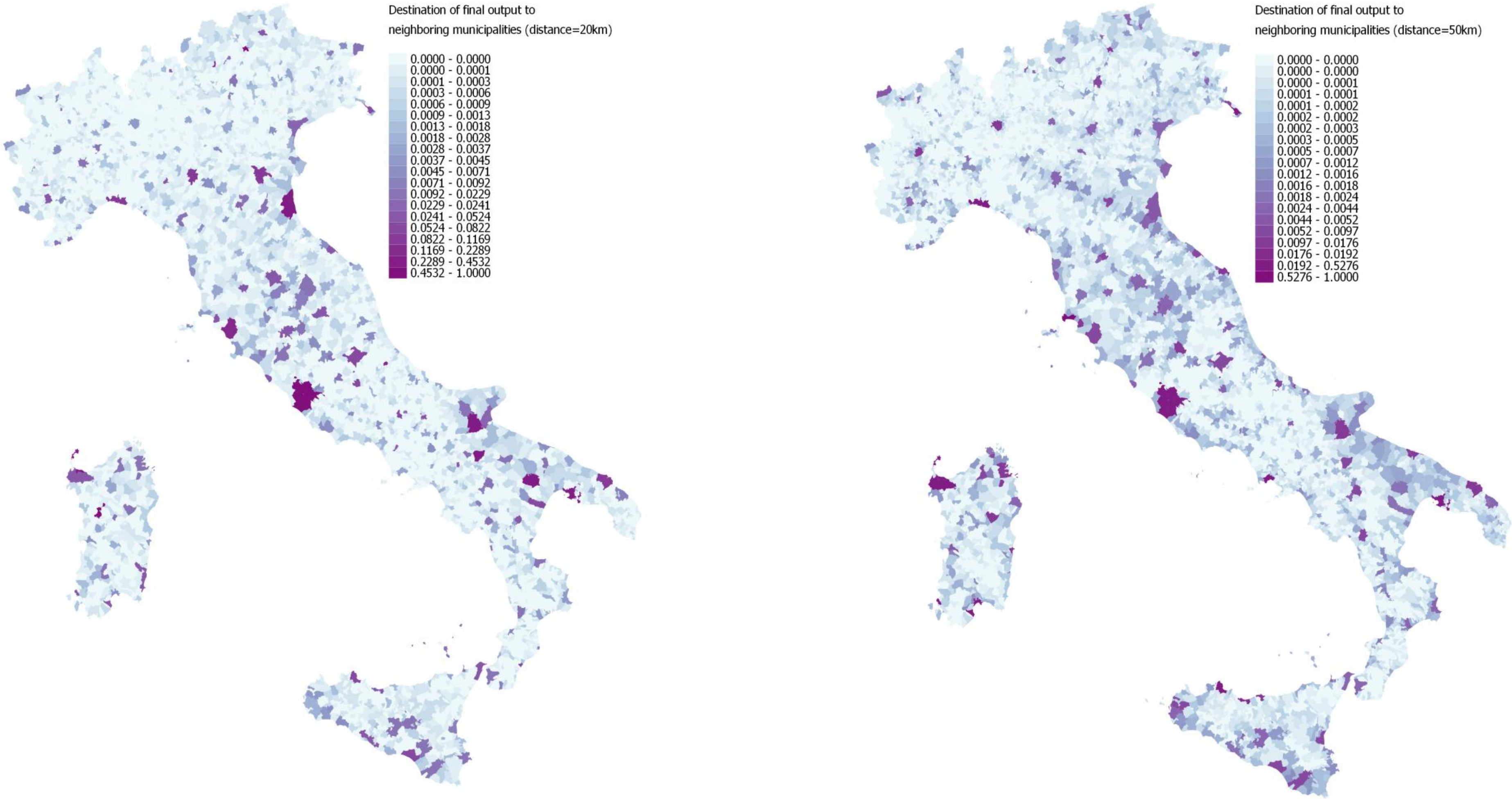


Figure 8 – Destination of final output in neighbouring municipalities (all sectors)

