Does Improved Tenure Security Reduce Fires? Evidence from the Greece Land Registry

Liang Diao*

Huiqian Song†

Abstract

While tenure security is essential to effective land management, there is little empirical evidence on its environmental impact. We show that improving tenure security through cadastre survey and land registry reduces agricultural fires. Exploiting the staggered rollout of the Hellenic Cadastre program across Greece from 2014 to 2019, we find those regions covered by the mandatory land registry witnessed a decline in agriculture fire events by 17 percent and burned areas by 38 percent. The land registry is accompanied by large increases in farming areas, investments, and fire suppression equipment, along with less stubble burning. The evidence suggests improved tenure security incentivizes landowners to exert larger fire-suppression efforts to protect land-attached investments, and to practice more long-term oriented land management.

*Simon Fraser University, Canada. E-mail: ldiao@sfu.ca

†Simon Fraser University, Canada. E-mail: huiqians@sfu.ca

1 Introduction

Wildfires are increasingly devastating in terms of extent, duration, severity, associated suppression costs, and loss of human lives, due to climate and land use changes (Flannigan et al. 2009; Flannigan et al. 2013; North et al. 2015; Bowman et al. 2017).[1] Unlike other natural disasters, wildfire risks can be largely affected by human behavior through landscape management and fire preparedness. In this regard, there are numerous studies on the direct impacts of fire policies implemented at the state level. However, little work has been done to evaluate the effectiveness of improved title security on the incentives of landowners to manage their farms in a way that mitigates wildfire risks.

Private landowners are the residual claimants of protected assets and hence directly benefit from mitigating fire risks. However, the incentives can be undermined by positive externalities — reducing the wildfire risk on one‘s property reduces the risk of the neighbouring properties. With binding contracts, landowners could share the costs of mitigating fire risks and efficiently invest in hazard mitigation. But those cost-sharing contracts are often prohibitively expensive due to uncertainty and asymmetric information (Allen 1998), which means landowners under-invest in fire mitigation (Rehm et al. 2003, Lueck and Yoder 2016, Langpap and Wu 2021, Brenkert–Smith et al. 2006). In this regard, landowners' efforts on fire mitigation may be most effective when everyone in the region is incentivized simultaneously to mitigate fire risks.

The Hellenic Cadastre is a nationwide land registry program in Greece, and provides a unique opportunity to assess the effectiveness of the fire mitigation measures taken by private landowners. The program establish a new land system with cadastral maps and digitally delineated boundaries. It provides several advantages in identifying the effects on fire events. First, the program rolls out at the regional unit (prefecture) level, which simultaneously improves the tenure security for all landowners in a large area. Second, the program was largely promoted and imposed under external pressure, making the timing mostly exogenous. Finally, current regulations of Greece strongly favor fire suppression, but provide only minor funding for fire prevention (Palaiologou et al. 2020, Palaiologou et al. 2021), leaving a large gap to be filled by private landowners.

[1] For costs on health care use, medical costs, and mortality, see Chay and Greenstone (2003), Jayachandran (2009), and Deryugina et al. (2019). For costs on working hours and productivity, see Borgschulte et al. (2018), Hanna and Oliva (2015), and Graff Zivin and Neidell (2012)

To evaluate the environmental impact of the program, we compile a novel dataset at the regional unit level for the period from 2010 to 2019. The dataset includes fire events and burned areas detected by satellites, the starting years of the Cadastre program from the official website, and various agricultural statistics from the Hellenic Statistic Authority. We use an event study approach to exploit the staggered rollout of the program. Specifically, we use a traditional two-way fixed effects method and a new estimator, DID_{M}, proposed by De Chaisemartin and d'Haultfoeuille (2020) to identify the environmental impacts over time and to interpret the estimates as the causal effects. The rich agricultural data also allows us to examine the changes in the agricultural investment and probe the possible channels.

We find the land registry reduces agricultural fire events by 17% and burned areas by 38%. The year-by-year analysis show the reduction starts in the second year and remains stable into the fifth year. Agricultural data suggest several explanations. First, with improved tenure security, farmers increase farming areas, livestock, and long-term investment such as tree planting and fallowing. The increased farming activities reduce abandoned agricultural areas along with the unmanaged fuel load. Second, farmers increase the stock of the equipment that is most suitable for fire suppression, which allows farmers to suppress and contain fires at the earliest opportunity. Third, farmers reduce stubble burning to preserve soil fertility.

Current evidence suggests that more long term oriented agricultural practices and larger fire mitigation efforts are the channel through which the land registry reduces fire events and burned areas. Consistent with this conjecture, we show fire events decline mainly in locations with high agricultural potential and during the day when people are most alert. On the contrary, agricultural fire events remain almost unchanged in barren lands and during the night.

Existing property rights literature have well documented the benefits of well defined property rights on increasing land investment (Besley and Ghatak 2010, Galiani and Schargrodsky 2011, Lin 1992 Fenske 2011), facilitating land trades (Besley 1995, Deininger 2003, Cotula 2009), accessing credit market (Malesky and Taussig 2009, De Soto 2000), and improving labor allocations (Field 2007, De Janvry et al. 2015). This paper provides new empirical evidence on the environmental impact of improved land titles. It is most closely related to work by Ali et al. (2014), who find a very large impact of improved tenure security on maintenance of soil conservation measures in Rwanda.

This paper also contributes to the recent discussion regarding the effective degree of uniform and mandatory boundary demarcation (Libecap and Lueck 2011, Arruñada 2017, Enemark et al. 2014, Enemark et al. 2016). To avoid demarcate low-value parcels, Arruñada (2018) recommends a contingent approach that allows landowners to voluntarily choose the geographic areas to title and the level of demarcation precision. Our results lend empirical support to the contingent approach by showing the fire mitigation effects of the Hellenic Cadastre mainly happen in fertile lands, where farmers benefit the most from clearly delineated property boundaries.

Scientists have extensively studied the meteorological causes of wildfires, such as higher temperatures, lower precipitation, and prolonged periods of drought, (Lagouvardos et al. 2019, Molina-Terrén et al. 2019, Bowman et al. 2017), but researches on their social-economic causes are thin. Arima et al. (2007) finds that in the Brazilian Amazon, increasing fire occurrences are driven by greater incentives for land clearing, due to rising agricultural commodity prices. In Sumatra, Indonesia, lack of large-scale landowners, government decentralization, and regional economic growth together cause more agricultural fires (Edwards et al. 2020, Stolle and Lambin 2003). We add to this literature by showing fires in Greece can be partially attributed to rural abandonment due to tenure insecurity.

2 Background

2.1 Greece Wildfires

In 2018, a devastating fire near Athens killed more than 100 people and injured 140, making it the second deadliest fire in the twenty-first century.[2] The flames also destroyed 40,000 pine and olive trees, along with 4,000 homes. Catastrophic wildfires have always been a severe threat to the Greek civilians and environment. From 2002 to 2016, wildfires in Greece burned more than one million hectares and claimed 165 lives, most of whom were civilians living in wildland-urban interface or wildland areas (Diakakis et al. 2016, Molina-Terrén et al. 2019). [3]

[2] See Greek Reporter: https://greekreporter.com/2018/12/15/death-toll-from-mati-fire-disaster-rises-to-100/

[3] Burned areas are obtained from the Global Wildfire Information System (GWIS)
Boschetti, L., Sparks, A., Roy, D.P., Giglio, L., San-Miguel-Ayanz, J., GWIS national and sub-national fire activity data from the NASA MODIS Collection 6 Burned Area Product in support of policy making, carbon inventories and natural resource management, developed under NASA Applied Sciences grant #80NSSC18K0400, Using the NASA Polar Orbiting Fire Product Record to Enhance and Expand the Global Wildfire Information System (GWIS).

The increasing wildfire risks are partially driven by the deterioration in the local climate — higher temperatures, lower precipitation, and prolonged periods of drought (Lagouvardos et al. 2019, Molina-Terrén et al. 2019, Thornes and Wainwright 2004). But the extreme weather plays only a minor role in fire events compared to human activities. Recent studies estimate that nature ignitions contribute to less than 5% of burned areas, while the majority are human-caused, either accidentally or deliverately (Ganteaume et al. 2013, Goldammer et al. 2019, Blandford 2019).

One major driver of the increased fire hazard is the abandonment of agricultural areas (Moreira et al. 2011). From 1960 to 2007, 871 hectares of agricultural lands (about 6 percent of total surface) were encroached by shrubland in Aetoloakarnania, the largest Greece prefecture (Xystrakis et al. 2017). Similar patterns were observed across Greece (Kolios and Stylios 2013, Kizos and Koulouri 2006). The abandonment of agricultural areas allows the encroachment of shrublands that are more fire prone, creates unmanaged flammable biomass, and contributes significantly to changing fire regimes (Morehouse et al. 2011, Blandford 2019, Henderson et al. 2005). Another contributing factor is agricultural burning, commonly practiced by Greek farmers to clear land (Liacos 2015, Mouflis and Gitas 2007). While most agricultural burnings are well controlled, some may escape due to sudden change in wind direction or strength, combined with inadequate firebreaks (Mouflis and Gitas 2007).

Behind agricultural burning and the abandonment of agricultural land is the lack of tenure security under the traditional land system. Albeit being the easiest way to clear land, repeated burnings of straw can gradually reduce microbial biomass in cropped soils, leading to reduced productivity in the long run (Rasmussen and Parton 1994, Collins et al. 1992). Conservative alternatives to burning crop residues, such as residue mulching, can maintain soil fertility, but typically require an upfront cost, while their benefits only appear in the following years (Erenstein 2003). The investment nature of those conservative practices require tenure security to ensure landowners can capture all the benefits (Rioux and San Juan 2016, Neill and Lee 2001, Erenstein 2003). Similarly, in the absence of tenure security, landowners tend to over-exploit land fertility and bias investment decisions against long-term land maintenance. The decline in land fertility in turn, often leads to land abandonment (Barbier and Burgess 2001, Barbier 1997). The Hellenic Cadastre program revokes this trend by establishing a new land system with clearly delineated boundaries.

