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THE EXPOSURE OF ITALIAN MANUFACTURING FIRMS TO HYDROGEOLOGICAL RISK

by Michele Loberto* and Riccardo Russo*

Abstract

This paper introduces a new methodology for assessing the exposure of Italian companies to natural hazards, which accounts for the distribution of companies' activity across different sites and locations. We apply this methodology to evaluate the exposure of manufacturing companies to flood and landslide risks. The shares of manufacturing workers directly exposed to floods and landslides are 29% and 5% respectively. The exposure to hydrogeological risk is correlated with company characteristics, in particular with the number of company sites.

JEL Classification: D22, Q54, R11.

Keywords: natural disasters, floods, landslides, climate risk, firms.

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* Bank of Italy.

1 Introduction[1]

Weather-related extreme events have a significant impact on economic activity. Between 1980 and 2020, total economic losses from these events amounted to about €450 billion in the European Union (European Environment Agency, 2022), and without effective mitigation and adaptation strategies, economic losses are expected to increase dramatically in the future because of climate change (Feyen et al., 2020). Yet, several information gaps exist in many countries regarding the exposure of economic agents to climate-related physical hazards.

This paper focuses on hydrogeological risks, i.e., floods and landslides. Floods are particularly relevant, as they are the most damaging natural catastrophes in Europe. With the increasing temperatures associated with climate change, the economic losses in Europe may reach €44 billion per year by 2100 (Dottori et al., 2023). Landslide phenomena also constitute a relevant risk factor in Italy, with an estimated frequency of 1,000 events per year (ISPRA, 2023), 100 of which significantly affect houses, firms, and road networks. Moreover, a recent policy (Law 213/2023) introduced mandatory insurance against damage from natural disasters for Italian firms as of December 31, 2024. Therefore, figuring out businesses' exposure to hydrogeological risks is crucial for insurance companies and, more generally, to understand how many firms would be affected by this new policy.

This paper proposes a new methodology for improving the assessment of firms' exposure to floods and landslides by exploiting a rich set of data on companies, particularly about the spatial distribution of companies' activity.[2] Indeed, assessing flood and landslide risks is challenging because these types of extreme events are highly localized, and researchers often only know the location of the company headquarters and not the exact location of branches. In this work, we extract data on companies' headquarters and branches from the Italian business registry (InfoCamere) and georeference the exact location of all establishments.[3] InfoCamere also provides the number of employees by municipality for each company. Exploiting the employees' distribution, we estimate the relevance of each branch for a company. These two pieces of information allow us to accurately estimate each company's exposure to natural hazards.

[1]We thank L. Bartiloro, I. Faiella, and A. Felettigh for their comments and suggestions. The opinions expressed are those of the authors and do not necessarily reflect the views of the Bank of Italy or the Eurosystem. All errors are our own.

[2]We improve the methodology introduced in Loberto and Russo (2024) by increasing the accuracy of the geolocation of the companies premises and the distribution of employment by establishment.

[3]InfoCamere reports information on both companies and sole proprietorships. However, information on sole proprietorships is less accurate than information on companies. Therefore, we focus on companies, but we show in Appendix C that our dataset has a good representativeness of the universe of firms.

When only the headquarters' location is available, and this information is used to measure the exposure to floods and landslides, each firm is either fully exposed or not at all. That is an inadequate criterion for assessing the exposure of multi-branch firms. When branch locations are available, we can build a continuous exposure index for each company by leveraging employment information. In particular, we identify which establishments are exposed to floods and landslides by exploiting the hazard maps provided by the Italian Institute for Environmental Protection and Research (ISPRA). ISPRA maps are the most detailed hazard maps available to us at this moment, although we should remark that these maps feature important drawbacks, especially in terms of limited comparability among regions. Then, we compute the weighted share of establishments at risk for each company (or administrative units) by using the number of employees as weights to elaborate a set of indicators synthesizing overall exposure.

Based on our results, about 35% of manufacturing companies are exposed, to some extent, to floods and landslides. Considering their entire workforce, including workers in non-exposed branches, these companies account for about half the manufacturing employees, but only 34% of manufacturing employees work in establishments exposed to floods or landslides. Floods are the most relevant hazard: 29.4% of the companies have at least one establishment exposed to flood risk, while 8.3% have at least one unit exposed to landslides. Only 2.9% of the companies are exposed to both hazards. Exposure to both risks is uncommon because hydrogeological factors determining flood or landslide susceptibility tend to be mutually exclusive. In particular, floods are more likely on level ground, while landslides occur in hilly or mountainous areas.

We also observe a few relevant facts. First, most companies are fully exposed to flood risk, i.e., all employees are in establishments exposed to some level of flood risk, or they are not exposed at all – i.e., none of the employees work in establishments at risk. Instead, a small fraction of companies (3.9% for floods and 1.4% for landslides) have only a partial exposure. Still, these companies account for a large share of all employees since these are multi-branch, and therefore usually larger, firms.[4]

Second, the likelihood of being exposed to hydrogeological hazards is correlated with company characteristics, particularly for flood risk. The likelihood of exposure to one of the two hazards is positively correlated with the number of company establishments. For landslide risk,

[4] As expected, accounting for branches dramatically affects the measurement of exposure for large multi-branch firms. In particular, we compare our results to the case where the exposure is measured only based on the location of the headquarters, as is often the case in the literature due to data limitations. We focus on overall exposure to floods and landslides, and we find that the share of companies not exposed to flooding decreases by 3 percentage points when correctly accounting for branches. We observe a smaller decrease (1 p.p.) for landslides.

the number of establishments is the only relevant company characteristic. Regarding flood risk, instead, exposure is more likely for larger (as measured by the number of employees or total assets) and older companies, even after controlling for the number of establishments. Firms with a higher share of tangible assets over total assets are less likely to be exposed to floods, and this is consistent with the hypothesis that companies with a large share of tangible capital are more likely to be located in safe areas.

Third, conditional on being exposed to flood hazards, the exposure is lower for larger companies than for smaller ones. This result is consistent with the hypothesis that a wider geographic dispersion of the company's business activity may be a factor in mitigating the risks associated with exposure to physical hazards.

Finally, we perform additional exercises to assess the extent of uncertainty in exposure estimates due to inaccuracies in the identification of the exact location of the companies. In particular, we consider the issue of the precision of the geocoding service – i.e., the tool that converts an address in a set of geographical coordinates – and of the actual position of the firm's premises. The latter refers to the entire area covered by the building, which can significantly affect the risk assessment compared to considering only the set of geographical coordinates corresponding to the address. The estimation error on the share of exposed employees at the national level is negligible. However, these uncertainties can significantly affect results in smaller administrative units where the number of companies is limited. This highlights the critical importance of using reliable geocoding tools when performing such analyses.

Related Literature: This paper is related to the literature that explores the impact of natural hazards on firms. In particular, we focus on flood and landslide risk.

Focusing on the impact of flood risk, Jia et al. (2022) find that increased flood risk has a negative impact on business demography, employment, and output. However, other studies do not find consistent evidence (Hannaoui et al., 2023). Moreover, there is a similar disagreement about the impact of floods on business performance. A few studies show that the impact of floods on business performance is positive (Leiter et al., 2009; Coelli and Manasse, 2014).

This effect could be due to the recovery process following a flood event. In the recovery stage, there is often a large flow of aid from the central government to flood-affected areas. More recent studies find negative and persistent effects of floods on business performance and survival (Fatica et al., 2022; Clò et al., 2023). Severe measurement issues plague all these papers, as they cannot accurately identify firms that were hit by the flood, and they consider only companies' headquarters.[5]

Concerning landslides, Donnini et al. (2020) defined a granular economic susceptibility indicator that captures the interconnection between physical and economic exposure for supporting policymakers to implement prevention and mitigation actions and to underline potential "hotspots" that need to be monitored. The study, limited to the Umbria region, highlights low potential economic losses for firms since the areas with the highest landslide susceptibility are mostly residential.

The methodology exposed in this work identifies companies exposed to physical risk more precisely by leveraging information about branches. Several works in the past went in the same direction, although their goals differed from our paper. Indaco et al. (2021) analyzed Hurricane Sandy's impact on New York business establishments. They showed that the hurricane harmed employment and affected subsequent firms' location choices. However, their analysis is at the land lot level, not the company level. Castro-Vincenzi (2024) disposed of detailed information for the automotive sector, including assembly plants and country of sale, and used them to investigate companies' adaptation strategies resulting from extreme floods. Finally, Bressan et al. (2024) develop a methodology that quantifies the physical risk of geolocalized productive assets in Mexico to evaluate expected losses in the financial system. They find that investor losses are underestimated up to 70% when neglecting precise asset-level information (i.e., evaluating exposure to physical risks based on headquarters address or regional averages).

This paper is related to recent contributions that consider the impacts of physical risks associated with climate change on businesses in Italy. Meucci and Rinaldi (2022) provide an assessment of Italian banks' exposure to floods and landslides related to lending to non-financial corporations. As in our paper, they use data on the distribution of companies' employees by municipalities. However, they assume that employees are uniformly distributed inside the municipality and do not exploit the information about the location of the establishments. Frigo and Venturini (2024) geolocate the addresses of headquarters and branches for a representative sample of Italian firms (INVIND). Differently from our paper, they explore the determinants of companies' propensity to insure against natural hazards.

The paper is organized as follows. Section 2 describes the data sources and the steps we

[5] Leiter et al. (2009) identify floods at the NUTS2 level and consider all companies inside the region as flooded. Coelli and Manasse (2014) and Clò et al. (2023) follow a similar approach but at the municipality level. Fatica et al. (2022) observe floods at the NUTS3 level and classify as flooded those firms located in an area with ex-ante high flood risk.

follow to construct our dataset. Section 3 illustrates the methodology we adopt for measuring the exposure of firms to flood risk, and Section 4 reports the main results. Section 5 concludes.

2 Data

2.1 Data on companies

Our primary data source on companies is the Italian business register, a public register maintained by InfoCamere. The business register – hereafter InfoCamere – reports all the information relating to company headquarters (*Sede Legale*) or branches/local units (*Unità Locali*) in Italy with an update frequency ranging from daily to yearly, depending on the type of variable to be updated.[6] From InfoCamere, we retrieve the following company data: the name, the VAT code, the NACE code, the legal form of the company, the date of establishment and the date of termination, and the address of each establishment, either headquarters or branches. The address is the key information we exploit to retrieve the exact location of the establishment. For branches, we know the typology of the establishment. The most frequent typologies are factories, warehouses, shops, workshops, and offices. Moreover, the dataset reports the number of employees by municipality for each company at the end of the year. Therefore, when firms only own one establishment in a municipality, we know the exact number of employees for that premise. Otherwise, we assume that the employees of a company inside a municipality are uniformly distributed across all establishments inside that municipality. Appendix B reports the details about the workflow we use for creating the dataset.

The dataset includes 282,374 active companies as of December 31, 2022 (Table 1, Panel A). These companies operate through 411 thousand establishments and employ 3.4 million workers. The average number of employees is 12, and the median is 2. Companies are, on average, 24 years old. The share of companies holding secondary branches is 26.5%. For most applications, we will focus on the 189,903 companies reporting a strictly positive number of employees: these are 67% of the original sample (Table 1, Panel B).[7] For these companies, the average number of employees is 18, and the median is 5, while there are no significant differences in the distribution of companies' age with respect to the universe of all manufacturing

[6] Branches/local units correspond to various productive sites, e.g., deposits, factories, and shops, whereas headquarters indicate the official location the company has declared for fiscal and legal affairs.

[7] Statistics on employment do not include entrepreneurs. Therefore, firms reporting no employees are those operated only by entrepreneurs. However, there may be a few cases of non-active companies still reported as active in the business registry.

Table 1: SUMMARY STATISTICS

	Number of companies	Percentiles							Mean	St.dev.
		Min	1	25	50	75	99	Max		
Panel A: Full sample										
Employees	282,374	0	0	0	2	8	152	33,873	12	113
Age	280,843	1	1	10	22	35	69	159	24	16
Number of sites	282,374	1	1	1	1	2	6	409	1	2
Panel B: Companies with employees										
Employees	189,903	1	1	2	5	12	203	33,873	18	137
Age	189,604	1	2	11	22	36	69	159	24	16
Number of sites	189,903	1	1	1	1	2	7	409	2	2
Panel C: Single-branch companies										
Employees	207,601	0	0	0	2	6	55	2,293	5	16
Age	206,189	1	1	11	22	36	68	154	24	16
Panel D: Multi-branch companies										
Employees	74,773	0	0	1	7	19	372	33,873	30	216
Age	74,654	1	1	9	19	34	72	159	23	17
Number of sites	74,773	2	2	2	2	3	10	409	3	3
Panel E: Companies with balance sheet data										
Employees	120,752	0	0	3	8	16	270	33,873	24	171
Age	120,662	1	3	9	19	33	72	159	23	16
Number of sites	120,752	1	1	1	1	2	8	409	2	3
Total assets	120,752	1	29	418	1,251	4,084	140,257	124,001,619	11,538	381,235
Tangible assets	120,752	0	0	27	169	852	29,480	6,766,595	2,107	29,405
Tangible investments	120,752	0	0	0	12	94	5,169	751,000	345	4,262
Turnover	120,752	0	8	405	1,251	4,036	133,657	74,712,264	10,725	247,935
Value added	120,752	-181,235	-79	111	376	1,110	28,148	10,899,766	2,276	38,196
Cashflow	120,752	-294,398	-500	21	87	335	12,160	10,619,783	970	33,178
Return on assets	120,752	-9,800	-50	2	5	11	48	1,076	5	66

Note: This table reports the descriptive statistics for the main variables included in our dataset. Panel A shows the statistics for the full sample. Panels B-D display the same statistics, excluding companies without employees (Panel B) and restricting the dataset to single-branch (Panel C) or multi-branch companies (Panel D). Finally, Panel E shows the descriptive statistics for companies for which we can retrieve balance sheet data from the CERVED dataset. The monetary variables in panel E are in thousands of euros. Return on assets is reported in percentage points.

companies.

