On the prevalence of Forest Fires in Spain

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On the prevalence of Forest Fires in Spain

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Abstract

We study the prevalence of forest fires in Spain in the long run by computing the probability that a forest tree, as opposed to shrub or bush, will be lost to fire over the course of the year. Climate change is first shown to increase the likelihood of this event. Next, we document how risk grew dramatically from 1961 up to the democratic era (c. 1980) and has since receded to less than 2 trees lost per thousand. We bring together the socio-economic drivers identified for this trend reversal. Our finding is commensurate with the evolution of the same risk in neighboring Mediterranean countries.

Keywords: Iberian Peninsula; Forest Fire; Wildfire drivers; Climate Change; Land use; Economic Growth

Highlights

- Forest wildfire risk is computed for Spain since 1961
- Filtered risk is shown to statistically rise and then fall
- Underlying risk will not disappear
- Socio-economic drivers are shown to matter
- A similar fall in risk is observed in France and Italy

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1 Introduction

1.1 Context

Forests are a treasured natural heirloom whose importance was recognized long ago in Iberia by the Visigothic Liber Iudiciorum (654) codifying the burning a wood (cf. Book 8, Title 2) as a crime distinct from the preexisting arson of Roman law (cf. Valbuena et al. (2010)). The mythical value of forests is captured by Calvino (1957)'s start of chapter 4 "in antichi tempi una scimmia che fosse partita da Roma saltando da un albero all'altro poteva arrivare in Spagna senza mai toccare terra".[1] As recounted by Harrison (1992), many civilizations have developed collective forest myths; some still influential today are the German romantic "renaturierung" movement aiming to free forests from human pressure (cf. Wilson (2012)), the American transcendentalism celebrating nature immersion or the Shintoist *sacred shrine forest* of Japan (cf. Rots (2015)). Unsurprisingly, the mass-media give extended exposure to the awful sight of burning trees when wildfires strike (cf. Olynk Widmar et al. (2022)) but, as Doerr and Santín (2016) observe, the social perception of wildfires, as an utter bad, further becoming increasingly frequent and devastating, is rather mistaken.

For one, McLauchlan et al. (2020)'s manifesto calls for the recognition of "fire as a fundamental ecological process" and a rethinking of our relation to it. Beyond, this ontological position, the literature offers many studies of individual countries or regions showing a melioration of burnt area over recent decades, in particular around the Mediterranean. Yet, others report a worsening situation especially in terms of socio-economic impact (cf. Moreira et al. (2020)) while prospective ones portray complex transformations induced by climate change with a mostly negative outlook. Obtaining a robust characterization, if only for one particular region, is thus warranted to inform future policy choices. Even though most recent academic studies dedicated to Spain conclude to a falling wildfire impact (cf. §1.2), the current literature still feature inertia driven negative mentions. We thus aim to dispel those and confirm the wildfire melioration with a robust statistical analysis.

Rather than counting hectares of burnt woodland bundling trees, shrub and grass, we select the forest per the aforementioned reason and relate it to the standing stock which national inventories mesure precisely. Indeed, the post WWII period has witnessed a dedicated effort in advanced economies to return abandoned agricultural land to forest in order to limit structural excess food supply and, in this century, contribute to net-zero carbon budgets (cf. SOFO (2020)). Among others, the Spanish forest has grown by 60% over the last 6 decades and our analysis would not be thorough if we ignored that fact.[2] Combining the collected information about stock and impact

[1] In ancient days a monkey could have left Rome and skipped from tree to tree till it reached Spain, without ever touching earth.

[2] Vadell et al. (2016) identify a low ebb by the mid-19th century at about one half the 1961 level; forest restoration has thus a long history in this country.

allows us to compute a proper wildfire risk; once year-to-year variability is filtered, it is shown to rise, peak and then continuously fall. By going back long enough, we can identify a turning point: post WWII, forest fires in Spain were becoming more frequent and impactful but then peaked and started to recede at about the time democracy returned. We offer socio-economic clues as to why it took place. At any rate, this reversal presents an interesting development inso far as it shows that a worsening situation may be reverted even while climate change is turning Spain into a hotter and drier land, thus more susceptible to wildfires.

