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Questioni di Economia e Finanza

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ECONOMIC EXPOSURE TO WILDFIRES: A FIRM-LEVEL ANALYSIS BASED ON INNOVATIVE HAZARD MAPPING IN ITALY

by Riccardo Russo*, Silvia Degli Esposti**, Luca Ferraris**, Paolo Fiorucci**, Giorgio Meschi**, Nicolò Perello** and Andrea Trucchia**

Abstract

This paper provides a comprehensive assessment of the exposure of Italian businesses to wildfire risk, leveraging an innovative set of high-resolution wildfire hazard maps that are integrated with georeferenced firm-level data for assessing local exposure, as proxied by employment. The analysis offers a precise spatial matching between economic activity and wildfire susceptibility, thereby revealing pronounced geographical and sectoral heterogeneity: while only 1.4 per cent of Italian firms are currently exposed to wildfire hazard, the incidence is higher in southern regions and in sectors such as agriculture and construction. Moreover, nearly one third of wildfire-exposed establishments is also exposed to landslides. Turning to the economic consequences of wildfire events, the study finds that establishments affected by wildfires exhibit a similar probability of survival compared to their unaffected peers. Based on climate projections, the number of business sites exposed to wildfires can be estimated to increase by 3 per cent under the most conservative +1.5°C scenario and by 11 per cent under the +3°C scenario, with the largest increases in Puglia, Campania, and Lazio. This underscores the non-linear amplification of climate-related risks in the absence of effective adaptation strategies. These findings highlight the importance of integrating high-resolution physical risk data into economic and policy frameworks, both to improve the monitoring of climate-related vulnerabilities and to inform targeted adaptation and mitigation measures at the regional and sectoral level.

JEL Classification: D22, Q54, R11.

Keywords: natural disasters, wildfires, climate risk, firms.

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* Bank of Italy.

** CIMA Research Foundation.

1 Introduction[1]

Each summer, large areas of Europe are affected by wildfires, and the Mediterranean basin is particularly exposed. A preliminary JRC report (European Commission, 2025), based on the European Forest Fire Information System (EFFIS), estimated that in 2024 about 419 thousand hectares burned across Europe, including 51 thousand in Italy. This figure closely matches ISPRA estimates for the same year (ISPRA, 2024), which reported 51.4 thousand hectares, mainly in Sicily and Calabria. Examining the temporal trend, both the total burned area and the number of wildfires in Italy declined on average between 2000 and 2018, reflecting the impact of improved prevention policies introduced in the early 2000s (*Legge quadro in materia di incendi boschivi* n. 253/2000).

However, wildfires remain a significant source of risk and their impact is characterized by strong inter-annual variability, as demonstrated by the dramatic 2017 season[2]. Wildfires result in significant ecological, social, and economic impacts, causing large-scale loss of forest cover and biodiversity, damaging critical infrastructures such as power lines, transport networks, and water supply systems, as well as dwellings and productive sites. According to the EM-DAT database, between 2000 and 2025 wildfires caused 608 fatalities and an estimated 18.8 billion dollars in damages across EU-27 countries.[3]. The 2017 wildfires season in Portugal alone caused 117 fatalities and inflicted extensive damage to buildings and infrastructure, with losses estimated by the Portuguese government at €1.5 billion (San-Miguel-Ayanz, J. et al., 2020). The recent, large-scale 2025 Los Angeles wildfires not only caused a heavy toll in terms of human lives, but also contaminated public water supply (Haggerty and James, 2025) and led to service disruptions in several transmission facilities and research centres, such as the Mt. Wilson Observatory (Petri, 2025).

Wildfires occur when three factors coincide: a (possibly intentional) ignition source, sufficient fuel (e.g., dry vegetation), and favorable weather conditions. To assess fire

[1]The opinions expressed are those of the authors and do not necessarily reflect the views of the Bank of Italy or of the Eurosystem. For the CIMA Foundation, Paolo Fiorucci acted as the scientific reference of the convention underlying this work, Luca Ferraris served in his role as President of the Foundation.

[2]In 2017, Italy recorded one of its worst wildfire seasons, with over 160 thousand hectares burned (more than three times the annual average)

[3]Centre for Research on the Epidemiology of Disasters (CRED) / UCLouvain, 2025, Brussels, Belgium – www.emdat.be. These figures should be regarded as lower-bound estimates, since EM-DAT only includes events meeting specific criteria (at least 10 fatalities or 100 affected or any call for international assistance), and reporting of total damages is not mandatory.

danger, the Forest Fire Weather Index (FWI) is widely used worldwide; it is a synthetic indicator estimating the potential intensity and spread of wildfires based on temperature, relative humidity, wind speed, and precipitation. Since climate change affects all these determinants, it is natural to ask how wildfire occurrence will evolve over the coming century, irrespective of ignition mechanisms, be they natural or driven by human behaviour, including deliberate acts. The JRC PESETA[4] IV study (Feyen L. et al., 2020) estimates that within the European Union, if the average temperature rises by 1.5°C above pre-industrial levels, an additional 5 million people will be exposed to extreme wildfires on top of the current 63 million, and in the case of a 3°C increase the number of exposed individuals will rise by 15 million. Another study (Turco, M. et al. , 2023) predicts that the annual burned area in Mediterranean Europe could increase by at least 41% under a +1.5°C warming scenario, and by up to 187% under a +3 °C scenario.

As one of the main sources of physical risk to the economy, wildfires have increasingly been incorporated into stress-testing methodologies by central banks and policy institutions. The ECB's economy-wide climate stress test (Alogoskoufis, 2021), assessing the impact of alternative climate scenarios over a time horizon of 30 years, estimated that 22% of euro area bank exposures were loans to firms exposed to high[5] physical risk, and more than half of these loans are exposed to wildfires. More recently, the ECB also published a set of indicators that capture the exposure of the financial sector to transition and physical risk based on granular company data and climate metrics (ECB, 2025). Based on these indicators – which remain analytical tools and are therefore not used for official statistics – around 15% of the euro-area financial portfolio[6] is currently exposed to wildfires. This share is projected to rise to 17% under the RCP-8.5 scenario, an IPCC (Intergovernmental Panel on Climate Change) pathway assuming continuously increasing greenhouse-gas emissions. Finally, in May 2025, the Network for Greening the Financial System (NGFS) published a set of short term climate scenarios[7] aimed at providing a

[4]Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis (Phase IV). This study combines regional climate projections (from EURO-CORDEX) with biophysical impact models to evaluate how climate change might affect Europe across multiple sectors.

[5]Exposure is classified as high for a firm if the probability of suffering from a wildfire or a flood in a given year is over 1%.

[6]The analysis covers debt securities, equities, and loans issued by deposit-taking corporations (excluding central banks), non-money market investment funds, insurance corporations, and pension funds.

[7]`https://www.ngfs.net/en/publications-and-statistics/publications/ngfs-short-term-climate-scenarios-central-banks-and-supervisors`.

clear picture of the potential, immediate effects of climate change on financial stability. Particularly, in the *Disasters and Policy Stagnation* scenario a series of natural hazards affects all European countries between 2026 and 2027 (heatwaves, droughts and wildfires in 2026 followed by a combination of floods and storms in 2027). The effects of this event combination could lead to a significant decline in euro-area annual GDP by 2030, and higher inflation.

Taken together, this evidence and these estimates reveal the economic relevance of wildfires and underscore the need for detailed analyses of the economic sector's current exposure, as well as how this exposure may evolve in the future. This need is further accentuated by the absence of a European or Italian regulatory framework specifically addressing wildfire risk in the vicinity of industrial and commercial facilities – a stark contrast with the flood-risk context, where since 2007 the Floods Directive (Directive 2007/60/EC) regulates the presence of exposed assets in flood-prone areas.

The objective of this work is threefold: (1) to leverage an experimental, high-resolution set of wildfire hazard maps to accurately quantify the exposure of Italian companies to wildfires; (2) to match firm-level data with wildfire records in order to assess their effects on firm closures; and (3) to integrate these findings with the most recent climate projections. Before addressing these objectives in detail, the next section provides an overview of existing studies that have approached the topic from various perspectives.

Related literature Wildfires remain relatively underrepresented in the economic literature compared to other physical hazards. This section reviews empirical contributions that assess the geographic pattern of wildfire exposure and their direct and indirect economic consequences.

The aforementioned climate change-related indicators developed by the ECB assess wildfire exposure using high-resolution maps that provide wildfire probability estimates, rather than categorical risk classes, for the EU-27 area. These probabilities are derived from the Fire Weather Index (FWI) computed by Copernicus, combined with burned area and land cover satellite data from MODIS[8]. Additional geographic variables, such as proximity to human settlements, are incorporated into an XGBoost model to generate wildfire probabilities on a 2.5×2.5 km grid. The resulting probability map are then used

[8]Moderate Resolution Imaging Spectroradiometer developed by NASA, providing data on land cover, burned areas, vegetation, oceans, and atmospheric properties.

to produce a granular assessment of the financial sector's exposure. Finally, the analysis is aligned with Representative Concentration Pathway (RCP) scenarios, which capture potential future developments and point to a generalized increase in wildfire probability across all grid cells under both RCP 4.5 and RCP 8.5 scenarios[9].