Breaking down summary statistics between single-branch and multi-branch companies, the latter have, on average, 30 employees, which is six times the same statistic for single-branch companies (Table 1, Panels B and C). Age distributions, instead, are similar. Most multi-branch companies hold only two premises, i.e., the legal headquarters and a branch. The 99^{th} percentile of the distribution of the number of establishments is 10, and only a few firms own more than 50 establishments. Multi-branch companies are highly relevant when we look at aggregate economic activity, as they account for 67% of the employees covered by our dataset as of December 31, 2022.

For a subset of 120,752 corporations, we were able to retrieve the financial statements from the CERVED database, adding rich information about the firm's characteristics (Table 1, Panel

E).[8] These corporations are, on average, larger than other companies: the average number of employees is 24. Instead, the distribution of companies' age and the number of establishments is similar to the full sample. Balance sheet data refer to 2022. The average value of total assets of these firms is €11.5 million, and the average turnover is €10.7 million. We report additional descriptive statistics in Table 1.

To assess the representativeness of our dataset, we compared the distribution of firms and employees derived from our dataset with similar statistics from the dataset ASIA (*Registro statistico delle imprese attive*) compiled by the National Statistical Institute (Istat). Istat does not disseminate microdata at the firm level but publishes statistics on the number of firms and employees in each municipality by NACE code. Despite the caveats discussed in Appendix C, the correlation between the two datasets in the number of enterprises and employees by municipality-sector is 0.93 and 0.91, respectively.

2.2 Hazards

We use the most recent landslide and flood hazard maps provided by ISPRA (Trigila et al., 2021). ISPRA periodically updates hazard maps in compliance with Directive 2007/60/EC of the European Parliament and Council, which aims to establish a framework for assessing and managing hydrogeological risks. These maps are publicly available and used by national authorities to define safety regulations regarding land use and construction.

Regarding flood hazard, ISPRA provides three separate maps; each map corresponds to a different likelihood of a flood event, namely low, medium, and high probability. In this setting, the probability is measured in terms of the return period, defined as the average time between two floods. For example, a 100-year flood has a 1/100 or 1% chance of being observed in any year. The data includes the boundaries of all risky areas in Italy for each probability level. In low ($\boldsymbol{l}$) probability zones, the return period is greater than 200 years; in medium ($\boldsymbol{m}$) probability zones, it is 100-200 years; finally, in high ($\boldsymbol{h}$) probability zones, it is 20-50 years. In addition to these hazard levels, we also refer to no-risk ($\boldsymbol{n}$) areas, where the hazard maps do not assign a positive probability of floods. We use these maps to identify which headquarters and branches are within a flood-prone zone for each likelihood level.

It is worth remarking that flood hazard levels are not spatially exclusive, meaning that ISPRA classifies areas as being exposed to a given *or lower* level of hazard; if an area is exposed

[8] CERVED is a dataset including balance sheet data for about 700,000 corporations yearly.

to a high probability of floods, it is by definition also exposed to medium and low risk. We focus on the highest level of probability to which a geographic point is exposed.[9]

Concerning landslides, ISPRA defines four hazard levels: very high (P4), high (P3), medium (P2), and moderate (P1). Furthermore, in addition to the four levels defined above, ISPRA defined an additional level 'Aree di Attenzione', namely areas to which no hazard class has been assigned despite elements suggesting significant landslide danger. It is worth mentioning that each landslide hazard level translates into stringent limitations in urban planning: for instance, P4 areas allow interventions only if they aim to demolish or secure existing buildings.

ISPRA maps are the most detailed hazard maps available to us at this moment. Yet, these maps feature important drawbacks. First, flooding zones are identified by regional authorities (*Autorità di Bacino*), and these authorities do not follow a harmonized approach. Therefore, although ISPRA is spending effort to harmonize all outputs, regional comparability is limited.[10] Second, given that regional authorities must adopt risk management measures, the definition of hazard zones could be influenced by political and economic considerations (Jia et al., 2022). Finally, they do not report the expected water depth for each return period, which is a key variable for estimating expected losses.

3 Methodology

The methodology we developed aims at the computation of two types of synthetic indicators providing a compound evaluation of exposure at:

- **company level**: firms are considered geographically distributed entities. Each company establishment contributes to the overall exposure of the company according to its relative importance and the hazard level affecting it;

- **regional level**: this is a compound indicator at the administrative unit level, accounting for each establishment located within the administrative unit according to its relative importance and the hazard level affecting it.

[9] When we evaluate the extent of a low probability region, we will subtract all portions exposed to medium and high risk. Suppose that region i overlaps ISPRA areas L_i, M_i, and H_i at low, medium, and high probability of flood, respectively. Then, we will consider as being exposed to low probability only those points (and buildings) of L_i not overlapping with M_i and H_i.

[10] For example, the high probability flood scenario is not available for the provinces of Bolzano and Trento. In Calabria, instead, a high probability of flooding has been reported for almost all areas at risk of flooding.

Leveraging the information about the exact location of each establishment and the hazard maps, we determine the exposure level of each establishment to hydrogeological risk. In this step, we exploit the single point (longitude/latitude) corresponding to the address and in section 4.3 we show that this is a reasonable assumption at a sufficient aggregate level.[11] Then, we assign different importance to each productive unit according to the number of employees it hosts, either reported (when the unit is the only one in the municipality) or estimated, assuming a uniform distribution within the municipality (whenever a company has multiple units in the municipality). We cannot exploit alternative weighting variables, such as site-specific tangible assets or value added, as we lack this information.

Furthermore, we compute two different variants of both indicators:

- **level-sensitive** (E): the indicator accounts for the different hazard levels provided by ISPRA maps;
- **non-level-sensitive** (S): the indicator does not consider different hazard levels and only discriminates between exposed and not exposed units.

We introduce their exact formulas in the next paragraphs. Table 2 anticipates the naming convention adopted in these computations. Subscript L stands for landslides, and F stands for floods.

Table 2: NAMING CONVENTION FOR THE EXPOSURE INDICATORS

	Non-level-sensitive	Level-sensitive
Regional-level	S_F^R, S_L^R	E_F^R, E_L^R
Company-level	S_F^C, S_L^C	E_F^C, E_L^C

Note: This table summarises the naming convention we adopted for the exposure indicators. Level-sensitive indicators (E) account for the intensity of the hazard, while non-level-sensitive (S) do not differentiate among different levels of the hazard. The subscripts stand for floods (F) or landslides (L). The superscript refers to regional (R) or company-level (C) indicators.

3.1 Regional indicators

The first set of indicators aims to measure the potential exposure of manufacturing activity to flood or landslide events in a given area (i). We develop indicators down to the province level, although more granular estimates, e.g., at the zip code level, are feasible. To compute the non-level-sensitive indicator S^R, we first define U as the set of all manufacturing establishments

[11] The main issue is that the address can be georeferenced at the road access point. Therefore, the longitude/latitude coordinates do not identify the centroid of the building. Section 4.3 addresses this issue.

(headquarters and branches). Furthermore, we define w^u as the number of employees hosted by unit $u \in U$, and two hazard functions h_F^u and h_L^u as follows:

$$h_{F/L}^u = \begin{cases} 1 & \text{if unit } u \text{ is exposed to any level of flood/landslide hazard,} \\ 0 & \text{if unit } u \text{ is not exposed to flood/landslide hazard} \end{cases}$$

Units having $h_F^u = 0$ ($h_L^u = 0$) are those located in areas not covered by any of the ISPRA polygons for flood (landslide) hazards. With these elements, we can then define our indicator for administrative unit/region r, hosting a subset $\Theta(r)$ of the manufacturing units, as

$$S_{F/L}^R = \frac{\sum_{u \in \Theta(r)} w^u * h_{F/L}^u}{\sum_{u \in \Theta(r)} w^u} \tag{1}$$

This indicator returns the share of employees exposed to any level of risk in the region r.

To fully incorporate the different nuances of hazard level expressed by the ISPRA maps, we can also define a level-sensitive indicator, E_F^R and E_L^R. To do this, we first need to define two positive functions $f_F^u(k)$ and $f_L^u(k)$, monotonic in the level of hazard k, one for hydraulic risk and one for landslides, that captures the level of exposure for each unit u:

$$f_F^u(k) = \begin{cases} 0 & \text{if } u \text{ is not exposed,} \\ 1 & \text{if } k = \textbf{low}, \\ 2 & \text{if } k = \textbf{medium}, \\ 3 & \text{if } k = \textbf{high}, \end{cases} \qquad f_L^u(k) = \begin{cases} 0 & \text{if } u \text{ is not exposed,} \\ 1 & \text{if } k = \textbf{low}, \\ 1.5 & \text{if } u \text{ is in an Attention Area,} \\ 2 & \text{if } k = \textbf{medium}, \\ 3 & \text{if } k = \textbf{high}, \\ 4 & \text{if } k = \textbf{very high}, \end{cases} \tag{2}$$

We assigned the value 1.5 to landslide *'Attention Areas'* because no other information is available besides these areas being put on a watch list.[12] However, this is not crucial because only 0.7% of establishments fall in these areas. Therefore, we can define the regional, level-sensitive exposure indicator E_r^R for administrative unit r as:

$$E_{F/L}^R = \frac{\sum_{u \in \Theta(r)} w^u * f_{F/L}^u(k)}{\sum_{u \in \Theta(r)} w^u} \tag{3}$$

This indicator ranges:

[12] For floods, we could choose a different weighting scheme. For example, we may assign a weight equal to the inverse of the return period to each hazard level. The advantage of this indicator is that the weights have a clear probabilistic interpretation. However, we aim to define homogeneous score indicators for floods and landslides.

- from 0 to 3 for flood hazard, 0 meaning no employees at risk in the region i
- from 0 to 4 for landslide hazard

and its upper extreme corresponds to all employees in a given administrative unit being assigned to branches exposed to the highest hazard level.

3.2 Company level indicators

This section describes the indicators for assessing each company's exposure to flood and landslide hazards. These indicators capture the distributed nature of firms and correctly account for each secondary branch, weighting their relative importance based on the number of employees to convey the overall exposure in a single number for each company. Given the key role of the distribution of employees, these indicators are defined only for companies with a positive number of employees.[13]

If we consider company i, operating a set $\theta(i)$ of establishments, we define:

$$S^C_{F/L} = \frac{\sum_{u\in\theta(i)} w^u * h^u_{F/L}}{\sum_{u\in\theta(i)} w^u} \tag{4}$$

for the non-level-sensitive indicator and

$$E^C_{F/L} = \frac{\sum_{u\in\theta(i)} w^u * f^u_{F/L}(k)}{\sum_{u\in\theta(i)} w^u} \tag{5}$$

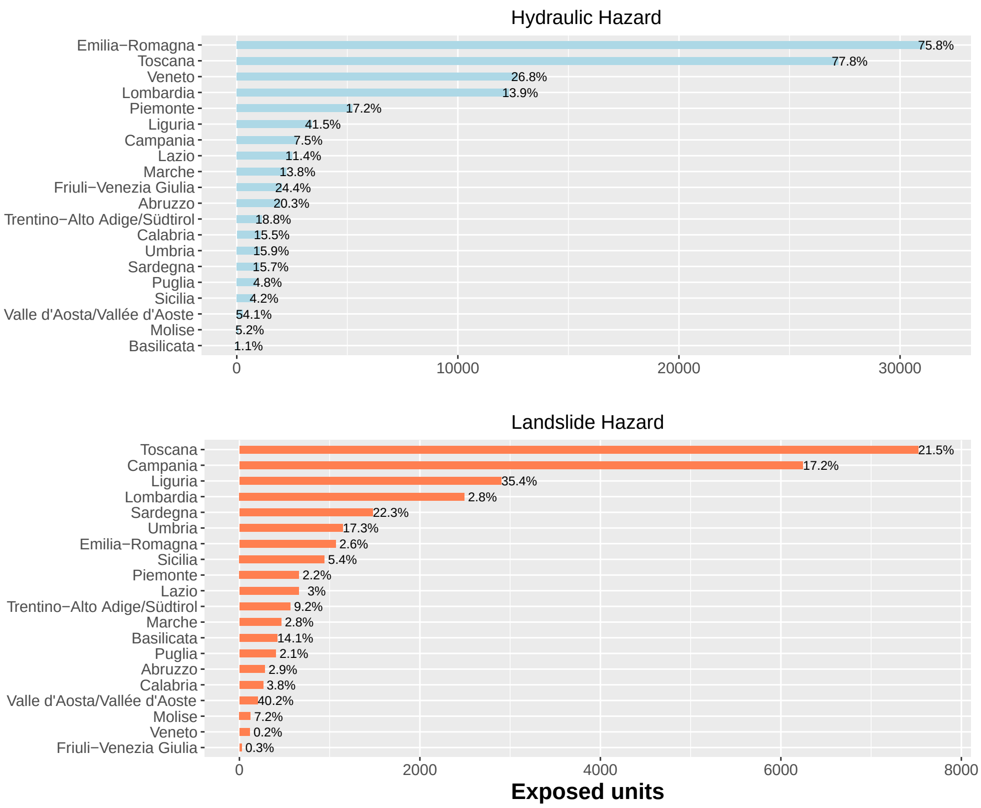
for the level-sensitive indicator. The only difference between the regional and company level indicators lies in the definition of ensembles $\Theta(i)$ and $\theta(i)$, a set of business units sharing the same geographic area for the former, the set of all productive sites for a given company in the latter.