1.2 Literature

Among positive wildfire outlooks, van Lierop et al. (2015) show, using satellite records over recent decades, a decreasing global trend of burned forest area; with similar methods, Andela et al. (2017) identify a large anthropogenic share for this decline while Earl and Simmonds (2018) attribute a lessened fire activity to global agricultural expansion and intensification. Forkel et al. (2019), however, extending the study period, question robustness and wonder what may be the cause since climate change is certainly not helping (cf. §2.2).

Prior efforts at characterizing the trend of forest fires in the Mediterranean include Turco et al. (2016) who study southern European countries over the relatively short period 1985-2011 to find a mostly falling risk; Silva et al. (2019), focusing on Iberia (Spain+Portugal) over 1975-2013, find a general melioration, further show that increased tension at the urban-rural interface explains the sole observed regional worsening in northern Portugal and also that climatic factors explain only part the observed trend. Studying a single province of the French Mediterranean over the long range, Ganteaume and Barbero (2019) find a decrease in large fire frequency and burned area, triggered by suppression and prevention efforts. Likewise, Ertugrul et al. (2021) observe a reduced fire severity and falling burnt area over the period 1990-2018 in Turkey, despite a clear negative impact of climate change. The duration of observation is crucial since the conclusion for some studies may be reversed today after the occurrence of extremely bad recent years i.e., neither is the Iberian wildfire burnt area nor the Turkish one falling anymore.[3] Such frailty indicates the need for longer periods of study to filter out the extremely large variation in seasonal weather patterns.

Beyond Mediterranean shores, negative wildfire development are increasingly ascribed to socioeconomic developments and related policies. Overseeing Africa, Zubkova et al. (2019) ascribe a rapid fall in burnt area to changes in agricultural practices. Úbeda and Sarricolea (2016), studying Chile, find a worsening likely caused by commercial exploitation of risky species and arson attacks against those. In the western US, the recent increase in the number of large fires with adverse socioeconomic impact has been linked to climate change (cf. Abatzoglou and Williams (2016)), expansion of settlements within fuel loaded areas (cf. Strader (2018)), systematic fire suppression

[3]Per our econometric estimation of these publicly available data.

(cf. Marlon et al. (2012)) and insufficient prescribed burns to reduce flammable material (cf. Miller et al. (2020)).

After this introduction, the next section expounds our method and data; we then present our econometric findings before offering a series of socio-economic explanations as to why the trend reversal took place.

2 Materials and Methods

2.1 Data Sources

We define, compute and study the share of **forests** lost to fire every year in Spain. We believe our location choice to be highly relevant because Spain is a fire prone country where the climate is wet enough during winter to allow for forest to grow but hot and dry during the summer to generate frequent fire kickoff and propagation (cf. comparison with France below). Additionally, wildfires, even small ones, have administratively recorded since 1961, a decade sooner than in neighboring countries.

Regarding our decision to concentrate on trees, two reasons guide our choice. Firstly, forests occupy a major place in the national psyche and correcting a possible misperception of wildfire stress calls for a focus on that specific subset of the natural environment. Secondly, forest land is well delineated and monitored by authorities, which allows us to better confide in the twin measures of "burnt" and "stock" areas published by different Spanish ministries. In doing so, we shall deviate slightly from the literature which has traditionally analyzed **woodlands** also including *shrub, bush and grass* for which burnt area is loosely estimated and stock is virtually unknown. Our forest *loss* data is sourced from the ecology ministry MITECO (2021) while the forest *inventory* is produced by the agriculture ministry MAPA (2021). We construct the *wildfire risk* ρ_t as the ratio of "burnt forest" B_t to "forest cover" C_t, both measured in hectares (Ha):

$$\rho_t = \frac{B_t}{C_t}$$

The long run average risk ρ_o may thus be interpreted as the probability that *a forest tree will be lost to wildfire over the year.*

Let us report first a few stylized facts about Spanish wildfires over woodlands (i.e., attacking forest, shrub, bush and grass). Over the recent period 1989-2021, tallies show that Spain suffers some 9 400 yearly small episodes,[4] each burning under one hectare (Ha), some 6 300 medium size fires and about 30 large fires, each destroying over 500 Ha. Next, we draw from the open-sourced effort of Civio (2020) covering the period 2001-2015; we compute the temporal distribution of wildfires across the year, observing that activity is quite elevated during spring, well before the traditional

[4]These were not reported separately before 1989.