2.2 Greece Land System and Hellenic Cadastre

The traditional Greece land system adopted in 1853 is based on personal registration of land, namely the system of registrations and mortgages.[4] Under the system, property owners register their land claims at mortgage offices without systematic land survey or mapping. The land titles, mortgages, and contracts are maintained in paper-form, and sorted alphabetically by last names. This person-based land system makes it difficult to tell how many people have claimed the same property (Papakostas 2018). According to the president of the national land registry authority, Dimitris Kaloudiotis, "If you calculated the total deeds that are registered, the country would be twice as big as it is." (Daley 2013). Furthermore, the land records are not associated with any systematic survey map. The boundaries of land parcels are defined by written descriptions and local conventions through expressions such as "between the olive tree and the well" or "between the donkey path and the forest" (Daley 2013).[5] The vague boundaries and the person-based registration often create multiple claims to the same property, inviting numerous land disputes which take years, sometimes a decade, for courts to settle (Papakostas 2018). The potential legal disputes force buyers to pay a high transaction fee to attorneys and mortgage offices (Rokos et al. 2010).

Facing large transaction costs of the traditional land system, Greece decided to create from scratch a new property-based land system. This new system first prepares the necessary IT infrastructure that allows the digital mapping of urban, agricultural, forested, and mountainous areas of the whole country. The government then awards cadastral survey contracts to the private sectors and roll out the program across the country.[6]

For each region, private contractors first produce the preliminary cadastral diagrams of an area based on orthophoto maps and ground evidence. Based on the preliminary cadastral maps, landowners declare their properties, verify or correct the boundaries. The corrected cadastral database is made available for public inspection and subject to further corrections based on petitions.

The land registration for private properties is mandatory. Registering one parcel costs 35

[4]The Island of Rhodes, the Island of Kos, and part of the island of Leros have a cadastral system implemented by the Italians in 1929 (Rokos et al. 2010).

[5]This traditional land system is metes and bounds, according to Libecap and Lueck (2011).

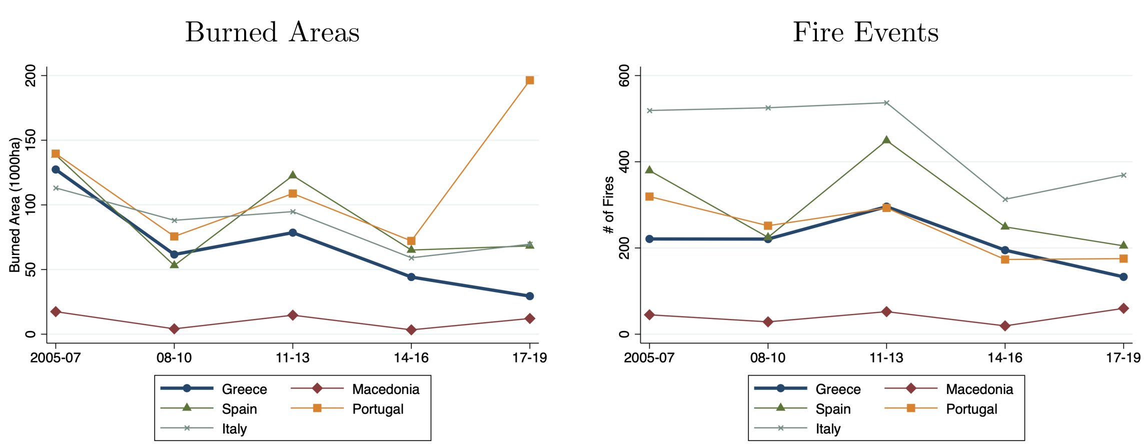
[6]We thank Dimitris Rokos, the planning director of Hellenic Cadastre, for providing us the details.

euros, with deductions for multiple agricultural parcels. Properties not claimed or registered will eventually be controlled and owned by the Greek government.

The Hellenic Cadastre progressed slowly at the beginning. Before being interrupted by the eurozone crisis in 2009, the program had covered less than 7.8% of the country's area (Rokos 2018). As part of the bailout agreements with the International Monetary Fund, Eurogroup, and the European Central Bank, Greece resumed and accelerated the cadastral survey in 2014. By 2019, the Hellenic Cadastre had covered more than 92% of the country's area. A recent survey targeting private landowners at land registry offices show that 79% of them believe the land registry will help resolve land disputes (Tsigarida (2019)). A report from World Bank 2019 similarly finds that the land registry allows local court to resolve property disputes more efficiently.

We focus on the last wave of land registration from 2014 to 2019 for two reasons. First, the external pressure from IMF and EU made the resummation timing of the Hellenic Cadastre largely exogenous. Second, the last wave covered 85% of the Greece lands, allowing a clear identification of its impact on fire events and burned areas. As shown in Figure 1, Greece saw a 63% decrease in the burned area and 55% decrease in fire events since the resumption of Hellenic Cadastre in 2014. This magnitude is larger than that of the northern neighbour (Macedonia) and those of other Mediterranean European countries (Spain, Portugal, and Italy).

Although the cross-country trends are quite informative, we need micro data to identify and estimate the causal effects of the Hellenic Cadastre. We also need specific variables to understand through which channel the land registry reduces wildfires.



Datasource: Global Wildfire Information System (GWIS)

Figure 1: 3-Year Average of Burned Areas and Fire Events, by Country

3 Data

We assemble a novel panel dataset from 2011 to 2020, containing land registration dates, fire events, land uses, and agriculture activities for 59 regional units in Greece.

3.1 Hellenic Cadastre and Administrative Divisions

To exploit the staggered rollout of the Hellenic Cadastre program, we collect the starting year of the land registry from the official website.[7]. Ideally, all areas under the same regional units (prefectures) are covered by the Cadastre program at the same time. However, there are scattered municipalities that have completed the land registry in the pilot before 2000. Those municipalities were once under the pre-Kapodistrias administrative division, but since 2010 have consolidated into one of 74 regional units under the Kallikratis Plan.

To overcome the inconsistency of administrative divisions, we first record the year of land registry for each municipality, as displayed in Figure 2.[8] We are able to locate 97 percent (5587 out of 5775) of the municipalities under pre-Kapodistrias administrative division. The unmatched ones either do not have clear starting years or cannot be geographically located. We then map those municipalities to 74 regional units under the current Kallikratis administrative division with the following rule: if more than 85% of the area in a regional unit has the same year of land registry, we consider the whole regional unit is covered by the Cadastre program in that year. Correspondingly, if more than 85% of the area in a regional unit remains the same status from 2014 to 2019, we put the regional unit into the control group. Under this threshold, 59 out of 74 regional units are included in the sample, as displayed in Figure 4.[9][10] We choose to analyze the impacts of the Cadastre program at the level of regional units instead of municipalities, because it is the administrative division for the period analyzed and the administration level at which agriculture data is tabulated by the Hellenic Statistical Authority.

[7]Land registry data are retrieved in August 2020 from https://ktimatologio.gr/anazitisi-periohon

[8]Vector layers of Greece administrative divisions are retrieved in August 2020 from Geoadata.gov.gr

[9]This threshold is chosen to strike a balance between keeping a sufficiently large sample size and minimizing the noise introduced by the different timing within the same regional unit.

[10]We exclude one special regional unit — Mount Athos, as it is adminstered by monasteries and only allow males to enter.

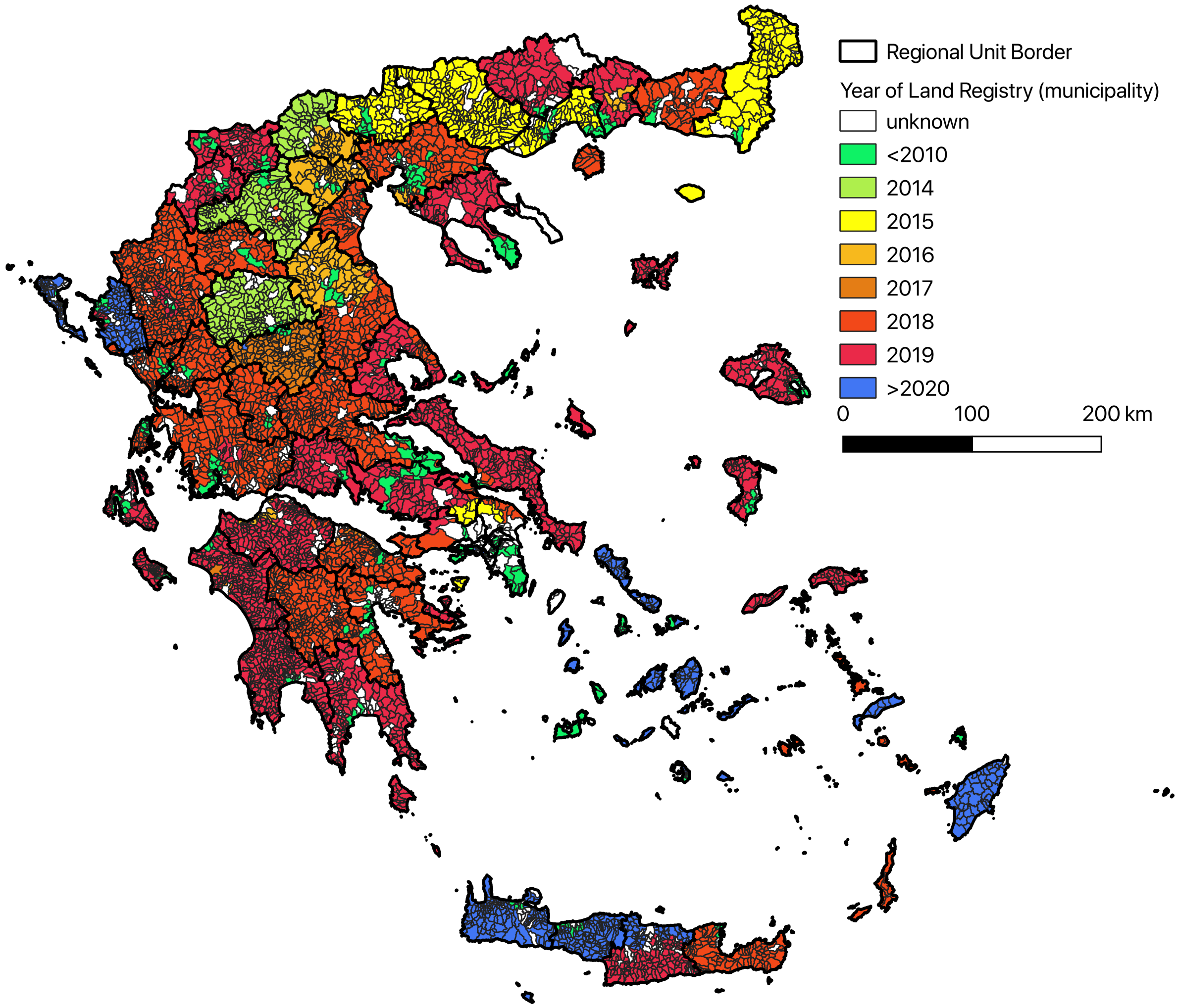


Figure 2: Year of land registry for municipalities under the pre-Kapodistrias administrative division