4 The exposure of manufacturing firms to the hydrogeological risk

Out of the full sample of 411,000 establishments (including headquarters and branches), 26.7% are exposed to floods and 6.8% to landslides; the share of units simultaneously exposed to both hazards is 1.7%. At the company level, 34.8% of firms are exposed to any of the two hazards: 29.4% of the 282,374 active companies have at least one unit exposed to flood risk, while 8.3%

[13] We consider only the establishments – headquarters or branches – located in Italy.

Figure 1: EXPOSED ESTABLISHMENTS BY REGION



Note: This chart displays the number of establishments exposed to flood (upper panel) and landslide (lower panel) hazards by the NUTS-2 region. The reported percentage values correspond to the regional share of exposed establishments.

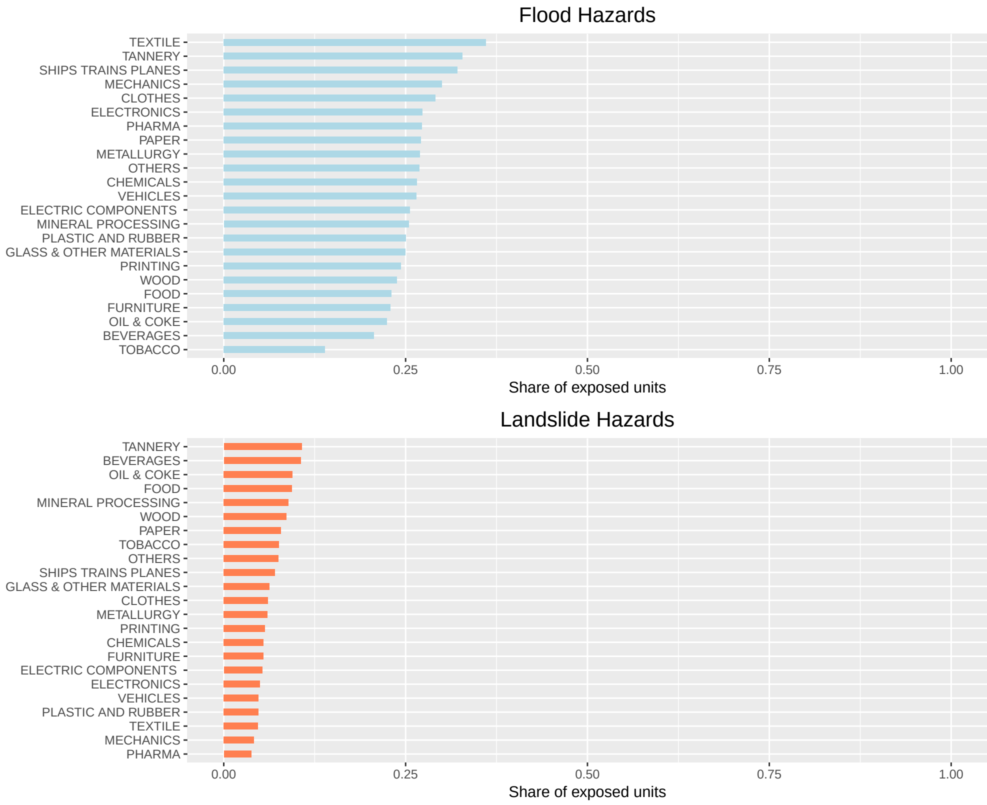
have at least one unit exposed to landslides. Only 2.9% of the companies own at least one establishment exposed to floods and one establishment exposed to landslides. Exposure to both risks is uncommon because hydrogeological factors determining flood or landslide susceptibility tend to be mutually exclusive. In particular, floods are more likely on level ground, while landslides usually occur in hilly or mountainous areas. The majority of companies and sites exposed to both hazards are located in Lombardia and Toscana.

While only 34.8% of the companies are exposed, they employ 1.7 million employees (51.9% of the total number of employees in the sample). Moreover, within the subset of companies for which we have financial statement data, the total turnover of exposed corporations is €750 billion (57.6% of the total), and tangible assets are €138 billion (54.4%).

More than one-half of the establishments exposed to floods are located in Emilia Romagna and Toscana (Figure 1). Toscana, together with Campania, also hosts the majority of sites exposed to landslides.

Figure 2 shows the share of exposed companies by their NACE code. The shares tend to be homogeneous and fluctuate around 25% for flood hazard and to 7% for landslide hazard.

Figure 2: SHARE OF EXPOSED ESTABLISHMENTS BY NACE SECTOR



Note: This chart displays the share of the establishments exposed to flood (upper panel) and landslide (lower panel) hazards by the NACE-2 digit sector.

However, we note that the tannery sector ranks first for landslide hazard and second for flood hazard. The textile sector ranks first for flood hazard due to the high water consumption of this industry, which tends to concentrate productive sites in the vicinity of rivers.

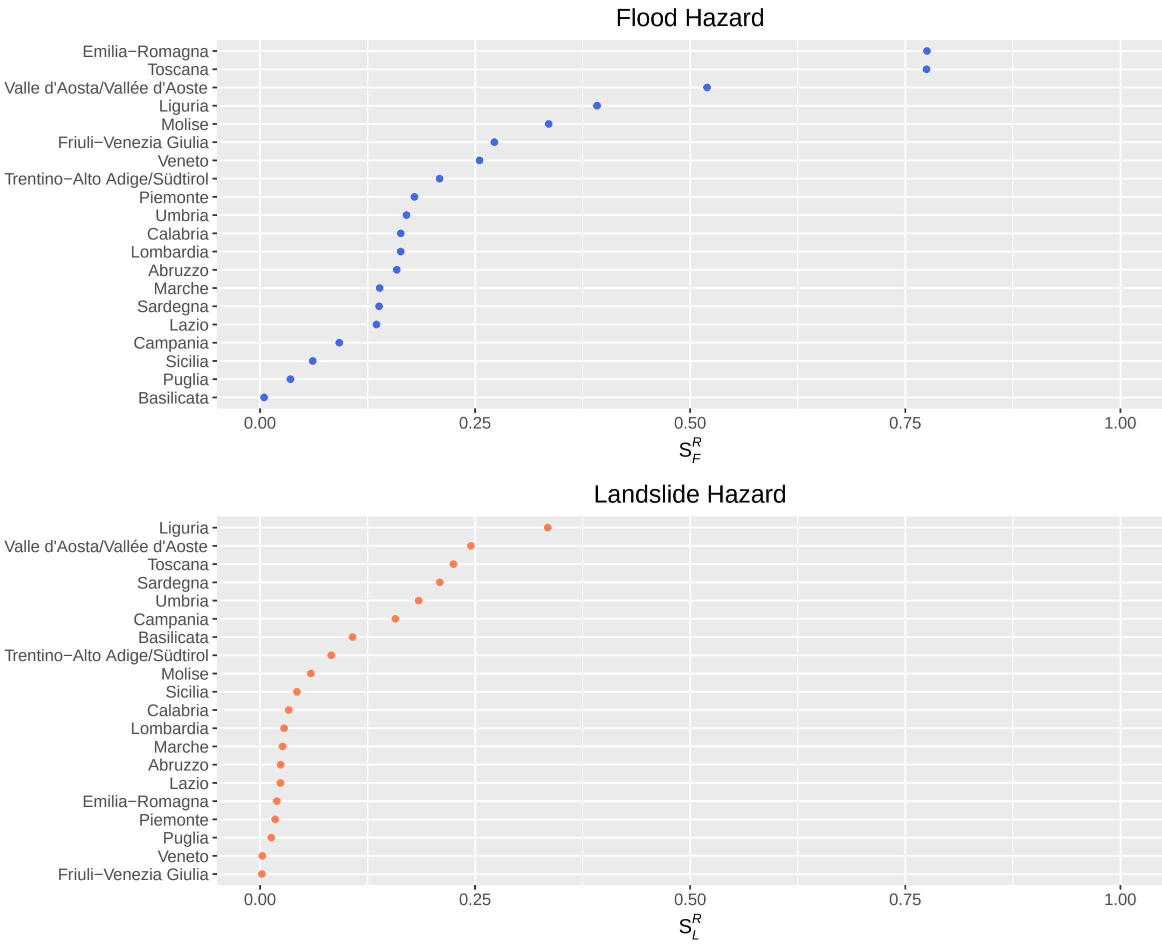
In the following, we will discuss the evidence based on the indicators presented in the previous section, giving weight to each establishment based on the number of employees. Then, we will investigate the correlation between exposure to flood and landslide hazards and company characteristics.

4.1 Exposure indicators

The non-level-sensitive indicator S^R in formula (1) represents the share of employees exposed to any hazard level for a given administrative unit. When aggregated at the national level, this indicator results in $S^R_F = 0.29$ and $S^R_L = 0.05$, i.e., the percentage of employees exposed to flood and hazard are 29 and 5%, respectively. These values are consistent with the previously reported statistics on the share of exposed units.

For ease of exposition, we start discussing the S^R indicator at the NUTS-2 level, and then

Figure 3: REGIONS' EXPOSURE TO HYDROGEOLOGICAL HAZARDS



Note: This chart displays the exposure indicators S_F^R (upper panel) and S_L^R (lower panel) calculated at the NUTS-2 regional level.

we increase the granularity of the indicators up to the NUTS-3 level. A caveat to keep in mind when interpreting these indicators is that they may have high values in small regions where the number of manufacturing firms is small. On the one hand, this indicator is the most relevant to residents and local policymakers. For example, in small regions there may be a few establishments that account for a significant portion of the economic activity. Therefore, disruptions in the production of these establishments could have serious consequences for the economy of the region. On the other hand, the national policymakers would be more interested in knowing the absolute number of businesses and workers exposed to flood risk in each region in order to set more efficient policies. In this work, we focus on information that is more salient to residents.

An additional caveat is that the comparability of the indicators between different NUTS-2 regions is hindered because of the lack of perfect harmonization among regions in the definition of the hazard maps (see Section 2.2). Yet, ISPRA hazard maps are the official maps for assessing hydrogeological risk in Italy and are the most widely used information source for this risk. For this reason, producing statistics based on ISPRA hazard maps is extremely important.

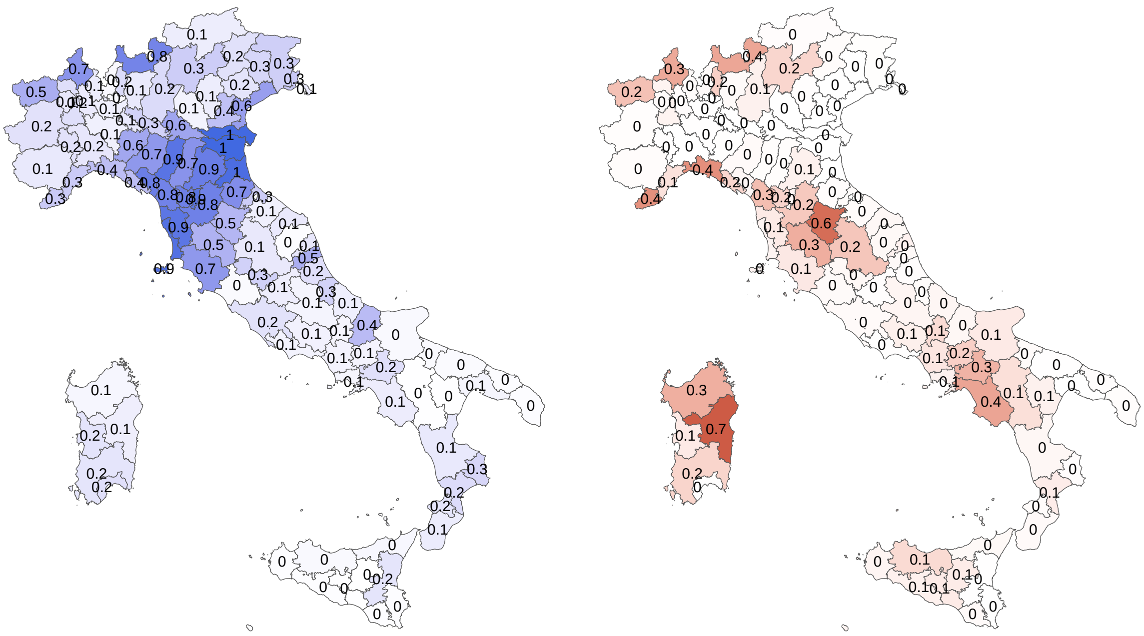
Regarding S_F^R, we observe three regions being exposed by more than 50% of their workforce in the manufacturing sector, namely Emilia Romagna, Toscana, and Valle d'Aosta (Figure 3, upper panel). Interestingly, the Molise region shows a discrepancy between the flood-related S_F^R (0.34) and the share of exposed productive units (0.05, see Figure 1). This pattern is due to a big productive site owned by an important automotive firm, hosting more than 2,000 employees and located in a medium-hazard area. Values for S_L^R tend to be smaller, in line with the previously reported share of exposed units (Figure 3, lower panel). Liguria attains the highest value for S_L^R, as 35% of manufacturing employees are in landslide-prone sites.

