

Forest fires across Italian regions and implications for climate change: a panel data analysis

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Abstract

In this paper, we analyze the determinants of monthly variations in forest fire frequency and on the size of the area burnt for Italian regions between 2000 and 2011. We employ panel data techniques, which allow capturing the dynamics of fire danger due to changes in past climatic conditions, after accounting for regional fixed effects to control region-specific unobserved and time-invariant factors. Results highlight a significant heterogeneity of the effects of driving factors across the Italian peninsula and weather seasons. Climatic conditions also show lasting effects within the year. Using climate change projections for 2016–2035, we then obtain the projected forest fire frequency and total area burnt across the Italian peninsula for the same period. Climate change is expected to increase the number of forest fires across the whole peninsula, which is more evident for the central part of Italy. Even though most of annual increases in fire events relate to the summer period, intensifications in frequency during autumn become more evident in the southern Italy. We extend finally our analysis to investigate the contribution of socio-economic factors to fire regime and the role of education and the containment of fraudulent activity is also highlighted.

Keywords Forest fires · Forestry · Climate change · Panel-data estimation

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1. Introduction

Forestland and trees offer vital services such as commercial and recreational uses, water and climate regulation services, and carbon sequestration activity. However, several forest disturbances undermine these service provisions. Compared to other factors (e.g., pests, plant diseases, wind, and frost), fire often represents the most threatening disturbance for forestland and trees in the southern Europe and Mediterranean area (Pausas et al. (2008) for Mediterranean area; Miranda et al. (2008) for Southern Europe; Dimitrakopoulos et al. (2011) and Koutsias et al. (2013) for Greece; Costa et al. (2011) for Portugal). Italy is not an exception being affected by relevant fire risk where it lists as the fourth country for importance on fire events in the Mediterranean area, after Portugal, Spain, and France (San-Miguel-Ayanz et al. 2017).

Through the whole Italian peninsula, 7077 fire events were registered on average each year between 2000 and 2011 with around 76,350 hectare (ha) of area burnt annually on average. Forest fires in 2017 have been recorded as one of the worst one during the last 30 years for Italy as vast fire occurrences have taken place during summer, adding to the already important events in autumn. Ironically, in the same year, the National Italian Institute for Statistics (ISTAT) stopped recording official data on forest sector statistics. Furthermore, in 2017, the role of the Italian police force under civil law (Corpo Forestale dello Stato: CFS) on forest management, a department that works under the Ministry of Agricultural, Food and Forestry Policies Forest State Body of the Forestry Department, was reduced as a consequence of the Madia law (ddl Madia: 7/8/2015, n.124). This body was in charge of the recording of all fire events in the Italian peninsula; a task which is now taken over by a supranational institution (i.e., the Emergency Management Service of the European Forest Fire Information System). However, this supranational institution will only record large-scale fires (i.e., fires that results an area burnt over 30 ha), making the overall fire monitoring very hard. On the other hand, the causes of forest fires in Italy go beyond the contingency of this situation and are linked to the governance system and to the institutional arrangements in the management of forest resources, amongst other causes.

There are key factors that explain the fire regime (intended as the frequency and intensity -area burnt- of the wildfire prevailing in an area over certain periods of time) and risk such as the region-specific factors (e.g., Martinez et al. 2009; Westerling et al. 2006, among others). For instance, institutional arrangements to manage forest resources may vary across different regions due to available resources to fight forest fires. Recent studies also

highlight that the value of forest ecosystems vary across regions, which requires different territorial forest management programs (see e.g., Rodríguez y Silva et al. 2012). On the other hand, some regions may have more of drier, mature, and dead materials, which is therefore more flammable compared to other regions (e.g., Blasi et al. 2005; Bernetti 2005). In the same lines, different forest types may be more prone to fires and could be clustered more in certain regions making those regions more exposed to fire danger (see e.g., Fernandes et al. 2010). In short, there are certain regional characteristics that differ from one another, which may lead to higher exposure of some regions to forest fires than others. In this paper, we use panel-data estimation techniques to control for these region-specific factors in our analysis.

A second group of factors that are found to be important for forest fires is the socio-economic conditions and human attitudes. For instance, due to increased human pressure on forests, most populated or active areas (such as the areas that have higher levels of tourism) are found to be more prone to forest fires (Catry et al. 2007; Martinez et al. 2009). Similarly, regions that have economic hardship (e.g., regions with high poverty or unemployment) are also associated with higher levels of forest fires (see e.g., Prestemon and Butry 2005; Torres Curth et al. 2012), which may be due to lower resources available to monitor forests. On the other hand, agriculture activities and land management to renovate livestock pastures also play an important role in forest fire ignition risk (see e.g., Moreira et al. 2009). Over the last years, the relevance of socio-economic factors and human pressure has been identified by the literature (see e.g., Ganteaume et al. 2013 for a review of socio-economic factors that are found to be important for fire ignition risk), which will be also examined in this paper.

Finally, physical and weather elements are undeniably recognized as major determinants of the exposure to fire risk and spread of fire (Pausas 2004; Westerling et al. 2006; Pausas and Bradstock 2007; Pausas and Fernández-Muñoz 2012; Pausas and Paula 2012; Koutsias et al. 2013; Rego and Silva 2014; Salis et al. 2014). Increase in temperature levels and decrease in rainfall leads to higher drought levels making forests more flammable [see e.g., Vasilakos et al. (2009) for rainfall's contribution, Littell et al. (2016) for relevance of drought for ignition risk] where Koutsias et al. (2012) highlight the interaction between fuel accumulation and weather patterns.

Understanding the effects of region-specific, socio-economic and weather elements on forest fire is essential to prepare for climate change impacts on future forest fire. Researchers have been traditionally utilizing fire indicators, such as the Canadian fire

weather index (FWI),¹ which considers the daily accumulated precipitation and instantaneous wind speed, humidity, and temperature (see e.g., Van Wagner and Pickett 1987; Bedia et al. 2013; Jolly et al. 2015; Bedia et al. 2015), neglecting, however, the consideration of socio-economic factors. In this paper, rather than investigating fire indices based on fire-specific factors, we examine the contributions of weather factors at first, and socio-economic conditions in a later step, on the monthly and yearly variation in forest fire regime in Italy, respectively. After investigating historical data and fire relations, the analysis is extended to project the impact of future climate change on forest fire.

This paper contributes to the literature in several different ways. First, in addition to consider geographical clusters (i.e., spatial grouping), it extends the analysis to the overall Italian peninsula, while most of existing studies for Italy only focus on regional fire events.² Secondly, previous studies normally do not account for time-invariant region specific factors and time-effects in their analysis, which could lead to omitted variable bias. Most are based on the observation of the simple historical trends and do not apply accurate statistical techniques to corroborate obtained results. Additionally, geographical-oriented approaches to forest fire analysis tend to consider fire realizations at some point in time (e.g., one specific year), neglecting fire temporal dynamics. This work, on the other hand, fully captures the dynamics of fire occurrence and the variations in weather conditions in time. By using panel-data estimation techniques we are able to account for time-invariant region-specific factors and time-effects, which are often omitted in the estimations. Time-invariant heterogeneity is represented by all those unobservable but relevant components characterizing a region, which are expected to be correlated with observed factors. Examples of region-specific factors are land and forest management, forest and fuel types, cultural values, regional and organizational culture, and land use among many other factors that can affect forest fire dynamics. While this instance represents a persistent problem in cross-sectional analysis, using panel data estimation techniques allows us to control for the regional heterogeneity. Finally, while very few studies evaluated the influence of socioeconomic conditions on the occurrence of forest fires, we also extended our analysis in this direction.

¹ FWI represents an estimation of the risk of wildfire based on the assumption that fire occurrence mainly depends on moisture content of litter and other fine fuels. Its computation requires considering meteorological parameters such as air temperature, relative humidity, wind speed, and precipitation.

² Examples of regional analyses are provided by Telesca and Lasaponara (2006) for central Italy; Bajocco and Ricotta (2008), Telesca et al. (2005) and Paziienza and Beraldo (2004) for southern Italy; Zumbrunnen et al. (2009) and Wastl et al. (2012) for northern Italy.

The paper is organized as follows. Section 2 briefly reviews the methodologies used to examine fire events and intensities and offers details on the proposed methodology. Section 3 summarizes the fire, weather and socio-economic data. Relationships between monthly forest fire frequency (area burnt) and weather variables for different geographical clusters are presented in Section 4. Section 4 also provides an estimation of the impact of projected changes in temperature and precipitation on forest fire frequency and total area burnt for different geographical clusters in Italy during 2016–2035. Section 5 concludes discussing policy implications.

2. Brief review of methodologies and estimation method

Several methodologies have been used within the existing literature to explain the main factors of fire risk. The choice of methodology strictly depends on the objective of the study, which can either be that of predicting future fire incidences or explaining the variation of the dependent variable. The choice of the methodology may also depend on the characteristics of the dependent variable, which can be discrete, dichotomous (when it only takes the values of 0 and 1), or continuous.

While several analyses implement stepwise-multiple linear regressions (i.e., multivariate ordinary least squares) when the dependent variable is continuous (e.g., Vadrevu et al. 2006), one of the most frequently implemented techniques within fire risk analysis is the binary response regressions (see e.g., Martinez et al. (2009) for the use logistic regression, and Wotton et al. (2003) for the use of Poisson regression). The application of binary regressions does not prevent the researcher from incurring into problems of bias and inconsistency of the estimates, if unobserved heterogeneity across regions/areas is not accounted in the analysis (Baltagi 2008). The spatial heterogeneity might rise due to a lack of structural stability or homogeneity of unit observation across space. Supposedly, Italian regions are heterogeneous in terms of cultural differences (Naveh 1995), land cover types (Bajocco and Ricotta 2008), law enforcement mechanisms, and the power and participation of local organizations to public life and economy. When this is the case, the fixed or random effects models should be used in the presence of panel data (Kousky and Olmstead 2010; Reetz and Brummer 2011). While there is a variety of cross sectional analyses investigating forest fire events, according to our knowledge, there are very few articles providing a panel data specification. Although Vadrevu et al. (2006) attempted to head towards this direction,

they do not fully exploit the advantages of a panel data approach as they analyze yearly data in a cross-sectional fashion. More recently, Hargrave and Kis-Katos (2013) employed panel data techniques to analyze how time-varying factors, such as increasing economic and agricultural activities, affected deforestation in the Brazilian Amazon.

On the same path, we propose a panel data approach to investigate the influence of weather and socio-economic conditions on fire occurrence and area burnt in Italian peninsula during the last decade, while accounting for the unobserved heterogeneity across regions. Fixed effects estimations are performed by adding region and time dummies to the regressions (Prestemon et al. 2002; Preisler et al. 2004). Regional effects may capture different forest covers, land management, culture, and law enforcement across the regions. On the other hand, year effects can capture a policy shift that influenced all of the regions at a given time.

Assuming N regions ($i = 1, 2, \dots, N$) and T periods of time ($t = 1, 2, \dots, T$), the standard representation of the fixed effect panel estimation method takes the following form:

$$y_{it} = \alpha_i + \gamma_t + X'_{it}\beta + \varepsilon_{it} \quad (1)$$

where y_{it} is the dependent variable (either the natural logarithm of the total number of fire events, or the natural logarithm of the total area burnt in hectares in a given region (i), in a given time (t)). α_i is the region dummy variable for regional fixed effects; γ_t is a year dummy variable which controls for time varying common shocks; vector of X_{it} includes the set of explanatory variables for a given region (i), in a given time (t) which are the weather and socio-economic variables depending on the empirical exercise; and ε_{it} is the standard white noise error term.