3.2 Wildfires and Land Use

Fire data are colleced through the Moderate Resolution Spectroradiometer (MODIS) instruments from two NASA satellites, Terra and Aqua (Giglio et al. 2016). These satellites detect fire activity based on thermal anomalies, surface reflectance, and land use with 1-km resolution. The satellites overpass Greece four times a day (around 00:30 am, 9:30 am, 12:30 pm, and 21:30 pm in local time), and identify active fire points by detecting thermal anomaly with 1-km resolution (Justice et al. 2002). Modis active fire data have been widely used in measureing fire events.[11] Our primary variable of interest is the location and date of fire events, along with a confidence index

[11] See Edwards et al. 2020, Morello et al. 2020, He et al. 2020, Zivin et al. 2020, Rangel and Vogl 2019

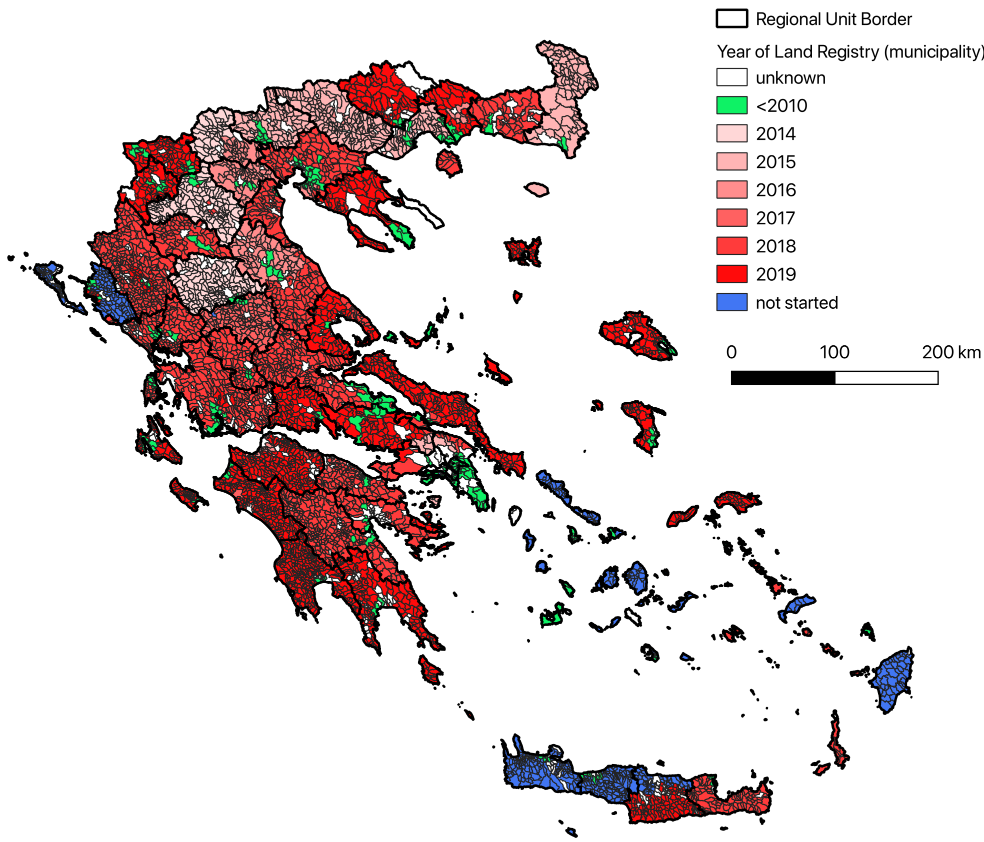


Figure 3: Year of land registry for municipalities under the pre-Kapodistrias administrative division

on a scale of 0-100, reflecting the probability that a fire occurred. Following Rangel and Vogl 2019, we weights fires by their probability, so that a fire that occurred with 50% probability is counted as 0.5 fire incidence. We also use the fire radiative power (FRP) and the brightness as a proxy for fire severity. A visualization of the all wildfires from 2011 to 2019 is given in Figure B1.

In addition to the fire events, we also obtain the burned areas from the Terra and Aqua combined MCD64A1 (Giglio et al. 2018). MCD64A1 is a global gridded product containing per-pixel burned-area with a 500m resolution. The product identifies persistent changes in surface reflectance due to burning. While Turco et al. (2019) finds the data set shows good agreement with ground-based data set for Mediterranean Europe when considering aggregating burned areas at NUTS3 level (equivalent to the regional unit level analyzed in this paper), other validation practices show that MCD64A1 grossly underestimate small agricultural fires (Boschetti et al. 2019, Padilla et al. 2015). To the extent that fire reduction is mainly driven by small-scale agricultural fires, an under-

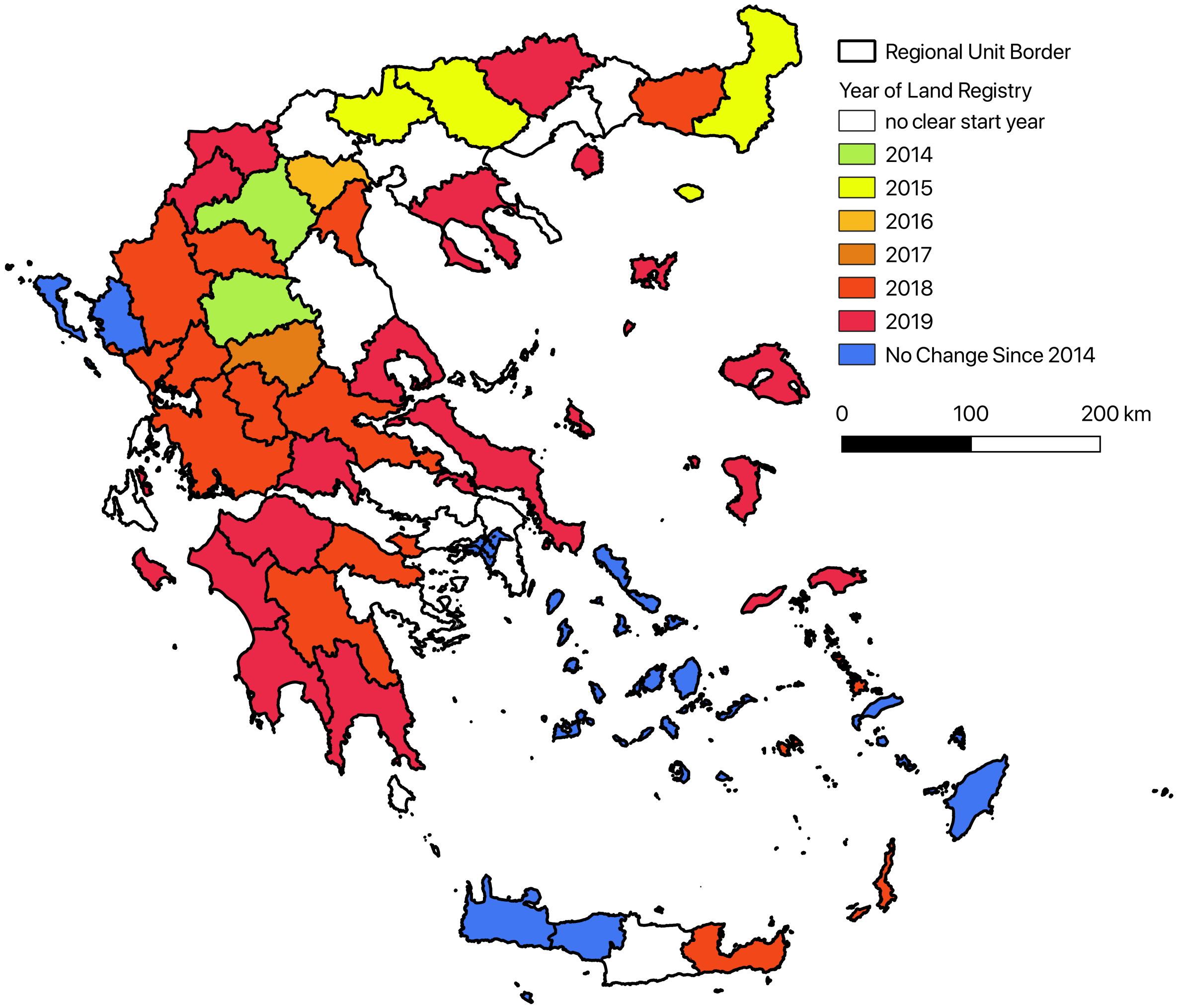


Figure 4: Year of land registry for regional units

estimation of the small burned areas is biased against our main findings.

To further investigate the fire types, we classify the fires by the land cover they spread through. We use CORINE Land Cover Changes (CLCC2018) detected by Sentinel 2 and Landsat 8 satellite. The data set is produced according to a common standard and provides a harmonized description of the development of land cover and land use in Europe (Feranec 2016). We georeferenced each fire to agricultural areas or forestareas.[12] Figure 6 displays the percentage change of the number of agricultural fires between 2014 and 2019 in each regional units. Table 2 compares the key variables of those regional units who receive land registry before 2017 to those who do not. The group

[12] Agricultural areas include arable land, permanent crops, vineyards, and pastures. Forest areas include broad-leaved forest, coniferous forest, and mixed forest.