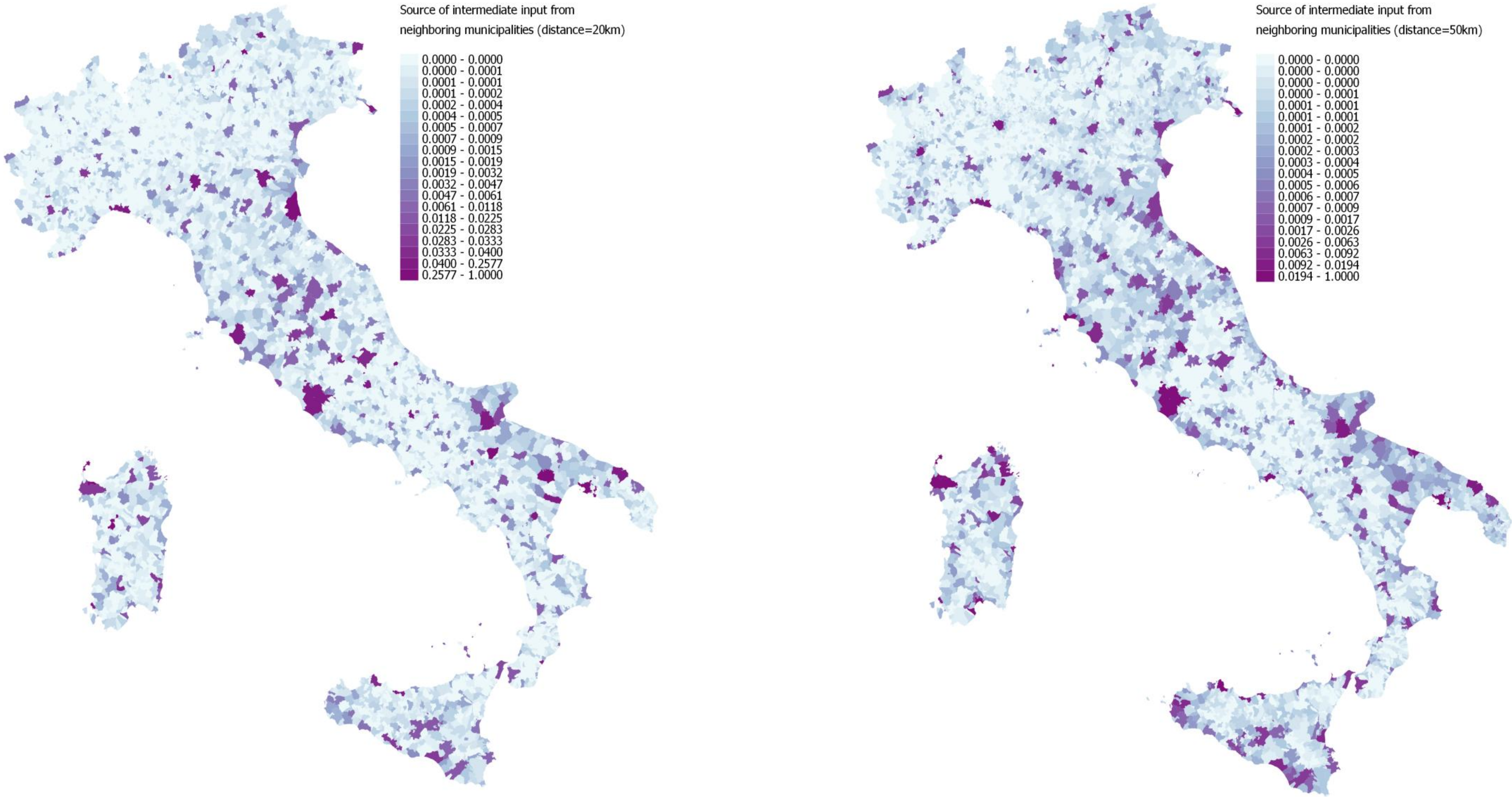


Figure 9 – Source of intermediate inputs in neighbouring municipalities (all sectors)