With noticing is that if α_i is correlated with any of the time-varying explanatory variable, regressing the dependent variable (i.e., forest fire events) on explanatory variables will lead to bias in the estimations. As a result, ordinary least squares (OLS) estimates would be biased coefficients and lead to invalid standard errors (Baltagi 2008). Hence, in this paper, we use fixed effects methodology where we control for region-specific time-invariant factors and time effects, which allows us to obtain unbiased coefficients and robust standard errors.

Throughout the empirical analysis section, we use the estimation technique proposed in Equation (1), however, the set of explanatory variables used in the empirical analysis were different depending on their availability. In particular, using (1), we first investigate the relationships between monthly weather conditions (i.e., monthly precipitation (millimetre) and temperature ($^{\circ}\text{C}$) levels) and monthly total forest fire events (area burnt) across the Italian

regions. In this exercise, we first consider the monthly data simultaneously (without differentiating between different seasons) to examine the effects of precipitation and temperature on forest fire events and area burnt (see Section 4.1). Then, we considered the effects of monthly weather conditions on forest fires events and area burnt for each month separately during January 2000 and December 2011 (see Sections 4.2 and 4.3) where we find that the effect of weather conditions vary across months and space. Given this heterogeneity of the effects, we use the estimates obtained in Sections 4.2 and 4.3 to predict forest fire regime under future climate (Section 4.4). To this aim, we employ projections on surface temperature (°C) and precipitation (%) levels reported in the IPCC 5th Assessment Report (IPCC 2013) for different geographical clusters in Italy. Finally, we use the estimation technique proposed in Equation (1) to assess the relation between fire regime and socio-economic factors, organizing data in a yearly fashion for both dependent and independent variables given that most of time-variant socio-economic variables are only available on yearly basis.

2.1 Method for choosing climate change projections

Climate change projections for Italy are derived from European-scale projections resulting from the ENSEMBLES project (<http://ensembles-eu.metoffice.com/>), which uses regional climate models (RCMs) driven by global climate models (GCMs). The underlying socio-economic scenario, governing the future amount of greenhouse gas concentration in the atmosphere leading to the assumed values of precipitation and temperature, is the A1B of the IPCC Special Report on Emissions Scenarios (SRES) (Morita et al. 2001).³

Projections provided for summer (June, July, and August (JJA) hereafter) and winter (December, January, and February (DJF) hereafter) are derived from major climate models developed around the world and are expressed in climate anomalies. Climate anomalies are obtained by differencing future climate conditions, 2016–2035 climate conditions, from the present ones, 1986–2005 climate conditions.⁴ Given that each model provides a different

³ The A1B scenario belongs to the A1 family assuming very rapid economic growth in the future and driven by a rapid introduction of new and more efficient technologies. This scenario also assumes that global population peaks in mid-century and declines thereafter. A major issue in this scenario is the convergence among regions, capacity building, and increased cultural and social interactions, which support the reduction of differences in per capita income across regions. The A1B, in addition, is characterized by balanced progress across all resources (including land use and energy) and technologies.

⁴ Simulations used relate to the following models: HadRM3Q0-HadCM3Q0, ETHZ-HadCM3Q0, HadRM3Q3-HadCM3Q3, SMHI-HadCM3Q3, HadRM3Q16-HadCM3Q16, SMHIBCM, DMI-ARPEGE, KNMI-ECHAM5, MPI-ECHAM5, DMI-ECHAM5 (for further details see IPCC 2013).

projection, it is common use to consider the multi-model ensemble-mean anomalies as they will always outperform most of the ensemble members.

Table 1 provides the minimum and maximum possible changes in temperature and precipitation for the summer (i.e., JJA) and winter (i.e., DJF) periods for three geographic clusters (i.e., north, center, and south of Italy).⁵ To remain within a conservative climate scenario, we compiled the average of these extreme cases (i.e., average of the minimum and maximum projections), and use the values reported in columns titled “mean” for the forest fire projections for the summer (JJA) and winter (DJF) periods.

<Table 1 approximately here>

For those months for which we did not have information on climate projections, i.e., March, April, and May (MAM hereafter) and September, October, and November (SON hereafter) we simulated two different scenarios making assumptions on future climate for the spring (i.e., MAM) and autumn (i.e., SON) periods. For the first scenario (Scenario 1), after observing past monthly trends and realizing existing similitudes at month level, the mean temperature and precipitation projections for the JJA are used for May, September, and October months, while the DJF values are used for March, April, and November. In other words, we use the mean temperature and precipitation projections for the JJA for the months between May and October, and the mean temperature and precipitation projections for the DJF for the period between November and April. For the second climate scenario (Scenario 2), average temperature and precipitation projections of JJA and DJF are used both for the spring (MAM) and autumn (SON) periods. The use of two scenarios allows us to perform a sensitivity analysis of climate change projections. Table 2 summarizes the final temperature and precipitation projections used for different time periods and geographical clusters of Italy. All the figures for temperature and precipitation have been firstly calculated for each month, as described above, and then used for each month.

<Table 2 approximately here>

In Section 4, we will examine the relationship between average temperature and precipitation with the total events (area burnt) over a given period. Hence, in order to obtain forest fire events (area burnt) projections, we need to obtain unit changes in temperature and precipitation with the climate change anomalies. However, climate change projections for

⁵ The distribution of fire data indicates that we should use two geographical clusters for the central Italy (i.e., central-north and central-south of Italy) in our analysis (see next section for details). Hence, for central-north and central-south clusters we use the climate change projections for central Italy since climate projections for the central Italy is not distinguished in two clusters.

precipitation are only available in percentage values (see Tables 1 and 2). To obtain unit changes in precipitation in each month with the climate change, we applied the percentage changes to the average precipitation levels in each month between 2000 and 2005 for north, centre, and south of Italy in order to obtain unit change in precipitation for each month between 2016 and 2035.⁶ We used the averages across 2000-2005 since values relative to the period 1986–2005 were not at our disposal for the geographic detail of our analysis. This is the closest period for which we have information about precipitation levels for all months across Italian regions. This approach can be applied as Italian climatology in 1986-2005 has been always characterized by specific elements that can be still captured also considering only 2000–2005 period. Meteorological events present a phenomenology that depends essentially on stable factors such as the orographic relief, the distance from the sea or from large reservoirs and the soil type determine local systematic variations of the meteorological signal (Esposito et al. 2015). Therefore, they are captured independently on the period on which the climatic averages are calculated. Overall, this final step allowed us to project unit changes in precipitation and temperature levels in each month with the climate change projections for all Italian regions, which will be then used to obtain forest fire event and area burnt projections.

3. Data set and statistics of major variables

From the data collection on both dependent, socio-economic factors, and climatic variables, we worked to reach a balanced data set (i.e., a set that contains all elements observed in all time frame for all regions of Italy), including information about fire events/area burnt (Section 3.1), precipitation/temperature levels (Section 3.2), and socio-economic conditions (Section 3.3.) for 19 regions.⁷ Fire and weather information was collected for all months between 2000 and 2011, while socio-economic factors are available on yearly basis.

⁶ For instance, if average precipitation in June is X millimetre (mm) for north of Italy between 2000 and 2005, unit change in precipitation for the north of Italy with the climate change projections will be $0.075X$ mm since the precipitation in June will be increased by 7.5% in June at north Italy.

⁷ We eliminated Valle D'Aosta region from our analysis due to lack of data on most of the socio-economic and climatic variables. This region is the least prone area to forest fires in Italy (i.e., on average, Valle D'Aosta had 15 fire events resulting 89 hectares of area burnt per year between 2000 and 2011) and we believe that its exclusion has no major impact on findings of this paper.

3.1 Fire across time and space and data organization in geographical clusters

The European Forest Fire Information System (EFFIS) of the European Commission Joint Research (CJR) Centre and the State Forestry Department of Italy (i.e., Corpo Forestale dello Stato) record monthly data which were used for the construction of two different dependent variables for all regions of Italy, covering the period between 2000 and 2011. The first dependent variable is the total number of fire events in each region at a given month. The second one is the total area burnt (in hectares) in each region at a given month. The two variables are highly and positively correlated across Italian regions but capture different aspects of fire dynamics.⁸ Therefore, using them both allows drawing important evidence and a richer interpretation of the analysis.

Among the Mediterranean countries, Italy represents one of the most prone areas to forest fires. For example, Moriondo et al. (2006) find that Italy experiences the highest increase in annual climatic extreme events in future scenarios conducted through return period analysis. Analyzing distributions over time and space of fire events and area burnt for each region during 2000–2011, we confirm that fire events cover the entire Italian peninsula, from the north to the south. However higher frequency and larger fire events occur in the south (Figure 1).⁹

<Figure 1 approximately here>

In addition to taking different connotation from north to south, fire occurrence and total area burnt in Italy show variation across different months and regions. According to the statistical mode and geographical location of fire occurrence and area burnt, we can distinguish amongst four geographical clusters showing similar forest fire characteristics (i.e., north, central-north, central-south, and south of Italy).¹⁰ As we move from south to north, we switch from unimodal (south) to a mix between bimodal and unimodal distributions (central-south) and from bimodal (central-north) to plurimodal (north) distributions of fire occurrence (Figure 2). The biggest incidence across space mainly relates to summer months, whereas the second pick in frequency is observed around March. This is likely the result of land management practices such as the use of fire by farmers and anglers to improve rangeland

⁸ Correlation between total area burnt and the number of fire events for all regions over time is 0.74.

⁹ This explains why the few existing Italian-based analyses on fire events mostly focus on southern Italy (Pazienza and Beraldo 2004; Bajocco and Ricotta 2008).

¹⁰ Regions listed in each geographical cluster are as follows. North: Piedmont, Lombardy, Liguria, Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, and Valle D'Aosta. Central-north: Emilia Romagna, Tuscany, Umbria, and Marche. Central-south: Lazio, Abruzzo, Molise, and Campania. South: Apulia, Basilicata, Sicily, Sardinia, and Calabria.

productivity and vegetation regeneration. Agricultural burning is a method commonly used by landowners and farmers to enhance soil fertilization, to prepare fields for harvest activity, and to dispose crop residues. However, despite this strategy traces back in time, Italians' expertise in prescribed burning may be considered as a fire hazard-reduction (rather than hazard-increase) strategy (Ascoli and Bovio 2013). In addition, when the temperatures start increasing, fine vegetation or dead fuels lose moisture rapidly, forest becoming more prone to early season fires (March and April period). In the north and parts of the central-north, events take place both during summer and winter periods, and these areas are characterized by a continental climate of having no proper dry season. In addition, as alive and woody vegetation has slower moisture dynamics, fire susceptibility is reached only late in the summer season (i.e., events last until late summer).

<Figure 2 approximately here>

3.2. Weather conditions across time and space

To understand the relationship between climatic factors and forest fire regime, we collected monthly averages of temperature and rainfall between 2000 and 2011 for each region, which are elaborated from the Italian Agriculture Research Council and the Research Unit for the Climatology and Meteorology for Agriculture.¹¹ Despite inter-annual variability, specific monthly dynamics can be identified for precipitation levels across geographical clusters (see Figure 3). Average precipitation levels increase during the winter period (i.e., between September and December) and lowers during the summer period (i.e., between May and August). However, average monthly precipitation varies across different geographical clusters where the precipitation levels are higher in the north than the south for almost all of the months. On the other hand, annual average of monthly temperatures also show a clear seasonal variation where average temperature progressively increases from January onwards and peaks in July (August for central south) to then decline (see Figure 4). This seasonal variation in precipitation and temperature has been accounted in the literature and found to be important factor explaining fire events (see e.g., Bajocco and Ricotta 2008), which will be

¹¹ The Italian Agriculture Research Council and the Research Unit for the Climatology and Meteorology for Agriculture are known as the Italian Consiglio per la Ricerca in Agricoltura and Unità per la Climatologia e la Meteorologia applicate all'agricoltura, which provide detailed climatic data for Italian regions. For more information visit at: <http://cma.entecra.it/homePage.htm>.

also accounted in this paper.¹²

<Figures 3 and 4 approximately here>

3.3 Socio-economic Factors

There exist several socio-economic factors that affect forest fire ignition probability and spread (see e.g., Ganteaume et al. 2013 for a comprehensive list of socio-economic driving factors of forest fire across Europe). Amongst others, we have made an effort to collect data on those factors that are more likely to affect the fire conditions in Italy. For example, differences in livestock density could explain, in some regions, an increase in the risk of fire occurrence due to maintenance of pastures (Lloret et al. 2002; Martinez et al. 2009). Furthermore, burning shrubland is a widespread practice in rural areas across the Mediterranean region to renovate livestock pastures (see e.g., Moreira et al. 2009). To capture these effects across regions and time, we use the natural logarithm of the total livestock units per kilometre square in a given region.