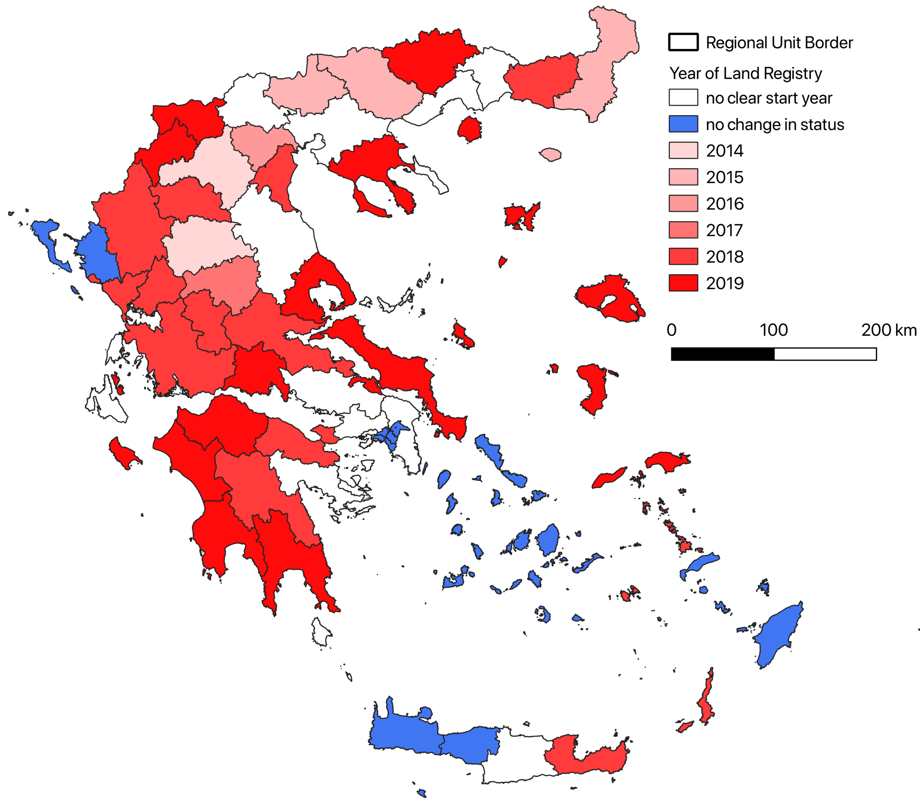


Figure 5: Year of land registry for regional units

receiving early treatment has a larger decrease in both the number of agricultural fire events and burned areas since 2014. It is the first indication that land registry decreased agricultural fires.

3.3 Agricultural Survey and Land Fertility

To investigate through which channel the Cadastre program affects fire events, we collect agriculture data for each regional unit from Hellenic Statistical Authority. The data is tabulated from the annual agricultural statistical survey which covers agriculture areas and equipment from 2011 to 2019, and livestock from 2013 to 2019. Agricultural areas can be roughly divided into areas for crops, gardens, trees, vineyards, and fallow land. Equipment includes more than 30 different types of agricultural machinery, and can be roughly categorized into combine harvesters, irrigation systems, tractors, sowing machines, sprayers, and other machinery. Livestock includes cattle, sheep, goats, and pigs.

We also measure the land fertility at the fire location by the maximum Caloric Suitability

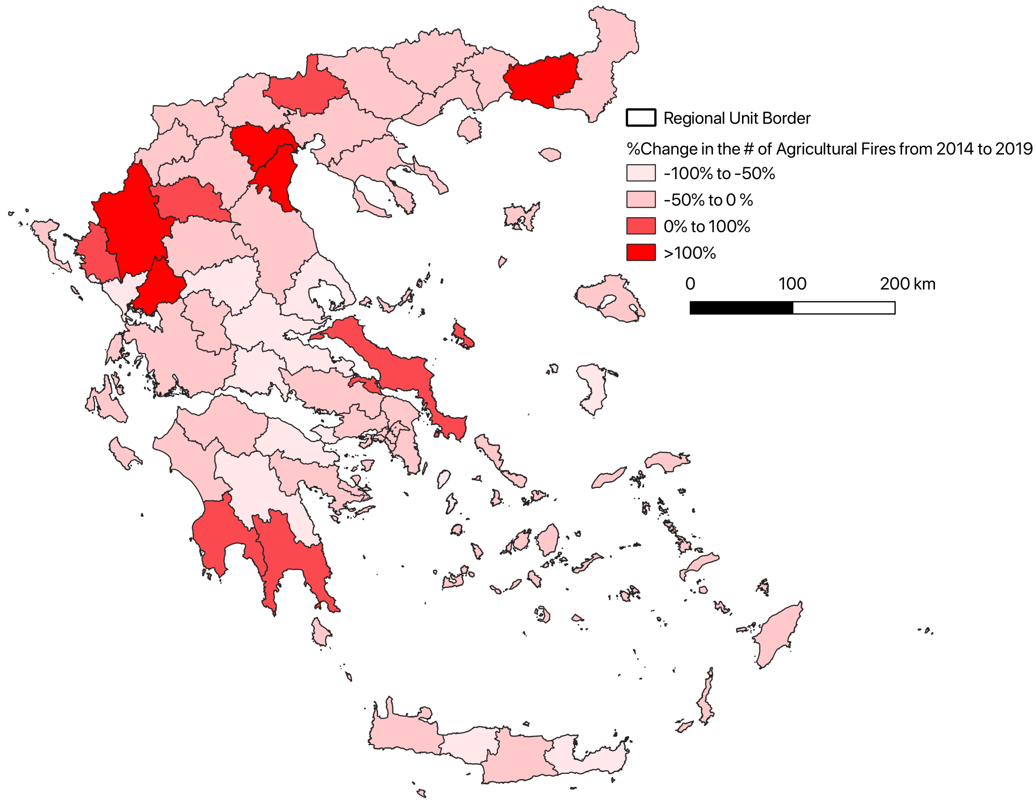


Figure 6: Percentage change in the number of agricultural fires between 2014 and 2019

(Galor et al. 2016, Galor and Özak 2016, Galor and Özak 2015).[13] The Caloric Suitability Indices measures the maximum potential caloric yield attainable based on various climatic and geographic characteristics, such as temperature. rainfall, soil quality, elevation, terrain ruggedness, steepness, etc. It has been widely used as a proxy for agricultural potential (Galor and Özak 2015, Hazarika et al. 2019). Table 1 shows the summary statistics of all the variables we applied here. For ease of interpretation, all measures are log-transformed.

3.4 Other Data

Since the frequency of agricultural fires may be correlated with weather conditions, we use the meteorological data collected by 55 weather stations across Greece (see Figure B2 in the Appendix for their locations).[14] Each station keeps monthly records of temperature and rainfall from 2011

[13] Specifically, we use the Post-1500CE, Maximum Calories Suitability obtained from https://ozak.github.io/Caloric-Suitability-Index

[14] Data are retrieved from Hellenic National Meteorological Service in Oct, 2021.

Table 1: Summary statistics

Variable	Obs	Mean	Sd.	Min	Max
number of agricultural fire events	531	.931	1.12	0	4.47
agricultural burned areas (km^2)	531	.681	1.19	0	5.2
vine area (km^2)	531	1.87	1.4	0	6.69
garden area (km^2)	531	1.64	1.09	0	4.5
total agricultural area (km^2)	531	4.91	2.06	0	7.35
crop area (km^2)	531	3.87	2.11	0	7.19
tree area (km^2)	531	9.82	3.13	0	13.7
fallow area (km^2)	531	2.96	1.62	0	5.77
# of sprayers	413	5.97	3.07	0	9.89
# of tractors	413	7.21	2.4	0	9.94
# of combine harvestors	413	4.91	2.21	0	8.03
# of irrigation systems	413	6.25	3.2	0	9.86
# of sowing machines	413	4.33	2.84	0	8.68
# of other machines	413	7.79	2.52	0	10.8
# of power dusters	413	2.49	2.25	0	7.8
# of high-pressure power sprayers	413	5.07	2.91	0	9.27
# of linear cultivator power sprayers	413	3.77	2.96	0	8.92
# of portable sprayers	413	4.68	3.05	0	9.07
fire events at locations with high agricultural potential	531	.603	1.04	0	4.47
fire events at locations with low agricultural potential	531	.4	.762	0	3.49
fire events during the day	531	.881	1.11	0	4.47
fire incidences during the night	531	.109	.349	0	2.85
fire events of high Fire Radiance Power	531	.553	.822	0	3.48
fire events of low Fire Radiance Power	531	.709	.976	0	4.2

Each observation is a regional unit by year. summary statistics show the natural log of all variables (eg. $ln(1+Y)$)

to 2019. We link the centroid of each regional units to the nearest weather station.[15] To account for the prolonged periods of drought, we aggregate the monthly data from March to Octorber to compute the yearly average temperature and the total rainfall for each regional unit during the fire season.[16] The temperature and the rainfall are hereafter referred as “weather control”.

We also use demographic data from Eurostat, including population density, GDP, and employment.[17] The data are available at the regional level from 2011 to 2018.

[15]The average distance is about 35km.

[16]The average temperature and rainfall by month is displayed in Figure B3 in the Appendix.