The JRC performed a quantitative assessment of wildfire hazard across 1366 NUTS-3 regions in Europe (Gomez et al., 2025). The analysis relies on regional evaluations of the Fire Weather Index (FWI) to estimate both the share of the population exposed to at least one week of high-to-very-extreme fire danger and the expected annual economic damage. The study also provides projections under scenarios of +1.5°C to +4°C global temperature increase, showing that the highest current economic losses in Europe are observed in Italy (€640 million per year), with expected increases of approximately 20% even under the most limited warming scenario (+1.5°C).

Another study (Meier et al., 2023) matches EFFIS data to Eurostat economic time series to capture the effect of wildfires on employment and GDP growth in Southern Europe (Spain, Portugal, Italy and Greece) at NUTS-3 level. The study finds that each additional wildfire reduces local GDP growth by 0.026%, which translates into an average loss of €12–20 million per NUTS-3 region. The effect on employment is sector-specific: retail and tourism experience a decline in average annual employment growth, while insurance and real estate see compensating increases. A similar analysis conducted across U.S. counties (Walls and Wibbenmeyer, 2023) also reveals local, sector-specific impacts on employment growth: a temporary decline in the hospitality sector, a short-term increase in health services, and, most notably, a persistent rise in construction employment. The Bureau of Labor Statistics confirmed this result by linking wildfire records with data from the Quarterly Census of Employment and Wages (Luo, 2023). For the period 2003–2021, the study shows that construction employment in California counties increased by up to 10% within the first 18 months following major wildfires.

Finally, a recent article from UCLA (Li and Yu, 2025) investigates the economic repercussions of wildfires by combining fire perimeter data from the Fire and Resource Assessment Program (FRAP) with county- and sector-level GDP from the Bureau of Economic Analysis (BEA) for the period 2001–2022. Drawing on a reduced-form regression of historical data, they estimate GDP losses from wildfire exposure and apply the model to project

[9] These two IPCC scenarios differ in that RCP4.5 assumes emissions stabilization, while in RCP8.5 emissions continue to rise throughout the century.

that the Palisade and Eaton fires of January 2025 will result in approximately $4.6 billion lost GDP for Los Angeles County.

2 Mapping the Economic Exposure to Wildfires in Italy

We rely on two main sources of data. First the InfoCamere business register, providing detailed information on firms which we have georeferenced to locate individual establishments and secondary branches. This step is essential to accurately capture the exposure of multi-branch companies, as thoroughly documented in Loberto and Russo (2024). Second, the high-resolution wildfire hazard maps developed by the Centro Internazionale in Monitoraggio Ambientale (CIMA Research Foundation). By combining these datasets, we can spatially match economic activity with wildfire risk levels, offering a granular picture of exposure across Italy.

2.1 Company Data

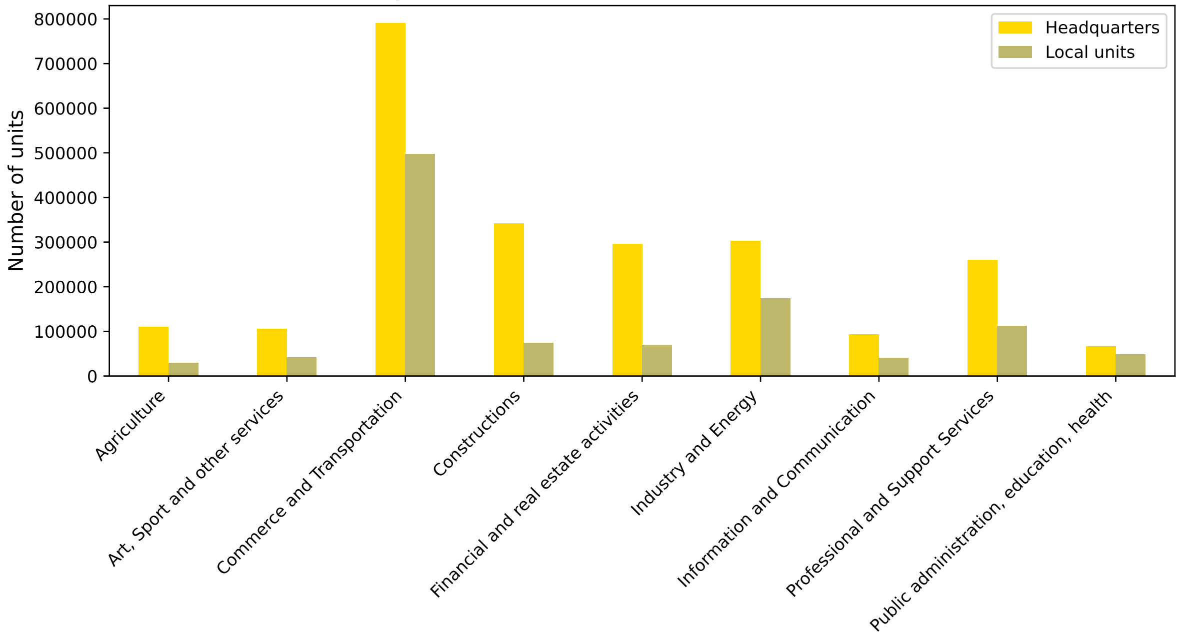
A total of 2.37 million firms were extracted from the InfoCamere register, restricted to those active as of December 31, 2023. The dataset also contains 1.1 million secondary units, for a total of 3,457,522 company sites. Figure 1 illustrates the distribution of firms and their establishments across economic macro-sectors, while Table 1 reports descriptive statistics on employees, firm age, and the number of business sites. The majority (73%) of companies is monobranch, while a large share (47%) of companies reports zero employees. The employment count excludes individual companies, sole proprietorship and certain forms of employment, such as freelance contracts and occasional collaborations. For a subsample of 757 thousand corporations, more detailed information is available from Cerved, which annually provides reclassified financial statements and a range of credit and risk indicators for Italian incorporated companies. This subsample excludes firms other

Table 1: Summary - Infocamere sample

Variable	N	Min	25	50	75	Max	Mean	St.dev.
Employees	2,366,929	0	0	1	3	69,924	6	112
Age (years)	2,003,295	0	6	14	26	217	18	15
Number of sites	2,366,929	1	1	1	2	13,528	1	10

Note: summary statistics for companies in the Infocamere sample, as observed in 2023 at year end.

Figure 1: Firms by macro-sector



Note: composition of InfoCamere sample in terms of activity sector. Headquarters and secondary units, as observed in 2023 at year end.

Table 2: Summary - Cerved subsample

Variable	Min	25	50	75	Max	Mean	St.dev.
Employees	0	1	3	9	69,924	14	197
Number of sites	1	1	1	2	13,528	2	16
Total assets	1	161	469	1,506	109,628,474	5,079	189,160
Tangible assets	0	4	31	193	37,127,894	1,170	63,006
Turnover	0	149	464	1,475	43,746,769	4,420	112,832
Value added	-384,201	33	128	417	8,472,105	997	21,033

Note: summary statistics for the 756,834 companies in the Cerved sample as observed in 2023 at year end. Monetary variables are in thousands of euros.

than corporations, as well as companies in activities classified as financial or real estate, or having zero total assets or revenues. Summary statistics for the Cerved subsample are shown in Table 2.

2.2 Hazard maps

Wildfire susceptibility is influenced by a complex interplay of factors such as vegetation continuity, land cover, topography, and climate. These variables can vary significantly over short spatial distances – especially in Mediterranean regions, where the landscape is highly fragmented and diverse. High-resolution maps are thus essential to capture fine-scale variations in terrain and vegetation that directly affect fire probability and spread, and identify specific assets at risk, such as industrial facilities or commercial buildings.

The hazard mapping adopted in this work was developed by CIMA in collaboration with Consiglio Nazionale delle Ricerche (CNR) and the Universities of Lausanne and Rome. These maps form the backbone of the RISICO Wildfire Early Warning System (EWS), Italy's wildfire hazard monitoring and alert system, currently used by the Italian Civil Protection Department (Perello et al., 2025) to support decision-making at the national scale, particularly for issuing alert messages to regional authorities. The maps have also been adopted by the World Bank in the production of the Wildfire Social Risk Index (World Bank, European Commission, 2024), a spatial indicator that identifies high-risk areas that have lower firefighting capacity and higher social vulnerability.