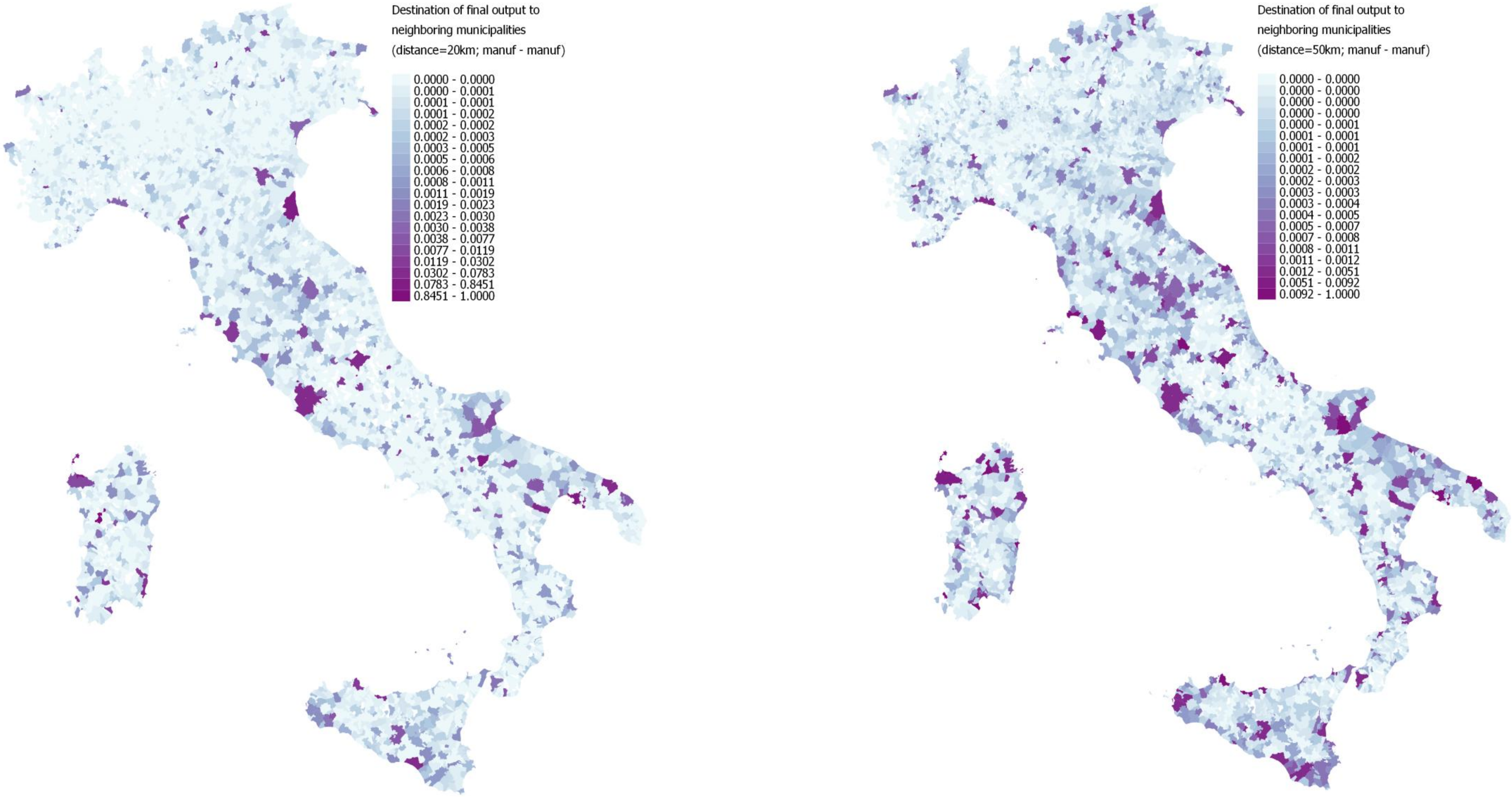


Figure 10 – Destination of final output in neighbouring municipalities (manufacturing to manufacturing)