Similarly, the existence of agricultural activities may also affect the likelihood of forest fires. For instance, Ricotta et al. (2012) find that decreased human impact associated with agriculture land abandonment leads to a statistically significant decline in fire ignition probability in Sardinia. To capture the effect of the presence of agricultural activity across the regions, we use the percentage of employment in agriculture as a proxy. In the same lines, most populated or active areas (e.g., closeness of forests to the roads and railways) are found to be more prone to forest fires because of the increased human pressure (Catry et al. 2007; Martinez et al. 2009). This effect is accounted for by using the natural logarithms of population density (i.e., total population in a region divided by the total area in kilometre squares) and railway density (i.e., kilometres of regional railways divided by the total regional area in kilometre squares).

Finally, socio-economic well-being of a region may play a role in human induced and intentional forest fires. Especially in the past, forests have been voluntarily set on fire to create firefighting jobs or to gain land for agriculture and pasture, which were retained more valuable than logging (Leone et al. 2002). Indeed, low timber returns along with negligent forest management can result in higher fire risk (Gonzalez-Olabarria and Pukkala 2011). For instance, Prestemon and Butry (2005) found positive associations between poverty and

¹² In this analysis, we do not control for the monthly wind speed since it has been noted that it does not provide any explanation to monthly variations in forest fires (see e.g., Lasslop et al. 2015 for a discussion on this).

unemployment rates with the arson ignition rates. However, de Torres Curth et al. (2012) found that the areas with fewer fires tend to be characterized by population with higher levels of education. To capture the effects of these socio-economic factors, we consider the variables of relative poverty (measured by the percentage of population in a given region that live under relative poverty line), education (measured by the percentage of the population aged between 25 and 64 with tertiary education attainment), and illegal activity (measured by the number of extortions per 100,000 inhabitants).

The complete list of the socio-economic factors considered is provided in Appendix Tables 10 where Table 3 offers the descriptive statistics for the indicators used in the regression analysis. It can be seen that socio-economic conditions show good variation across the regions and geographical clusters.

<Table 3 approximately here>

4. Results

4.1 Weather effects on fire events and area burnt

In this subsection, we first investigate the relationship between monthly precipitation and temperature levels across time (i.e., between January 2000 and December 2011) and forest fire events or area burnt during the same period, after controlling for regional and time fixed effects. In this case, we do not account for the potentially different effects of weather conditions on forest fires and total area burnt in different seasons and consider whole set of panel data simultaneously.

Tables 4 and 5 offer the relationships between monthly weather factors (temperature and precipitation) and monthly forest fire events and total area burnt for the whole Italian peninsula, north, central-north, central-south and south of Italy, respectively. Findings confirm a clear regional heterogeneity across space and time (except for southern Italy). Regional and time effects explain around 30% of the monthly variation in fire events in the north, central- north and central-south of Italy, as highlighted from the R-squares obtained when we use regional and time dummies only. Regional effects only explain 7% of the variation in forest fires in the south of Italy. To disentangle the additional effect of weather components (i.e., additional explanatory power), we introduce weather factors into the analysis after accounting for the regional and time fixed effects. Adding monthly weather data in time (t) and their lagged values, we observe that in all geographical clusters, with exception of the south, fire frequency (area burnt) in a given month (t) is negatively

associated with precipitation levels occurring in that month (t) and in the two previous months (t – 1 and t – 2). In the south, the effects of precipitation lasts one month rather than two months. For example, for the Italian case (i.e., the results that are presented in the first column of Table 4), an increase in average precipitation level by 10 millimetres in time (t), (t – 1), and (t – 2) (i.e., precipitation levels in a given month and two previous months) corresponds to a decrease in fire frequency by 8.9%, 7.8%, and 3.4%, respectively.¹³

<Tables 4 and 5 approximately here>

On the other hand, warmer temperatures in month (t) imply significantly higher fire frequency (area burnt) in the whole peninsula. Temperature shows lasting effects in the south of Italy, where higher temperature in previous month (t – 1) increases fire frequency in month (t). An increase of one degree Celsius in month (t) and (t – 1) corresponds, respectively, to a 15% and 3% increase in fire frequency in south of Italy. Whereas, a similar increase in temperature in month (t) leads to 0.9%, 5.7%, 5.5% increases in fire frequency in north, central-north and central-south of Italy, respectively.

Overall, both precipitation and temperature have lasting effects on fire frequency and total area burnt, although the effect declines as the weather realization becomes more distant in time (i.e., the effects of previous months' weather conditions on fire events and area burnt become increasingly lower in time). Finally, looking at the additional explanatory power of weather conditions, a good portion of the monthly variations in fire events (area burnt) is explained by variations in weather variables (i.e., between 20% and 70% of the monthly variation in fire events and area burnt is explained by the weather factors).¹⁴

The results presented in Tables 4 and 5 suggest that the effects of weather variables on fire regime differ across geographical clusters, and from those obtained for the whole Italian peninsula. This outcome, corroborated by a poolability test, suggests the use of different geographical clusters rather than analyzing the whole peninsula together.¹⁵ In addition, whilst we treated the weather effects as similar across different months and seasons,

¹³ Since the log-linear transformation is used in our regressions, we can obtain how a unit change in weather components correspond to a percentage change in the dependent variable by $[(e^\beta - 1) \times 100\%]$, where β is the coefficient for the weather component in interest.

¹⁴ The additional explanatory power of weather factors is obtained by the differences between the R-square values obtained when regional and time dummies, and weather variables are included in the analysis (i.e., when all relevant factors are included in the analysis) and the R-square values obtained when only the regional and time dummies are used in analysis.

¹⁵ We conducted likelihood-ratio (LR) tests to examine whether the different geographical clusters can be pooled together. We reject the null hypothesis that assumes homogenous slope coefficients across different geographical clusters, which suggests that different geographical clusters cannot be pooled together to examine the relationship between weather factors and fire events (area burnt).

it is reasonable to expect that their effects differ across months. For instance, in Table 4, we found that the precipitation levels have lasting effects in time on forest fire events for all geographical clusters, however these lasting effects of precipitation are likely to be different across different months. Therefore, in the next subsections, we examine the relationships between weather factors and forest fire variables in a given month for different geographical clusters of Italy.

4.2 Disentangling the effects of monthly weather on fire frequency

In this subsection, we disentangle the effects of weather variables on forest fire events across the months for different geographical clusters of Italy where the findings are offered in four different panels in Table 6. Panels A and B of Table 6 provide results for the north and central-north of Italy identifying the complexity of the fire cycles in these regions across different months. For almost all months, higher monthly precipitation levels decrease the number of fire events in the same month. Lasting effects of precipitation levels exist but do not show a definite path and furthermore the effect of precipitation declines in time (i.e., the effect of precipitation in previous months is lower). Temperature presents a different effect on the number of fire events. While in the northern Italy (except for February, May, and September), a rise in temperature levels leads to increases in fire events in respective months (see Panel A of Table 6). Whereas, in the central-north, changes in temperature explain the fire events between June and November. After considering the region effects, the additional explanatory power of weather variables is predominant during December and January (i.e., winter season), and in June and July (i.e., summer period) in the northern Italy. Whereas, the greater portion of the fire events between February and April, and between July and November are explained with the variation in precipitation and temperature levels in the central-north of Italy.

<Table 6 approximately here>

In terms of their relationships with fire events, a similar situation can be observed when we move to the central-south, compared to north and central-north of Italy, for both precipitation and temperature, although different paths emerge across the months (see Panel C of Table 6). Lasting effects of more humid climate occur as increases in precipitation levels in a given month, between May and October, not only decrease the number of fire events in the same month but also in the following ones. Similarly, increases in temperature between April and September lead to higher number of fire events. Yet, the variation in temperature

levels during the winter period (October–December and January–March) has no significant effect on fire events. We can also observe that except for few months, the additional explanatory power of weather variables is high, after accounting for region-specific fixed effects.

Compared to other regions, despite precipitation still explains the monthly variations in fire events, the effect in the south is relatively lower (see Panel D of Table 6). Variation in precipitation levels during the winter period (November, December, and January) has no direct or lasting effect. However, precipitation levels during the spring, summer and autumn still show significant effects. One aspect that differs from other geographical areas is that temperature levels in February and March explain the variation in fire events in these months at the 1% significance level. However, fire frequency in August seems to be affected by the precipitation levels in the same period and in the previous month, rather than by temperature, signalling a greater impact played by drought rather than by a warm climate.

4.3 Disentangling the effects of monthly weather on the area burnt

In this subsection, we conduct a similar empirical analysis to Section 4.2, however, we now we examine the weather factors' relationships with the total area burnt across different geo- graphical clusters where the findings are reported in four panels of Table 7.

<Table 7 approximately here>

More specifically, Panel A of Table 7 reports our findings for the northern Italy. We find that the regional fixed effects explain between 20% and 60% of the variation in the area burnt during the specific months in the case of northern Italy (i.e., see R-square values obtained with the fixed effects in Panel A of Table 7). After controlling for region specific effects, weather variables still explain a good portion of the variation in area burnt during a given month, except for few cases. Higher precipitation levels lead to lower land burnt in almost all months except for April, August, and October. During winter (October–December) precipitation increases have persistent declining effects on the area burnt, highlighting the importance of humid climate in mitigating the spread of fire events across larger areas. Relatively warmer temperatures lead to increases in area burnt for almost the entire year. The persistency of the effects of temperature is limited compared to effects of precipitation on area burnt.

In the central-north of Italy, instead, temperature levels appear to be significant only for June and August, while the effect of warmer temperatures in June and September lasts

until July and October (see Panel B of Table 7). On the other hand, precipitation levels are significant and negatively associated with the area burnt in a given month (with the only exception of January), emphasizing the relevance of soil moisture which minimizes the total area burnt during the fire events. Lasting effects of precipitation take place during the spring (February–April) and summer (June–August) periods. Higher precipitation in these periods reduces the portion of area burnt in consecutive months underlining the relevance of humid climate in mitigating the spread of fire events across larger areas. Weather variables in summer explain additional 20%, 43%, and 62% of the area burnt variation from June, July, and August, respectively. This is an important result since 67% of the total area was burnt in this geographical cluster between 2000 and 2011 precisely during this season.

Panel C of Table 7 offers the detailed findings for the central-south of Italy. For most of the winter period (November to February), the monthly precipitation explains the variation in area burnt in respective months. High temperature and low precipitation levels in consecutive months between July and October lead to higher area burnt in the same months. Weather variables explain additional 39%, 42%, 42%, and 34% of the variation in July, August, September, and October, respectively. Like the central-north, 89% of the total area burnt between 2000 and 2011 occur in these months highlighting the importance of the weather factors. Finally, the lasting negative effects of precipitation on reducing the burnt area is an important factor for the spring period where the weather variables' additional explanatory power during the spring period (February–April) is 30%.