[17]Data is assessed on July, 2020 from https://ec.europa.eu/eurostat/web/main/data/database

Table 2: Summary statistics

	2011-2013					2014-2019					
Variable	Obs	Mean	Sd.	Min	Max	Obs	Mean	Sd.	Min	Max	ΔMean
Regional units receiving land registry before 2017											
# of agricultural fire events	42	1.63	1.71	0	4.47	84	1.24	1.37	0	4.19	-.49**
agricultural burned areas (km^2)	42	1.26	1.59	0	4.7	84	.482	.987	0	4.16	-.527*
total agricultural area (km^2)	42	4.12	2.96	0	7.35	84	4.01	3.02	0	7.34	-.107
crop area (km^2)	42	3.79	3.03	0	7.19	84	3.7	3.02	0	7.18	-.0879
tree area (km^2)	42	2.12	1.94	0	5.56	84	1.96	1.85	0	5.34	-.158
fallow area (km^2)	42	2.36	1.69	0	5.31	84	2.53	1.97	0	5.41	.171
# of sprayers	14	4.74	4.02	0	8.99	84	4.9	3.91	0	9.44	.162
# of high-pressure sprayers	14	3.9	3.32	0	8.39	84	4.06	3.42	0	8.75	.155
Regional units not receiving land registry before 2017											
# of agricultural fire events	135	.917	1.01	0	3.72	270	.734	.898	0	3.86	-.287***
agricultural burned areas (km^2)	135	.897	1.37	0	4.88	270	.547	1.03	0	5.2	-.132
total agricultural area (km^2)	135	5.32	1.52	.442	7.29	270	5.1	1.62	0	7.33	-.222
crop area (km^2)	135	4.13	1.72	0	6.79	270	3.81	1.75	0	6.76	-.323
tree area (km^2)	135	3.92	1.81	.245	6.67	270	3.5	1.93	0	6.78	-.414*
fallow area (km^2)	135	3.38	1.3	.172	5.54	270	2.98	1.57	0	5.77	-.4**
# of sprayers	45	6.62	2.18	0	9.56	270	6.26	2.75	0	9.89	-.354
# of high-pressure sprayers	45	5.61	2.43	0	8.88	270	5.35	2.71	0	9.27	-.264

Each observation is a regional unit by year. summary statistics show the natural log of all variables (eg. $ln(1+Y)$)

4 Main Results

4.1 Treatment Effects of Land Registry

We start by examining whether the land registry affects fire incidents and burned areas by the two-way fixed effects method. Exploiting the asymmetric timing of the program across the regional units, we run the following regression:

$$Y_{i,t} = \alpha_i + \beta Registry_{i,t} + \theta X_{i,t} + \delta_t + \epsilon_{i,t} \tag{1}$$

The key variable of interest is $Registry_{i,t}$, a binary indicator of whether the regional unit i has started the land registry in year t. $Y_{i,t}$ is the natural log of fire incidents or burned areas in agricultural fields or in forest in year t at regional unit i. X_{it} is the weather controls including temperature and rainfall during the fire season in year t at regional unit i. δ_t and α_i are regional unit fixed effect and year fixed effect respectively. Standard errors are clustered at the regional unit level.

Table 3: Land Registry on Fire Events and Burned Areas

Dependent Variable:	Log, # of Fire Events		Log, Burned Area	
	(1) Agriculture	(2) Forest	(3) Agriculture	(4) Forest
Land Registry	-.177*	-.0781	-.476**	-.122
	(.105)	(.066)	(.182)	(.116)
Total Rainfall	-.000307*	-.000104	-.000608*	-.000185
	(.000182)	(.000211)	(.000315)	(.000248)
Avg. Temperature	.0162	.023	.0365	-.0295
	(.0572)	(.0515)	(.109)	(.0892)
Mean of Dep. Var.	4.76	.64	5.62	.99
Year FE	X	X	X	X
Regional Unit FE	X	X	X	X
Observations	531	531	531	531

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the natural log of agricultural and forest fire events in columns (1) and (2), and the natural log of agricutural and forest burned areas in columns (3) and (4). *Mean of Dep. Var.* shows the average number of fire events and the average burned areas in km^2 (without natural log). Standard errors are clustered at the region unit level.

Table 3 displays the main effect of land registry on agricultural fires in columns 1 and 3.[18] The land registry reduces agricultural fire events and burned areas fell by 17 percent and 38 percent respectively.[19] Both estimates are statistically significant. Not surprisingly, rainfall during fire seasons significantly reduces agricultural fires.

On the other hand, the land registry has no significant impact on forest fires in columns 2 and 4. The sizes of treatment effects are much smaller than those for agricultural fires. That is because most forest is owned by the state and thus uncovered by the land registry program.

To examine the year-by-year effects of the land registry, we estimate a similar regression as Equation , but replace key variables of interest by indicators for years relative to the start year of

[18] In Appendix A Table A6, we use the inverse hyperbolic sine transformation (arcsinh) of fire events and burned areas, and obtain quantitatively similar results.

[19] The burned areas reduces by exp(-0.476)-1 = 38%

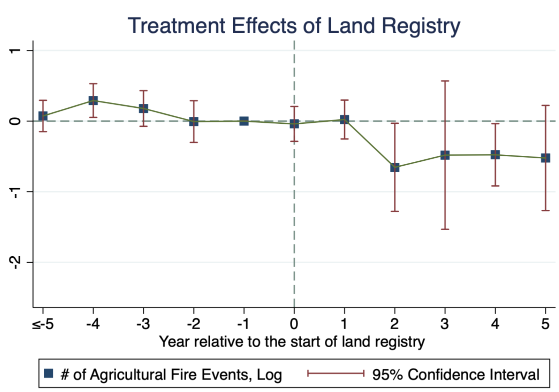
the land registration, or the event time:

$$Y_{i,t} = \alpha_i + \beta_k \sum_{k \geq -4, k \neq -1}^{4} Registry_{k,i} + \theta X_{it} + \delta_t + \epsilon_{i,t} \tag{2}$$

where $Registry_{k,i}$ are the binary indicators on the kth year relative to the omitted event year $Registry_{-1}$, the year immediately before the Cadastre program.

As shown in Figure 7, agricultural fire events fell by 50 percent in the second year into the land registry. The reduction decreases and stablizes at around 40 percent in the following years. Meanwhile, the agricultural burned areas fell by 63 percent in the second year and 83 percent in the fifth year.

Agricultural Fire Events, Log



Agricultural Burned Areas, Log

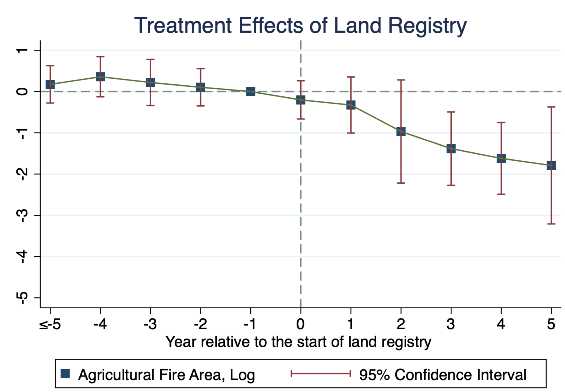


Figure 7: Trends of Fire Events and Burned Areas

4.2 Internal Validity

The DiD estimator would identify the causal impact of the Hellenic Cadastre if we were to assume that no unobserved variables exist that simultaneously influence changes in fire events and the timing of land registry. While untestable, this identification assumption is more plausible trends in outcomes across treatment groups as already shown in Figure 7 are parallel in the years prior to the land registry.

Furthermore, the resummation of the Hellenic Cadastre in 2014 was imposed externally, making the starting year largely exogenous. The original intention of the Cadastre program is to facilitate land taxation, exploitation of public property, economic development, and investment. To our best knowledge, its environmental impacts are largely unanticipated.

To examine the question of why some regional units implemented the land registry earlier than others, we use the agricultural data from the Hellenic Statistic Authority and demographic data from Eurostat. We run a cross-sectional regression where the dependent variable is the year of land registry. We examine whether characteristics at the regional unit level in 2013 predict the timing of the land registry. We set the year of the land registry as 2020 for untreated regional units, as this were the original plan in the absence of the Covid19 pandemic.

As shown in Table 4, the area of cropland appears to be a strong determinant for the timing of land registry. Specifically, one standard deviation increase in the crop area makes the land registry 0.7 year earlier. In the next subsection, we show that controlling for crop area and other weak determinants (eg. population density and total agricultural machinery) does not change the main results. Importantly, the total fires in the past from 2008 to 2012 have almost no impact on the timing of the land registry, which provides some reassurance that the land registry program was not designed to mitigate fire risks.

4.3 Robust Checks

The analysis in the previous section shows cropland areas along with other weak determinants (eg. population density and total agricultural machinery) can affect the timing of the land registry. These differences between early and late treated regional units are not a threat to our identification strategy as long as they are largely uncorrelated with changes over time in agricultural fires. To address this concern, we first verify that changes over time in agricultural fire events and burned areas were not correlated with the timing of land registry in Table A5 and A5 in Appendix A.

We then control for crop area and other weak determinants (eg. population density and total agricultural machinery), and find the main results remain the same in Table A3 in Appendix A. Importantly, Figure B5 in Appendix B shows crop areas were not trending differently prior to the land registry. The above robust tests greatly reduce the concern that the timing of land registry were reversely affected by factors affecting differential changes in agricultural fires.

The current sample includes 59 regional units that have the same year of land registry or remain

Table 4: Determinants of Land Registry Year

Dependent Variable:	Year of Land Registry			
	(1)	(2)	(3)	(4)
Total Machinery	.0000177	-.0000276	-.0000191	-.0000341
	(.0000184)	(.0000206)	(.0000135)	(.0000233)
Agricultural Area	-.00267***			
	(.000869)			
Vine Area		.00318		.00696
		(.00934)		(.0102)
Fallow Area		-.000728		-.000229
		(.00351)		(.0038)
Crop Area		-.00266***		-.00215*
		(.000906)		(.00115)
Tree Area		.00139		.00181
		(.00144)		(.00156)
Garden Area		.027		.0291
		(.0169)		(.0186)
Log, Total Fires in Last Five Years			-.0232	.0145
			(.159)	(.152)
Latitude			-.475***	-.0317
			(.127)	(.168)
Longitude			-.0261	.112
			(.0949)	(.0946)
Population Density			.000281	.000284
			(.000246)	(.000228)
Regional GDP			-.000379	-.000454
			(.000634)	(.00063)
Regional Employment			.00469	.00942
			(.0242)	(.0238)
P-value of F-test	0	0	.001	0
Adj. R-squared	.27	.48	.32	.44
Observations	52	52	52	52

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Linear Regression. The dependent variable is the year of land registry. Regional units have not received the land registry by 2019 are assumed to begin the land registry in 2020, as this were the original plan in the absence of the Covid19 pandemic. We use data in 2013 for all independent variables.

the same status for more than 85%. We further restrict the sample by increasing the threshold to 90%, and estimate the year-by-year treatment effects of land registry for the remaining 50 regional units. Table A2 in the Appendix A shows the effects are similar and statistically significant.