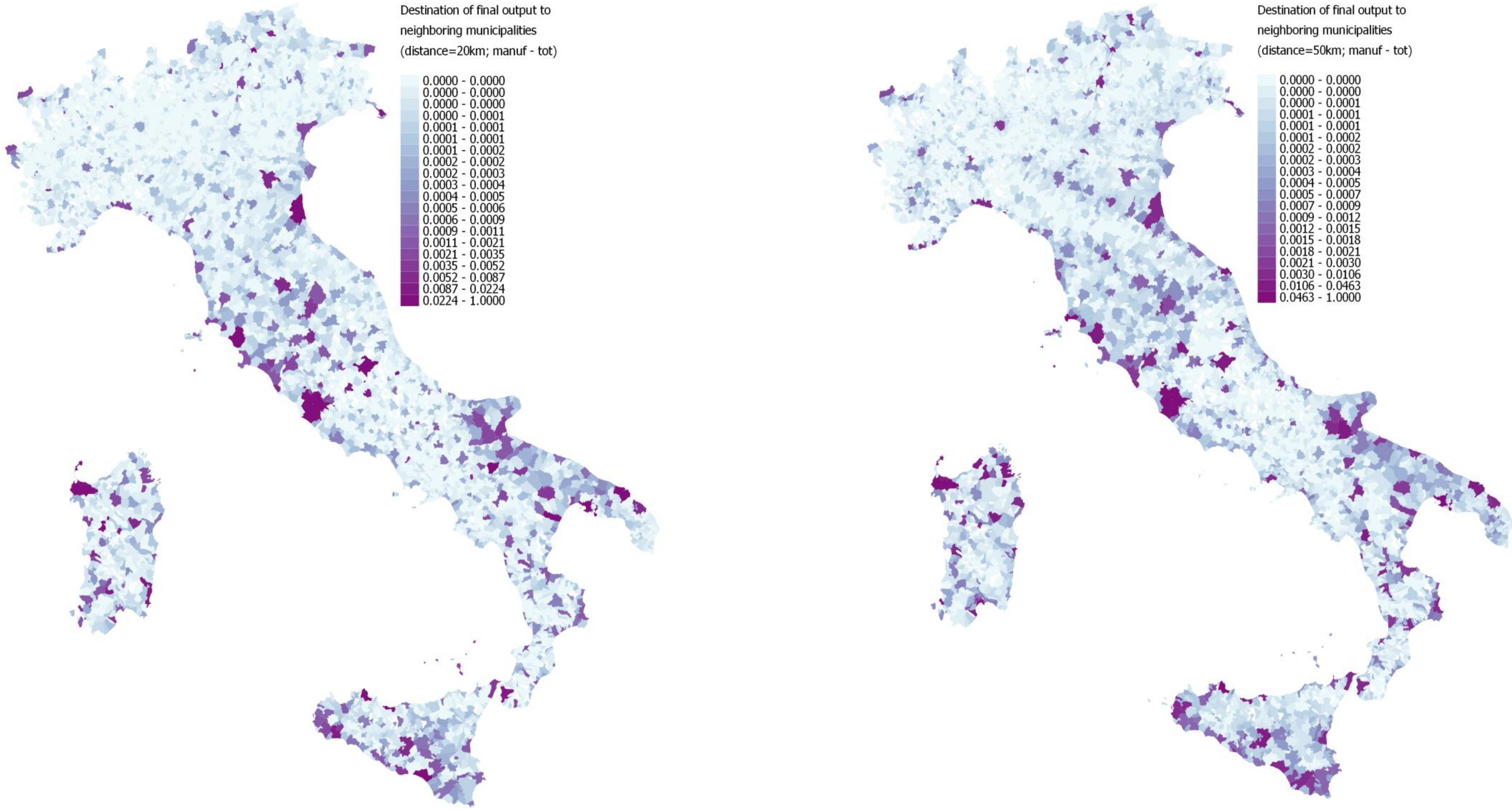


Figure 11 – Destination of final output in neighbouring municipalities (manufacturing to all sectors)