When computing the S^R indicators at the province level, we observe that the exposition to flood hazard is highest in eastern Emilia Romagna (Romagna) and northern Tuscany (Figure 4). Concerning landslides, instead, the highest values of S_L^R are found in Oristano and Arezzo provinces, where more than 50% of manufacturing employees are exposed. When taking into account the severity of hazards, the E^R indicators at the province level confirm this broad picture for flood-related hazards (Figure A1). However, for landslides, we see a group of northern provinces (Imperia, Verbania, and Sondrio) growing considerably in the ranking, indicating a higher hazard level on average.

We now turn to the company-level indicators. The non-level-sensitive indicator S^C, corresponding to the share of employees exposed to any level of physical risks, is summarized in Table 3. Since the indicator uses the number of employees as weight, companies lacking this information are removed in this part of the analysis. The majority of companies have null exposure to both types of hazards. On the other hand, 55 and 15 thousand Italian manufacturing companies are exposed to flood and landslides, respectively, and their S^C is greater than 0. A small (3.9% for floods and 1.4% for landslides) fraction of companies have partial exposure to physical risks ($0 < S^C < 1$), meaning only part of their workforce is in areas with non-zero hazards. We can see that these companies have, on average, a larger number of employees and account for 25% (flood hazard) and 10% (landslide hazard) of the workforce in our sample.

The histogram in Figure 5 shows the level-sensitive company indicator E^C. The indicator, described in formula 5, provides a continuous scale of values that accounts for the percentage of employees exposed in each company, after accounting for the exposure level of all establish-

Figure 4: PROVINCES EXPOSURE TO HYDROGEOLOGICAL HAZARDS



Note: This chart displays the exposure indicators S_F^R (left panel) and S_L^R (right panel) calculated at the NUTS-3 regional level. The value of the indicator is reported inside the boundaries of the province.

Table 3: COMPANIES EXPOSURE TO HYDROGEOLOGICAL HAZARDS

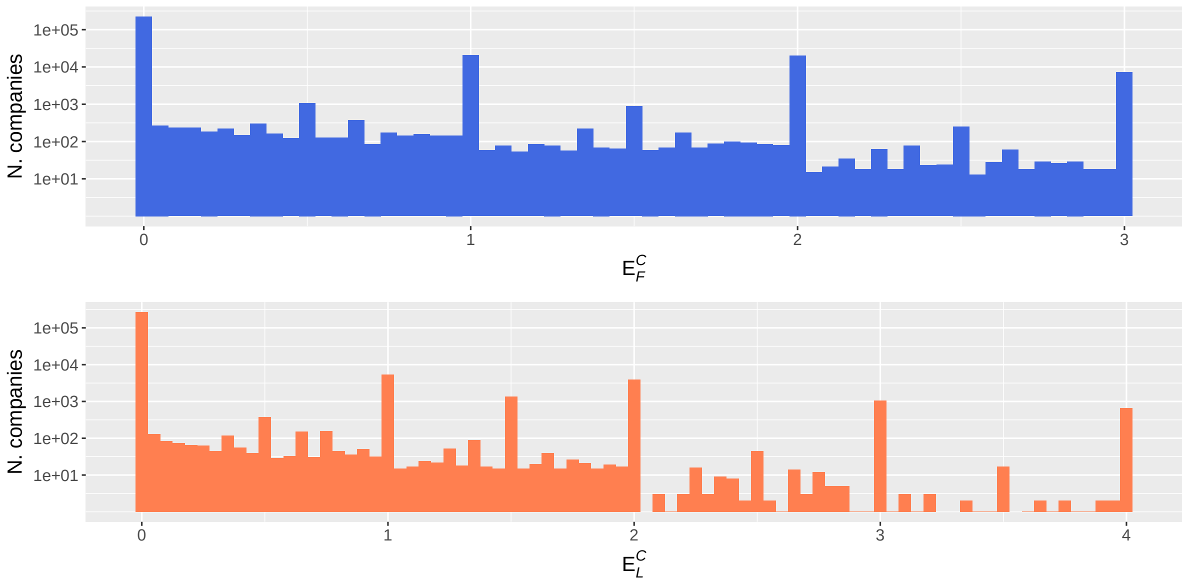
	Exposure			
	None $S_{F/L}^C = 0$	Low $0 < S_{F/L}^C < 0.5$	Moderate $0.5 < S_{F/L}^C < 1$	Full $S_{F/L}^C = 1$
		Flood Hazard		
N. companies	133,908 (70.5%)	5,047 (2.7%)	2,364 (1.2%)	48,710 (25.6%)
N. employees	1,855,917 (55%)	578,042 (17%)	269,634 (8%)	655,205 (20%)
Avg. employees	14	115	114	13
		Landslide Hazard		
N. companies	175,330 (92.2%)	2,137 (1.1%)	666 (0.3%)	11,896 (6.3%)
N. employees	2,922,085 (87%)	286,812 (9%)	39,324 (1%)	110,577 (3%)
Avg. employees	17	134	59	9

Note: This table reports the distribution of companies and employees by different levels of exposure to flood and landslide hazards. The exposure to hazards is measured based on the non-level-sensitive indicators S_F^C and S_L^C. For each exposure category, we report the average number of company employees.

ments. Although most companies display an integer value for this indicator due to the absence of secondary branches or productive sites, multi-branch companies take on continuous values.[14]

[14] For landslides, there is a peak at 1.5 due to single-branch companies located in '*Aree di Attenzione*'.

Figure 5: LEVEL-SENSITIVE INDICATORS OF COMPANIES EXPOSURE



Note: This chart shows the histogram of the distribution of the level-sensitive exposure indicators E_F^C (upper panel) and E_L^C (lower panel) calculated at the company level.

Accounting for branches is crucial because indirect exposure via secondary units can significantly raise the hazard level for companies far away from risky areas. For example, the center of Milan is *per se* not exposed to any of the hazards considered in this work. However, many companies in this area have exposure values significantly deviating from zero, meaning their exposure is exclusively due to their secondary branches (detailed map in Figure A2).

Other works, such as ECB (2024), compute risk-related indicators assigning all employees to the company headquarters due to missing data on branch location. In our sample, adopting this approach would lead to a three percentage point overestimate in the number of companies considered safe for the flooding hazard and a corresponding 17 p.p. overestimate in the number of employees (Table 4). A similar effect is observed for landslides, although to a smaller extent (1 and 7 p.p). Our approach avoids this optimistic bias by accounting for partially exposed companies, most of which are large multi-branch firms, as shown in Table 3.

Table 4: COMPARISON OF COMPANIES AND EMPLOYEES COUNT WITH AND WITHOUT LOCAL BRANCH INFORMATION

	Exposure		
	Null	Partial	Full
	Flood		
N. companies			
HQ only	138,498 (73%)		51,531
HQ + branches	133,908 (70%)	7,411	48,710
Employees			
HQ only	2,430,154 (72%)		928,644
HQ + branches	1,855,917 (55%)	847,675	655,206
	Landslide		
N. companies			
HQ only	176,967 (93%)		13,062
HQ + branches	175,330 (92%)	2,803	11,896
Employees			
HQ only	3,202,545 (95%)		156,253
HQ + branches	2,922,085 (87%)	326,136	110,577

Note: This table compares company and employee count when computed according to the methodology exposed in this paper (*HQ + branches*) or considering only headquarters (*HQ only*). The indicators *HQ only* are obtained by assigning all employees to the headquarters.

4.2 Exposure to physical hazards and companies' characteristics

In the previous section, we outlined the main evidence of the overall exposure of the manufacturing sector to flood and landslide hazards. In this section, instead, we investigate whether there is a correlation between hydrogeological risk exposure and companies' characteristics. Without having the ambition to identify causal relationships, the goal of this section is to understand whether, for example, small firms are more likely to be exposed than larger firms.

We proceed in two steps. First, we study the relationship between the likelihood of being exposed to flood or landslide hazards and the company's characteristics. For this first analysis, we build two dummy variables: *FLOODEXP* is equal to 1 if a firm has at least one employee in a flood-prone area, and 0 otherwise; *LANDEXP* is defined similarly for landslides. We consider a binary variable for measuring exposure because, in this first step, we focus on which firms are more likely to be affected by hydrogeological hazards. Since only a small share of firms have partial exposure to these hazards, using binary variables is a reasonable simplification.

Then, we restrict the analysis to companies that have some exposure to the hazards, and leveraging the indicator S_F^C described in the previous section, we assess how companies' characteristics are correlated with the intensity of the exposure to hydrogeological hazards.

We consider several companies' variables retrieved from the business register or financial statements provided by CERVED. Financial statements are available only for a subset of companies (see Table 1), but as we will show below, this restriction does not introduce significant distortions. A first set of variables allows us to study the link between the likelihood of being exposed to the hazards and company size. These variables are the number of employees, total assets, and the number of establishments. We expect that larger companies have more establishments and, therefore, are more likely to be exposed to hydrogeological hazards.

Then, we consider different measures of company profitability – value added to total assets, turnover to total assets, and the return on assets – and financial soundness, i.e., such as cash holdings to total assets, leverage (defined as financial debt out to financial debt and equity), and the probability of default (a score variable computed by CERVED). We include these variables to investigate whether good companies have a similar exposure to bad companies. As the issue of climate change-related extreme events is becoming salient, companies will adapt to the new landscape eventually by competing for safer locations (Kahn, 2021). Worse companies may face more difficulties in adapting to climate change compared to better companies, and this can amplify the pre-existing differences between the two groups. While we do not expect to find significant differences to have built up so far, our analysis can provide insights into the differences in starting points in the adaptation race among different companies.

Following the same rationale, we also investigate the link between the likelihood of being exposed to hydrogeological hazards and company age. Younger companies may have been incorporating the concern about the increased frequency of extreme events in their location choice while relocating may be costly for older companies. However, younger companies may also be financially constrained. Then, if safer locations command a price premium compared to riskier locations, locating in a safe area may be unaffordable for young firms.

Finally, an additional variable of interest is the ratio of tangible assets to total assets. Tangible assets include real estate and machinery, which may suffer significant damages from floods. Although the main contribution of this paper is assessing the potential effects of floods and landslides on companies' activity instead of physical damages, it is still interesting to investigate if companies with a higher share of tangible assets over total assets are more or less likely exposed to hydrogeological hazards. A positive correlation between the share of tangible assets and the likelihood of being exposed to natural hazards implies that the companies hit by a flood or a landslide may incur the greatest damages.

We start our analysis by inspecting a set of bin scatter plots reporting the simple average of *FLOODEXP* and *LANDEXP* for different percentiles of the distribution of a company feature. As *FLOODEXP* and *LANDEXP* are two dummy variables equal to 1 if a company is exposed to the hazard, these charts report how the share of companies exposed to the hazard varies conditional on the values of each company characteristic discussed above. Starting from exposure to floods, we observe that company size is positively correlated with the likelihood of being exposed to flood according to all measures of size. The share of exposed companies more than doubles when moving from the first percentile to the last percentile of the distribution of employment or total assets (Figure A3). The share of exposed companies among those with six or more establishments is above 60 percent, while this share is about 25 percent for single-establishment companies (Figure A5a). The share of exposed companies is positively correlated with company age and with two out of three measures of profitability (value added to total assets and turnover to total assets), while it is negatively correlated with the share of tangible assets (Figure A3). The variation of the share of exposed companies across the distribution of these variables is much smaller compared to the variables measuring company size, confirming that company size is the most relevant variable linked to the likelihood of being exposed to hydrogeological hazards. The bin scatter plots for cash holdings to total assets, the leverage, and the probability of default do not depict a specific pattern (Figure A3 and A5b), suggesting that these variables are quite uncorrelated with the likelihood of being exposed.

Turning to the exposure to landslides, we do not find clear patterns in the share of companies exposed to this hazard by company characteristics (Figure A4). The main explanation for this result is that the share of companies exposed to landslides is too small to find significant variation across company characteristics. The only relevant variable is the number of establishments, which is positively related to the share of exposed companies (Figure A5a).

An obvious issue with the univariate analysis is that company characteristics are correlated, and some of the correlations observed above may disappear once controlling for other characteristics. An additional concern is that there may be sectoral specificities driving the results. For example, as discussed above, textile firms usually are in flood-prone areas. Then, we run the following logit model:

$$logit\left(\mathrm{E}(Y_i \mid \mathbf{X}_i)\right) = \beta \mathbf{X}_i \tag{6}$$

where the dependent variable Y is, alternatively, *FLOODEXP* or *LANDEXP*. The set of covariates $\mathbf{X}$ includes the variables discussed above. We include a set of NACE 2-digit industry dummies to control for sectoral specificities. We cluster standard errors at the NACE 2-digit level.

Table A1 reports the results for the exposure to flood risk. Column (1) shows the results over the full sample of firms with at least one employee. The exposure to flood risk is positively correlated with the number of employees, age, and number of establishments. Notice that the parameters of all three variables are statistically significant, although the variables are positively correlated. Column (2) shows that the results are similar when restricting the analysis to the subset of companies for which we have financial statements data. In column (3), we include financial statements variables, showing that the insights from the previous regressions hold even controlling for additional firm characteristics.[15] The coefficients of the financial variables are not statistically significant, except for the ratio of tangible assets over total assets, which is negative. Therefore, firms with a higher share of tangible assets over total assets are, *ceteris paribus*, less likely to be exposed to floods. Although this result is only a conditional correlation, it is consistent with the hypothesis that companies with a large share of tangible capital are more likely to locate in safe areas because they are more concerned about the potential damages of floods. This hypothesis deserves to be investigated in the future.