The methodology applied to produce these maps combines an assessment of **wildfire susceptibility** – defined as the static probability of a fire occurring in a given area – with an evaluation of **wildfire intensity** – defined as the rate of heat energy released during a fire – to produce an overall wildfire hazard score:

- **Susceptibility** maps are derived from Trucchia et al. (2023) using machine-learning methods (Random Forest) that model wildfire occurrence probability based on EFFIS historical records and a set of independent variables listed in Table 3. These maps were produced on a 500×500 m grid covering 13 countries in the eastern Mediterranean and southern Black Sea basins. An analysis of variable importance indicates that climate and topography are the most important drivers of wildfire occurrence, followed by anthropic factors and finally by vegetation. The predicted wildfires occurrence probabilities were subsequently used to assign each pixel to low, medium, or high susceptibility.

- **Intensity** mapping was produced using a fuel-based evaluation that relies exclusively on plant functional types (fuel type) to define four intensity classes, reported

Table 3: Input variables for susceptibility mapping

Category	Variables
Topographic variables	Elevation; **slope**; aspect (north/east components).
Land cover variables	Vegetation type; tree cover density; neighbouring vegetation composition (2nd-order Moore neighbourhood).
Climatic variables	Annual mean temperature; annual maximum daily temperature; **cumulative annual precipitation**; mean annual wind speed; **maximum consecutive dry days**; maximum consecutive wet days; annual mean relative humidity (43-year averages).

Sources: CORINE Ladcover 2018, ERA-5, Copernicus Land Monitoring Service, NASA SEDAC, MERIT DEM. Variables shown in bold correspond to those with the highest importance scores according to the RF algorithm.

in Table 4. These classes represent increasing fire intensity, defined according to the potential fire-spread capacity and flame height.[10]

Both the wildfire intensity and susceptibility maps are provided on a 500×500 m pixel map. Each pixel is assigned to one of the 12 wildfire hazard classes in the intensity / susceptibility contingency matrix shown Table 5. The numerical ordering of these classes is not monotonic in terms of severity: class identifiers jointly encode information on fire occurrence likelihood and potential impact, rather than representing a simple increasing scale of hazard magnitude. Figure 2 illustrates the hazard map at the national scale in Italy. Although providing a consistent spatial representation of wildfire danger, it is important to emphasize that this map is static and does not incorporate time-varying factors such as meteorological conditions. As a standalone product, however, it is useful for identifying long-term spatial patterns and for highlighting areas where preventive measures may be prioritized.

Table 4: Wildfire intensity classes and typical vegetation coverage

Intensity class	Description	Vegetation type
1	Low intensity surface wildfire	Crops, grasslands, vineyards
2	Medium intensity surface wildfire	Broadleaves, fruit and olive trees
3	High intensity surface wildfire	Shrubs, sclerophyllous vegetation
4	Very high intensity crown fires	Conifers, mixed forest

Note: vegetation cover is obtained from Corine Land Cover 2018.

[10]For instance, broadleaved forests and coniferous forests differ substantially: in coniferous stands, flames can more easily reach heights of 30 m or more.

Table 5: Hazard Contingency Matrix

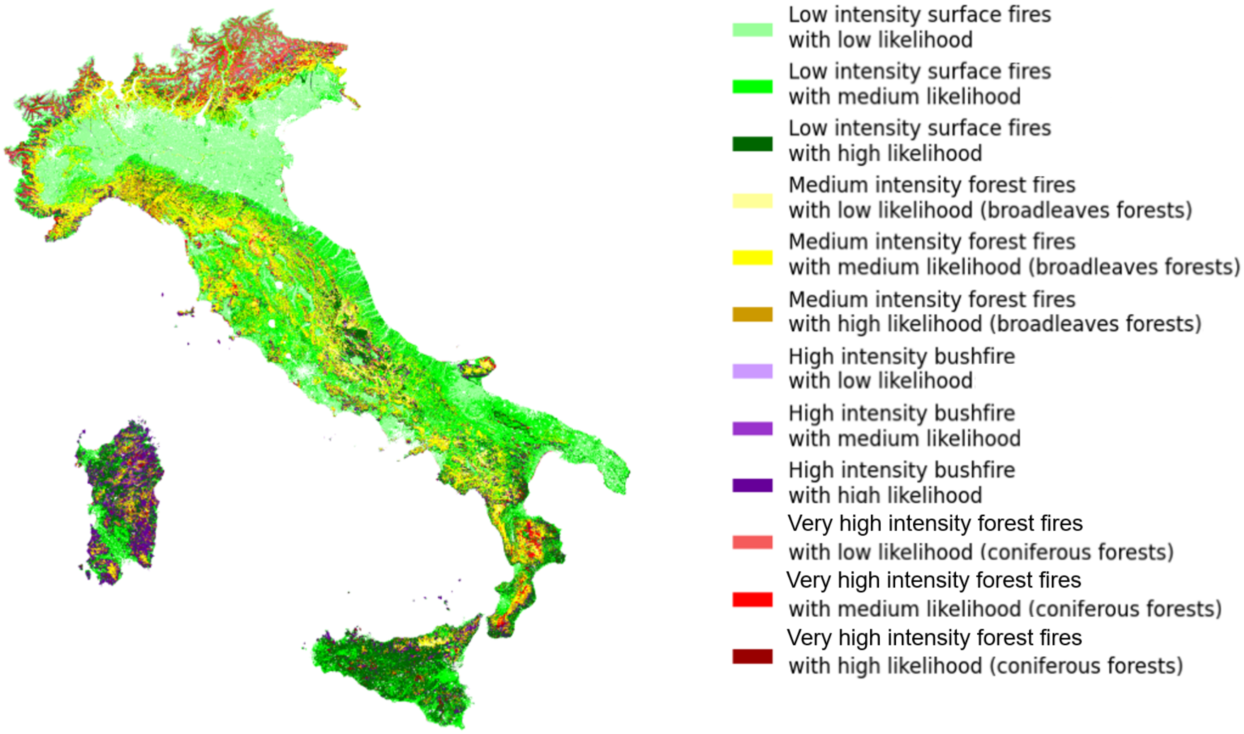
<table>
<tr><th colspan="2" rowspan="2">HAZARD MATRIX</th><th colspan="4">FUEL TYPE</th></tr>
<tr><th>1
Grasslands and croplands</th><th>2
Broadleaves</th><th>3
Shrublands</th><th>4
Coniferous and Eucalyptus</th></tr>
<tr><td rowspan="3">SUSCEPTIBILITY</td><td>1
Low</td><td>1
low intensity surface fires with low likelihood</td><td>4
medium intensity forest fires with low likelyhood</td><td>7
high intensity bushfire with low likelihood</td><td>10
very high intensity forest fires with low likelihood</td></tr>
<tr><td>2
Medium</td><td>2
low intensity surface fires with medium likelihood</td><td>5
medium intensity forest fires with medium likelihood</td><td>8
high intensity bushfire with medium likelihood</td><td>11
very high intensity forest fires with medium likelihood</td></tr>
<tr><td>3
High</td><td>3
low intensity surface fires with high likelihood</td><td>6
medium intensity forest fires with high likelihood</td><td>9
high intensity bushfire with high likelihood</td><td>12
very high intensity forest fires with high likelihood</td></tr>
</table>

Note: The contingency matrix is obtained by matching susceptibility and intensity (fuel type) scores and classifies wildfire-prone areas into twelve categories, ranging from low-intensity surface fires with low likelihood to occur (1) to vey high-intensity forest fires with high likelihood (12).

The national wildfire register overseen by the Carabinieri Forestali[11], which has been systematically compiled since the early 2000s from ground-validated burned-area polygons, was used as part of the validation workflow. This archive is independent from the EFFIS dataset used to derive the susceptibility maps and therefore allows us to assess which of the twelve hazard classes defined in Table 5 actually correspond to past wildfire occurrence across the Italian territory. Nearly 73% of the observed burned areas belongs to high susceptibility categories (3-6-9-12), emphasizing the strong influence of highly susceptible fuel–hazard configurations on past wildfire activity. Conversely, low-susceptibility classes account for only 2% of the burned area, largely within the low-intensity category.