Variation in temperature levels across the months is relatively more important in the south of Italy than in any other geographical cluster where high temperature in a given month and/or previous month leads to more area burnt in all months with the exceptions of January, April, and November (see Panel D of Table 7 for detailed findings for the south of Italy). Similarly, lower levels of precipitation extend the portion of land burnt in all months except for January and December. Therefore, we can suggest that drought (i.e., low precipitation and high temperature levels) plays an important role in explaining the variation in area burnt between May–July and September–October. This finding is particularly important since 96% of the area gets on fire between May and October in south Italy. Overall, we can summarize that the relatively high temperature and low precipitation, or a combination of the two (i.e., drought), explain between 18% and 41% of the variation in area burnt in all months but the winter period (November, December, and January) in the south of Italy after controlling for the region-specific factors.

4.4 Climate Change Implications

In this subsection, we use the first and second climate scenarios (see Tables 1 and 2) to present predicted number of fire events and area burnt during the winter (DJF), spring (MAM), summer (JJA), autumn (SON), and annually for different geographical clusters of Italy by using the significant coefficients on weather variables from Tables 6 and 7, respectively. Projected forest fire events and area burnt for each geographical cluster are for 2016–2035 period relative to 2000–2005 period to be consistent with the climate scenarios. It should be noted that climate scenarios 1 and 2 can be considered as conservative as they average the projected levels of temperature and precipitation variation simulated by climate models (see Section 2.1). Table 8 reports the projected percentage changes in fire events and area burnt in different seasons for four geographical clusters of Italy with both climate change scenarios (see Appendix Tables 11 and 12 for the detailed fire event and area burnt projections for geographical clusters with climate scenarios 1 and 2, respectively).

<Table 8 approximately here>

Climate changes exert a pressure on fire regime in both climate scenarios from north to south suggesting an increase fire frequency and land burnt during the period between 2016 and 2035. The annual number of fire events in the north, central-north, central-south and south of Italy is projected to increase by ~ 11–12%, 16%, 25%, and 9–10.5%, respectively. Clearly, the effects of climate change on fire events varies across geographical clusters where the effect of climate change would affect the central Italy the most compared to other regions. On the other hand, the seasons in which forest fire event increments are different across different geographical clusters. Major increases in forest fires in the north of Italy is projected to be in the winter and summer periods. In the central-north, most of the annual increase is driven by fires occurring in the summer period. For the central-south of Italy, fire events are projected to increase by 30% and 20%, during summer and autumn, accounting for additional 300 and 50 fire occurrences, respectively. Finally, the highest annual percentage increase in fire events in southern Italy is expected to be during the autumn period (ranging between 19% and 27% depending on the scenario). Overall, even though there is a major increase in summer fire events for all clusters, projections also highlight a rise of autumn fire events compared to the past, especially in the central-south and south of Italy.

A clear distinction between results obtained about fire frequency and those relative to the variation of land burnt, as a function of climate change, is that the portion of land affected by fires is projected to expand in all geographical clusters. Climate change could favor fire

danger and propagation and lead to the occurrence of more extreme fire events (i.e., fire events that result in larger areas being burnt), procuring higher damage to humans and ecosystems and requiring more costly suppression activities.¹⁶ This could be the result of the effect of climate change on moisture dynamics and alteration of fire susceptibility in specific regions; effects that are captured by the panel data estimation methods employed. From north to south, across all geographical clusters, land areas burnt are projected to increase by 23-27%, 34%, 75%, and 26% per annum (see Table 8 for area burnt projections). As a result, around additional 2400, 1100, 9000, and 11,000 ha of forest area will be touched by fire in north, central- north, central-south, and south of Italy, respectively (see Appendix Tables 11 and 12 for the details). These annual values are mostly driven by fire dynamics taking place during summer. However, percentage increases in the area burnt under climate change are relatively higher during autumn in central-south and south of Italy, suggesting higher suppression challenges and damage effects on land for these two clusters in the future. Finally, even though in north Italy the increase in the number of fire events in spring is limited, the area burnt during the same period is expected to raise by 1200–1300 ha in the two scenarios.

4.5 Yearly variations in the fire events and area burnt and the role of socio-economic factors

To test the relevance of socio-economic variables in explaining the fire events and area burnt, we move to a yearly-based analysis since the data on socio-economic factors are only available on yearly basis. The relevance of weather variables' effect on fire events and area burnt has been highlighted using monthly panel data estimations where they have been found to play a varying role in different seasons across different geographical clusters. In the following regressions, annual averages of precipitation and temperature have been included as control variables.

Panels A and B of Table 9 report the statistically significant socio-economic factors when the dependent variable is the natural logarithm of fire events and area burnt, respectively, even though the list of explanatory variables that were used in this analysis is

¹⁶ In this paper, we analyze the total area burnt during a given month not the extreme events themselves, but the findings of this paper suggest that on average, each fire event would result in more area burnt with the climate change anomalies.

provided in Appendix Table 10.¹⁷

<Table 9 approximately here>

Our findings suggest a negative relationship between education levels and fire regime in most of the Italian areas, after the inclusion of regional dummies and weather variables in regression analyses. A percentage increase in tertiary education in north, central-north and central-south of Italy leads to a decrease of 11%, 7%, and 2.2% in fire events, respectively. It should be noted that the fixed effect model (i.e., the estimation model that includes regional dummies) is designed to examine the causes of changes within a region over-time. The effect of education can be captured only when regional dummies are included.¹⁸ Despite the fact that it is rarely investigated within the literature, the resulting relation between education level and fire “hazard” appears to be supportive of existing studies. Locations characterized by low instruction level show higher fire risk (de Torres Curth et al. 2012). In principle, education level can affect forest regime both directly and indirectly. For example, education plays an important role in determining the distribution of income: higher level of educational attainment improves income levels and reduces income inequality (Glaeser et al. 2004; Crespo Cuaresma et al. 2013; Coady and Dizioli 2018, among many others) which may then increase the resources available for firefighting and prevention.

Beyond the importance of education levels we also find that in southern regions, illegal activities represent an additional driver after accounting for the regional effects and weather factors. A marginal (unit) increase in extortion activities per 100,000 inhabitant leads to increases in fire frequency and total area burnt by 4.6% and 7%, respectively. This finding is in accordance with the literature suggesting the importance of human induced and intentional forest fires (Leone et al. 2002; Bovio et al. 2017).

In sum, even though major drivers of seasonal fires are due to weather factors, annual variations in fire events and area burnt are also closely linked with some of the socio-economic factors and improvements in education levels and fighting against illegal activities on human-induced fires could mitigate the ever-increasing pressure of climate change’s impact on forest fires.

¹⁷ All the variables listed in the Appendix Table 10 are used in the regressions one at a time after controlling for the yearly variation in temperature and precipitation. However, most of the variables were not significant once weather variables are accounted for. Additionally some of the variables produce high multicollinearity (i.e., high VIF values) and hence they are dropped from the regressions (see e.g., Vadrevu et al. 2006; Martinez et al. 2009 for similar procedure).

¹⁸ For instance, when we do not include regional dummies in our regressions and utilize pooled ordinary least squares (OLS) estimations, we do not find any significant relationship between education and forest fires.

5. Concluding Remarks

We analyze the contributions of weather (i.e., temperature and precipitation) and socio-economic factors in explaining fire regime (i.e., number of event and area burnt) across four geographical clusters in Italy (north, central-north, central-south, and south) between 2000 and 2011. Panel data estimation techniques allowed us to obtain the effects of weather factors on forest fires after controlling for region-specific time-invariant factors and fire temporal dynamics.

Results highlight a clear regional heterogeneity across space and time where the regional fixed effects explain a good portion of the variation in forest fire events and area burnt. Each region has their own morphological, meteorological, socio-economical, and cultural characteristics. From area to area, high temperatures, water stress caused by low rainfall are responsible of the total fire scenario. Time and region effects included in the model through the panel estimation technique have proven to be relevant. While these effects are not identified in most studies, our results suggest that they should be controlled for by the future studies.

Furthermore, our study highlighted the fact that the effects of weather factors on fire regime show variation across seasons and geographical locations. In the north of Italy, weather conditions can explain fire regime in different months identifying its plurimodal distribution. In addition, variation in temperature and precipitation can show lasting effects in time. The same is true for central-north where effects of precipitation taking place around spring and summer periods also last in the following months. For central-south we observe a bi-modal distribution of fire data as the greatest explanatory power of weather factors is associated to the periods of February–April and July–October. For the south, three major fire periods can be disentangled during a year: February–March, May, and July–October. Consecutive high temperature and low precipitation levels during autumn (i.e., high drought levels in autumn) increase fire events and area burnt in the same period in the southern Italy.

By projecting fire regime as a function of future climate change, we observe that all clusters show an annual increase in the number of events and area burnt between 2016 and 2035 relative to the period of 2000–2005. The most affected area will be the central-south of Italy, with fire events and area burnt are projected to increase by 25% and 75%, respectively. Northern Italy will experience a higher fire frequency during the winter period, while in the central-north the annual rise in frequency is mostly driven by the projected fire events during the summer season. Central-south is projected to experience 30% and 20% increase in the

number of fires during the summer and autumn periods, respectively. Overall, while most frequent fire events will occur mainly in summer, confirming the past trends, a new path is reported for fires taking place in the central-south and south of Italy during the autumn period, which highlights the importance of more fire suppression efforts during autumn period in the central-south and south of Italy than the ones observed in the past. Finally, it is worth noting that the projected increases in area burnt in the northern Italy is expected to increase even though the projected increase in fire events is at modest levels. This increase in spread of fire could be a result of the impact of climate change on soil conditions, moisture content of litter and other fine fuels. The fire season could then become longer, more intense and extreme as reduced rainfall, heat waves, and drought events increase the water stress of the vegetation making it highly flammable. In sum, compared to the past, our findings suggest that there is clear change in the forest fire phenomenon across different seasons and geographical clusters and the interactions of climatic factors and forests have new connotations.

Beyond weather parameters, socio-economic factors also contributes to the explanation of forest fire regimes. Higher levels of education lead to decreases in the number of fire events and total area burnt in all geographical clusters with the exception of southern Italy. Whereas, a major contribution to fire regime in the southern Italy is due to the existence of criminal activity, exerting pressure on forest land. These two socio-economic factors are found to be important in explaining yearly variation in forest fires and area burnt after controlling for regional effects and weather variables.

The projected situation in fire regime calls for the development of initiatives to reduce risks of forest fires and their potential environmental and socio-economic impact.

On the one hand, a containment of the effects can be achieved through increasing education and awareness to foster protection of common goods. On the other hand, the solution may come from a revision of the present forest and fire management strategies, currently relying almost exclusively on extinction and emergency response, rather than monitoring and prevention, resulting in high costs and partial efficacy in extreme fire seasons. Rather than working at suppressing fires, it would be more efficient and effective to invest in fire prevention, implementing active forest management and active surveillance. Land and fuel management could also help in fuel-oriented silviculture, facilitating less flammable species or using prescribed burning to mitigate fire intensity. Prevention at lower costs can involve the revitalization of the economy through recreational and cultural tourism, biomass use, timber production, and protection of forest food products. Contrasting forest

abandonment and deterioration allows for a larger supply of forest products and reduces the vulnerability to fires.

The implementation of these strategies would require a process of governance re-organization for the whole sector. However, despite the forest land represents one of the major infrastructure for Italy, this sector has been neglected by politicians. This is also supported by the recent events that have characterized the Italian forest sector lately: the suppression of the Italian police force (Corpo Forestale dello Stato) in charge of the recording of all fire events in the Italian peninsula, and the termination of the recording activity on forest sector statistics by the National Italian Institute for Statistics. These two recent governance decisions will make the monitoring and management of the fire phenomenon more difficult under more extreme climate conditions in the future.