We also use other measures of agricultural fires and burned areas as dependent variables, such as the inverse hyperbolic sine transformation (arcsinh) or normalizing agricultural fires by the areas of regional units. The results are quantitatively similar, as shown in In Table A6 in Appendix A.

In addition, recent literature has noticed that the traditional two-way fixed-effect method is not robust, as it may assign incorrect weights to the treatment effects when they are heterogeneous (De Chaisemartin and d'Haultfoeuille 2020). Particularly, when a previously treated group is later used as a control group, the traditional two-way FE estimator picks up the difference in the treated effects of the treated group, which effectively assigns a negative weight to one of the treated effects. The negative weight, in turn, can flip the sign of average treatment effects.

To solve the issue, we apply the DID_M estimator proposed by De Chaisemartin and D'Haultfœuille (2020). Essentially, the DID_M estimator only uses stable groups — in our case, the untreated group — as control groups, thereby addressing the possible negative weight issue. De Chaisemartin and d'Haultfoeuille (2020) show that DID_M is an unbiased estimate of the average treatment effect of all switching regional units under a series of assumptions, including the common trends assumption. Nevertheless, the DID_M often has a larger variance than that of the two-way fixed effect estimators.

Table A1 in Appendix A shows that the treatment effects under DID_M estimator are quantitatively similar to (or somewhat larger than) the treatment effects under two-way fixed effects estimators (see Appendix A for the construction and the regression results of DID_M estimator).

5 Channels and Mechanism

To understand why improved tenure security through the land registry can reduce agricultural fires, we analyze changes in agriculture acitivities. Using annual agricultural survey data, we explore three possible channels: farming expansions which reduce fuel loads, increased fire suppression equipment which allows farmers to suppress and contain fires at the earliest opportunity, and reduced stubble burning to preserve soil fertility.

5.1 Farm Expansion and Investment

Increased farming activities under the Hellenic Cadastre program is plausible to reduce agriculture fires. Existing literature attributes the rampant fires in Greece partly to the high fuel load caused by the abandonment of agricultural fields (Morehouse et al. 2011, Moreira et al. 2011, Blandford 2019). Securer tenure induced by the land registry reduces the threat that land-attached investment will be appropriated by others, before the owner reaps all its benefit. Greece people thus may return to the rural areas and expand agricultural lands. To explore this channel, we run the same two-way fixed effects specification as in Equation 4.1 on farming areas. The result in column 1 of Table 5 shows that the land registry increases the total farming area by 16%. The effects are statistically significant. This is the first indication that the land registry removes tenure uncertainty, thereby incentivizing farmers to expand agricultural lands.

Table 5: Land Registry on Farming Areas

	(1) All	(2) Crop	(3) Tree	(4) Fallow	(5) Vine	(6) Garden
Land Registry	.155**	.152*	.189***	.38**	-.0459	.0575
	(.0695)	(.0795)	(.0535)	(.143)	(.0653)	(.0565)
Mean of Dep. Var.	412	216	113	50	24	8
Year FE	X	X	X	X	X	X
Regional Unit FE	X	X	X	X	X	X
Observations	531	531	531	531	531	531

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The sample covers farming areas from 2011 to 2019. The dependent variable is the natural log of the area of all farming land, crop, tree, fallow land, vine, and garden in columns (1), (2), (3), (4), (5), and (6) respectively. *Mean of Dep. Var.* show the average of dependent variables in km^2 (without natural log).. Crop includes various cereals, grains, and fodder plants. Tree includes fruit trees, nut-bearing trees, and olive trees. Vine includes various types of grapes. Garden includes vegetables, seedbeds, and ornamental plants. Standard errors are clustered at the region unit level.

The results in columns 2 to 6 (also in Figure B5) show the effects of land registry on crop, tree, fallow, vine, and garden.[20] The large increases in the fallow area (46%) and tree area (21%) are worth noting.[21] Fallowing replenishes nutrients in the soil, and allows a higher crop yield when the land is planted again. Similarly, it usually takes farmers several years to grow trees and decades to

[20]Garden includes vegetables, seedbeds, and ornamental plants. Crop includes various cereals, grains, and fodder plants.

[21]Fallow area increases by exp(0.38)-1=46%. Tree area increases by exp(0.19)-1=21%.

reap all the benefits. Large increases in these land-attached and long-term investments are strong evidence of farmers' enhanced confidence in securing their land title (Goldstein and Udry 2008, Deininger and Jin 2006, and Besley 1995).

In sum, the findings indicate that the land registry secures farmers' property rights, thereby allowing them to make short-term investments such as livestock and annual crops, as well as long-term investments such as fallowing land and planting trees. To the extent that agriculture abandonment is one of the major causes of wildfires in Greece (Fernandes 2013, Colantoni et al. 2020), an increase in farming and grazing activities can reduce fire events and sizes, as it reduces fuel (biomass) accumulation, stop the encroachment of shrublands, and increases the chances of early fire detections.

5.2 Fire Suppression Equipment

With valuable assets attached to the land, Greece farmers may actively seek ways to fight wildfires. Based on the interviews with people in Elia, a place heavily affected by the summer fires across Greece in 2007, Zirogiannis (2009) finds that most local villagers actively combated fires to protect their villages, even when they were ordered to evacuate by the government. Their participation significantly reduced the damage caused by the fire blazes.

To explore this channel, we run the same two-way fixed effects specification as in Equation 4.1 on farming equipment. The result in column 1 of Table 6 shows that the land registry increases the number of sprayers as tractor auxiliary components by 14%. Sprayers are considered as "natural fire wagons" and are recommended as fire mitigation equipment (Vogltance et al. 2007, Jones 1943). In Greece, local farmers often operate their tractors along with water sprayers to combat fire blazes (Zirogiannis 2009), as illustrated by Figure B4 in Appendix B.

While having sprayers on the farm allows farmers to contain wildfires at the earliest opportunity, it may be merely a side effect of the farming expansion. With securer tenure, farmers may mechanize farming and increasingly use sprayers attached to tractors to apply pesticides and fertilizer. If that is the case, one would expect to find increases in all farming equipment. However, as shown in Table 6 column 2 to 5, tractors, combine harvests, sowing machines, irrigation systems, and other equipment have a much smaller increase since the land registry. It is thus unlikely that the original intention of stocking the sprayers is to mechanize farming.

Table 6: Land Registry on Equipment

	(1) Sprayer	(2) Tractor	(3) Combine	(4) Sowing	(5) Irrigation	(6) Other Machinery
Land Registry	.142	.0841	.0518	-.109	-.0129	.0853
	(.0974)	(.0766)	(.0654)	(.132)	(.0854)	(.114)
Mean of Dep. Var.	2918	4445	463	754	4009	8191
Year FE	X	X	X	X	X	X
Regional Unit FE	X	X	X	X	X	X
Observations	413	413	413	413	413	413

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The sample covers agricultural machinery from 2013 to 2019. The dependent variable is the natural log of the number of sprayers, tractors, combine harvesters, sowing machines, irrigation systems, and other equipment in columns (1), (2), (3), (4), (5) and (6) respectively. *Mean of Dep. Var.* show the average number of the equipment before log transformation. Standard errors are clustered at the region unit level.

Furthermore, we can separately examine the dynamics of various types of spraying and irrigation devices. As presented in Table 7, only the number of high-pressure power sprayers increases significantly by 20% among various types of sprayers, likely because pressured water is most effective in fighting fires (Holman 1946 pp. 33-35, Timmins 1976 pp. 10). On the contrary, the equipment that is designed only for irrigation purposes, such as duster sprayers, sprinklers, and drip irrigation systems either increases insignificantly or decreases since the land registry.

Putting it all together, it is most likely that farmers stock sprayers, especially those high-pressure ones, to protect their land-attached investment. The high-pressure power sprayers on the farm are handy tools for farmers to contain fires before the arrival of firefighters, and likely reduce the fire events that are detectable by satellites.

5.3 Stubble Burning

It is also possible that securer tenure reduces the practice of stubble burning, which is a common practice to clear the land in Greece (Liacos 2015). At a low cost, stubble burnings can increase crop yield in the short run, as it changes soil moisture and nutrient availability as well as controls weeds and insects (Rice and Garcia 1994). But repeated burnings of straw can gradually reduce microbial biomass in cropped soils, leading to reduced productivity in the long run (Rasmussen and Parton 1994,Collins et al. 1992). Improved property rights secure the benefits in the long run, and may induce landowners to choose more sustainable soil management through less stubble burning.

Table 7: Land Registry on Sprayer Type

	(1) Pressure Sprayer	(2) Duster Sprayer	(3) Linear Sprayer	(4) Portable Sprayer	(5) Self-propelled Sprinkler	(6) Drop Irrigation
Land Registry	.196*	-.379**	.111	.124	.0718	-.0642
	(.105)	(.171)	(.191)	(.171)	(.126)	(.127)
Mean of Dep. Var.	1214	125	505	1075	636	1685
Year FE	X	X	X	X	X	X
Regional Unit FE	X	X	X	X	X	X
Observations	413	413	413	413	413	413

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The sample covers agricultural machinery from 2013 to 2019. The dependent variable is the natural log of the number of high-pressure power sprayers, duster sprayers, linear cultivator power sprayers, portable power sprayers, self propelled sprinklers, and drip irrigation systems in columns (1), (2), (3), (4), (5), and (6) respectively. *Mean of Dep. Var.* show the average number of the equipment (without natural log). Standard errors are clustered at the regional unit level.

While satellite images cannot tell the cause of agriculture fires, we can infer stubble burnings based on their characteristics. First, they tend to be limited in size. To measure the size of fires, we use fire radiance power (FRP) provided by MODIS fire data.[22] Second, most stubble burnings happen during early fall (Karali et al. 2014), since the sowing of major crops in Greece is usually carried out in mid-November (Damalas and Lithourgidis 2011,Lithourgidis et al. 2006). Figure 8 shows the average number of fire events by months and sizes. Consistent with the seasonal distribution of stubble burning, agriculture fires of small size start to increase in September and peak in October, right before the cultivating season.