Another insight from column (3) is the larger likelihood that companies with a high probability of default will be exposed to flood risk compared to financially sound companies. In the univariate analysis, instead, there are no meaningful differences in the share of exposed companies for different levels of the probability of default (Figure A5b). Chart A6 shows that the positive correlation in column (3) arises because we control for company size. In particular, the difference in the share of exposed firms between companies with a high and low probability of default is positive and increasing in company size.

Columns (4)-(6) display the breakdown of the results for single-branch and multi-branch companies. The main results discussed above hold for both types of firms, except for the correlation between the probability of default and exposure to flood hazards. The latter is statistically significant only for single-branch firms.[16]

[15]When we include total assets among the covariates, we remove employment as the two variables are highly correlated.

[16]Looking at the two types of companies separately, additional covariates are correlated with the exposure to flood hazards. For example, for multi-branch companies, we observe a positive correlation of exposure with the ratio of value added over total assets and a negative correlation with the ratio of cash over total assets and the

We considered a more restrictive specification for single-branch companies, including both NACE 2-digits and province fixed effects. This specification is robust to the potential methodological differences in hazard maps across regions at the cost of exploiting only within-province heterogeneity. Columns (8)-(9) show that the positive correlation between the exposure to flood hazard and firm's size and probability of default holds even in this restrictive setting. In contrast, the correlation with age and with the ratio of tangible assets to total assets is no longer statistically significant.

We performed a similar analysis for the exposure to landslide hazard (Table A2). We do not find robust evidence of a correlation between exposure to this hazard and firms' characteristics, except for the number of establishments and firms' size. Differently from the exposure to flood hazards, the likelihood of being exposed to landslide hazards is negatively correlated with the firm's size. Landslide risk is significant in mountainous areas, which have several disadvantages – besides natural hazards – for establishing large enterprises. The limited relevance of this type of risk to firms plausibly explains why we do not find positive correlations between risk exposure and other firm characteristics.

The correlation of exposure with the number of establishments is an expected result since, as the number of establishments increases, it is more likely that at least one is in a risky area. Focusing on floods – as we do not find meaningful results in the previous analysis for landslides – in the second step of our analysis, we restrict the sample to the companies exposed to the flood hazard, and we run an OLS regression of S_F^C on the same covariates included in model 6. Table A3 reports the results of this analysis. The main result is that the coefficients associated with firm size and the number of establishments are negative, even restricting the analysis to multi-branch firms. To sum up, large firms with many branches are more likely to be exposed. However, conditional on being exposed to flood hazards, their overall exposure is lower than that of smaller firms. This result is consistent with the hypothesis that a wider geographic dispersion of the company's business activity may be a factor in mitigating the risks associated with exposure to physical hazards.

4.3 Robustness

The accuracy of our results relies on the precision of the hazard maps provided by ISPRA and the location of manufacturing establishments. Regarding the hazard maps, we cannot assess

return on assets.

how their potential inaccuracies may affect our results. On the second issue, however, we can perform some robustness exercises.

Inaccuracies related to geolocation can arise because of errors in the addresses reported in InfoCamere, the lack of precision of the geocoding service, and the actual position of the firm's premises. To evaluate the impact of these sources of uncertainty, we report two additional exercises assessing the robustness of our indicators.

Precision of the location. Geocoding service providers usually don't disclose accuracy metrics for their products and only provide a quality score for each geocoding operation.

To estimate an approximate geocoding error distribution for companies in our dataset, we manually evaluated a sample of 200 establishments for which the true location of the business activity was known. The results can be summarized as follows:

- 83% of the geocoded addresses fall within 20 m of the true location
- 5% fall between 20 and 100 m
- 2% fall between 100 and 500 m
- 10% of the addresses are geocoded more than 1 km away from their true location

According to these values, a set of Monte Carlo simulations was performed by artificially injecting noise as follows:

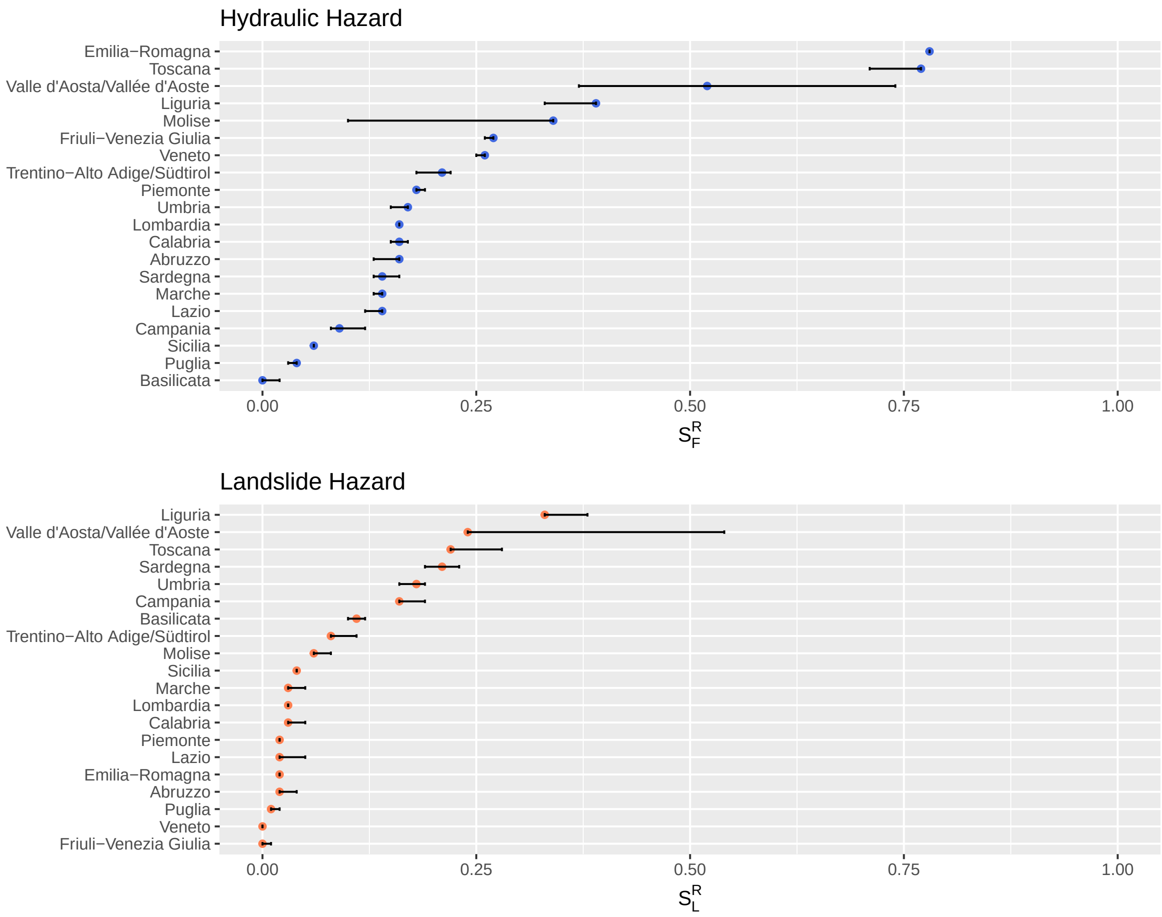
1. observations in the dataset are randomly shuffled
2. the first 83% of observations is left untouched
3. for the rest of the observations random values are added to the latitude and longitude values (in decimal degrees) to match the findings of the manual assessment[17]

The simulation was repeated ten times, and estimators were computed based on these artificial datasets.

We first focus on the impact of this perturbation exercise on the regional indicators S^R, namely the shares of employees exposed to any level of flood hazard. At the national level, the S^R_F indicator changes from 0.29 to 0.285 (a half percentage point decrease in the share of

[17] more specifically, for 5% of the observations a uniform distribution between -0.001 and 0.001 decimal degrees was used, for the next 2% a uniform distribution between -0.01 and 0.01 and the last 10% a uniform distribution between -0.1 and 0.1

Figure 6: GEOCODING-RELATED UNCERTAINTY OF THE REGIONAL EXPOSURE INDICATORS



Note: This chart displays the baseline calculations of S_F^R (upper panel) and S_L^R (lower panel) at the NUTS-2 level (blue and orange dots) and the related uncertainty bars. The extremes of the bars are the minimum and maximum values of the indicators from a Monte Carlo simulation.

exposed employees) while the S_L^R changes from 0.05 to 0.06 (1 p.p. increase). Figure 6 shows the same S_F^R and S_L^R indicators for each region (already reported in Figure 3) together with the largest fluctuations obtained over the ten simulations (error bars). Considering the flood hazard, the largest uncertainty is observed in the smallest regions (Molise and Valle d'Aosta), where data points are scarce and the perturbation exercise results in a large fluctuation of the S^R indicator (the share of exposed employees changes by 24 and 22 percentage points, respectively). For the rest of the regions, the potential error in S_F^R is within 6 percentage points. This source of error affects regions in different directions, likely due to different morphologic characteristics that lead to different shapes of the ISPRA polygons for flood hazards.

The outcome is similar for landslide hazards. The potential measurement error is significant only for Valle d'Aosta (30 percentage point variation in the share of employees exposed to landslides). For all other regions, S_L^R varies at most by 6 percentage points. Interestingly, geocoding inaccuracies have a systematic negative impact on the landslide indicator. This pattern might be due to many productive sites being located very close to the edge of landslide-prone areas, which requires high precision to correctly assess the actual level of exposure.

When looking at the company level indicators S_F^C and S_L^C, the perturbation exercise only affects 43,570 (15.4%) and 24,506 (8.7%) companies for flood and landslide hazards, respectively. Moreover, in most cases, the indicator switches from 0 to 1 or vice versa. That is due to single-branch companies that are moved out of their original polygon after the noise injection procedure.

In general, the geocoding uncertainty associated with the S_F^C and S_L^C indicators may not be negligible and, in that case, must be taken into account when using our procedure for risk assessment.[18]

Building location. A geocoding service returns the coordinates of the address and a qualitative measure of the corresponding accuracy. The interpretation of geographic points varies from case to case. They can either coincide with the centroid of a building or with a point on the road; however, in some cases, the centroid of streets, squares, or zip codes is returned. Without further knowledge, it is reasonable to assume that most assets belonging to a productive site coincide with (or are located within) a building, making it useful to verify whether our results are stable when we refine the geographic coordinate by adjusting it to match the position of the closest building.

OpenStreetMap provides access to information on building perimeters, and we used this information to associate the closest building to each data point in our dataset. To avoid incorrect matchings, we consider only data points with a building within a radius of 100 meters. Then, we computed the S_F^R and S_L^R indicators at the regional level. Table A4 displays the results. The discrepancies never exceed 0.06 in absolute value (namely 6 percentage points in the share of exposed employees), and the error terms are mostly positive, indicating a potential underestimate of the exposure indicators due to this source of uncertainty. As an example, A7 shows a case in which the address is georeferenced at the road access point, which is flood-safe. In contrast, the closest building is exposed to the highest hazard level, even if their distance is small.

[18] The size of the geocoding-related error is not constant over space, even if the perturbation procedure is the same for the whole country. That is due to the different shapes of the ISPRA polygons in different regions: the narrower the shape, the higher the impact of spatial inaccuracies.

5 Conclusions

This paper proposes a new methodology for assessing Italian manufacturing companies' exposure to natural hazards. This methodology avoids identifying companies' locations with their headquarters and instead accounts for the distribution of companies' activities across different sites and locations. We apply this methodology to evaluate the exposure of manufacturing companies to flood and landslide hazards, and we develop a set of indicators that provide a continuous measure of each company's risk profile.

We find that about 29% of manufacturing companies are exposed to floods and 8% to landslides. The shares of manufacturing workers exposed to floods and landslides are about 29% and 5%, respectively. Most companies are fully exposed to flood risk, i.e., all employees are in establishments exposed to some level of flood risk, or they are not exposed at all – i.e., none of the employees work in establishments at risk. Instead, a small fraction of companies have partial exposure to flood risk. Still, these companies account for a large share of all employees since these are multi-branch and, therefore, usually larger companies.

The exposure to flood risk is positively correlated with some company characteristics, and in particular size, age, and number of establishments. Firms with a higher share of tangible assets over total assets – which is a proxy of higher vulnerability to physical risks – are less likely to be exposed to floods, possibly due to an endogenous location choice. Conditional on being exposed to flood hazards, the exposure is lower for larger companies than for smaller ones. This result is consistent with the hypothesis that a wider geographic dispersion of the company's business activity may be a factor in mitigating the risks associated with exposure to physical hazards.

This work is a first step in measuring the exposure of the Italian productive system to physical hazards related to climate change. Proper measurement of exposure to physical risks at the aggregate and individual firm level is necessary to define effective public adaptation and mitigation policies. In addition, more information about exposure to risks is critical for raising awareness among companies so that they can undertake adaptation strategies to deal with future risks. However, ISPRA maps allow only imperfect comparability across regions. For this reason, our results should be interpreted with caution, and an important direction for future research is to validate these results by exploiting alternative hazard maps.

In the future, we aim to extend this work to all productive sectors and other physical hazards (like wildfires or draughts) that will become more frequent due to climate change. At the same time, a very relevant research direction is the correct quantification of the uncertainty underlying individual companies' exposure estimates for both current and future risks. Assessing potential long-term impacts under different climate and socioeconomic scenarios would be especially useful in preparing the Italian productive system to face the challenges posed by climate change.