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Appendix

<Tables 10, 11 and 12 approximately here>

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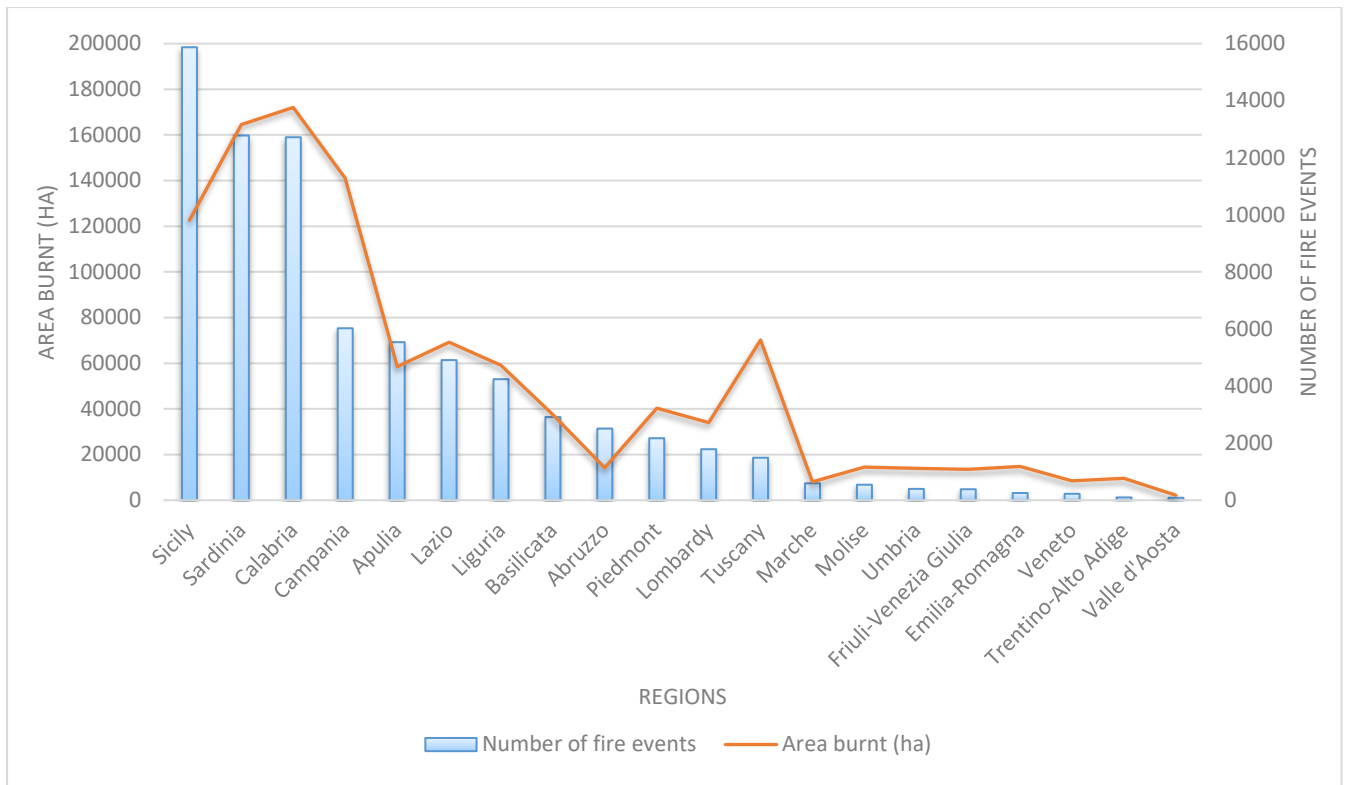


Figure 1. Total number of fire events and area burnt between 2000 and 2011 across Italian regions

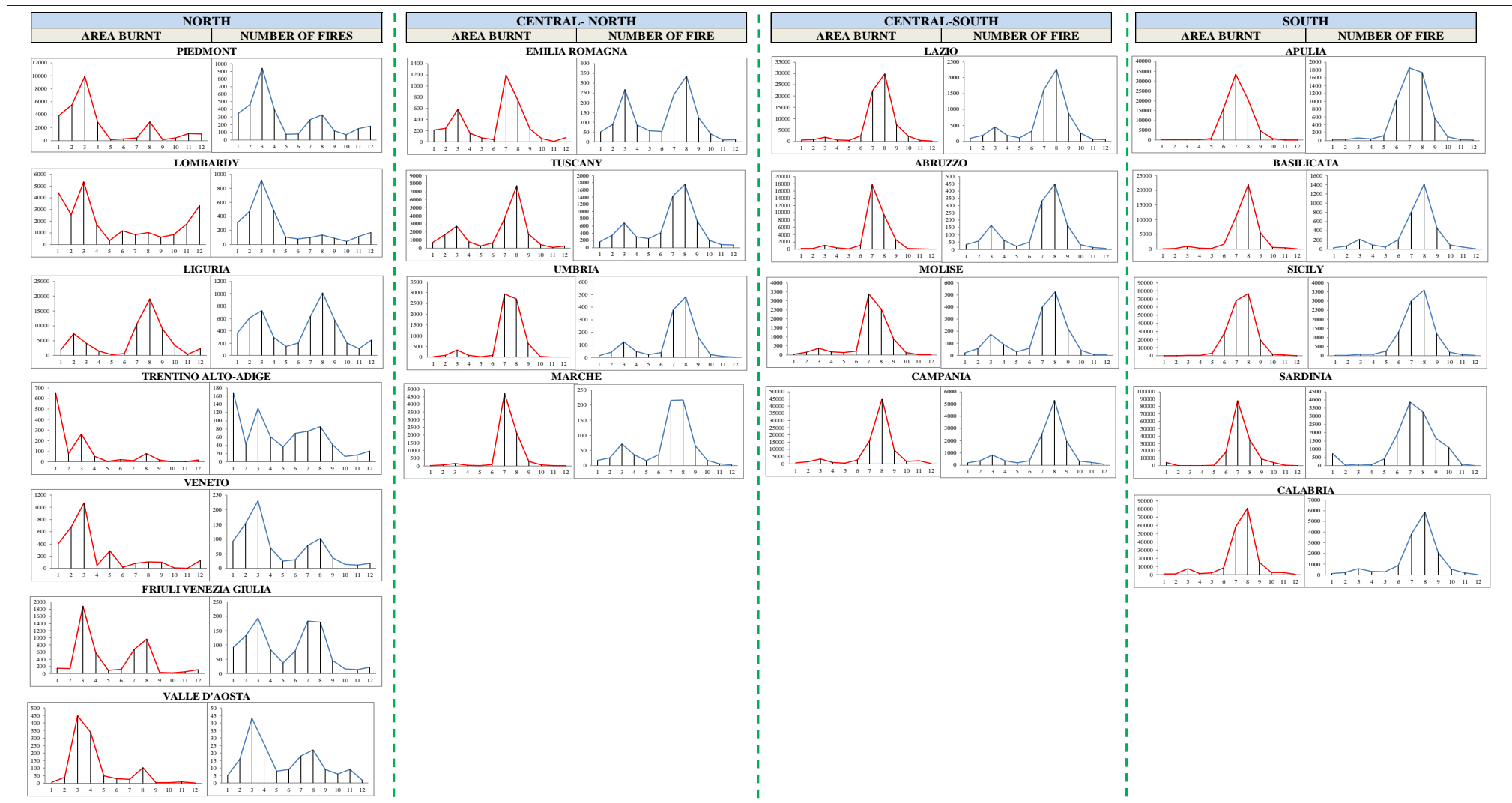


Figure 2. Monthly average number of fire events and area burnt for different geographical clusters between 2000 and 2011

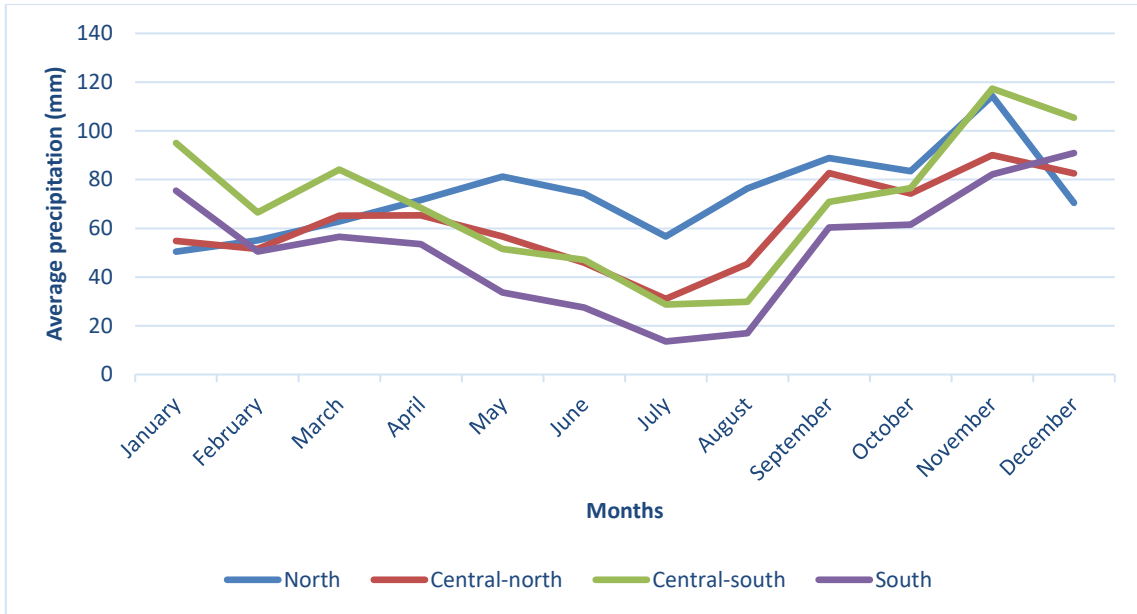


Figure 3 Monthly mean precipitation levels across geographical areas (mm)

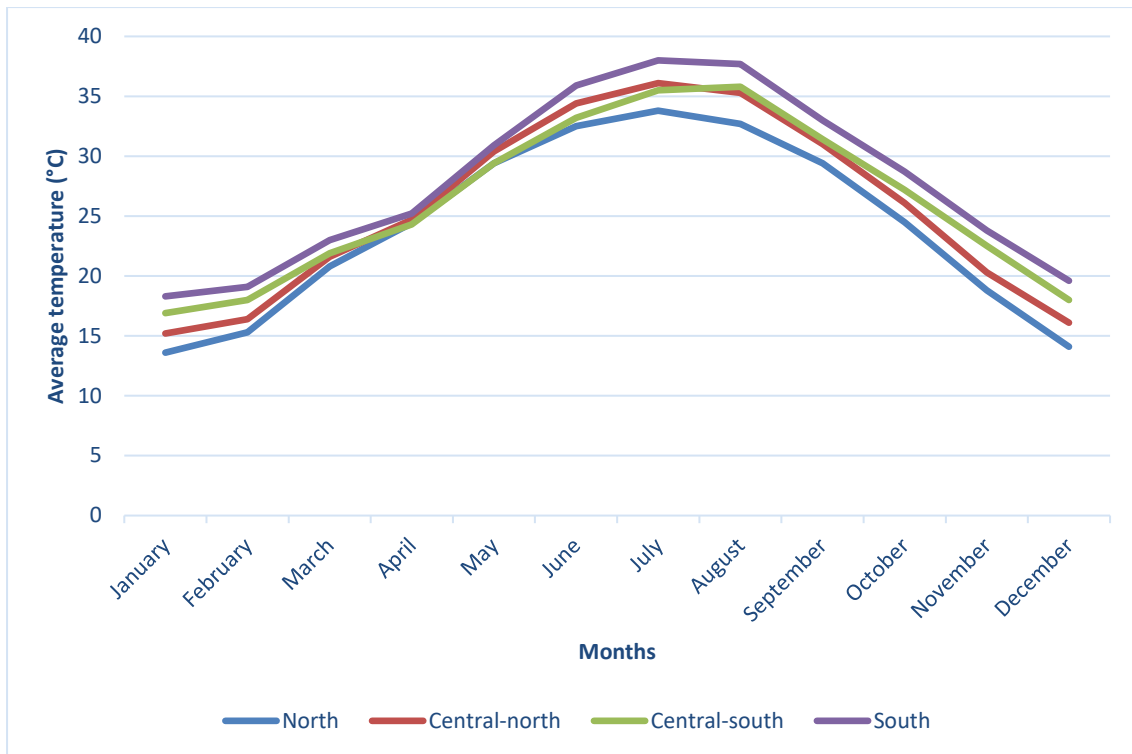


Figure 4 Monthly mean temperature levels across geographical areas (°C)