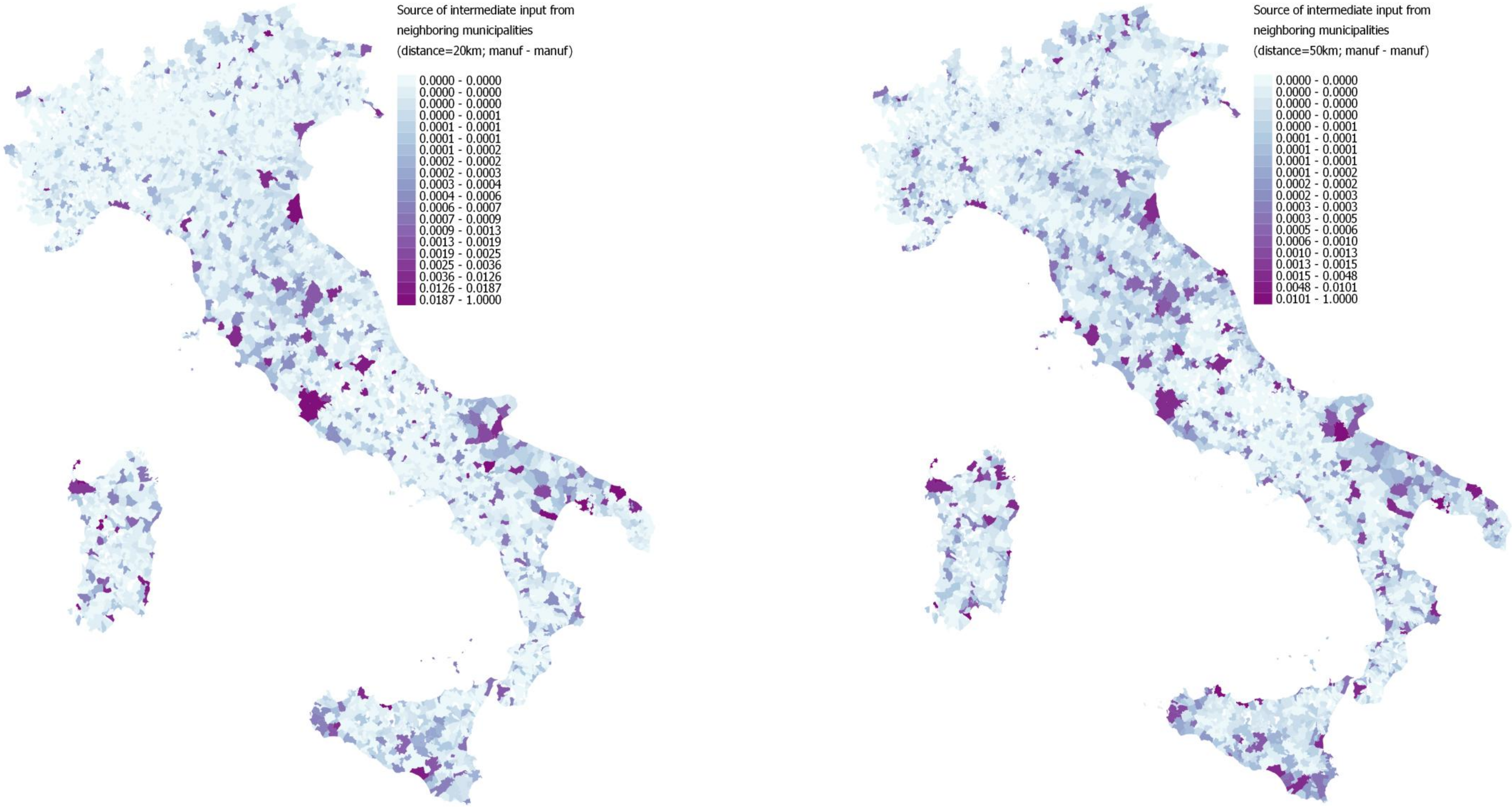


Figure 12 – Source of intermediate inputs in neighbouring municipalities (manufacturing to manufacturing)