"fire season" as already noted by Costafreda-Aumedes et al. (2018). We appreciate on Figure 2 the August peak where some 10 km^2 of woodlands burn in a single day. To grasp the extent of wildfires, one could say that *almost every spaniard witnesses a fire or its smoke plume on a yearly basis.*

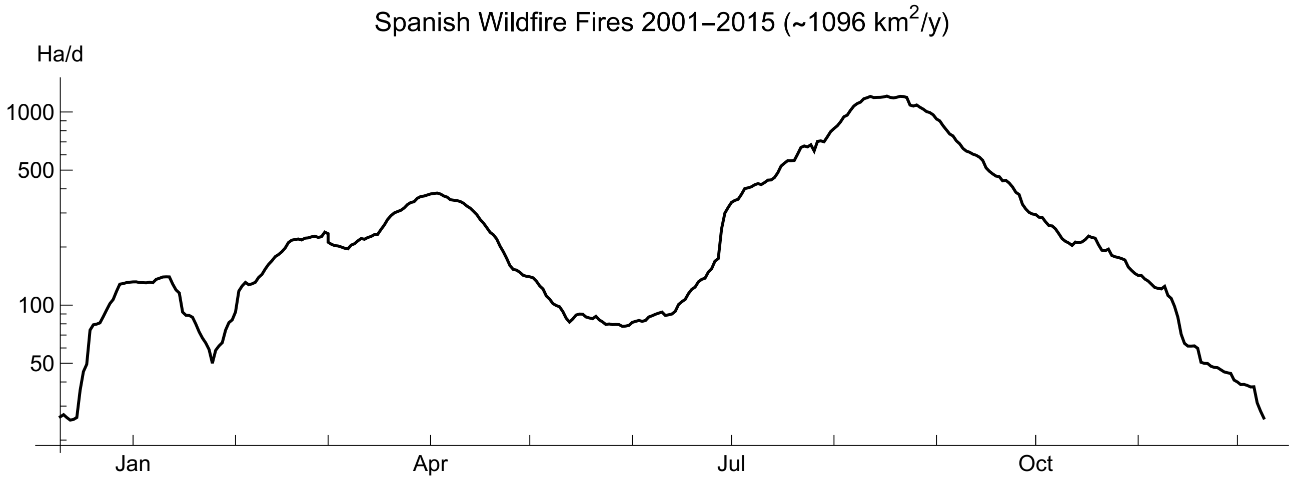

Figure 1: Distribution of daily burned area across the year

The well known anthropogenic role in wildfire starts noted by Balch et al. (2017) for the US and de Rigo et al. (2017) for the EU appears clearly in the tally of causes displayed in Table 1 with an overwhelming role for agriculture. Even so, large fires are routinely classified as natural disasters because weather and climate play a dominant role in turning a small fire into a large one (e.g., prolonged drought, strong wind).

Cause	Farming motive	Negligence	Farming error	Economic	Pyromania	Lightning	Restart	Unknown
Burn Ha	36.40%	15.50%	12.70%	17.80%	5.00%	4.60%	2.70%	5.40%

Table 1: Spanish Wildfire Causality (2006-2015)

As we detail in Boccard (2021), the statistical analysis of disasters is a difficult endeavor (cf. Tedim et al. (2018) on defining extreme wildfires). Indeed, whereas rain and wind are everyday events whose intensification into a storm or flood is infrequent, a disastrous storm or flood is even more exceptional for any given local community. It is precisely because disasters of natural origin are triggered by extreme weather that their statistical study requires knowledge about "extremes", aka. the upper tail of the empirical distribution of the underlying weather event. Spanish wildfires stand in contrast as they occur at such a high frequency. This feature generates in turn a considerable amount of data, ultimately allowing a robust statistical treatment. Our task would be much harder in a country with a milder climate such as France where BDIFF (2021) data reveals a contrast between the southern Mediterranean and the Atlantic/continental north. The former is host to solely 23% of forest land but accounts for 75% of burned area (since 1979) i.e., a fire risk an order of magnitude larger. Henceforth, statistical analysis over northern France (or for that matter

Germany) would require many times more data to reach the same degree of confidence.