Table 1. Climate change projections for temperature (°C) and precipitation (%) applied to north, centre, and south of Italy in winter and summer periods. *Source:* own elaboration from IPCC (2013)

Geographic Cluster	Temperature			Precipitation		
Summer projections (JJA)						
	Min	Max	Mean	Min	Max	Mean
North	0.90°C	1.20°C	1.05°C	+5%	+10%	+7.5%
Centre	1.20°C	1.50°C	1.35°C	0%	-5%	-2.5%
South	0.90°C	1.20°C	1.05°C	0%	-5%	-2.5%
Winter projections (DJF)						
	Min	Max	Mean	Min	Max	Mean
North	0.90°C	1.20°C	1.05°C	-5%	-10%	-7.5%
Centre	0.90°C	1.20°C	1.05°C	0%	-5%	-2.5%
South	0.30°C	0.60°C	0.45°C	-5%	-10%	-7.5%

Table 2. Final temperature and precipitation projections used for different geographical clusters of Italy

Geographical cluster	Scenario 1			Scenario 2		
	Period	Temperature	Precipitation	Period	Temperature	Precipitation
North Italy	May – Oct (JJA)	1.05°C	+7.5%	MAM	1.05°C	0%
				JJA	1.05°C	+7.5%
	Nov – Apr (JDF)	1.05°C	-7.5%	SON	1.05°C	0%
				DJF	1.05°C	-7.5%
Central Italy	May – Oct (JJA)	1.35°C	-2.5%	MAM	1.20°C	-2.5%
				JJA	1.35°C	-2.5%
	Nov – Apr (JDF)	1.05°C	-2.5%	SON	1.20°C	-2.5%
				DJF	1.05°C	-2.5%
South Italy	May – Oct (JJA)	1.05°C	-2.5%	MAM	0.75°C	-5%
				JJA	1.05°C	-2.5%
	Nov – Apr (JDF)	0.45°C	-7.5%	SON	0.75°C	-5%
				DJF	0.45°C	-7.5%

Notes: The mean temperature and precipitation projections for the JJA are used for May, September, and October months, while the DJF values are used for March, April, and November in Scenario 1. The mean temperature and precipitation projections of JJA and DJF are used both for the spring (MAM) and autumn (SON) periods in Scenario 2.

Table 3. Summary statistics of socio-economic variables					
Variable	Mean	Standard Deviation	Minimum	Maximum	N
Summary statistics for all the regions in Italian peninsula					
<i>ln</i> Livestock intensity	3.09	0.67	1.44	4.74	228
Percentage of employment in agriculture	5.38	2.90	1.36	12.79	228
<i>ln</i> Population density	5.06	0.57	4.05	6.04	228
<i>ln</i> Railway density	1.19	0.40	0.53	2.18	228
Relative poverty	12.78	8.59	2.50	30.80	228
Percentage of territory degree	12.36	2.66	6.70	19.60	228
Extortion per 100,000 inhabitants	8.52	3.98	2.25	21.44	228
Summary statistics for the regions in the northern Italy					
<i>ln</i> Livestock intensity	3.28	0.99	1.44	4.74	72
Percentage of employment in agriculture	3.50	1.66	1.36	8.81	72
<i>ln</i> Population density	5.27	0.55	4.22	6.00	72
<i>ln</i> Railway density	1.13	0.32	0.53	1.47	72
Relative poverty	5.60	1.70	3.30	9.90	72
Percentage of territory degree	12.28	2.54	7.95	18.70	72
Extortion per 100,000 inhabitants	5.90	2.09	2.25	10.48	72
Summary statistics for the regions in the central-north of Italy					
<i>ln</i> Livestock intensity	3.03	0.53	2.39	3.91	48
Percentage of employment in agriculture	3.84	0.81	2.03	5.90	48
<i>ln</i> Population density	4.98	0.23	4.57	5.26	48
<i>ln</i> Railway density	1.21	0.24	0.92	1.52	48
Relative poverty	5.75	1.54	2.50	9.10	48
Percentage of territory degree	13.54	2.22	9.40	17.20	48
Extortion per 100,000 inhabitants	6.92	1.79	3.29	10.88	48
Summary statistics for the regions in the central-south of Italy					
<i>ln</i> Livestock intensity	3.16	0.28	2.69	3.63	48
Percentage of employment in agriculture	5.09	2.41	1.53	11.46	48
<i>ln</i> Population density	5.20	0.72	4.26	6.04	48
<i>ln</i> Railway density	1.24	0.60	0.54	2.18	48
Relative poverty	16.56	6.70	6.00	27.00	48
Percentage of territory degree	13.37	3.07	8.70	19.60	48
Extortion per 100,000 inhabitants	10.77	4.38	4.76	21.44	48
Summary statistics for the south regions of Italy					
<i>ln</i> Livestock intensity	2.86	0.40	2.31	3.61	60
Percentage of employment in agriculture	9.10	1.91	4.98	12.79	60
<i>ln</i> Population density	4.75	0.53	4.05	5.33	60
<i>ln</i> Railway density	1.20	0.39	0.71	1.83	60
Relative poverty	23.50	4.26	13.30	30.80	60
Percentage of territory degree	10.69	1.79	6.70	14.00	60
Extortion per 100,000 inhabitants	11.17	4.02	4.54	19.86	60

Table 4. Relationship between weather variables and fire events without differentiating for seasonal effects

Variables	All regions	North	Central North	Central South	South
Precipitation (t)	-0.0093*** (0.001)	-0.0077*** (0.001)	-0.0092*** (0.001)	-0.0088*** (0.001)	-0.0078*** (0.001)
Precipitation (t-1)	-0.0081*** (0.001)	-0.0064*** (0.001)	-0.0085*** (0.001)	-0.0067*** (0.001)	-0.0072*** (0.001)
Precipitation (t-2)	-0.0035*** (0.000)	-0.0034*** (0.001)	-0.0039*** (0.001)	-0.0024*** (0.001)	-0.0009 (0.001)
Temperature (t)	0.0631*** (0.003)	0.0088** (0.004)	0.0553*** (0.005)	0.0535*** (0.011)	0.1425*** (0.010)
Temperature (t-1)					0.0296*** (0.010)
Observations	2,679	846	564	564	705
Regional effects	YES	YES	YES	YES	YES
Year effects	YES	YES	YES	YES	NO
Fixed effects R ²	0.240	0.304	0.322	0.313	0.072
R-squared	0.587	0.516	0.658	0.648	0.766

Notes: Robust standard errors are reported in parentheses. ***, **, and * present the 1%, 5% and 10% significance level respectively.

Table 5. Relationship between weather variables and area burnt without differentiating for seasonal effects

Variables	All regions	North	Central North	Central South	South
Precipitation (t)	-0.0127*** (0.001)	-0.0086*** (0.001)	-0.0105*** (0.002)	-0.0118*** (0.002)	-0.0105*** (0.002)
Precipitation (t-1)	-0.0114*** (0.001)	-0.0079*** (0.001)	-0.0116*** (0.002)	-0.0089*** (0.001)	-0.0096*** (0.002)
Precipitation (t-2)	-0.0053*** (0.001)	-0.0040*** (0.001)	-0.0045** (0.002)	-0.0039*** (0.001)	-0.0002 (0.002)
Temperature (t)	0.0907*** (0.008)	0.0493*** (0.012)	0.0630*** (0.013)	0.0785*** (0.018)	0.2162*** (0.017)
Temperature (t-1)					0.0585*** (0.016)
Observations	2,679	846	564	564	705
Regional effects	YES	YES	YES	YES	YES
Year effects	YES	YES	YES	YES	NO
Fixed effects R ²	0.261	0.348	0.247	0.247	0.071
R-squared	0.537	0.516	0.510	0.577	0.745

Notes: Robust standard errors are reported in parentheses. ***, **, and * present the 1%, 5% and 10% significance level respectively.

Table 6 Panel A. Monthly variations in fire events in the north of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0100*** (0.003)	-0.0090*** (0.003)	-0.0113*** (0.003)	-0.0054*** (0.002)	-0.0043** (0.002)	-0.0096*** (0.002)	-0.0105*** (0.003)	-0.0047 (0.003)	-0.0059** (0.002)	-0.0019 (0.002)	-0.0045*** (0.002)	-0.0083** (0.003)
Precipitation (t-1)	-0.0080** (0.003)			-0.0037** (0.001)		-0.0057*** (0.002)	-0.0064*** (0.002)				-0.0043** (0.002)	-0.0057*** (0.002)
Temperature t	0.1428** (0.054)	0.0117 (0.056)	0.0532 (0.056)	0.0842* (0.044)	0.0678 (0.047)	0.1767*** (0.055)	0.1272** (0.052)	0.1666*** (0.059)	0.0860 (0.053)	0.1459*** (0.046)	0.0931* (0.047)	0.1420* (0.076)
Temperature (t-1)				0.0889** (0.043)			0.0908* (0.053)			0.0932** (0.038)		
Fixed effects R-squared	0.199	0.441	0.418	0.529	0.365	0.224	0.483	0.476	0.495	0.456	0.357	0.274
R-squared	0.472	0.546	0.606	0.649	0.480	0.554	0.702	0.645	0.556	0.614	0.477	0.537
Additional explanatory power of climatic data	0.273	0.105	0.188	0.120	0.115	0.330	0.219	0.169	0.061	0.158	0.120	0.263

Table 6 Panel B. Monthly variations in fire events in the Central-north of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0040 (0.004)	-0.0240*** (0.005)	-0.0138*** (0.004)	-0.0155*** (0.003)	-0.0066** (0.003)	-0.0078*** (0.003)	-0.0200*** (0.002)	-0.0139*** (0.003)	-0.0044 (0.004)	-0.0096** (0.004)	-0.0070*** (0.002)	-0.0023 (0.002)
Precipitation (t-1)			-0.0171*** (0.005)	-0.0059** (0.003)	-0.0086** (0.004)	-0.0077*** (0.003)	-0.0107*** (0.002)	-0.0135*** (0.003)	-0.0179*** (0.003)		-0.0042* (0.002)	-0.0045** (0.002)
Precipitation (t-2)			-0.0070* (0.004)				-0.0072*** (0.002)	-0.0099** (0.005)			-0.0054** (0.002)	
Temperature t	0.0993 (0.063)	0.0835 (0.059)	0.0370 (0.072)	0.0482 (0.058)	0.0777 (0.051)	0.1099* (0.061)	0.0567 (0.035)	0.1666*** (0.052)	0.0727 (0.047)	0.1787** (0.077)	0.0003 (0.056)	0.0467 (0.066)
Temperature (t-1)							0.0960*** (0.030)			0.1169** (0.058)		
Fixed effects R-squared	0.426	0.328	0.319	0.482	0.620	0.690	0.614	0.403	0.480	0.303	0.309	0.352
R-squared	0.460	0.560	0.603	0.689	0.722	0.826	0.912	0.816	0.749	0.546	0.564	0.472
Additional explanatory power of climatic data	0.034	0.232	0.284	0.207	0.102	0.136	0.298	0.413	0.269	0.243	0.255	0.120