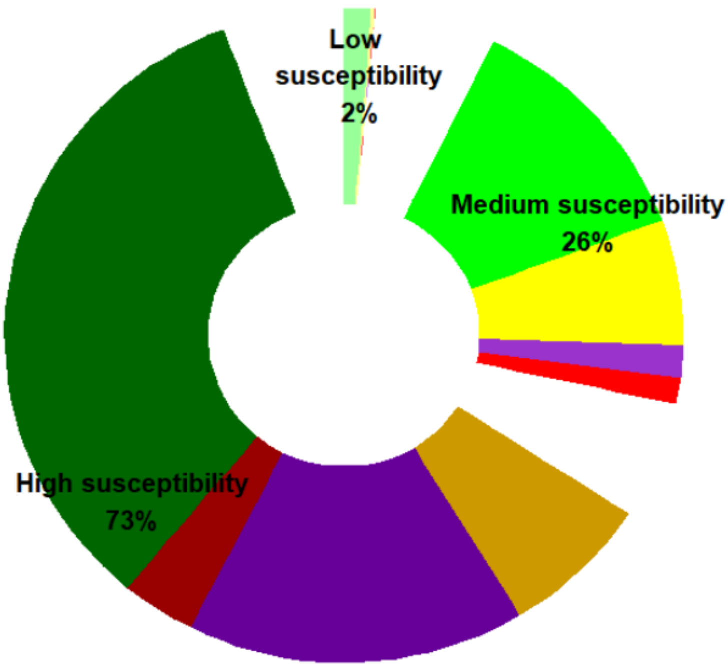
[11]Pursuant to Art. 7(2), Legislative Decree 177/2016. Before 2016 the register was managed by Forestry Corps - *Corpo Forestale dello Stato*.

Figure 2: Wildfire Hazard Map at national scale



Note: The map displays the final hazard classification across the entire Italian territory.

Figure 3: Hazard classification of areas burned between 2007 and 2023



Note: Colors follow the same palette of Figure 2. Different hazard classes are aggregated by their susceptibility level. The majority of burned areas fall over pixels associated with high-susceptibility hazard classes (hazard classes 3,6,9,12). Source: CIMA maps and Carabinieri Forestali wildfire register.

2.3 Results

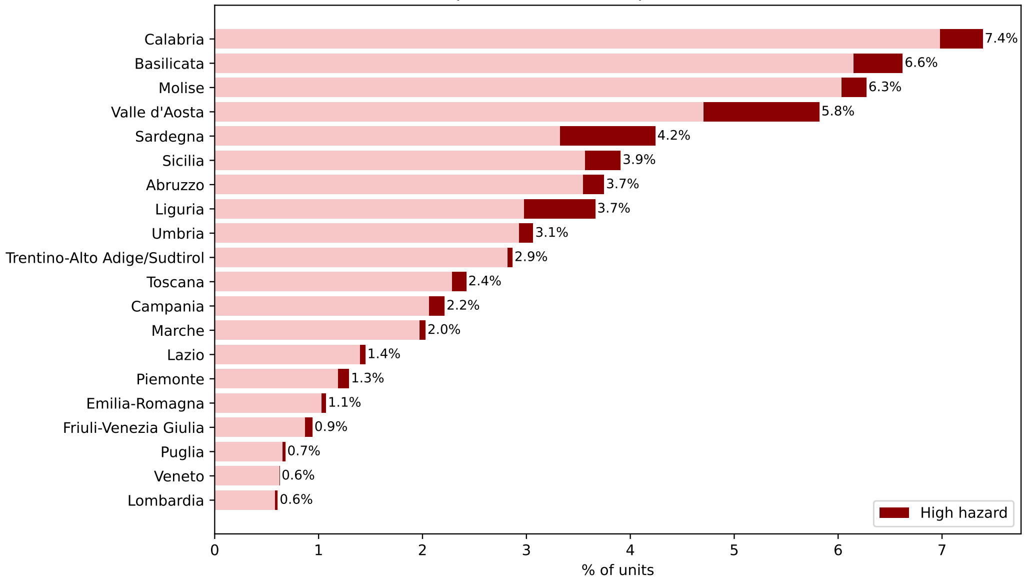
Within the proposed framework, companies and their production sites are considered exposed to wildfire hazard when located within specific classes of the hazard contingency matrix (Table 5), namely:

- **3**: low intensity surface fires with high likelihood;
- **5 and 6**: medium intensity forest fires with medium to high likelihood;
- **8 and 9**: high intensity bushfires with medium to high likelihood;
- **11 and 12**: very high intensity forest fires with medium to high likelihood.

These hazard classes intentionally exclude categories associated with low susceptibility. This choice is consistent with the empirical evidence shown in Figure 3, which indicates that, over the 2007–2023 period, only a marginal share of wildfires occurred in low-susceptibility pixels. Moreover, firms located in pixels assigned to classes 9 and 12 in Table 5 are classified as exposed to high hazard, as these categories correspond to the highest probabilities of fast-spreading fires with very high flame heights – i.e., the most dangerous wildfire conditions in the matrix.

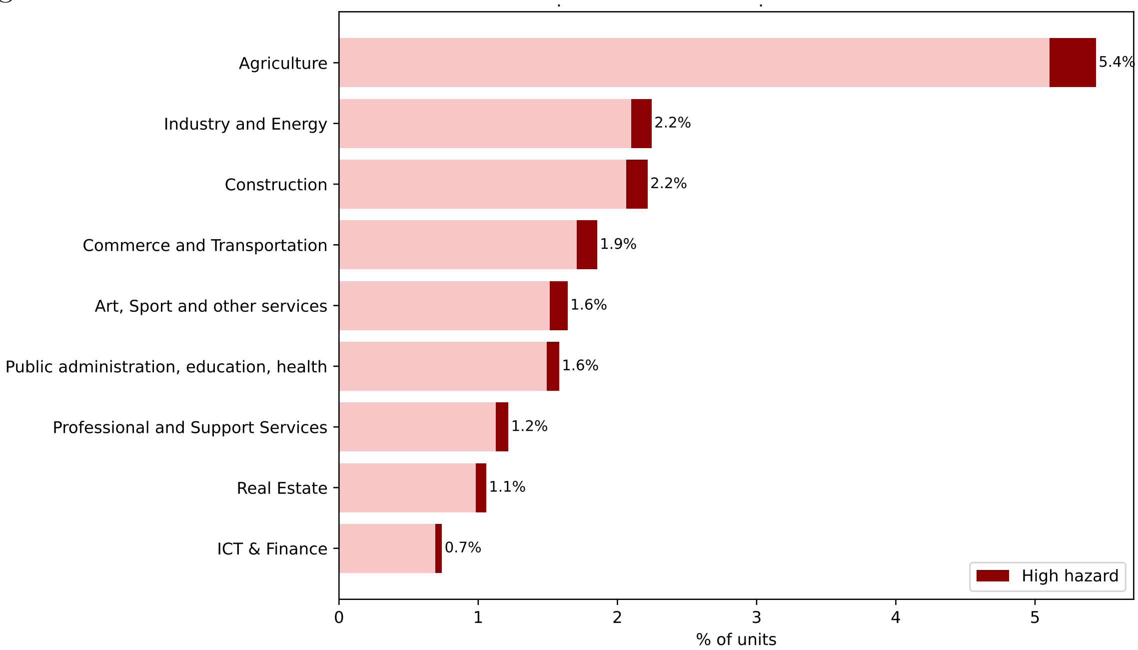
Adopting this classification, 64,801 out of 3,457,522 sites are exposed to wildfires, namely 1.9% of the total. When restricting the analysis to high-hazard classes, 4,603 sites (0.1%) fall within these categories. Figures 4 and 5 illustrate the regional and macro-sectoral distribution of these sites, respectively. The first plot highlights a clear geographical pattern, with southern regions generally exhibiting higher exposure, consistent with climatological expectations. Notably, however, a considerable share of units in Valle d'Aosta (5.8%) is also exposed. This region shows the highest concentration of units in the high-hazard category, as its territory is extensively covered by coniferous forests and therefore highly susceptible to crown fires. Agriculture is the most exposed macro-sector, followed by constructions and industry (the latter encompassing manufacturing, energy and mineral extraction). The balance-sheet information in the CERVED subsample offers a more quantitative picture and reveals that, although only 2.7% of sampled firms are exposed to wildfire hazard, they account for 17.8% of total assets and 22.7% of tangible assets.

Figure 4: Share of productive units exposed to wildfires by Region



Note: The percentages refer to productive sites, including both headquarters and secondary units. High hazard corresponds to classes 9 (*High intensity bushfire with high likelihood*) and 12 (*Very high intensity forest fires with high likelihood*).

Figure 5: Share of productive units exposed to wildfires by Macrosector



Note: same as Figure 4.

Going back to the InfoCamere universe and following the methodology described in Loberto and Russo (2024), a set of indicators have been computed by measuring the share of employees exposed to wildfires. Two sets of indicators are computed – one referring to geographic regions (S_W^R) and the other to companies (S_W^C). Each establishment in the sample is assigned a hazard score based on its geographic coordinates, and a weighted average is then calculated for each company or region, using the number of employees as weight[12]. Figure 6 shows the S_W^R indicator, namely the share of exposed workers in each italian province: the highest value is reached in Enna province, where 20% of the workforce is employed in sites prone to wildfire, while at national level $S_W^R = 0.014$, namely 1.4% of italian employees are exposed. Table 6 summarizes the corresponding company-level indicator (S_W^C), defined as the proportion of a company's workforce located at wildfire-exposed sites. This indicator allows the sample to be classified into four ascending exposure categories. Only 1.4% of Italian firms are exposed to wildfires ($S_W^C > 0$)[13], and for two-thirds of these firms, exposure is total, meaning that their entire workforce operates in fire-prone areas (S_W^C=1). The remaining firms have only a part of their workforce in areas at risk of wildfires.