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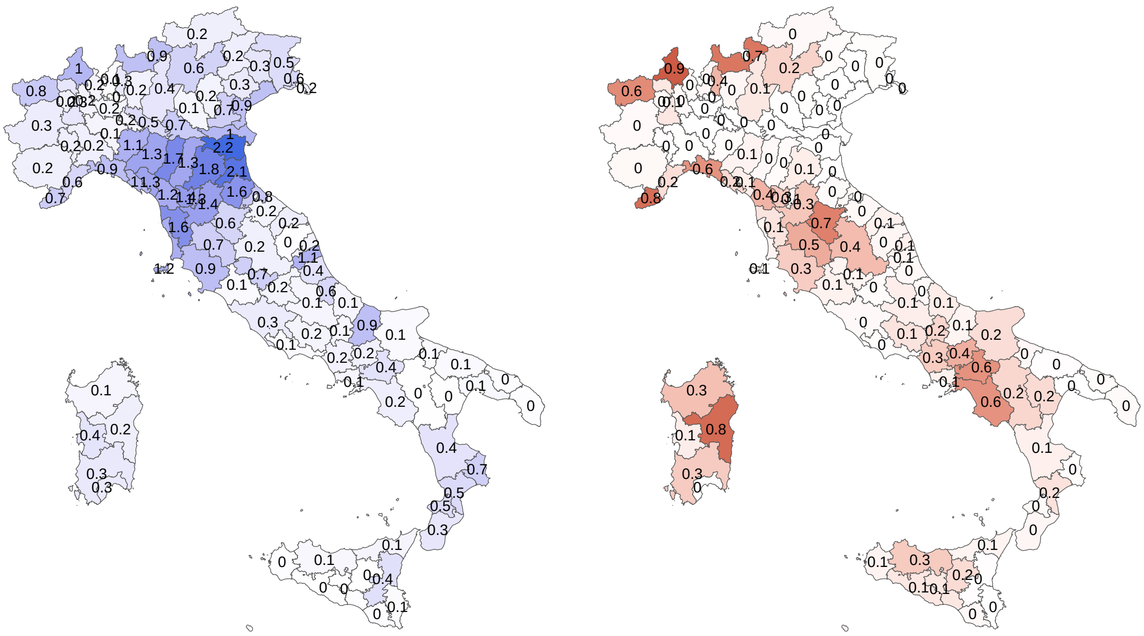
Appendix

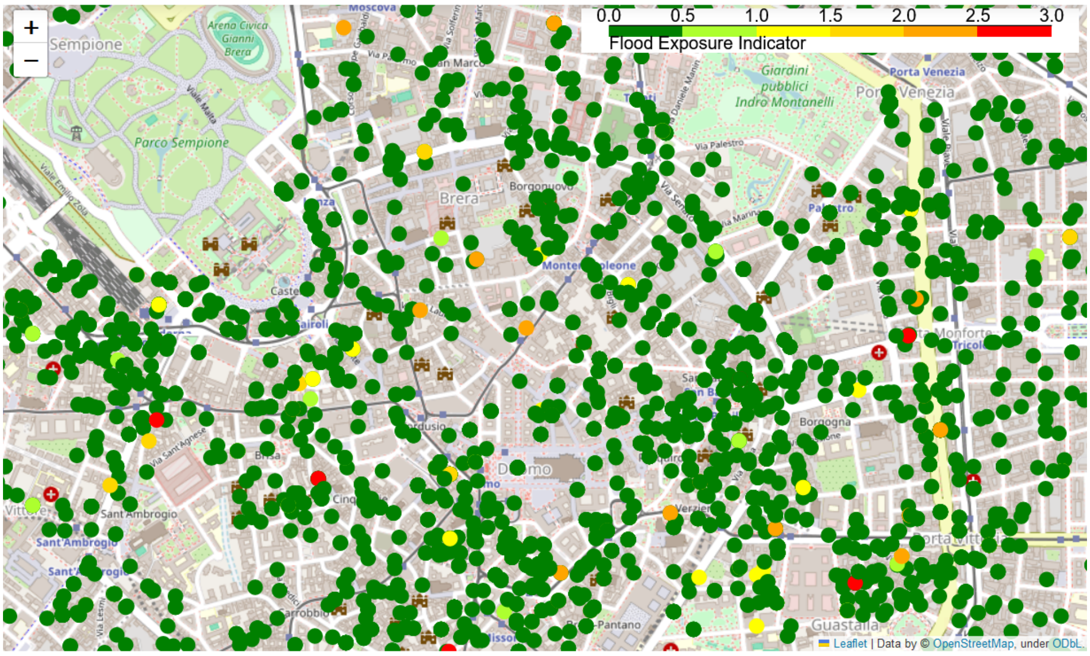
A Supplementary figures and tables

Figure A1: Level-sensitive exposure indicators at the provincial level

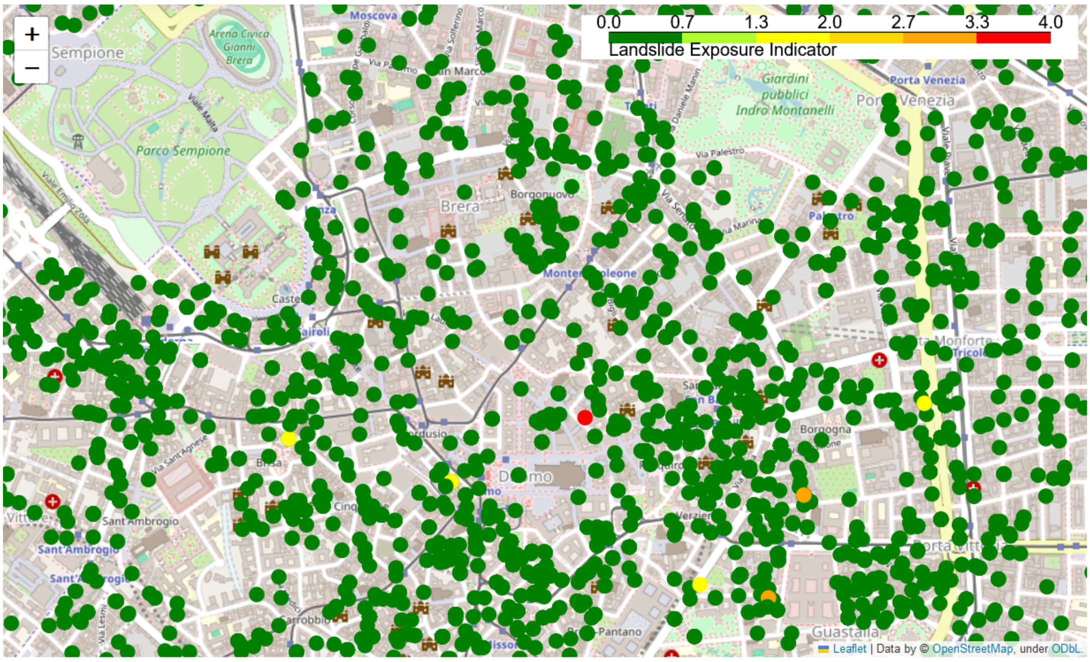


Note: This chart displays the level-sensitive exposure indicators E_F^R (left panel) and E_L^R (right panel) calculated at the NUTS-3 regional level. The value of the indicator is reported inside the boundaries of the province.

Figure A2: Companies exposure in Milan



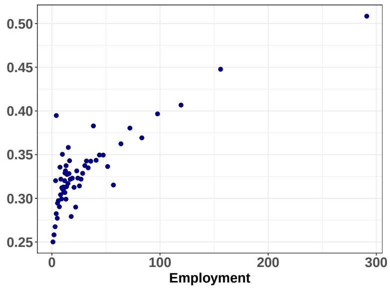
(a) Flood



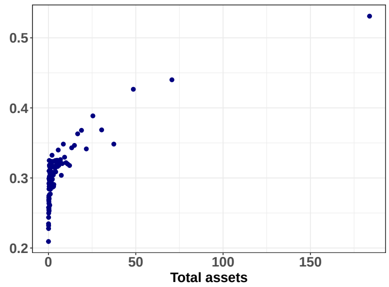
(b) Landslide

Note: This chart reports the location of the manufacturing company headquarters in Milan downtown. The color scale represents the values of the E_F^C (upper panel) and the E_L^C (lower panel) indicators.

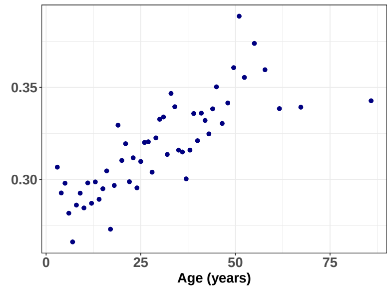
Figure A3: EXPOSURE TO FLOODS AND COMPANIES' CHARACTERISTICS



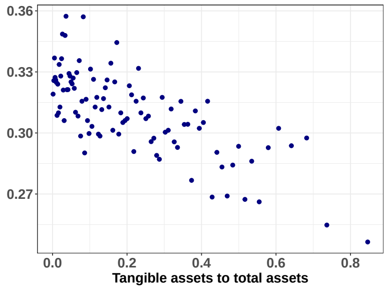
(a) Employment



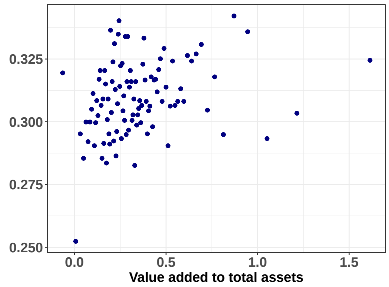
(b) Total assets



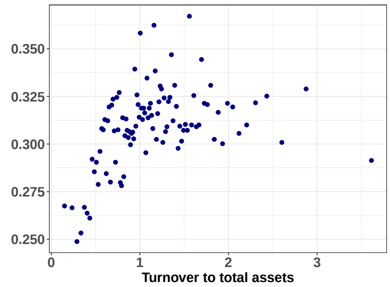
(c) Age



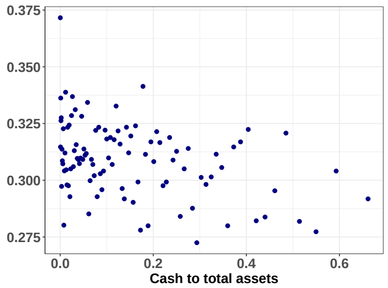
(d) Tangible assets



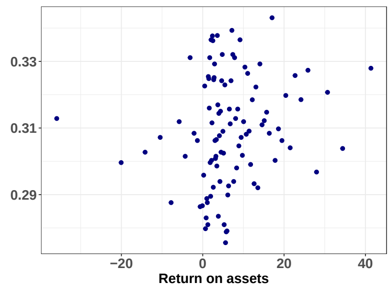
(e) Value added



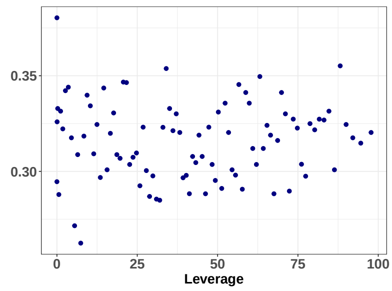
(f) Turnover



(g) Cash



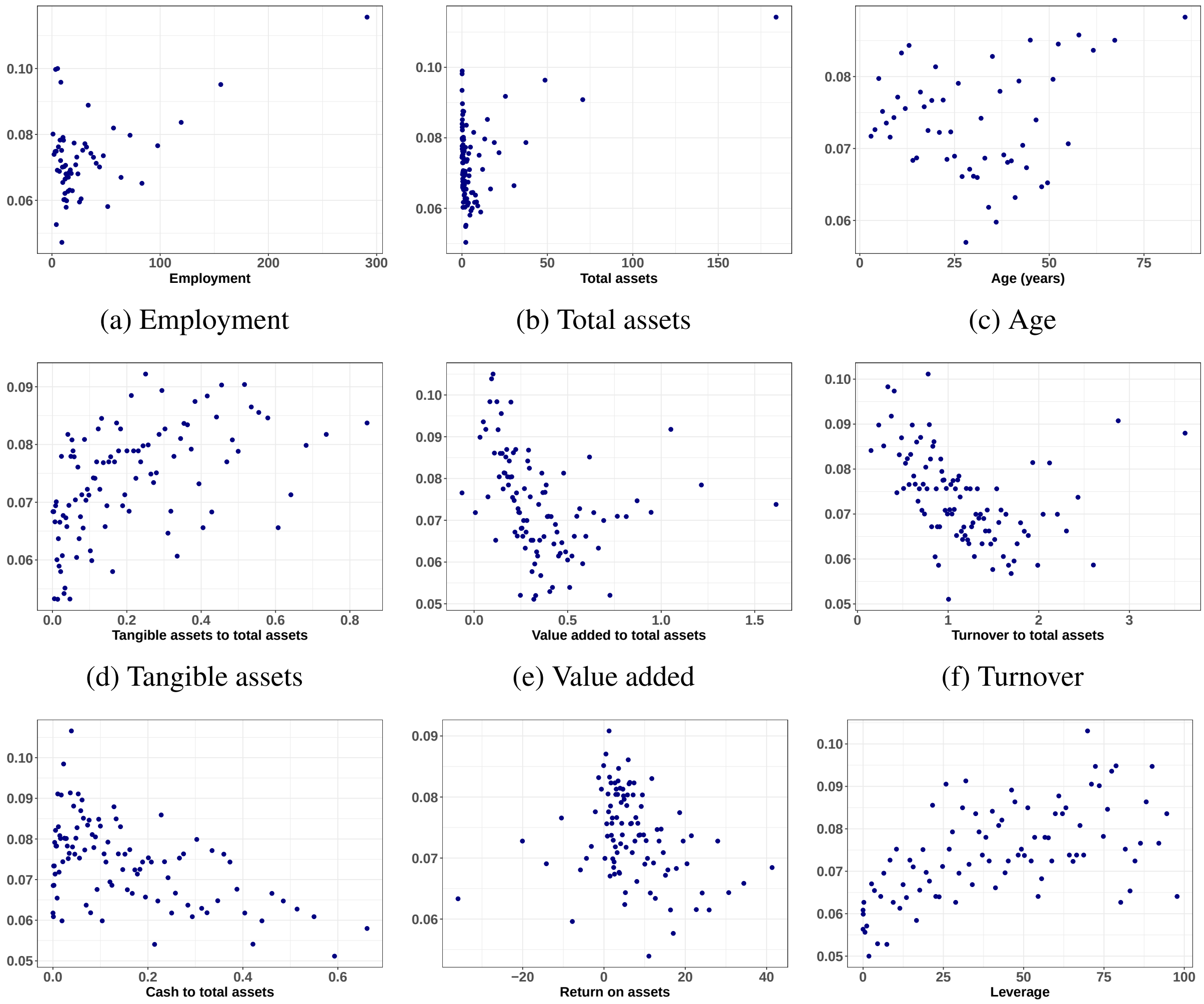
(h) Return on assets



(i) Leverage

Note: This chart reports a set of bin scatter plots showing the relation between companies' characteristics and a dummy equal to 1 if the company is exposed to floods. We consider nine variables: the number of employees, total assets, age of the company, tangible assets, value added, turnover, cash, return on assets, and leverage. Tangible assets, value added, turnover, and cash are plotted as a ratio to total assets. Total assets are reported in thousands of euros. The dots are the simple average of the dependent variable (i.e., the share of firms exposed to floods) for each percentile of the distribution of each company's characteristic considered. We windsorized all variables at the 1^{th} and 99^{th} percentiles of the distribution, except for age and leverage.