Table 6 Panel C. Monthly variations in fire events in the Central south of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0072** (0.003)	-0.0142*** (0.004)	-0.0102*** (0.004)	-0.0071 (0.005)	-0.0068** (0.003)	-0.0011 (0.004)	-0.0156*** (0.004)	-0.0177*** (0.002)	-0.0061 (0.004)	-0.0088*** (0.002)	-0.0023** (0.001)	-0.0048** (0.002)
Precipitation (t-1)		-0.0061*** (0.002)				-0.0074** (0.003)	-0.0039** (0.002)	-0.0157*** (0.004)	-0.0205*** (0.005)	-0.0071** (0.003)		
Precipitation (t-2)						-0.0049** (0.002)	-0.0076*** (0.003)			-0.0103* (0.005)		
Temperature t	0.0601 (0.077)	0.0328 (0.048)	0.0007 (0.064)	0.3219*** (0.085)	0.1489** (0.071)	0.2519*** (0.084)	0.2405*** (0.054)	0.0209 (0.024)	0.1125** (0.046)	0.0438 (0.093)	0.0345 (0.044)	0.0151 (0.039)
Temperature (t-1)								0.1158** (0.057)		0.1143*** (0.041)		
Temperature (t-2)										0.1300* (0.065)		
Fixed effects R-squared	0.403	0.412	0.269	0.314	0.480	0.618	0.640	0.634	0.463	0.447	0.521	0.307
R-squared	0.516	0.654	0.423	0.627	0.600	0.793	0.887	0.916	0.823	0.783	0.583	0.402
Additional explanatory power of climatic data	0.113	0.242	0.154	0.313	0.120	0.175	0.247	0.282	0.360	0.336	0.062	0.095

Table 6 Panel D. Monthly variations in fire events in the South of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0007 (0.003)	-0.0096* (0.005)	-0.0093*** (0.003)	-0.0093** (0.004)	-0.0077 (0.006)	-0.0092*** (0.003)	-0.0184*** (0.002)	-0.0094** (0.004)	-0.0049 (0.003)	-0.0023 (0.003)	-0.0049 (0.003)	-0.0023 (0.002)
Precipitation (t-1)			-0.0078*** (0.003)		-0.0109** (0.004)			-0.0096* (0.005)	-0.0128* (0.007)	-0.0138*** (0.003)	-0.0075* (0.004)	
Temperature t	0.0887 (0.087)	0.1425*** (0.048)	0.0893*** (0.033)	0.1042 (0.064)	0.1604*** (0.058)	0.1063*** (0.024)	0.0893*** (0.019)	0.0481 (0.054)	0.2311*** (0.054)	0.1054** (0.045)	0.0579 (0.094)	0.0900* (0.048)
Temperature (t-1)										0.1123** (0.046)		
Fixed effects R-squared	0.260	0.388	0.435	0.446	0.404	0.692	0.623	0.527	0.343	0.495	0.263	0.146
R-squared	0.280	0.537	0.675	0.522	0.644	0.795	0.771	0.653	0.614	0.700	0.327	0.227
Additional explanatory power of climatic data	0.020	0.149	0.240	0.076	0.240	0.103	0.148	0.126	0.271	0.205	0.064	0.081

Notes: Robust standard errors are reported in parentheses. ***, **, and * present the 1%, 5% and 10% significance level respectively.

Table 7 Panel A. Monthly variations in area burnt in the north of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0214*** (0.005)	-0.0155*** (0.004)	-0.0139*** (0.005)	-0.0007 (0.004)	-0.0063** (0.003)	-0.0172*** (0.004)	-0.0157*** (0.006)	-0.0030 (0.005)	-0.0058* (0.003)	-0.0022 (0.004)	-0.0095*** (0.003)	-0.0169*** (0.004)
Precipitation (t-1)				-0.0042 (0.003)		-0.0084** (0.003)					-0.0059* (0.003)	-0.0063** (0.003)
Precipitation (t-2)												
Temperature t	0.1835** (0.077)	0.1188 (0.089)	0.2627*** (0.091)	0.1489* (0.081)	0.0496 (0.062)	0.1914* (0.099)	0.1733* (0.096)	0.3330*** (0.117)	0.0634 (0.071)	0.1924** (0.081)	0.1797*** (0.068)	0.1188 (0.113)
Temperature (t-1)				0.1537** (0.070)								
Fixed effects R-squared	0.236	0.420	0.468	0.519	0.380	0.205	0.446	0.455	0.560	0.438	0.403	0.285
R-squared	0.584	0.516	0.606	0.656	0.466	0.529	0.564	0.613	0.592	0.480	0.551	0.551
Additional explanatory power of climatic data	0.348	0.096	0.138	0.137	0.086	0.324	0.118	0.158	0.032	0.042	0.148	0.266

Table 7 Panel B. Monthly variations in area burnt in the central-north of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0006 (0.005)	-0.0333*** (0.008)	-0.0220*** (0.005)	-0.0191*** (0.006)	-0.0109** (0.005)	-0.0142*** (0.006)	-0.0230*** (0.008)	-0.0164*** (0.005)	-0.0201*** (0.007)	-0.0127*** (0.004)	-0.0060*** (0.002)	-0.0076** (0.004)
Precipitation (t-1)			-0.0221*** (0.007)	-0.0084** (0.004)			-0.0235*** (0.007)	-0.0286*** (0.004)				
Precipitation (t-2)								-0.0197*** (0.006)				
Temperature t	0.1122 (0.081)	0.0720 (0.103)	0.0872 (0.097)	0.0362 (0.091)	0.0102 (0.064)	0.2445* (0.135)	0.0768 (0.107)	0.3221** (0.123)	0.1858 (0.124)	0.1046 (0.082)	0.0584 (0.056)	0.0991 (0.127)
Temperature (t-1)							0.1380* (0.078)			0.2191** (0.091)		
Fixed effects R-squared	0.334	0.332	0.253	0.442	0.466	0.351	0.199	0.192	0.255	0.218	0.316	0.307
R-squared	0.357	0.602	0.570	0.579	0.532	0.554	0.627	0.811	0.531	0.520	0.459	0.402
Additional explanatory power of climatic data	0.023	0.270	0.317	0.137	0.066	0.203	0.428	0.619	0.276	0.302	0.143	0.095

Table 7 Panel C. Monthly variations in area burnt in the central-south of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0099** (0.005)	-0.0235*** (0.005)	-0.0136** (0.006)	-0.0133* (0.007)	-0.0079 (0.006)	-0.0057 (0.010)	-0.0363*** (0.008)	-0.0242*** (0.004)	-0.0361*** (0.007)	-0.0177*** (0.005)	-0.0049*** (0.002)	-0.0090*** (0.002)
Precipitation (t-1)		-0.0090** (0.003)	-0.0076* (0.004)				-0.0106* (0.006)	-0.0312*** (0.008)	-0.0195* (0.010)	-0.0150** (0.006)		
Temperature t	0.1204 (0.128)	0.0552 (0.067)	0.0838 (0.089)	0.3687** (0.137)	0.1963** (0.085)	0.4449** (0.221)	0.3431** (0.166)	0.0896* (0.045)	0.1464* (0.079)	0.1201* (0.064)	0.0176 (0.086)	0.0013 (0.059)
Temperature (t-1)							0.3166*** (0.107)	0.1700* (0.098)		0.1976** (0.086)		
Temperature (t-2)										0.3933** (0.148)		
Fixed effects R-squared	0.295	0.351	0.144	0.234	0.320	0.397	0.352	0.422	0.299	0.433	0.464	0.342
R-squared	0.392	0.656	0.444	0.557	0.517	0.570	0.740	0.839	0.721	0.768	0.515	0.485
Additional explanatory power of climatic data	0.097	0.305	0.300	0.323	0.197	0.173	0.388	0.417	0.422	0.335	0.051	0.143

Table 7 Panel D. Monthly variations in area burnt in the south of Italy

Variables	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Precipitation t	-0.0004 (0.008)	-0.0025 (0.009)	-0.0116* (0.006)	-0.0057** (0.003)	-0.0035 (0.010)	-0.0251*** (0.008)	-0.0315*** (0.007)	-0.0231*** (0.006)	-0.0065 (0.006)	-0.0002 (0.005)	-0.0110* (0.006)	-0.0021 (0.005)
Precipitation (t-1)		-0.0091* (0.005)			-0.0124* (0.006)	-0.0154* (0.009)			-0.0300*** (0.010)	-0.0192*** (0.006)		
Precipitation (t-2)										-0.0149* (0.009)		
Temperature t	0.2222 (0.159)	0.2186*** (0.077)	0.2161*** (0.072)	0.1081 (0.111)	0.3424*** (0.122)	0.1381** (0.058)	0.0068 (0.064)	0.1740** (0.068)	0.3237*** (0.084)	0.2850*** (0.078)	0.1742 (0.171)	0.2288** (0.107)
Temperature (t-1)						0.1338** (0.066)	0.1327*** (0.047)		0.2445* (0.128)	0.1538** (0.074)		
Fixed effects R-squared	0.232	0.327	0.477	0.376	0.394	0.589	0.498	0.368	0.198	0.243	0.283	0.122
R-squared	0.262	0.561	0.763	0.441	0.664	0.772	0.710	0.632	0.610	0.592	0.325	0.238
Additional explanatory power of climatic data	0.030	0.234	0.286	0.065	0.270	0.183	0.212	0.264	0.412	0.349	0.042	0.116

Notes: Robust standard errors are reported in parentheses. ***, **, and * present the 1%, 5% and 10% significance level respectively.