Table 6: Summary Statistics – S_W^C indicator

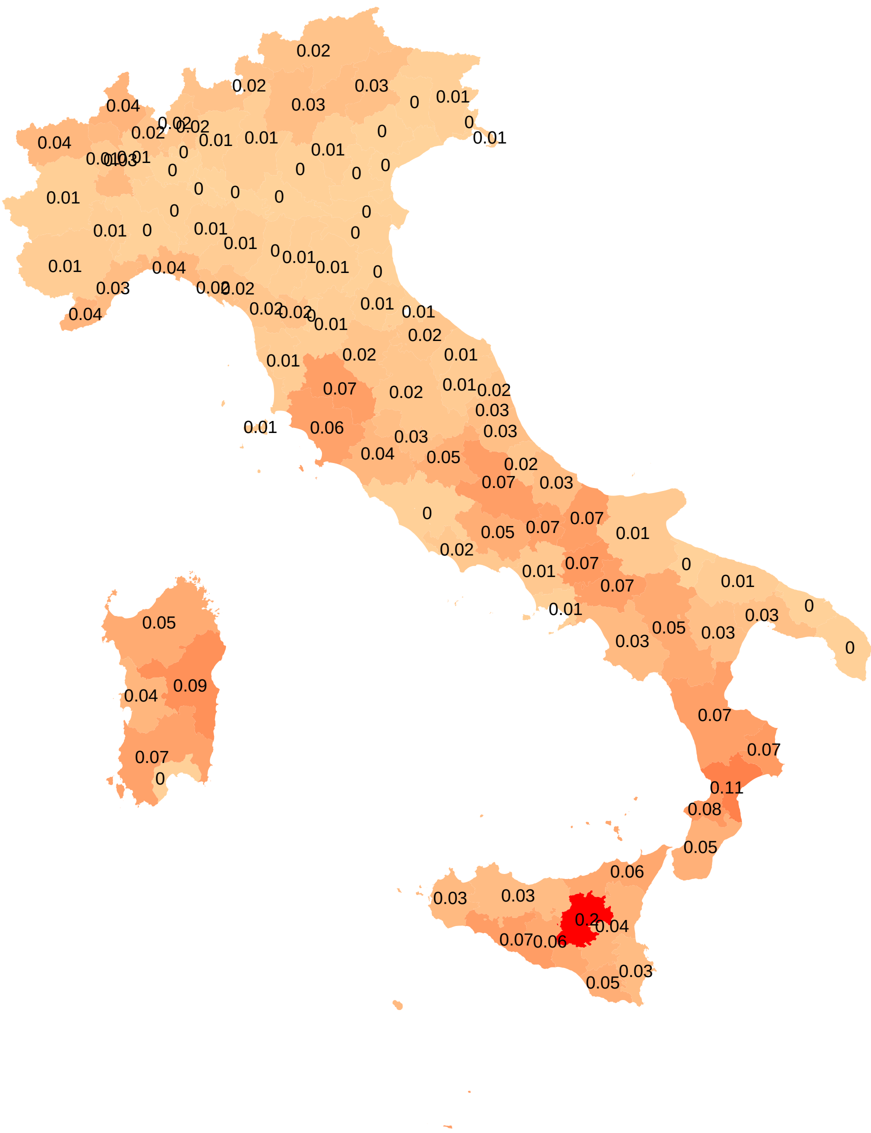
	Company Exposure to Wildfires			
	Null	Low	Medium	High
	$S_W^C = 0$	$0 < S_W^C <= 0.5$	$0.5 < S_W^C < 1$	$S_W^C = 1$
Nr. companies (thousands)	2121.6	8.7	1.2	19.6
% companies	98.6	0.4	0.1	0.9

Note: absolute number and percentage of companies in four bins of the S_W^C indicator, corresponding to four increasing levels of wildfire exposure. The S_W^C indicator represent the company-level share of employees exposed to wildfires.

[12] 215,793 firms with multiple branches but no employees in any of them are excluded from this computation, as workforce information is necessary to assign the correct weight to each establishment.

[13] 2.3% if we include the aforementioned 215,793 firms and assume employees are equally distributed across all sites.

Figure 6: S_W^R INDICATOR – REGIONAL EXPOSURE TO WILDFIRES



Note: province-level S_W^R indicator, corresponding to the share of employees exposed to wildfires in each province.

Comparing these figures with ECB indicators is challenging because they measure different quantities (shares of companies and employment versus portfolio of loans) and rely on different mapping approaches and hazard definitions. However, the proportion of companies exposed to wildfires in Italy (1.4%) is not far from the corresponding share of portfolio located in areas with a high probability of fire (i.e., fires expected every 50 years), namely 2.8%. Although the two methodologies use different maps, both exclude companies in areas with non-zero exposure, but low susceptibility.

Compared to other sources of physical risk, wildfires affect a smaller share of Italian firms than floods (26.6% of exposed firms) and landslides (8.6%)[14]. Adopting a multi-hazard perspective, it is interesting to investigate the association between the different natural hazards, to verify if common geographical determinants are present. Tables 7(a) and 7(b) report contingency tables for wildfire–landslide and wildfire–flood exposure. While joint susceptibility to wildfires and floods is relatively uncommon, exposure to both wildfires and landslides affects around 19,000 sites (0.5% of the sample), which corresponds to more than 30% of all productive sites exposed to wildfires. This pattern is consistent with the fact that one of the main input variables used in the production of CIMA maps is terrain slope, which is also a key determinant of landslide occurrence. Simultaneous exposure to all three hazards is very rare, affecting only 1,290 sites (0.04%).

To further investigate which firm-level characteristics are associated with a higher likelihood of wildfire exposure, structural variables from the InfoCamere and CERVED datasets are employed within a simple regression framework. The analysis relies on a

Table 7: Contingency Tables of multi-Hazard Exposure

(a) Wildfires vs Floods
(Thousands of sites)

	Wildfires	
Floods	No	Yes
No	2580	60
Yes	813	5

(b) Wildfires vs Landslides
(Thousands of sites)

	Wildfires	
Landslides	No	Yes
No	3163	46
Yes	229	19

Note: The figures represent thousands of productive sites (∼ 3.5 milion overall), including both headquarters and secondary units.

[14] These shares are computed by extending the framework in Loberto and Russo (2024), originally applied only to manufacturing, to the entire set of establishmennts in InfoCamere.

binary dependent variable ***FIREXP***, equal to one if the firm has at least one site located in an area exposed to wildfire hazard, and employs a logistic specification to model the probability of exposure.

Since multi-branch firms operate across multiple locations, they are structurally more likely to be exposed to physical hazards: greater geographic diversification mechanically increases, ceteris paribus, the probability that at least one establishment lies in an affected area. For this reason, the logarithm of the number of establishments is included in the specification ($log(\mathrm{n}_{site})$), together with firm age and the average employment (average number of employees per site). The regression also incorporates macro-sector fixed effects to account for industry-specific heterogeneity, largely reflecting the patterns shown in Figure 5. Finally, when available, balance-sheet information from CERVED is also included.

Table 8 reports the results of the regression analysis. The estimation is carried out in multiple steps because detailed balance-sheet information is not available for all firms; as a consequence, the full-sample specification must remain parsimonious and includes only $log(\mathrm{n}_{site})$, firm age, and average employment. Column (1) shows that wildfire exposure is positively associated with the number of establishments, while average employment exhibits a negative association and firm age has no significant effect. The coefficient on the number of establishments (in logarithm) is close to one, meaning that doubling the number of sites approximately doubles the odds of being exposed, while the negative coefficient on average employment suggests that firms operating smaller units – such as warehouses or storage facilities – tend to face a higher likelihood that at least one site falls into the fire-risk category. This evidence remains robust when the analysis is restricted to the CERVED subsample (Column 2), although the coefficient on average employment loses significance – likely due to the narrower variation in workforce size within this subset. When adding structural variables (Column 3), the $log(\mathrm{n}_{site})$ coefficient is stable, while the ratio of tangible to total assets is positive and strongly significant. This evidence contrasts with analysis of flood exposure in Loberto and Russo (2024), where a negative coefficient was found and interpreted as suggesting that firms with a higher share of tangible capital tend to be located in safer areas. However their analysis is limited to the manufacturing sector. To rule out that this discrepancy stems from sectoral composition, particularly the inclusion of the highly exposed agriculture sector,