Figure A4: EXPOSURE TO LANDSLIDES AND COMPANIES' CHARACTERISTICS



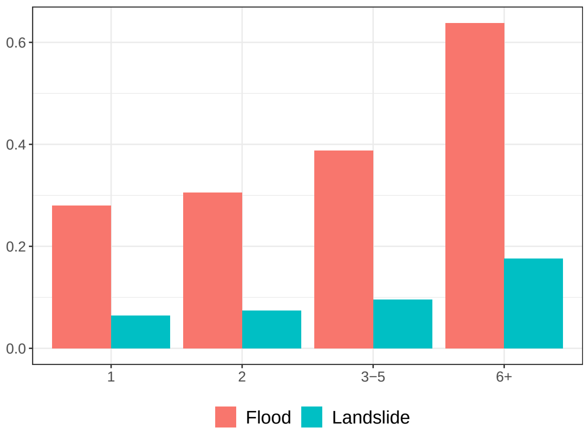
(a) Employment (b) Total assets (c) Age

(d) Tangible assets (e) Value added (f) Turnover

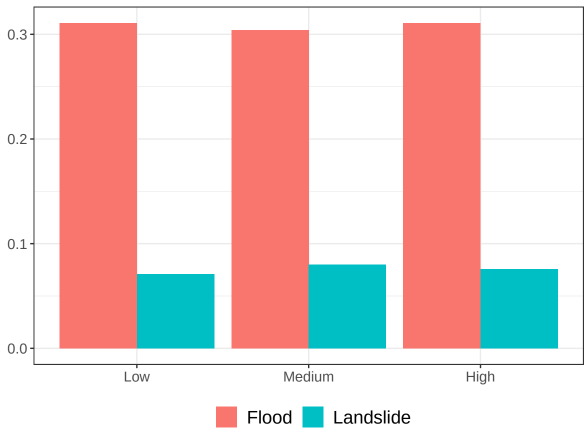
(g) Cash (h) Return on assets (i) Leverage

Note: This chart reports a set of bin scatter plots showing the relation between companies' characteristics and a dummy equal to 1 if the company is exposed to landslides. We consider nine variables: the number of employees, total assets, age of the company, tangible assets, value added, turnover, cash, return on assets, and leverage. Tangible assets, value added, turnover, and cash are plotted as a ratio to total assets. Total assets are reported in thousands of euros. The dots are the simple average of the dependent variable (i.e., the share of firms exposed to landslides) for each percentile of the distribution of each company's characteristic considered. We windsorized all variables at the 1^{th} and 99^{th} percentiles of the distribution, except for age and leverage.

Figure A5: ADDITIONAL RESULTS ON HAZARDS AND COMPANIES' CHARACTERISTICS



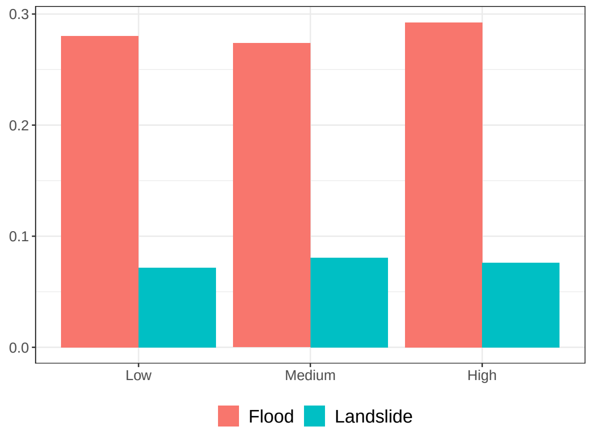
(a) Number of establishments



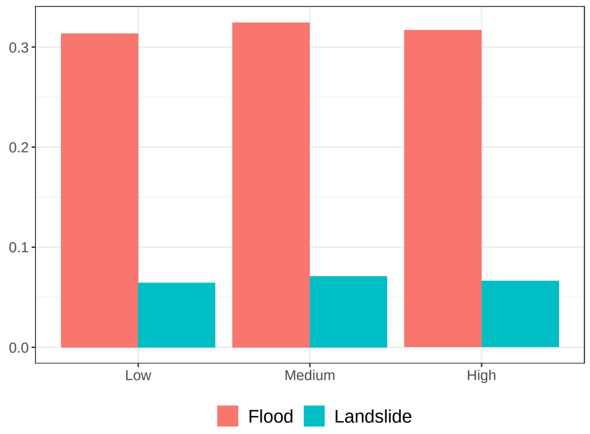
(b) Probability of default

Note: This chart displays the share of companies exposed to floods and landslides by the number of company establishments and their probability of default (as estimated by CERVED).

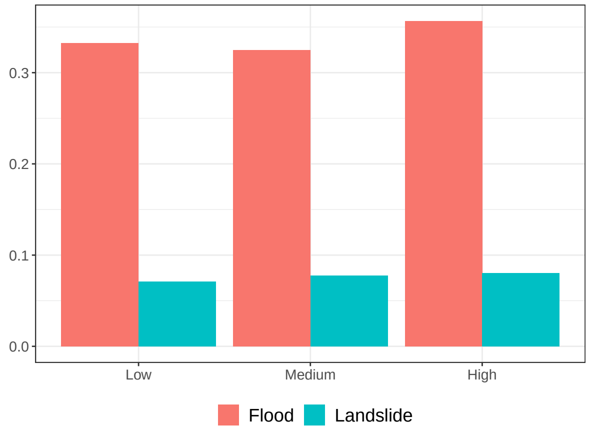
Figure A6: HAZARDS, PROBABILITY OF DEFAULT, AND COMPANY'S SIZE



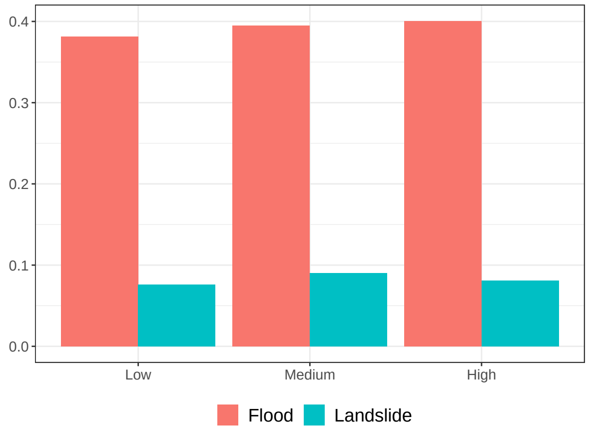
(a) 0-9 employees



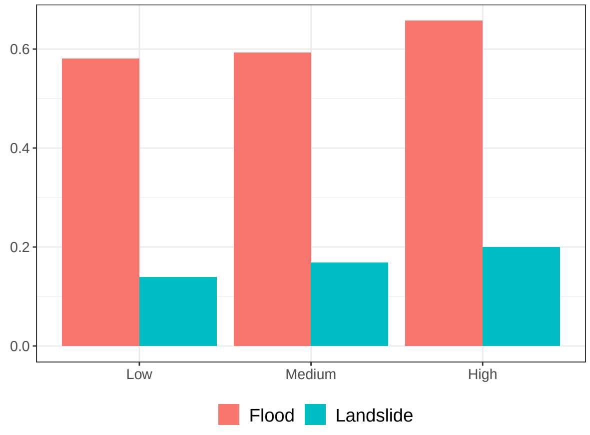
(b) 10-19 employees



(c) 20-49 employees



(d) 50-249 employees



(e) 250 employees or more

Note: This chart displays the share of companies exposed to floods and landslides by their probability of default (as estimated by CERVED) and number of employees.

Figure A7: Geocoding accuracy

Note: This map shows the impact of the use of OSM buildings on the evaluation of flooding hazard: the blue star corresponds to the original geocoded address (no flood exposure), the red star to the closest building and actual location of the company assets (high flood hazard).

Table A1: EXPOSURE TO FLOODS AND COMPANIES' CHARACTERISTICS

	FLOODEXP								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All companies			Multi-branch companies		Single-branch companies			
Employees	0.074***	0.080***		0.092***		0.049***		0.036***	
	(0.010)	(0.012)		(0.012)		(0.013)		(0.010)	
Age	0.058***	0.041**	0.052***	0.044**	0.044**	0.048***	0.050***	-0.024***	-0.011
	(0.015)	(0.017)	(0.017)	(0.018)	(0.018)	(0.015)	(0.019)	(0.006)	(0.013)
Establishments	0.378***	0.408***	0.395***	0.715***	0.731***				
	(0.036)	(0.041)	(0.034)	(0.036)	(0.034)				
Total assets			0.074***		0.079***		0.051***		0.024**
			(0.011)		(0.013)		(0.015)		(0.011)
Tangible assets/Total assets			-0.323***		-0.251***		-0.329***		-0.072
			(0.053)		(0.047)		(0.083)		(0.059)
Value added/Total assets			0.086		0.176**		-0.007		0.002
			(0.084)		(0.072)		(0.082)		(0.021)
Turnover/Total assets			0.056		0.029		0.085**		0.039***
			(0.035)		(0.028)		(0.041)		(0.013)
Cash/Total assets			-0.096		-0.147**		-0.092		-0.023
			(0.069)		(0.072)		(0.087)		(0.098)
Return-on-assets			-0.0003		-0.002***		0.002		0.001
			(0.0003)		(0.0006)		(0.001)		(0.001)
Medium risk			0.021		-0.009		0.046**		0.051
			(0.023)		(0.044)		(0.021)		(0.043)
High risk			0.091***		0.034		0.135***		0.074*
			(0.022)		(0.034)		(0.029)		(0.038)
Observations	189,730	107,896	107,805	59,109	43,881	130,619	63,924	129,946	63,538
NACE 2-digit fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
Province fixed effects								✓	✓

Note: This table reports the results of a logit regression where the dependent variable (*FLOODEXP*) is a dummy equal to one if a company has at least one employee in a flood-prone area. Companies with no employees are excluded. Column 1 shows the estimates on the full sample with the exogenous variables available for all firms. Results in columns 2-3 are based on the restricted dataset that includes balance sheet data. Results for multi-branch and single-branch companies are reported separately in columns 4-5 and 6-9, respectively. The number of employees, age, number of establishments, and total assets are in logs. Standard errors are clustered by the NACE 2-digit sector.

Table A2: EXPOSURE TO LANDSLIDES AND COMPANIES' CHARACTERISTICS

	LANDEXP								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All companies			Multi-branch companies		Single-branch companies			
Employees	(0.024)	(0.020)		(0.015)		(0.037)		(0.019)	
Age	0.017	-0.004	0.016	0.043**	0.019	-0.018	0.003	0.043***	0.099***
	(0.017)	(0.023)	(0.028)	(0.018)	(0.039)	(0.018)	(0.026)	(0.015)	(0.025)
Establishments	0.495***	0.509***	0.551***	0.737***	0.803***				
	(0.050)	(0.066)	(0.075)	(0.076)	(0.090)				
Total assets			-0.078***		-0.071***		-0.108***		-0.084***
			(0.019)		(0.026)		(0.023)		(0.016)
Tangible assets/Total assets			0.086		0.303***		-0.029		0.0001
			(0.057)		(0.099)		(0.094)		(0.091)
Value added/Total assets			-0.027		0.001		-0.084		0.051
			(0.131)		(0.135)		(0.166)		(0.107)
Turnover/Total assets			-0.109		-0.111		-0.104		-0.026
			(0.079)		(0.083)		(0.106)		(0.041)
Cash/Total assets			-0.214*		-0.111		-0.301**		-0.219**
			(0.126)		(0.136)		(0.144)		(0.102)
Return-on-assets			0.003***		0.002*		0.004***		0.004***
			(0.0008)		(0.001)		(0.001)		(0.001)
Medium risk			0.048		0.075*		0.025		0.060
			(0.046)		(0.039)		(0.058)		(0.052)
High risk			-0.002		0.013		-0.016		0.041
			(0.055)		(0.084)		(0.050)		(0.065)
Observations	189,730	107,896	107,805	59,109	43,881	130,619	63,924	111,763	52,851
NACE 2-digit fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
Province fixed effects								✓	✓

Note: This table reports the results of a logit regression where the dependent variable (*LANDEXP*) is a dummy equal to one if a company has at least one employee in a landslide-prone area. Companies with no employees are excluded. Column 1 shows the estimates on the full sample with the exogenous variables available for all firms. Results in columns 2-3 are based on the restricted dataset that includes balance sheet data. Results for multi-branch and single-branch companies are reported separately in columns 4-5 and 6-9, respectively. The number of employees, age, number of establishments, and total assets are in logs. Standard errors are clustered by the NACE 2-digit sector.