A final observation comforting our decision to focus on forests is a lack of standardization in international reports. For instance, the French Mediterranean database only records the burnt area of forest while the BDIFF effort at the national level is a non exhaustive voluntary compilation of provincial reports covering al woodlands (cf. Vogel (2019) p13). Portugal and Italy, like Spain, collect exhaustive information distinguishing forest from shrub while Greek and Maghreb countries estimates in EFFIS (2019) are build from satellite data whose poor accuracy is revealed by the comparison with official counts in the previous 4 countries.

2.2 Climate Change

Due to their elevated frequency when compared for instance to flash floods, wildfires have long been the most visible natural scourge of the Iberian peninsula. Even though the climate is varied, from semi-arid on the Mediterranean to oceanic on the Atlantic, most Iberian regions enjoy a warm summer (e.g., Spanish Galicia & Northern Portugal) which is conducive to forest fires (cf. map in Jiménez-Ruano et al. (2017)). Using data from the World Bank, we recall on Figure 2 how climate change is already making Spain hotter and drier, allowing to confirm a rising underlying *wildfire risk* over our period of inquiry 1961–2021. The econometric analysis reveals that temperature is rising and rainfall falling (p-values below 1‰). On that basis, Turco et al. (2018) estimate the evolution of the climate-fire relationship, allowing them to anticipate that fire-intensifying signals should fall but that burned area should nevertheless increase. Likewise, Varela et al. (2019) anticipate a doubling of risky days in the Mediterranean. while Calheiros et al. (2021) forecast an extension and displacement of pyro-regions of heightened fire risk. Globally, Jolly et al. (2015) anticipate a lengthening of the fire season as well as a doubling of fire prone areas. The meta review of Dupuy et al. (2020) confirms such finding across more than one hundred studies.

3 Results

We analyze the share ρ_t of Spanish forests lost to fire every year. Because seasonal weather patterns vary widely, the wildfire incidence is highly irregular from one year to the next, requiring some filtering to characterize temporal evolution and, if possible, identify trends. Our reproducible econometric analysis (cf. rpubs.com/nboccard/fuego) may be summarized as follows: the autoregressive moving average (ARMA) model selection based on the Akaike information criterion (AIC) suggests to employ 5 lags, meaning that the first harmonic of the time series ρ_t is 5. Figure 3 therefore displays the moving average $\hat{\rho}_t = \frac{1}{5}\sum_{i=0}^{4}\rho_{t-i}$ (bold black curve) atop the wildfire risk (gray dots), using a "per-thousand" logarithmic scale. The nadir is nearly zero at 0.25‰ in 2018 while the zenith is 18‰ in 1994, a full two orders of magnitude difference. Over the last decade,