Table 8: Wildfire exposure and companies' characteristics

	FIREXP			
	(1)	(2)	(3)	(4)
$log(n_{site})$	0.961***	1.01***	1.06***	0.848***
	(0.036)	(0.052)	(0.060)	(0.008)
Average Employment	-0.096**	-0.077	-0.014	-0.112***
	(0.038)	(0.062)	(0.076)	(0.013)
Age	0.001	0.002	0.0008	-0.001***
	(0.001)	(0.001)	(0.0009)	(0.0003)
Total assets			-0.056*	0.008
			(0.029)	(0.006)
Tangible / Total assets			1.09***	0.450***
			(0.121)	(0.036)
Value added/Total assets			-0.004	-0.046**
			(0.005)	(0.022)
Credit risk			0.029	0.098***
			(0.021)	(0.020)
Observations	1,261,261	788,592	787,903	112,595
Squared Correlation	0.021	0.028	0.031	0.027
Pseudo R^2	0.049	0.062	0.069	0.065
BIC	301,290.9	184,999.9	183,496.7	25,759.8
Macro-sector fixed effects	✓	✓	✓	
2D NACE FE				✓

Note: This table reports the results of a logit regression where the dependent variable is a dummy equal to one if a company has at least one site in a wildfire-prone area. Column (1) shows the estimates on the InfoCamere sample, while Column (2) reports the same estimates on the CERVED subsample. Results in Column 3 include balance sheet data. Column (4) reports results for the sample restricted to manufacturing firms.

the model was re-estimated on manufacturing firms only (Column 4). The tangible asset effect persists, albeit in a weaker form, supporting the robustness of this paper's result[15].

The opposite signs of the tangible-to-total assets ratio in the wildfire and flood exposure models may point to distinct spatial or behavioral dynamics. Whereas wildfire hazard predominantly affects non-urban areas – where larger and more tangible asset-intensive facilities tend to be located – flood hazard may also threaten urban zones situated near river systems. Beyond spatial factors, such differences might also reflect firms' perceptions of specific hazards, shaping location decisions in ways that influence exposure patterns. A greater tolerance of wildfire hazard and a stronger aversion to flood risk could contribute to the observed patterns.

[15] As a robustness check, the regression was also applied to the manufacturing sector using flood exposure (FLOODEXP) as the outcome variable; the negative relationship reported in previous work is confirmed, despite minor differences in model specification.

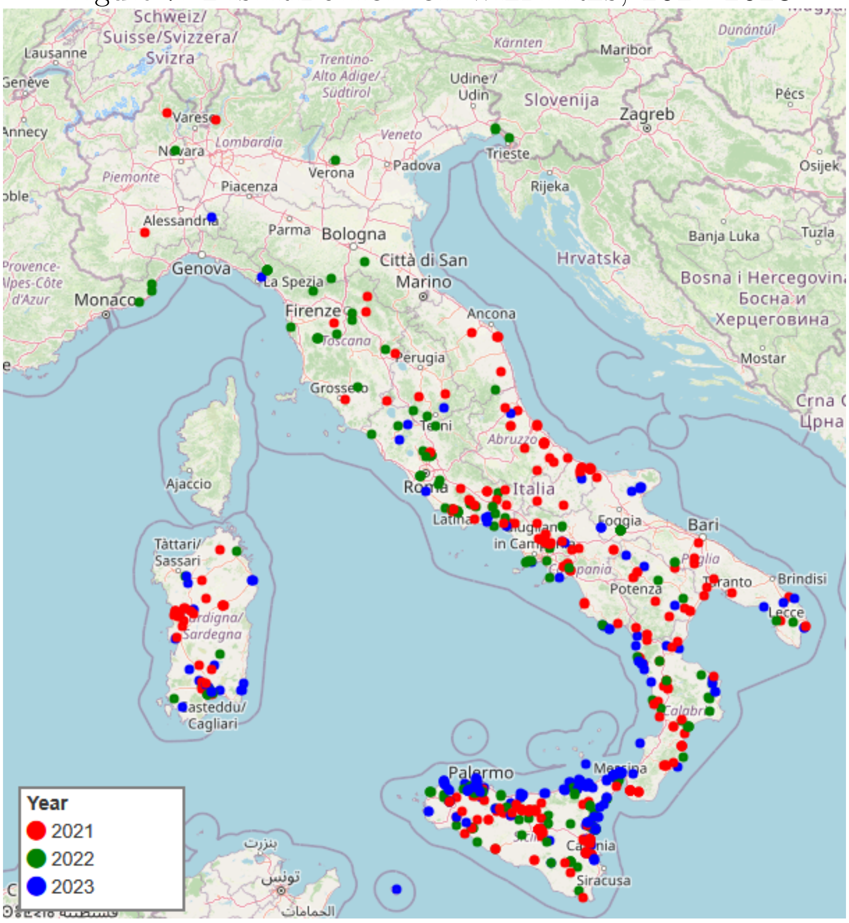
3 Empirical Assessment of Wildfire Impacts

Having assessed potential exposure in the previous section, we now match the InfoCamere dataset with a high-resolution wildfire register to examine where wildfires actually occurred and which sectors and areas were affected.

Burned-area data have been collected from the wildfire register previously described and managed by Carabinieri Forestali , focusing on 17,700 wildfires that burned approximately 319,700 hectares between 2021 and 2023 and including information on ignition dates. Although the original wildfire register covers a longer historical period, our analysis is restricted to 2021–2023, which are the years for which detailed data on firms' secondary units are available.

According to these datasets, between 2021 and 2023 wildfires affected a total of 1,777 establishments in Italy – equivalent to 0.5‰ of all sites. The highest numbers were

Figure 7: Distribution of wildfires, 2021-2023



Note: colored dots represent wildfire impacted business sites. Each dot can correspond to multiple establishments.

Table 9: ESTABLISHMENTS HIT BY WILDFIRES IN 2021-23 BY ACTIVITY SECTOR

Commerce and Transportation	672
Industry and Energy	350
Constructions	232
Professional and Support Services	161
Agriculture	141
Art, Sport and other services	68
Financial and real estate activities	58
Public administration, education, health	54
Information and Communication	41

recorded in 2023 (700) and 2021 (655), with a lower figure in 2022 (422). Figure 7 illustrates the heterogeneous geographical distribution of these events, which predominantly affected southern regions and with northern regions showing only marginal firm involvement. Moreover, the spatial patterns vary across years, with different clusters of incidents emerging in distinct areas, for instance Abruzzo in 2021, Northern Tuscany in 2022 and coastal Sicily in 2023. Table 9 reports the number of company sites affected by wildfires, grouped by economic sector. The distribution largely reflects the general composition of the Italian economy (Figure 1). Consistent with the exposure patterns in Figure 5, agriculture is markedly overrepresented among wildfire-affected sites (7.9%), relative to its 4% overall share.

Since the wildfire register is censored at 2023, and detailed information on firms location is available only from 2021, the available time span is too limited to implement thorough causal designs to assess the impact of wildfires on firm activity. We therefore adopt a simple survival analysis on firms affected by wildfires, where survival is defined as the conditional probability that an establishment i, observed in year t, remains in the dataset after 1 year. Formally, the survival probability is defined as:

$$P_{i,t} = \Pr\left(i \text{ exists at } t+1 \,\middle|\, i \text{ exists at } t\right) \tag{1}$$

where the variable t only takes the values 2021 and 2022. Importantly, this measure does not distinguish between permanent closure and relocation; it solely captures whether a particular branch continues to appear in the dataset in the subsequent year.

Table 10 presents summary statistics on the survival rate, as defined in Equation (1), for the entire InfoCamere sample. These values, however, vary substantially across

Table 10: One-year survival rates

	2021	2022	2023	Overall
$P_{i,t}$	92.7	91.7	91.9	**92.1**

Note: Overall and year specific survival rates for firm branches in the Infocamere sample (%).

sectors and regions (see Figures A1 and A2 in the Appendix), and given the relatively small number of wildfire-affected firms and their uneven geographical and sectoral distribution, a direct comparison of their survival rates with those of the overall population is not meaningful. We therefore employ sample matching techniques, which are widely recognized for reducing bias in the estimation of treatment effects in non-randomized settings (Stuart, 2010). In our case, this approach allows us to construct a control group of structurally similar establishments, thereby enabling a more reliable comparison. The matching strategy adopted in this analysis consists of three steps:

1. We first compute the survival probability for establishments affected by wildfires.
2. We then construct a control group of structurally similar samples – but not exposed to wildfires – using a k-nearest neighbor (KNN) algorithm.
3. This matching procedure is repeated in a bagging-like fashion, generating 200 distinct control groups and, consequently, an empirical distribution of survival probabilities for matched, unaffected establishments.