Geographical clusters	Time frame	Scenario 1		Scenario 2	
		Fire events	Area burnt	Fire events	Area burnt
Northern Italy	Winter (DJF)	13.81	19.33	12.78	14.91
	Spring (MOM)	9.32	38.14	4.89	32.34
	Summer (JJA)	16.90	35.73	17.55	36.01
	Autumn (SON)	3.65	5.17	5.95	7.21
	Annual	12.01	26.60	10.58	23.08
Central-north Italy	Winter (DJF)	2.01	2.83	2.01	2.83
	Spring (MOM)	4.17	4.99	4.17	4.99
	Summer (JJA)	24.27	52.41	24.27	52.41
	Autumn (SON)	5.21	5.38	4.84	5.29
	Annual	15.93	34.54	15.89	34.53
Central-south Italy	Winter (DJF)	3.01	4.82	3.01	4.82
	Spring (MOM)	13.95	15.13	15.16	16.46
	Summer (JJA)	29.95	86.02	29.95	86.02
	Autumn (SON)	20.86	44.30	18.98	40.66
	Annual	25.37	75.02	25.23	74.62
Southern Italy	Winter (DJF)	7.25	12.46	7.25	12.46
	Spring (MOM)	13.76	20.50	11.75	19.05
	Summer (JJA)	6.58	21.02	6.58	21.25
	Autumn (SON)	26.74	70.79	19.47	71.48
	Annual	10.52	25.55	9.13	25.77

Table 9. Relationship between forest fires and socio-economic factors

Panel A. Yearly variations in fire events (Dependent variable: ln (fire events))								
VARIABLES	North		Central-north		Central-south		South	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Precipitation	-0.0040 (0.005)	-0.0006 (0.005)	-0.0275*** (0.006)	-0.0234*** (0.006)	-0.0077* (0.004)	-0.0082* (0.004)	-0.0087* (0.004)	-0.0140*** (0.005)
Temperature	0.3359*** (0.099)	0.3480*** (0.096)	0.2574** (0.122)	0.3504*** (0.107)	0.3587*** (0.116)	0.3554** (0.143)	0.0471 (0.102)	0.0718 (0.101)
Education		-0.1117*** (0.023)		-0.0747*** (0.027)		-0.0223** (0.011)		
Extortion per 100,000								0.0449** (0.023)
Observations	72	72	48	48	48	48	60	60
FE R-squared	0.691		0.686		0.796		0.681	
R-squared	0.726	0.796	0.855	0.878	0.864	0.866	0.695	0.715
Panel B. Yearly variations in area burnt (Dependent variable: ln (area burnt))								
VARIABLES	North		Central-north		Central-south		South	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Precipitation	-0.0046 (0.012)	-0.0055 (0.010)	-0.0506*** (0.012)	-0.0408*** (0.012)	-0.0210*** (0.008)	-0.0095 (0.010)	-0.0235*** (0.008)	-0.0313*** (0.008)
Temperature	0.6943*** (0.236)	0.7172*** (0.238)	0.2287 (0.274)	0.4432* (0.219)	0.4535* (0.239)	0.7484** (0.297)	0.2270 (0.139)	0.1414 (0.142)
Education		-0.3382*** (0.052)		-0.2478*** (0.088)		-0.2113** (0.091)		
Extortion per 100,000								0.0673* (0.039)
Observations	72	72	48	48	48	48	60	60
FE R-squared	0.616		0.317		0.549		0.523	
R-squared	0.682	0.754	0.568	0.686	0.683	0.725	0.605	0.629

Notes: Robust standard errors are reported in parentheses. ***, **, and * present the 1%, 5% and 10% significance level respectively. For each specification, column 1 uses the climatic factors in the analysis. Whereas, column 2 uses both the climatic and socio-economic factor simultaneously.

Table 10. List of variables, description, and source of data

Variable name	Description	Derivation	Source of data	Use
Fire events	Total number of fire events during a given period	ln (number of fires events)	JRC and CFS ¹	Used for main model
Area burnt	Total hectares of area burnt during a given period	ln (Size of land burnt in hectares)	JRC and CFS	Used for main model
Average precipitation on January, ..., December	Monthly average precipitation in mm for January, ..., December	Monthly average precipitation at a given region in January, February, ..., December	Elaboration from CRA-CMA	Used for main model
Average temperature on January, ..., December	Monthly average temperature in Celsius for January, ..., December	Monthly average temperature at a given region in January, February, ..., December	Elaboration from CRA-CMA	Used for main model
Total precipitation in a given year	Total precipitation during a given year	Total precipitation between January and December in millimetres in a given	Elaboration from CRA-CMA	Used for main model
Average temperature in Celsius in a year	Average temperature in Celsius	Average temperature between January and December in Celsius in a given year	Elaboration from CRA-CMA	Used for main model
Population Density	Population density	ln (Total population/regional area in km ²)	Elaboration from ISTAT ²	Used for main model
Rail density	Railway density	ln (km of regional railways/ regional area in km ²)	ArcGIS maps ³	Used for main model
Relative poverty	Relative poverty	% of population that lives below a relative poverty line.	ISTAT ⁴	Used for main model
Education	Percentage of the population aged 25-64 with tertiary education attainment	(Population aged 25-64 with tertiary education attainment among people aged 25-64 / Total population aged 25-64)*100	EUROSTAT ⁵	Used for main model
Extortion per 100,000	Number of extortions every 100,000 inhabitants	(Total number of extortions in the region/Total population in the region)*100,000	Elaboration from ISTAT	Used for main model
Agriculture employment	Percentage of employment in the agricultural sector	(Number of people employed in the agricultural sector/Total number of employees)*100	Elaboration from ISTAT	Used in the main model
ln(livestock intensity)	Livestock intensity	ln (Total livestock units in a given region/regional area in km ²)	Elaboration from ISTAT	Used for main model
Unemployment	Total unemployment rate	(Total number of people unemployed at a region/Total labour force at the region)*100	Elaboration from ISTAT	Additional control
Illegal associations per 100,000	Number of illegal associations every 100,000 inhabitants	(Total number of illegal association in region/Total population of the region)*100,000	Elaboration from ISTAT	Additional control
Fraud per 100,000	Number of frauds every 100,000 inhabitants	(Total number of frauds in a region/Total population of the region)*100,000	Elaboration from ISTAT	Additional control
Smuggling per 100,000	Number of smuggling every 100,000 inhabitants	(Total number of smuggling in a region/Total population of the region)*100,000	Elaboration from ISTAT	Additional control
Crime per 100,000	Number of crimes every 100,000 inhabitants	(Total number of crimes in a region/Total population of the region)*100,000	Elaboration from ISTAT	Additional control

¹JRC: Joint Research Centre (<http://effis.jrc.ec.europa.eu/>); CFS (Corpo Forestale dello Stato): State Forestry Department of Italy.

² ISTAT: The National Institute for Statistics (<https://www.istat.it/en/>)

³ See ArcGIS maps at <http://www.mapcruzin.com/free-italy-arcgis-maps-shapefiles.htm>

⁴ According to ISTAT “A household is defined as poor in relative terms if its consumption expenditure is equal to or below the relative poverty line, which is calculated on the basis of data from the household consumption survey”

⁵ <http://ec.europa.eu/eurostat/data/database>

Table 11. Projected effects of climate change on the fire events and area burnt in each geographical cluster with Scenario 1

Panel A. Projected effects of climate change on fire events in each geographical cluster					
	Winter (DJF)	Spring (MOM)	Summer (JJA)	Autumn (SON)	Annual
Projected changes in fire events in northern Italy					
Average events (2000-2005)	418.33	447.33	322.33	134.83	1322.83
Predicted events (2016-2035)	476.12	489.03	376.81	139.75	1481.72
Percentage change in events	13.81	9.32	16.90	3.65	12.01
Projected changes in fire events in central-north of Italy					
Average events (2000-2005)	66.83	144.33	426.00	86.33	723.50
Predicted events (2016-2035)	68.18	150.36	529.40	90.83	838.77
Percentage change in events	2.01	4.17	24.27	5.21	15.93
Projected changes in fire events in central-south of Italy					
Average events (2000-2005)	61.17	197.00	1021.67	236.50	1516.33
Predicted events (2016-2035)	63.01	224.49	1327.69	285.84	1901.02
Percentage change in events	3.01	13.95	29.95	20.86	25.37
Projected changes in fire events in southern Italy					
Average events (2000-2005)	39.33	212.17	2835.00	653.17	3739.67
Predicted events (2016-2035)	42.19	241.35	3021.58	827.81	4132.93
Percentage change in events	7.25	13.76	6.58	26.74	10.52
Panel B. Projected effects of climate change on area burnt in each geographical cluster					
	Winter (DJF)	Spring (MOM)	Summer (JJA)	Autumn (SON)	Annual
Projected changes in area burnt in northern Italy					
Average area burnt (2000-2005)	4363.01	3594.47	1550.21	1115.15	10622.84
Predicted area burnt (2016-2035)	5206.32	4965.59	2104.04	1172.76	13448.71
Percentage change in area burnt	19.33	38.14	35.73	5.17	26.60
Projected changes in area burnt in central-north of Italy					
Average area burnt (2000-2005)	378.20	506.55	2042.57	327.19	3254.50
Predicted area burnt (2016-2035)	388.91	531.82	3113.07	344.78	4378.58
Percentage change in area burnt	2.83	4.99	52.41	5.38	34.54
Projected changes in area burnt in central-south of Italy					
Average area burnt (2000-2005)	177.56	723.94	9598.40	1619.57	12119.48
Predicted area burnt (2016-2035)	186.12	833.48	17855.19	2336.98	21211.78
Percentage change in area burnt	4.82	15.13	86.02	44.30	75.02
Projected changes in area burnt in southern Italy					
Average area burnt (2000-2005)	156.66	1539.71	39805.69	4209.28	45711.33
Predicted area burnt (2016-2035)	176.17	1855.29	48171.89	7188.96	57392.32
Percentage change in area burnt	12.46	20.50	21.02	70.79	25.55
Notes: All projected changes are obtained by using the significant estimates from Tables 6 and 7 for each geographic cluster for the fire events and area burnt, respectively. In this scenario, the projected mean temperature and precipitation levels for May, September and October (November, March and April) are considered to be the same as the respective mean projection for the summer (winter), respectively.					

Table 12 Projected effects of climate change on the fire events and area burnt in each geographical cluster with Scenario 2**Panel A.** Projected effects of climate change on fire events in each geographical cluster

	Winter (DJF)	Spring (MOM)	Summer (JJA)	Autumn (SON)	Annual
Projected changes in fire events in northern Italy					
Average events (2000-2005)	418.33	447.33	322.33	134.83	1322.83
Predicted events (2016-2035)	471.80	469.23	378.90	142.86	1462.78
Percentage change in events	12.78	4.89	17.55	5.95	10.58
Projected changes in fire events in central-north of Italy					
Average events (2000-2005)	66.83	144.33	426.00	86.33	723.50
Predicted events (2016-2035)	68.18	150.36	529.40	90.51	838.45
Percentage change in events	2.01	4.17	24.27	4.84	15.89
Projected changes in fire events in central-south of Italy					
Average events (2000-2005)	61.17	197.00	1021.67	236.50	1516.33
Predicted events (2016-2035)	63.01	226.87	1327.69	281.38	1898.95
Percentage change in events	3.01	15.16	29.95	18.98	25.23
Projected changes in fire events in southern Italy					
Average events (2000-2005)	39.33	212.17	2835.00	653.17	3739.67
Predicted events (2016-2035)	42.19	237.11	3021.58	780.35	4081.23
Percentage change in events	7.25	11.75	6.58	19.47	9.13

Panel B. Projected effects of climate change on area burnt in each geographical cluster

	Winter (DJF)	Spring (MOM)	Summer (JJA)	Autumn (SON)	Annual
Projected changes in area burnt in northern Italy					
Average area burnt (2000-2005)	4363.01	3594.47	1550.21	1115.15	10622.84
Predicted area burnt (2016-2035)	5013.62	4757.05	2108.49	1195.54	13074.70
Percentage change in area burnt	14.91	32.34	36.01	7.21	23.08
Projected changes in area burnt in central-north of Italy					
Average area burnt (2000-2005)	378.20	506.55	2042.57	327.19	3254.50
Predicted area burnt (2016-2035)	388.91	531.82	3113.07	344.49	4378.29
Percentage change in area burnt	2.83	4.99	52.41	5.29	34.53
Projected changes in area burnt in central-south of Italy					
Average area burnt (2000-2005)	177.56	723.94	9598.40	1619.57	12119.48
Predicted area burnt (2016-2035)	186.12	843.12	17855.19	2278.14	21162.57
Percentage change in area burnt	4.82	16.46	86.02	40.66	74.62
Projected changes in area burnt in southern Italy					
Average area burnt (2000-2005)	156.66	1539.71	39805.69	4209.28	45711.33
Predicted area burnt (2016-2035)	176.17	1833.09	48264.41	7218.28	57491.96
Percentage change in area burnt	12.46	19.05	21.25	71.48	25.77

Notes: All projected changes are obtained by using the significant estimates from Tables 6 and 7 for each geographic cluster for the fire events and area burnt, respectively. In this scenario, the projected mean temperature and precipitation levels for the spring (MON) and autumn (SON) are considered to be the average of projected mean temperature and precipitation levels for the winter (DJF) and summer (JJA) periods for each respective geographical cluster.