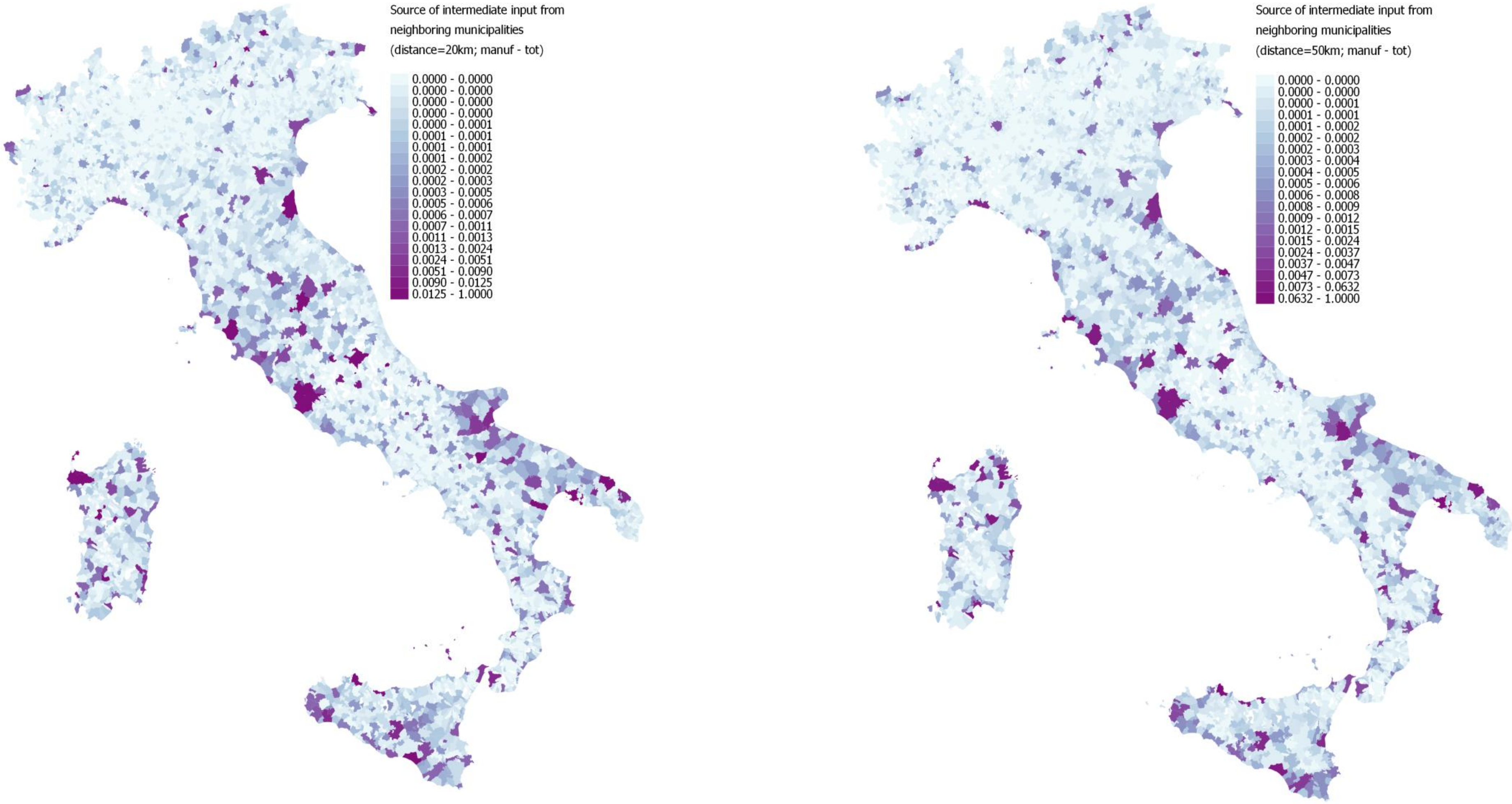


Figure 13 – Source of intermediate inputs in neighbouring municipalities (manufacturing from all sectors)

5 Conclusion

Very few effort has been devoted until know to addressing the most appropriate socio-economic values for determining exposure to natural disasters in an ex-ante perspective and in assessing the cost suffered by local areas in an ex-post perspective. This study is, to our knowledge, an attempt of moving toward this direction. We have used administrative and statistical data to estimate a set of economic information that can be employed to map the potential economic exposure of narrowly defined geographical units (e.g. municipalities) in terms of direct and indirect socio-economic consequences of natural disasters. These types of maps can be integrated into existing and emerging models for risk assessment or as benchmark for urban planning, risk mitigation policies and risk prevention.

Besides providing estimates of direct socio-economic exposure to natural disasters, we also develop and compute different measures of indirect socio-economic exposure. These indicators are particularly useful to quantify the overall potential economic impact of natural disasters on specific areas, also beyond the boundaries of the location that is directly affected by natural disasters. Our results show that even though all indicators (direct and indirect exposure) are positively correlated, due to structural differences across municipalities (mostly in terms of density of population and economic activities), these correlations are far from perfect and suggest that differences in the economic structure of municipalities may result in different transmission of shocks to neighboring municipalities as a consequence of natural disasters.