The KNN algorithm used to identify the control sample relies on four firm-level characteristics: economic activity sector[16], NUTS-2 region, number of employees, and firm age. For each wildfire-affected establishment, a pool of the 50 nearest neighbors was identified in the full sample based on KNN output; Figure 8 provides an example of the five closest neighbors for one of the affected firms. From each pool of 50 nearest neighbors, one candidate establishment was randomly drawn for each affected establishment and similarly for each of the 200 iterations. In other words, each of the 200 control samples is constructed by selecting, for every wildfire-affected establishment, one observation randomly chosen from its corresponding set of 50 nearest neighbors.

The empirical distribution of survival rates for matched, non-treated firms is shown in Figure 9, together with a maximum likelihood fit of the beta distribution. The observed

[16] 2-digit ATECO.

Figure 8: KNN matching

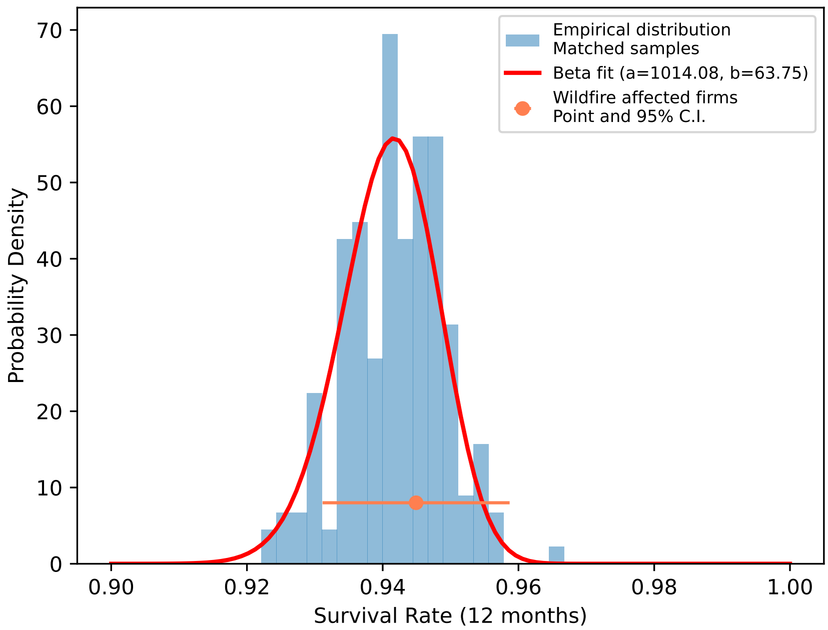
Treated Sample				Matched Control Samples			
Activity denomination	**Province**	**Age**	**Employees**	**Activity denomination**	**Province**	**Age**	**Employees**
Manufacture of other electronic components	Cagliari	39	3	Manufacture of other metal objects	Cagliari	39	3
				Manufacture of iron and copper objects	Oristano	39	2
				Manufacture of doors and windows	Nuoro	39	3
				Manufacture of metal structures	Oristano	39	3

Note: Result of KNN matching for a single establishment. On the left, characteristics of one of the 1777 establishment that were hit by a wildfire. On the right, the 5 nearest neighboring, wildfire unaffected peers identified by the KNN procedure.

survival rate of wildfire-affected establishments (94.5%), reported in orange in the figure together with its 95% statistical uncertainty interval, is fully consistent with the fitted beta distribution (p-value = 0.69). This finding indicates that firms directly affected by wildfires do not exhibit reduced survival, possibly because the damages and operational disruptions were limited, or mitigated by insurance interventions.

However, a longer historical perspective – currently not attainable given the limitations of the available datasets – could reveal sectoral or regional patterns that cannot be identified at present, while access to insurance records, which are not yet available, would allow for a more comprehensive interpretation of these findings.

Figure 9: Sampling distribution of survival rate



Note: The figure compares the empirical distribution of survival rates obtained from matched samples with the estimated survival rate for wildfire-affected firms.

4 Projected Wildfire Risk for Italian Businesses

This section provides a forward-looking assessment of how the exposure of Italian firms to wildfires may evolve in the coming years. Building on the results of Section 2, possible future scenarios are examined with the aim to offer an evidence-based perspective on the potential increase of vulnerability that climate change could induce across Italy. Projections are based on the Climate Impact Explorer (CIE[17]), which is an interactive platform designed to visualize how climate change effects will evolve over time under different global warming scenarios. It provides insights over more than 30 indicators at both national and NUTS-2 level, including temperature changes, flood risks, crop failures, and population exposure to hazards – such as wildfires.

The latter indicator captures future changes in the share of the population residing in areas affected by at least one wildfire per year. However, this measure is not directly comparable with the firm-level results presented in Section 2. A meaningful comparison requires a strong assumption – namely, that the spatial distribution of firms mirrors that of the population. To assess the plausibility of this assumption, we match firm-level and population figures from the 2011 ISTAT census on the smallest sub-municipal geographical units available, namely census zones. We thus compute the correlation between the number of inhabitants and the number of firm branches within each census zone. As shown in Table A1, this correlation varies substantially across regions, reaching its maximum in Basilicata (0.66) and its minimum in Liguria (0.27).

Taking these geographical disparities into account, we proceed to interact the CIE projections with our firm-level data to identify where the increase in exposure is expected to be the most pronounced. This approach allows us to construct a regional ranking based on projected changes in exposure, which can then be compared with the regional patterns documented in Section 2. Table 11 presents the projected increase in the number of productive sites exposed to wildfires across regions. The table does not refer to a specific year because this indicator depends solely on the assumed temperature increase. A global warming of +1.5°C could occur as early as 2030 under the RCP8.5 scenario or the NGFS Current Policy scenario, and around 2035 under RCP2.4. In contrast, a +3.0°C increase

[17]https://climate-impact-explorer-2024 .climateanalytics.org/ - Developed by Climate Analytics in collaboration with the Potsdam Institute for Climate Impact Research, ETH Zürich, and the NGFS, the tool is supported by organizations such as the ClimateWorks Foundation and Bloomberg Philanthropies.

Table 11: Increase in wildfire-exposed establishments (absolute numbers)

Region	Temperature increase (°C)	
	1.5	3.0
Abruzzo	50	150
Basilicata	50	140
Calabria	60	230
Campania	350	1400
Emilia-Romagna	60	280
Friuli-Venezia Giulia	-	-
Lazio	330	1100
Liguria	-	90
Lombardia	60	260
Marche	40	190
Molise	-	50
Piemonte	-	140
Puglia	350	1200
Sardegna	80	330
Sicilia	200	830
Toscana	100	470
Trentino-Alto Adige/Sudtirol	-	60
Umbria	-	110
Valle d'Aosta	-	-
Veneto	-	120

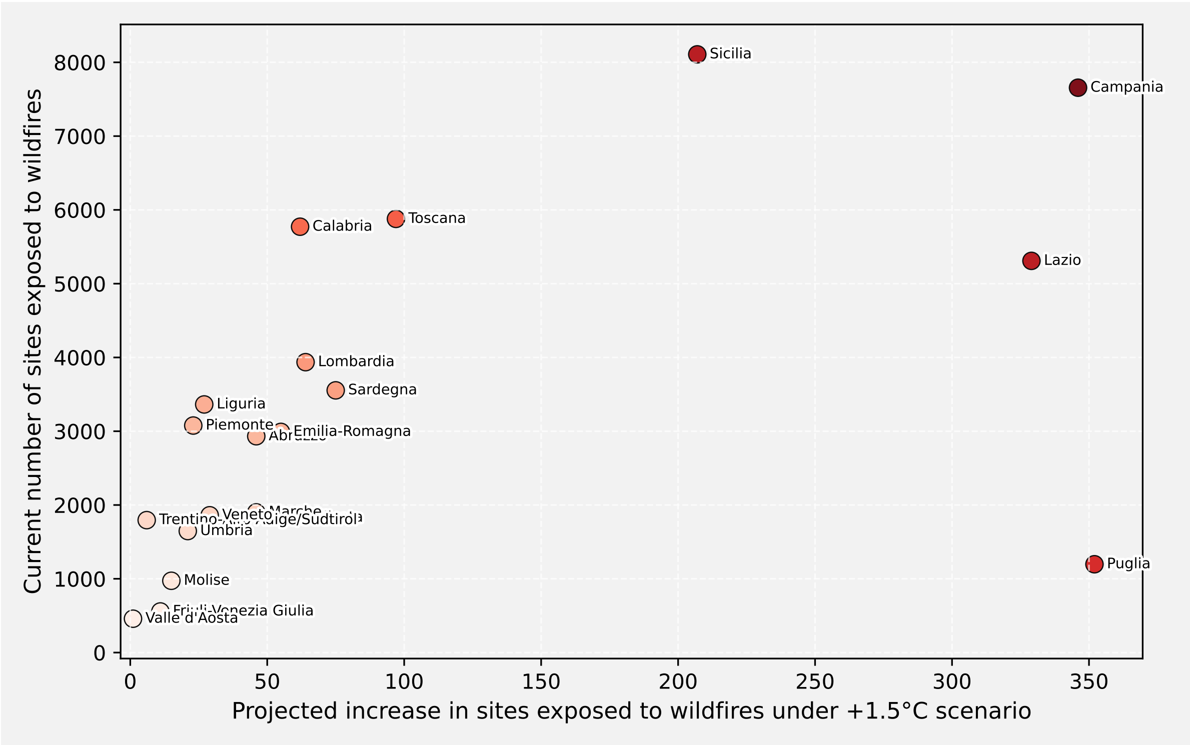
Note: expected increase in number of establishments located in areas burnt by wildfires at least once a year according to CIE and derived under the assumption that population and firms share a comparable spatial distribution.

is projected for 2065 under RCP8.5 and by 2100 under the NGFS Current Policy scenario. These projections indicate that Puglia, Campania, and Lazio are expected to experience the most significant impacts, particularly if the +3.0°C scenario materializes. Figure 10 illustrates the comparison between current exposure (y-axis) and its projected evolution (x-axis) in absolute numbers.