We then proceed to evaluate the impacts of the land registry on those suspected stubble burnings, using the same specification as in Equation 2. Figure 9 shows the treatment effects, which roughly indicate the percentage reduction of the number of fires since the land registry. We find a 26% reduction in the number of suspected stubble burnings — small-sized fires in October. As placebo tests, we do not find any significant effects of the land registry on fires of large size or in the seasons other than the early fall. The above results suggest that landowners reduce the practice of stubble burnings to preserve soil fertility when they have improved property rights.

[22]Specifically, the fire events are divided into two groups separated by the median of FRP.

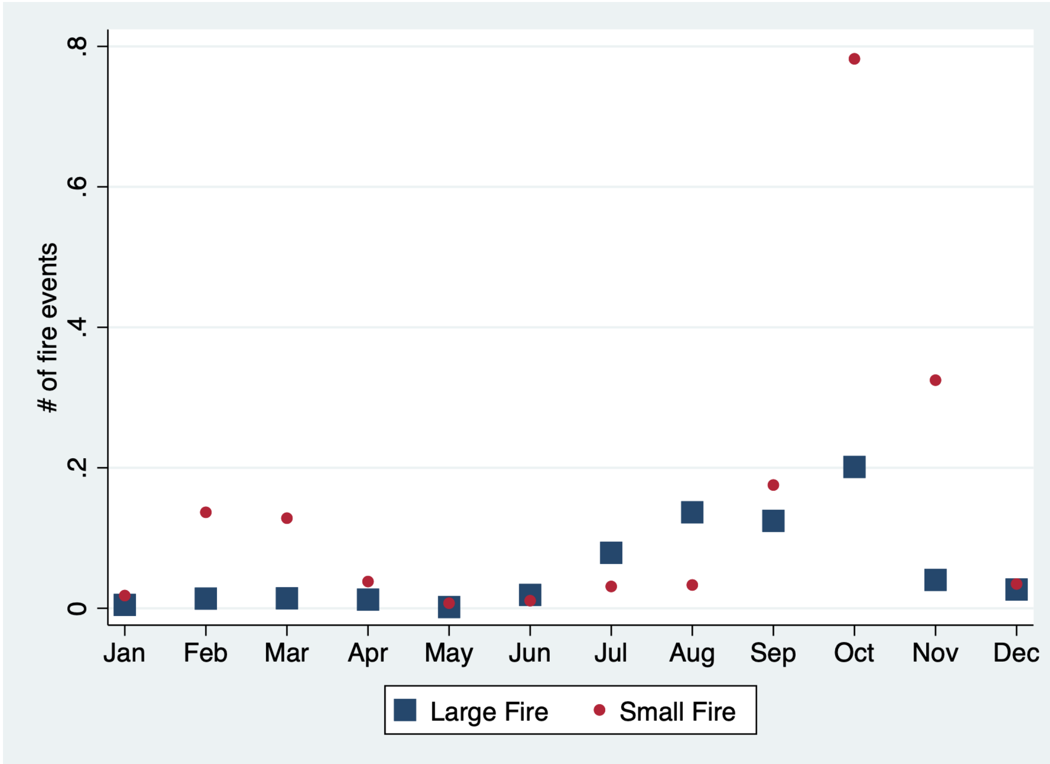


Figure 8: Average fire events by fire sizes and month

5.4 Heterogenous Effects

The evidence so far suggests that the land registry incentivize private owners to mitigate fire risks by reducing stubble burnings, increasing agricultural investments, and stocking fire suppression equipment. If the above agricultural activities lead to the fire reduction, we can test two implications. First, the land registry reduces more fires in fertile lands than in barren lands, as farmers will develop the most fertile land first. Second, the land registry reduces more fires in the daytime than in the nighttime, since it is more likely for fire suppression equipment to take effect during the day when people are awake and alert to fire hazards.

To test the first implication, we measure the land fertility by the maximum Caloric Suitability at the fire location (Galor et al. 2016, Galor and Özak 2016, Galor and Özak 2015). The fire events are then divided into two groups by the median maximum Caloric Suitability — fires on high agricultural potential lands and low potential lands. We then use the two-way fixed effects specification to examine the impact of the land registry on three categories separately. Columns 1-2 in Table 8 shows that the reduction of fire events (17%) mainly happens in fertile lands, while

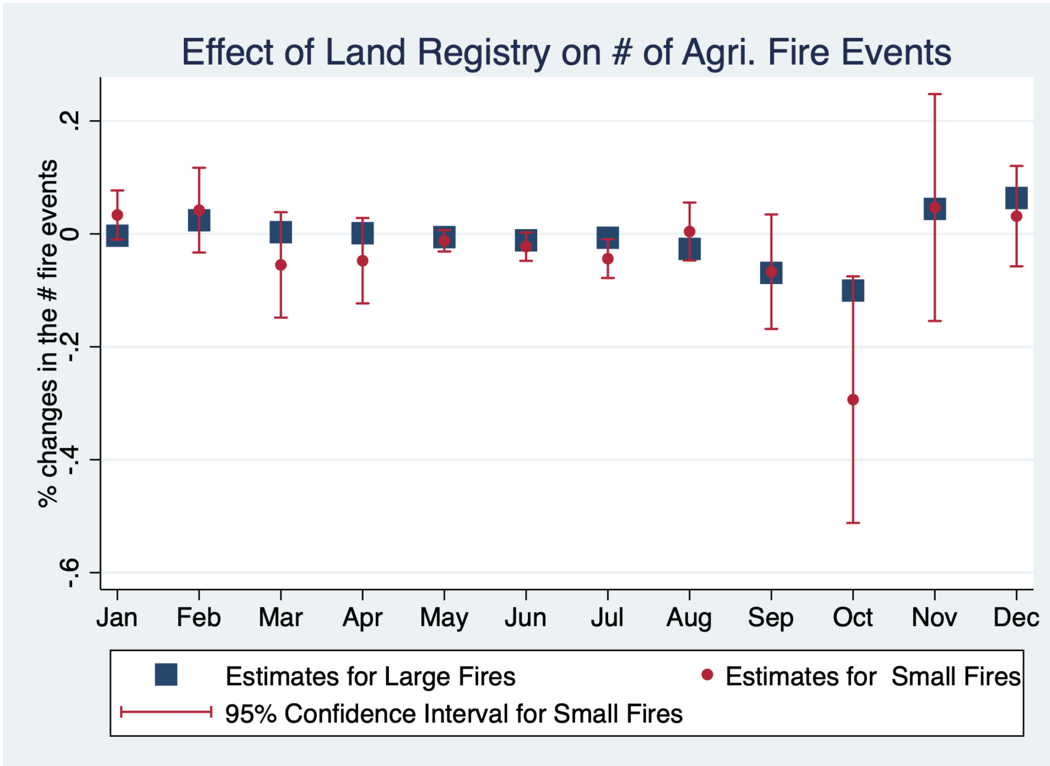


Figure 9: Average treatment effects of the land registry on fire events

the decrease of fire events in barren lands is much smaller and not statistically significant.

To test the second implication, we examine the impact of the land registry on fires detected in the daytime and fires detected in the nighttime separately. Columns 3 and 4 in Table 8 shows that the reduction of fire events is mainly driven by fires detected in the daytime (19%), while the fire events detected in the nighttime remain almost unchanged.

The above results once again confirm the main channel across time and space. The land registry reduces the type of fires at fertile lands where land-attached investment increases the most, and during the day when the wildfires are most likely spotted and contained by farmers.

6 Conclusion

For the first time, we show that improved property rights through complete cadastre and clearly delineated boundaries can effectively reduce agricultural fire events and burned areas. We provide evidence on this phenomenon by analyzing the Hellenic Cadastre which from 2014 to 2019, digitalized the property boundary on 85% of Greece lands. The mandatory land registry resolves

Table 8: Land Registry on Heterogenuous Wildfires

	(1) Agri. High	(2) Agri. Low	(3) Daytime	(4) Nighttime
Land Registry	-.174*	-.0705	-.188*	-.0429
	(.104)	(.0641)	(.105)	(.0493)
Mean of Dep. Var.	3.33	1.39	4.52	.23
Year FE	X	X	X	X
Regional Unit FE	X	X	X	X
Observations	531	531	531	531

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the natural log of the number of agricultural fires in high agricultural potential lands in column (1), low potential lands in column (2), in the daytime in column (3), and in the nighttime in column (4). *Mean of Dep. Var.* shows the average number of fire events (without natural log). Standard errors are clustered at the regional unit level.

potential land disputes and provides tenure security for agricultural landowners. The landowners in turn, expand farming areas, increase long-term investment such as fallowing land and tree planting, stock more fire suppression equipment, and reduce stubble burning. The evidence suggests that the large reduction in fire events and burned areas are likely driven by more long term oriented land management associated with improved property rights.

The case study of Greece complements the recent findings of a human-driven decline in global burned area by Andela et al. (2017), who show the decline is mainly driven by agricultural expansion. In particular, they suggest that human presence reduces fire activities, likely because people increase investment, reduce agricultural waste burning, and exert more fire suppression efforts to protect valuable assets.

The large effect of fire mitigation done by private landowners shows that larger investment in land is an important pathway through which improved property rights reduce fire hazards. It suggests that policies incentivizing private landowners to mitigate wildfires should receive more considerations.

Our study has some limitations driven in part by data availability. First, we cannot pin down the motivation of landowners behind the changing agricultural practices associated with improved property rights. Second, we cannot quantify the fire damage saved by the land registry. Finally, we cannot disentangle how much reduction in fires is driven by increased fire suppression equipment, less stubble burning, and farming expansion. Data at the farm level may shed light on these issues.

References

Abdurrahman, Muhammad Isa, Sukalpaa Chaki, and Gaurav Saini (2020). Stubble burning: Effects on health & environment, regulations and management practices. *Environmental Advances 2*, 100011.