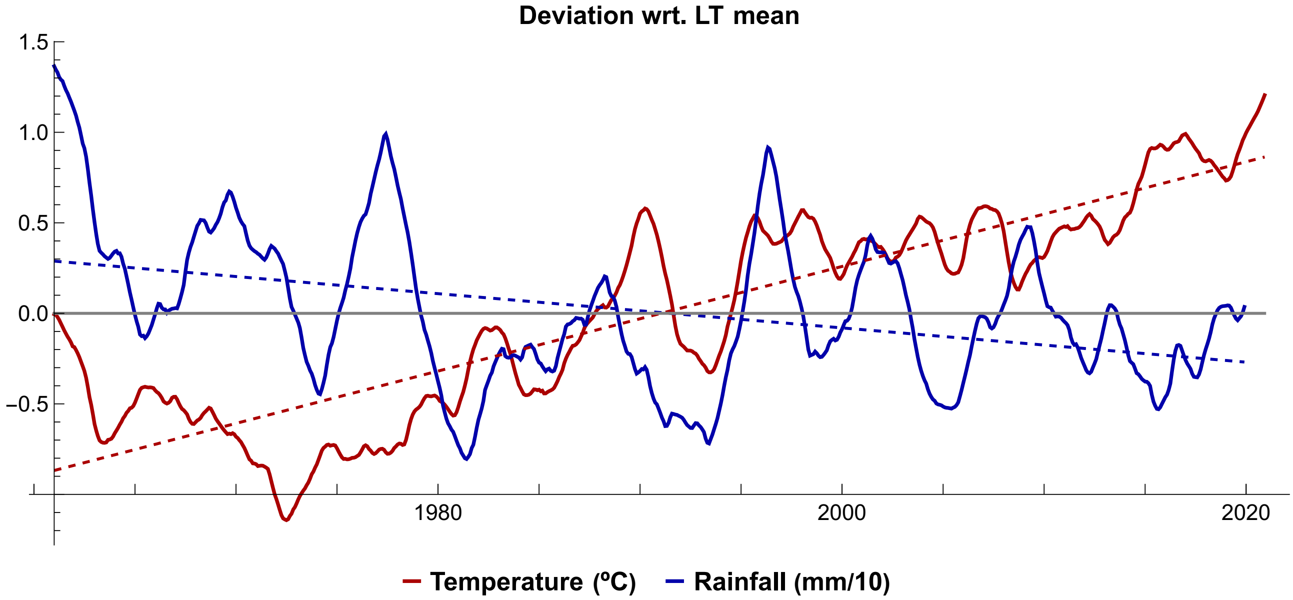

Figure 2: Spanish Summer Climate (1961-2021)

the average is a low 1.6‰, reaching 1.4‰ in 2021.[5] A structural break is apparent around 1980. We henceforth check for the presence of a unit root with the Phillips and Perron (1988) test. As we obtain a very low p-value, we reject the null hypothesis (unit root), meaning that forest fire risk is trend stationary (TS) over the entire period. We then test for a break in the risk trend using the first difference and applying a test for structural change. The Bayesian information criteria (BIC) recommended by Bai and Perron (2003) suggests one break in 1980 with pre and post slopes of 0.46 and −0.22 (in ‰), although with limited significance (p-values of 2% and 10%). As shown in Table 2 below, the linear fit of forest risk against time has a significative downward trend.

To put our finding into perspective, we compare it with neighboring Mediterranean countries where authorities also specifically collect the forest burnt area and perform regular forest inventories. We gather wildfire data from DPFM (2021) for the "French Mediterranean Forest" (labeled France*) which has been monitored since 1973 (cf. Ruffault et al. (2016)). Using the forest inventory from IGN (2015), we compute the forest wildfire risk for this region; the average over the last decade stands at $\bar{\rho} = 1.9‰$, slightly higher than the Spanish one at $\bar{\rho} = 1.6‰$.[6] We proceed likewise with the Italian forest burnt area data from ISPRA (2021), starting in 1970, and forest inventory from CREA (2021); the average over the last decade is $\bar{\rho} = 3.8‰$, twice as much as in France. For Portugal, we extract the forest burnt area from ICNF (2021), staring 1980, and the forest cover from ICNF (2020); the average over the last decade is an heightened $\bar{\rho} = 19.3‰$ driven by the extreme wildfires of 2017. The comparative econometric analysis of the 4 countries is shown in Table 2 over the same period 1980-2021 (for comparability). We observe a statistically meaningful downward

[5]Beware that the literature often refers to *absolute burned woodlands* whose historical maximum arose in 1985.

[6]Note that "forest cover" estimates are more spaced in time (wrt. Spain) and more importantly, we only have one 2009 estimate of the share of Mediterranean region with respect to the entire French continental forest (22%).