The approach developed in this study as well as the type of data that are employed may be particularly useful for academic and policy-relevant evaluations of risk assessment and damage cost evaluation of natural disasters, from both an ex-ante and ex-post perspective. The indicators we propose could be further refined to account for the specificities of the case study for which they are employed. It could be useful, for example, to geo-reference all economic activities of a narrowly defined area (i.e. smaller than the administrative boundaries of a municipality), to use more detailed information about the distance between the municipality of reference and the economic activities that could potentially suffer from indirect damages or, finally, to select a reduced number of sectors due to their higher or lower exposure to direct or indirect damages.

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Appendix - Detailed information on top and bottom municipalities

Table A1 – Top and bottom municipalities

Municipality	Province	Population density
Top 10		
Casavatore	Napoli	12224
Portici	Napoli	12110
San Giorgio a Cremano	Napoli	11089
Melito di Napoli	Napoli	9688
Napoli	Napoli	8082
Frattaminore	Napoli	7661
Bresso	Milano	7602
Arzano	Napoli	7423
Atrani	Salerno	7355
Cardito	Napoli	6958
Bottom 10		
Ribordone	Torino	1.5367
Rassa	Vercelli	1.5253
Massello	Torino	1.5160
Balme	Torino	1.5149
Carrega Ligure	Alessandria	1.5021
Valsavarenche	Aosta	1.3530
Rhemes-Notre-Dame	Aosta	1.3128
Acceglio	Cuneo	1.1483
Argentera	Cuneo	1.0359
Briga Alta	Cuneo	0.9199

Municipality	Province	Employees per sq kilometre
Top 10		
Milano	Milano	4294
Fiera di Primiero	Trento	3212
Casavatore	Napoli	2532
Torino	Torino	2514
Corsico	Milano	2389
Sesto San Giovanni	Milano	2134
Cologno Monzese	Milano	2103
Napoli	Napoli	1949
Arzano	Napoli	1920
Bresso	Milano	1889
Bottom 10		
Dogna	Udine	0.1563
Ingria	Torino	0.1356
Montelapiano	Chieti	0.1209
Semestene	Sassari	0.1071
Tramonti di Sopra	Pordenone	0.0967
Briga Alta	Cuneo	0.0958
Oncino	Cuneo	0.0739
Ribordone	Torino	0.0459
Acquacanina	Macerata	0.0373
Carrega Ligure	Alessandria	0.0367