Although the absolute figures reported in this section are relatively moderate, the projected increase in wildfire-exposed productive sites is significant, rising by approximately 1,900 units under a +1.5°C warming scenario and by 7,200 units under a +3.0°C scenario, the latter corresponding to an 11% increase relative to current numbers. This underscores the non-linear amplification of climate-related risks and highlights the importance of timely adaptation and mitigation strategies to reduce potential economic and environmental impacts.

It should also be acknowledged that these projections do not consider potential improvements in wildfire management, such as those achieved between 2000 and 2018 which

Figure 10: Current vs projected exposure (+1.5°C)



Note: the y-axis reports the current number of sites exposed to wildfires according to CIMA maps. The x-axis represents the expected increase in number of establishments located in areas burnt at least once a year by wildfires according to CIE and derived under the assumption that population and firms share a comparable spatial distribution.

already delivered significant results.

5 Conclusions

This paper provides a granular, data-driven assessment of wildfire risk for Italian firms, leveraging high-resolution hazard maps developed through an advanced methodology that integrates multiple data sources – topography, land cover, and climate variables – via innovative machine-learning techniques. This methodology produces wildfire exposure maps at 500 × 500 m resolution, which is 25 times higher than the resolution of similar maps employed in prior studies on economic exposure to wildfire risk, thereby allowing precise spatial alignment with economic activity.

The results indicate that wildfire exposure – as proxied by the share of exposed employees – among Italian firms is currently modest in aggregate terms (1.4%) but highly concentrated in specific sectors and regions. Agriculture stands out as particularly exposed, while southern regions – especially Calabria, Basilicata and Molise – face the highest hazard levels. These findings align with climatological expectations and highlight the spatial heterogeneity of climate-related risks. Firm-level characteristics play a critical role: multi-site operations and a higher share of tangible assets is associated with more intense wildfire exposure.

Regarding the economic consequences of wildfire events, a simple survival analysis indicates no significant short-term (i.e. one-year-ahead) effect on business continuity. This could be due to the fact that, although firms were located within the burned areas – as assessed through geocoded wildfire registries – the damages sustained were limited, possibly leading to minor operational disruption. Additional evidence will be essential to corroborate this interpretation, particularly insurance records and firm-level datasets with longer temporal coverage that would allow integrating financial indicators such as balance sheets, revenues, and income, thereby enabling more robust assessments of vulnerability and resilience over time.

Finally, in the absence of firm-specific climate projections – and using population-related projections as a proxy, under a set of methodological assumptions – available scenarios suggest only a moderate increase in exposure over the coming decades. Under a +3°C pathway, the number of sites at risk may grow by roughly 11%, with the largest increases observed in Lazio, Campania, and Puglia.

However, robust projections of firms' exposure to wildfires will only be possible once hazard maps explicitly incorporate climate-scenarios, such as RCP pathways. In this regard, the maps used in the present study are currently being refined to ensure a stronger alignment with established climate-change modelling frameworks. Building on these methodological advancements, future work should aim to extend the spatial scope beyond Italy, enabling comparison with other countries and supporting the development of coordinated and coherent adaptation strategies.

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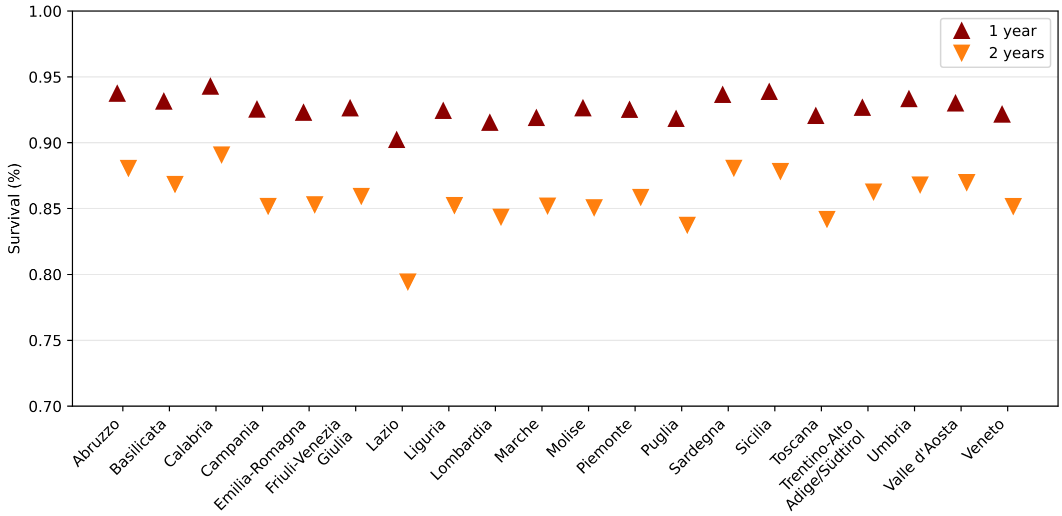
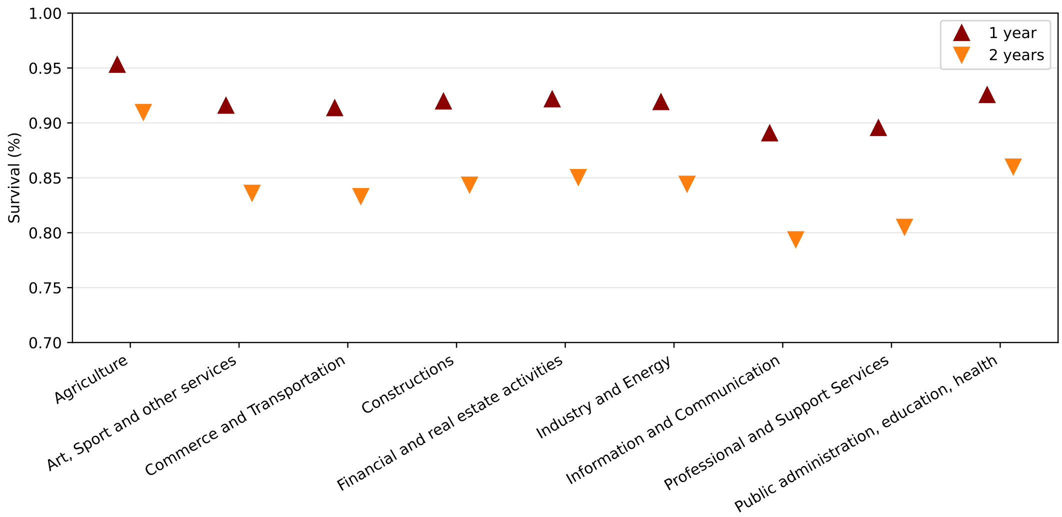
Appendix: additional Figures and Tables

Figure A1: Firm survival rate, by Region



Note: These values are obtained evalutaing the survival probability defined in Equation (1) over the InfoCamere dataset.

Figure A2: Firm survival rate, by Sector



Note: Same as Figure A1.

Table A1: Correlation between population and number of establishments

Region	
Piemonte	0.53
Valle d'Aosta	0.45
Lombardia	0.45
Trentino - Alto Adige	0.44
Veneto	0.57
Friuli - Venezia Giulia	0.46
Liguria	0.28
Emilia-Romagna	0.46
Toscana	0.45
Umbria	0.50
Marche	0.53
Lazio	0.39
Abruzzo	0.55
Molise	0.60
Campania	0.40
Puglia	0.51
Basilicata	0.66
Calabria	0.50
Sicilia	0.47
Sardegna	0.50

Note: Correlation between population and number of productive sites evaluated in each region using the set of 2011 Census zones as statistical unit.