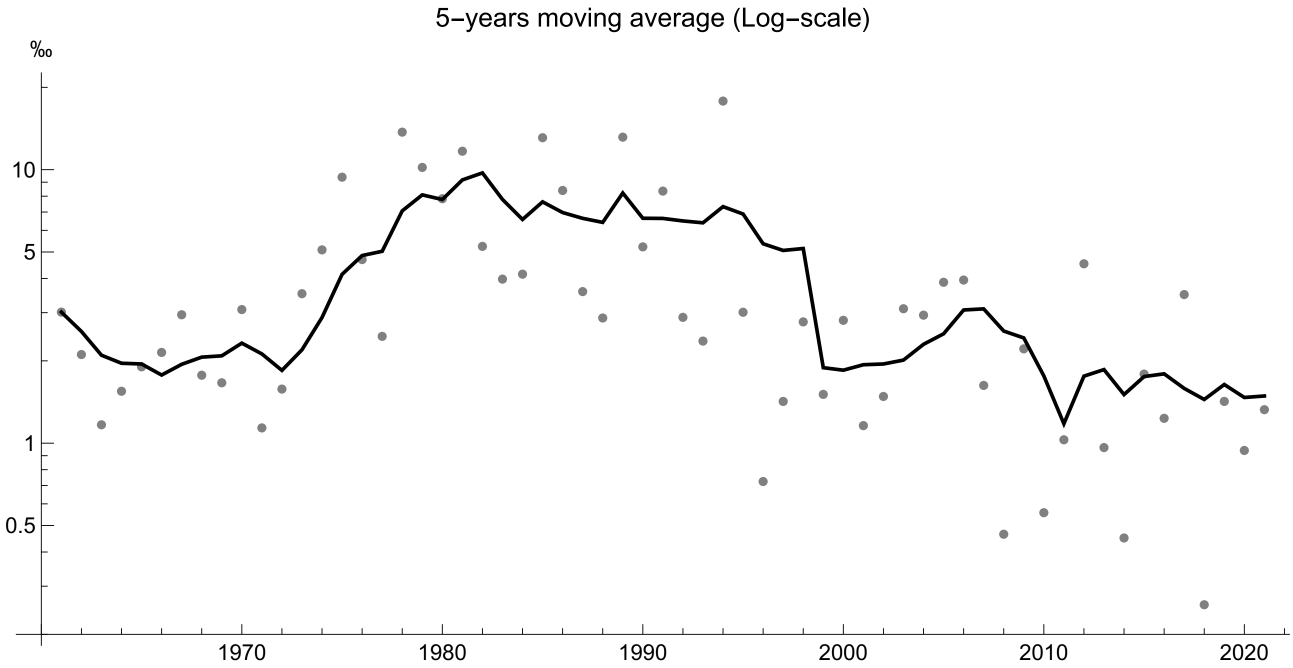

Figure 3: Forest Wildfire Risk in Spain

trend for France and Italy (more pronounced when starting from 1970) but an absence of trend for Portugal; the latter is due to the exceptional 2017 summer when a full 10% of the Portuguese forest was lost to wildfire (the worse outcome for Spain was 1.8% in 1994). Observe finally that pulling together all 4 countries, the wildfire risk in the northwestern Mediterranean is trending down.

Risk ρ	$\bar{\rho}$	slope	st dev	t-Stat.	P-Value
Spain	1.64	-0.187	0.041	-4.534	0.000
France*	1.92	-0.231	0.055	-4.171	0.000
Italy	3.85	-0.086	0.037	-2.349	0.024
Portugal	19.40	0.141	0.269	0.525	0.602
Together	3.90	-0.139	0.041	-3.327	0.002

Table 2: Wildfire risk trend

4 Discussion

4.1 Spain

The smoothed Spanish wildfire forest risk displays a reversal around 1980 which may be interpreted as a "democratic dividend". Indeed, meanwhile the authoritarian regime lasted (1939–1977), public woodlands were mostly treated as an economic asset, at the government's beck and call; the area lost to fires was rising alarmingly during the 1970s, even though a reforestation effort had already started. Chas-Amil et al. (2015) describe how combustible material accumulated in unmonitored woodlands for two basic reasons. Firstly, rural exile towards urban centers and foreign countries left large swath of land unoccupied. Secondly, the strong economic development of the 1960s allowed rural households to abandon fuelwood gathering in favor of purchasing fossil fuels to satisfy their energy needs and move cattle from outdoor pasture to indoor stables; both practices increased the flammable biomass material left unattended on soil.[7]

We believe the dramatic wildfire deterioration was reverted trough a series of profound societal changes. Firstly, the democracy push of the 1970s led to the inclusion of *environmental protection* in the newly drafted 1978 constitution, a feat at the time for a still developing country.[8] Crucially, this endorsement of "nature-as-a-national-treasure" extends across the entire political spectrum, even among the supporters of the former regime. This may be witnessed in the legislation timetable of Moreno et al. (2014) showing laws passed by progressives and conservatives (heirs to the regime) as they alternated in power since the first elections in 1979. Fueled (sic) by economic growth and adequate taxation, the protection of forests, which is a clear public good, has been dully financed[9] to deliver a spectacular fall in risk. This is best appreciated with the displayed risk curve which smoothes out the natural year-to-year variations in rain and wind activity. Not only did the absolute burned extension diminish but the forest cover also greatly increased, driven by a profound change in the economic structure of the country which permitted the devolution of abandoned agricultural land to its original forest state, as explained by Cervera et al. (2019).