Municipality	Province	Turnover per square kilometre
Top 10		
Cusano Milanino	Milano	1916733
Milano	Milano	1269516
Pioltello	Milano	1010112
Grandate	Como	975403
San Donato Milanese	Milano	917359
Corsico	Milano	748741
Bresso	Milano	705451
Assago	Milano	686283
Curno	Bergamo	668926
Sesto San Giovanni	Milano	596493
Bottom 10		
Bellino	Cuneo	5.4156
Tramonti di Sopra	Pordenone	4.7404
Cursolo-Orasso	Verbano-Cusio-Ossola	4.6218
Cervatto	Vercelli	3.9840
Montelapiano	Chieti	2.2980
Briga Alta	Cuneo	2.0478
Ribordone	Torino	2.0018
Carrega Ligure	Alessandria	1.2487
Acquacanina	Macerata	0.9868
Oncino	Cuneo	0.8024

Municipality	Province	Net capital stock per square kilometre - Total
Top 10		
Fiera di Primiero	Trento	2252
Milano	Milano	1580
Torino	Torino	955
Cattolica	Rimini	757
Cusano Milanino	Milano	745
Cologno Monzese	Milano	730
Bresso	Milano	640
Riccione	Rimini	622
Monza	Monza e della Brianza	619
Corsico	Milano	615
Bottom 10		
Semestene	Sassari	0.0122
Cursolo-Orasso	Verbano-Cusio-Ossola	0.0109
Camerata Nuova	Roma	0.0107
Briga Alta	Cuneo	0.0097
Caprauna	Cuneo	0.0081
Montelapiano	Chieti	0.0066
Oncino	Cuneo	0.0055
Acquacanina	Macerata	0.0034
Ribordone	Torino	0.0026
Carrega Ligure	Alessandria	0.0020

Table 9 – Top and bottom municipalities (by type of capital good)

Municipality	Province	Net capital stock per square kilometre - Buildings	Municipality	Province	Net capital stock per square kilometre - Machinery
	Top 10			Top 10	
Fiera di Primiero	Trento	2053	Fiera di Primiero	Trento	179
Milano	Milano	1404	Milano	Milano	134
Torino	Torino	837	Cusano Milanino	Milano	119
Cattolica	Rimini	721	Cologno Monzese	Milano	106
Cusano Milanino	Milano	615	Casavatore	Napoli	102
Riccione	Rimini	598	Pomigliano d'Arco	Napoli	94
Cologno Monzese	Milano	577	Corsico	Milano	91
Monza	Monza e della Brianza	559	Torino	Torino	86
Lissone	Monza e della Brianza	553	Pero	Milano	85
Bresso	Milano	546	San Donato Milanese	Milano	84
	Bottom 10			Bottom 10	
Cursolo-Orasso	Verbano-Cusio-Ossola	0.0083	Canosio	Cuneo	0.0027
Pramollo	Torino	0.0080	Perlo	Cuneo	0.0027
Camerata Nuova	Roma	0.0074	Montelapiano	Chieti	0.0021
Briga Alta	Cuneo	0.0071	Cursolo-Orasso	Verbano-Cusio-Ossola	0.0020
Caprauna	Cuneo	0.0055	Caprauna	Cuneo	0.0020
Oncino	Cuneo	0.0045	Briga Alta	Cuneo	0.0020
Montelapiano	Chieti	0.0045	Oncino	Cuneo	0.0008
Acquacanina	Macerata	0.0029	Ribordone	Torino	0.0008
Ribordone	Torino	0.0018	Carrega Ligure	Alessandria	0.0006
Carrega Ligure	Alessandria	0.0014	Acquacanina	Macerata	0.0005