Table A3: EXTENT OF THE EXPOSURE TO FLOODS AND COMPANIES' CHARACTERISTICS

	S_F^C				
	(1)	(2)	(3)	(4)	(5)
	All companies			Multi-branch companies	
Employees	-0.009***	-0.013***		-0.020***	
	(0.001)	(0.001)		(0.002)	
Age	-0.001	0.003*	0.003*	0.0008	0.007*
	(0.001)	(0.001)	(0.002)	(0.003)	(0.004)
Establishments	-0.180***	-0.176***	-0.180***	-0.170***	-0.181***
	(0.006)	(0.005)	(0.007)	(0.008)	(0.010)
Total assets			-0.007***		-0.013***
			(0.002)		(0.003)
Tangible assets/Total assets			-0.009		-0.026
			(0.009)		(0.017)
Value added/Total assets			-0.007		-0.014
			(0.004)		(0.010)
Turnover/Total assets			0.0005		0.0004
			(0.002)		(0.003)
Cash/Total assets			0.018**		0.050***
			(0.008)		(0.018)
Return-on-assets			-1.8×10^{-5}***		-1.7×10^{-5}**
			(4.7×10^{-6})		(6.95×10^{-6})
Medium risk			-0.002		-0.003
			(0.002)		(0.003)
High risk			0.0001		0.004
			(0.003)		(0.007)
Observations	55,976	33,292	33,266	20,195	15,392
R^2	0.308	0.296	0.294	0.133	0.140
NACE 2-digit fixed effects	✓	✓	✓	✓	✓

Note: This table reports the results of an ordinary least squares regression where the dependent variable (*FLOODEXP*) is the share of the company's employees in a flood-prone area. Companies with no employees are excluded. Column 1 shows the estimates on the full sample with the exogenous variables available for all firms. Results in columns 2-3 are based on the restricted dataset that includes balance sheet data. Results for multi-branch companies are reported separately in columns 4-5. The number of employees, age, number of establishments, and total assets are in logs. Standard errors are clustered by the NACE 2-digit sector.

Table A4: MEASUREMENT ERROR CAUSED BY IGNORING BUILDINGS PERIMETERS

Region	Δ S_F^R	Δ S_L^R
Abruzzo	+ 0.01	+ 0.05
Basilicata	+ 0.01	0.00
Calabria	+ 0.02	+ 0.01
Campania	+ 0.01	0.00
Emilia-Romagna	+ 0.01	0.00
Friuli-Venezia Giulia	+ 0.03	0.00
Lazio	+ 0.01	+ 0.01
Liguria	+ 0.04	+ 0.06
Lombardia	+ 0.01	0.00
Marche	+ 0.01	+ 0.01
Molise	0.00	- 0.01
Piemonte	+ 0.02	0.00
Puglia	+ 0.02	0.00
Sardegna	+ 0.01	+ 0.01
Sicilia	0.00	+ 0.01
Toscana	+ 0.02	+ 0.02
Trentino-Alto Adige	+ 0.05	+ 0.03
Umbria	+ 0.01	+ 0.01
Valle d'Aosta	0.00	- 0.04
Veneto	+ 0.02	0.00

Note: This table reports the differential in the values of the S_F^R and S_L^R indicators when calculated using the actual building perimeters recovered by OpenStreetMap instead of the geocoding coordinates.

B Construction of the dataset

This Appendix describes in detail the procedure followed to construct the dataset:

- We downloaded from InfoCamere all the information reported by the Business Registry about each manufacturing company that was plausibly active on December 31, 2022. We included in the sample a company if the first two digits of their ATECO (NACE code) were between 10 and 33. For each company, we found the list of local units (including the complete addresses) and the number of employees by municipality on December 31, 2022, in the business registry. The source of the employment data provided by InfoCamere is the National Institute of Social Security (INPS). Infocamere provides the data used in this work as a result of a supply agreement with the Bank of Italy, and the information contained is either updated daily (data on local units, main activities) or annually (number of employees per municipality). The same data is accessible from the InfoCamere website (*visura camerale*).

- When a company only owns one establishment in a municipality, we assign the number of employees to that establishment. Otherwise, we assume that the employees of a company inside a municipality are uniformly distributed across all establishments inside that municipality. For a sample of about 110 thousand firms, we checked the employment data at the municipality level provided by InfoCamere with an alternative dataset of microdata provided by INPS to Bank of Italy, and we found that the correlation between the two sources is close to 1. However, for some company sites, there was no information on the number of employees in InfoCamere. We attempted to recover data from the INPS microdata archive for these establishments. This effort successfully filled in missing employee information for $\sim$ 1100 company sites.

- We retrieved the longitude and latitude of each headquarters/local unit using the Google Maps API. We checked that the position provided by the Google Maps API was plausible using the official shapefile of the municipality borders, which is publicly available on the Istat website. We discard the outcome of the geocoding if the coordinates returned by the Google Maps API are outside the municipality reported in the business registry. We discarded about 2% of the outcomes, and for these addresses, we used the geocoding service provided by ESRI. In the final dataset, for 98.5% of the addresses, the coordinates associated with the address fall inside the municipality reported in the business registry.

- We determined the exposure of each premise to flood and landslide hazards by using the hazard maps publicly available on the Idrogeo website. The shapefiles are available at `https://idrogeo.isprambiente.it/app/page/open-data`.

C Comparison with other administrative data

In this appendix, we will compare the distribution of firms and employees derived from our dataset with similar statistics from the dataset ASIA (*Registro statistico delle imprese attive*) compiled by the National Statistical Institute (Istat).

ASIA is the most comprehensive dataset on Italian companies, containing detailed information on corporations and non-incorporated firms. The information set includes the distribution of each firm's employees among local units. Istat does not disseminate microdata at the firm level but publishes statistics on the number of firms and employees in each municipality by NACE code.

To assess the consistency of our dataset with ASIA, we calculate the number of firms (headquarters or local units) and the number of employees by municipality-NACE 2-digit code. Next, we merge our dataset with ASIA statistics. If there is no data in ASIA for a combination of municipality and NACE code, we impute zero for the number of firms and employees.

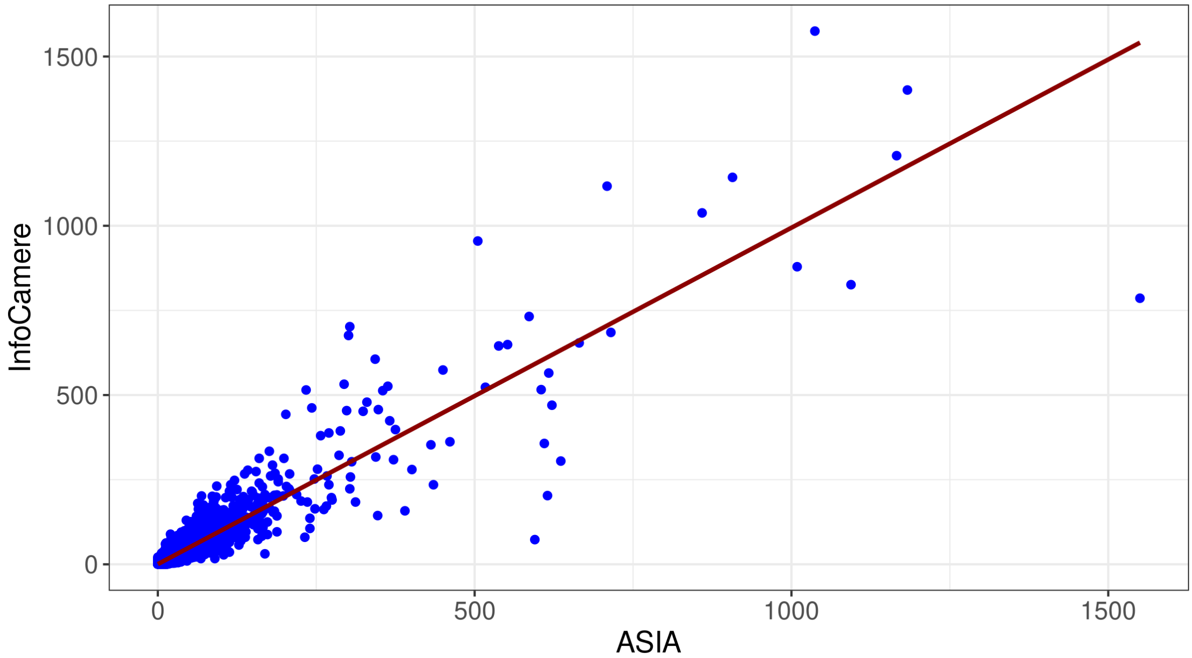
Before showing the results, we need to point out some issues. First, ASIA surveys all firms and workers (including self-employment), while our dataset includes only corporations. That means that ASIA's target universe is potentially larger than ours regarding firms and employees. For example, according to ASIA, there are more than 3,000 firms in the textile sector in the municipality of Prato, while they are about 1,000 according to our dataset.

Second, Istat assigns the NACE codes of local units based on their specific activity, while we observe only one NACE code per firm. For example, based on our dataset, the hydrocarbon production sector in the municipality of San Donato Milanese employs about 5,000 employees. In ASIA this number is less than 500 employees. The difference is due to the fact that this municipality hosts the administrative headquarters of Italy's largest hydrocarbon enterprise, and this unit is reclassified in the administrative services sector in ASIA.

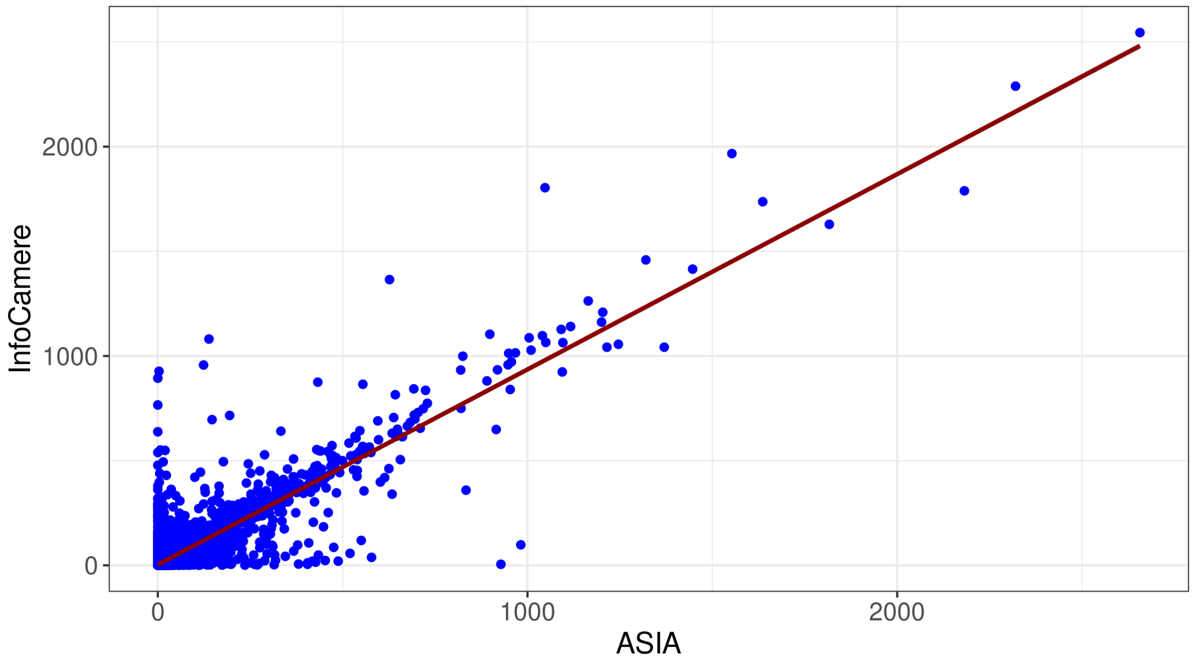
Figure A8 displays two scatter plots with the comparison results. Each plot reports on the x-axis the number of firms or employees according to ASIA, while the values computed on our dataset are on the y-axis.[19] Despite the caveats already reported, the results in Figure A8 show that the information in our dataset is consistent with ASIA. The correlation between the two datasets in the number of enterprises and employees by municipality-sector is 0.93 and 0.91, respectively.

[19] To improve the visualization of the results, figure A8a does not show the textile sector in the municipality of Prato, and figure A8b does not show the hydrocarbon production sector in San Donato Milanese.

Figure A8: Comparison between InfoCamere and ASIA



(a) Establishments



(b) Employees

Note: The chart reports a comparison between the distribution of establishments and employees according to our dataset and ASIA. The upper scatterplot reports the number of establishments by the municipality and NACE-2 digit sector from InfoCamere (y-axis) and ASIA (x-axis). The lower scatterplot displays the number of employees.