A possible key contribution to the continued fall in wildfire risk is prevention which in some years of this century amounts to more than one third of the entire wildfire national budget; an example is the winter campaign of prescribed burns, launched in 1998 which sees specialist teams coordinate with farmers and local authorities to reduce future fire risk at the *Wildfire Agricultural Interface* (WAI) and the *Wildland Urban Interface* (WUI). The value of this practice is buttressed by Rodrigues et al. (2020) who study the evolution of wildfire risk in Spain and find increased fire activity to be related to the presence of WUI while increased WAI boundary is found promoting winter fire frequency.[10]

Because the distribution of wildfire burnt area is highly skewed (in Spain as in any region) with most of the burnt area coming from large fires, the fall in risk is mostly due to their reduction to 20 from about 80 per year. Two distinct forces are at work. Firstly, the technological modernization of identification and suppression has successfully stopped most of the potentially dangerous small fires from growing into major fires. But beyond this "moneyed" achievement, it is the reduction of

[7]The detailed study of Colantoni et al. (2020) concludes that nomadic livestock stimulates grazing and prevents fuel accumulation at the WUI.

[8]The Portuguese constitution of 1976 also included environment protection whereas France waited until 2005.

[9]Annual official reports offer incomplete information on resources and budget dedicated to fire fighting; we may only point to a relative constancy (in real terms) at about 500€ per burned hectare.

[10]The importance of managing properly the WUI is demonstrated by Modugno et al. (2016).

the primary risk that is crucial. Indeed, the number of small fires fell from an average of 14 000 to 6 000 per year (and keeps falling) meanwhile the Spanish population grew from 30 to 47 millions. If one now recalls that the overwhelming majority of fires are started by humans inadvertently or for a personal benefit, we may conclude that prevention policies (see the list below) have been very successful at both the WUI and WAI.

4.2 Experience beyond Spain

The wildfire risk reduction previously characterized for the French Mediterranean forest takes place under a similar climate influence. Curt and Frejaville (2018) identify the following key instruments leading to this success : #1 prevention with regular thinning and compulsory scrubbing in risky areas of the WUI and WAI, #2 extended forest surveillance, #3 rapid and massive response to fire ignitions, #4 judicial persecution of arsonists, #5 incentives towards farmers to reduce traditional slash and burn and #6 educational campaigns towards city dwellers (e.g., seasonal prohibition of fire-prone activities such as BBQ).

In Portugal, the dire 2017 summer season with its heavy human toll pushed the local government to react strongly; as reported in 2021 by the Portuguese Prime Minister (2021), a doubling of overall spending with a greater emphasis on prevention, together with a tightening of safety rules have halved fire starts and burnt area in just 3 years; we additionally note that the year 2021 continued the positive trend.

The unpredictable evolution of wildfire impact across years is due to the natural variability of weather patterns which calls for a specific comment. The worst ever year for the Spanish forest, over 6 decades of monitoring, was 1994; this awful summer took place within a period of quickly reducing forest fires and did not change the downward trend that resulted from a long run protection effort, pushing back against (negative) climate change. Hence, it would have been wrong at the time to seize on popular angst and portend oncoming doom for the Spanish forest. It would have been likewise dishonest to declare after the uneventful 2018 that Spain was now free from forest fires. By the law of "reversion to the mean" which applies to natural phenomenons, a bad wildfire year is likely to be followed by some milder years and a fire-free year likely anticipates upcoming years of intense large fires.

4.3 Conclusion

In this century, forests have acquired a considerable amenity value for the urbanite citizens of wealthy nations, unmatched by the financial returns from the economic activities they still sustain. The Spanish case exposed here demonstrates how this public good can be protected at an affordable cost, reverting a previously worsening situation, even when climate change works to augment the underlying hazard. The sheer number of yearly wildfires is proof that disastrous large ones will never completely disappear but if we apply the maxim that "forest fires are put out in winter", most if not all small ignitions can be controlled during the fire season. As recalled by Alcasena et al. (2019), reducing the forest fire risk down to levels compatible with the natural regeneration of ecosystems requires a steady effort from authorities and citizens whose imprudent and/or criminal behavior remains responsible for an overwhelming share of wildfires.

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Statements & Declarations

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