Absher, James D. and Jerry J. Vaske (2006). An analysis of homeowner and agency wildland fire mitigation strategies. In *In: Peden, John G.; Schuster, Rudy M., Comps., Eds. Proceedings of the 2005 Northeastern Recreation Research Symposium; 2005 April 10-12; Bolton Landing, NY. Gen. Tech. Rep. NE-341. Newtown Square, PA: US Forest Service, Northeastern Research Station: 231-236.*

Alchian, Armen A. and Harold Demsetz (1973). The property right paradigm. *The journal of economic history 33*(1), 16–27.

Ali, Daniel Ayalew, Klaus Deininger, and Markus Goldstein (2014). Environmental and gender impacts of land tenure regularization in Africa: Pilot evidence from Rwanda. *Journal of Development Economics 110*, 262–275.

Allen, Douglas W. (1998). Property rights, transaction costs, and Coase: One more time. In *Coasean Economics Law and Economics and the New Institutional Economics*, pp. 105–118. Springer.

Andela, Niels, Douglas C. Morton, Louis Giglio, Yang Chen, Guido R. van der Werf, Prasad S. Kasibhatla, Rurth S. DeFries, G. J. Collatz, S. Hantson, and Silvia Kloster (2017). A human-driven decline in global burned area. *Science 356*(6345), 1356–1362.

Arima, Eugenio Y., Cynthia S. Simmons, Robert T. Walker, and Mark A. Cochrane (2007). Fire in the Brazilian Amazon: A spatially explicit model for policy impact analysis. *Journal of Regional Science 47*(3), 541–567.

Arruñada, Benito (2017). How to make land titling more rational. In *Brigham-Kanner Prop. Rts. Conf. J.*, Volume 6, pp. 73. HeinOnline.

Arruñada, Benito (2018). Evolving practice in land demarcation. *Land Use Policy 77*, 661–675.

Bank, World (1992). *World Development Report 1992: Development and the Environment*. The World Bank.

Barbayiannis, Nikolaos, K. Panayotopoulos, D. Psaltopoulos, and D. Skuras (2011). The influence of policy on soil conservation: A case study from Greece. *Land Degradation & Development 22*(1), 47–57.

Barbier, Edward B. (1997). The economic determinants of land degradation in developing countries. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences 352*(1356), 891–899.

Barbier, Edward B. and Joanne C. Burgess (2001). The economics of tropical deforestation. *Journal of Economic Surveys 15*(3), 413–433.

Besley, Timothy (1995). Property rights and investment incentives: Theory and evidence from Ghana. *Journal of political Economy 103*(5), 903–937.

Besley, Timothy and Maitreesh Ghatak (2010). Property rights and economic development. In *Handbook of Development Economics*, Volume 5, pp. 4525–4595. Elsevier.

Blandford, David (2019, April). "Burn Baby Burn" – Controlling the Risk of Wildfires in Greece. Technical Report 289654, Agricultural Economics Society - AES.

Borgschulte, Mark, David Molitor, and Eric Zou (2018). Air pollution and the labor market: Evidence from wildfire smoke. Technical report, Working Paper.

Boschetti, Luigi, David P. Roy, Louis Giglio, Haiyan Huang, Maria Zubkova, and Michael L. Humber (2019). Global validation of the collection 6 MODIS burned area product. *Remote sensing of environment 235*, 111490.

Bowman, David MJS, Andrés Moreira-Muñoz, Crystal A. Kolden, Roberto O. Chávez, Ariel A. Muñoz, Fernanda Salinas, Álvaro González-Reyes, Ronald Rocco, Francisco de la Barrera, and Grant J. Williamson (2019). Human–environmental drivers and impacts of the globally extreme 2017 Chilean fires. *Ambio 48*(4), 350–362.

Bowman, David MJS, Grant J. Williamson, John T. Abatzoglou, Crystal A. Kolden, Mark A. Cochrane, and Alistair MS Smith (2017). Human exposure and sensitivity to globally extreme wildfire events. *Nature ecology & evolution 1*(3), 1–6.

Brenkert–Smith, Hannah, Patricia A. Champ, and Nicholas Flores (2006). Insights into wildfire mitigation decisions among wildland–urban interface residents. *Society and Natural Resources 19*(8), 759–768.

Burby, Raymond J. and Peter J. May (1998). IntergovernmentalEnvironmental Planning: Addressing the Commitment Conundrum. *Journal of Environmental Planning and Management 41*(1), 95–110.

Burgess, Robin, Matthew Hansen, Benjamin A. Olken, Peter Potapov, and Stefanie Sieber (2012). The political economy of deforestation in the tropics. *The Quarterly journal of economics 127*(4), 1707–1754.

Butry, David and Geoffrey Donovan (2008). Protect thy neighbor: Investigating the spatial externalities of community wildfire hazard mitigation. *Forest Science 54*(4), 417–428.

Calleja, Juan Antonio, Marta Escolà, João Carvalho, Josep Maria Forcadell, Emmanuel Serrano, and Jordi Bartolomé (2019). Cattle grazing fails to control shrub encroachment in Mediterranean landscapes. *Rangeland Ecology & Management 72*(5), 803–811.

Chay, Kenneth Y. and Michael Greenstone (2003). The impact of air pollution on infant mortality: Evidence from geographic variation in pollution shocks induced by a recession. *The quarterly journal of economics 118*(3), 1121–1167.

Colantoni, Andrea, Gianluca Egidi, Giovanni Quaranta, Roberto D'Alessandro, Sabato Vinci, Rosario Turco, and Luca Salvati (2020). Sustainable Land Management, Wildfire Risk and the Role of Grazing in Mediterranean Urban-Rural Interfaces: A Regional Approach from Greece. *Land 9*(1), 21.

Collins, H. P., P. E. Rasmussen, and C. L. Douglas Jr (1992). Crop rotation and residue management effects on soil carbon and microbial dynamics. *Soil Science Society of America Journal 56*(3), 783–788.

Collins, Kathryn M., Owen F. Price, and Trent D. Penman (2015). Spatial patterns of wildfire ignitions in south-eastern Australia. *International Journal of Wildland Fire 24*(8), 1098–1108.

Collins, Timothy W. (2008). What influences hazard mitigation? Household decision making about wildfire risks in Arizona's White Mountains. *The Professional Geographer 60*(4), 508–526.

Collins, Timothy W. (2009). Influences on wildfire hazard exposure in Arizona's high country. *Society and Natural Resources 22*(3), 211–229.

Cotula, Lorenzo (2009). *Land Grab or Development Opportunity?: Agricultural Investment and International Land Deals in Africa.* Iied.

Daley, S. (2013). Who Owns This Land? In Greece, Who Knows? *NYTimes. com*.

Damalas, Christos A. and Anastasios S. Lithourgidis (2011). Winter barley performance on two different soils under conservation tillage systems. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science 61*(1), 33–38.

De Chaisemartin, Clément and Xavier D'Haultfœuille (2020). Difference-in-differences estimators of intertemporal treatment effects. *Available at SSRN 3731856*.

De Chaisemartin, Clément and Xavier d'Haultfoeuille (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review 110*(9), 2964–96.

De Janvry, Alain, Kyle Emerick, Marco Gonzalez-Navarro, and Elisabeth Sadoulet (2015). Delinking land rights from land use: Certification and migration in Mexico. *American Economic Review 105*(10), 3125–49.

De Soto, Hernando (2000). *The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else.* Civitas Books.

Deininger, Klaus and Songqing Jin (2006). Tenure security and land-related investment: Evidence from Ethiopia. *European Economic Review 50*(5), 1245–1277.

Deininger, Klaus W. (2003). *Land Policies for Growth and Poverty Reduction.* World Bank Publications.

Deryugina, Tatyana, Garth Heutel, Nolan H. Miller, David Molitor, and Julian Reif (2019). The mortality and medical costs of air pollution: Evidence from changes in wind direction. *American Economic Review 109*(12), 4178–4219.

Diakakis, Michalis, Gavriil Xanthopoulos, and Leontios Gregos (2016). Analysis of forest fire fatalities in Greece: 1977–2013. *International Journal of Wildland Fire 25*(7), 797–809.

Edwards, Ryan B., Rosamond L. Naylor, Matthew M. Higgins, and Walter P. Falcon (2020). Causes of Indonesia's forest fires. *World Development 127*, 104717.

Enemark, Stig, Keith Clifford Bell, Christiaan Lemmen, and Robin McLaren (2014). *Fit-for-Purpose Land Administration*. International Federation of Surveyors.

Enemark, Stig, Robin Mclaren, and Christiaan Lemmen (2016). Fit-for-purpose land administration: Guiding principles for country implementation.

Erenstein, Olaf (2003). Smallholder conservation farming in the tropics and sub-tropics: A guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems & Environment 100*(1), 17–37.

Fenske, James (2011, July). Land tenure and investment incentives: Evidence from West Africa. *Journal of Development Economics 95*(2), 137–156.

Feranec, Jan (2016). Project CORINE Land Cover. In *European Landscape Dynamics*, pp. 39–44. CRC Press.

Fernandes, Paulo M. (2013). Fire-smart management of forest landscapes in the Mediterranean basin under global change. *Landscape and Urban Planning 110*, 175–182.

Ferrara, Carlotta, Maurizio Marchi, Margherita Carlucci, Anastasios Mavrakis, Piermaria Corona, and Luca Salvati (2018). The 2007 crisis and Greek wildfires: A multivariate analysis of suppression times. *Environmental monitoring and assessment 190*(12), 1–12.

Field, Erica (2007). Entitled to work: Urban property rights and labor supply in Peru. *The Quarterly Journal of Economics 122*(4), 1561–1602.

Flannigan, Mike, Alan S. Cantin, William J. De Groot, Mike Wotton, Alison Newbery, and Lynn M. Gowman (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management 294*, 54–61.

Flannigan, Mike D., Meg A. Krawchuk, William J. de Groot, B. Mike Wotton, and Lynn M. Gowman (2009). Implications of changing climate for global wildland fire. *International journal of wildland fire 18*(5), 483–507.

Galiani, Sebastian and Ernesto Schargrodsky (2011). Land property rights and resource allocation. *The Journal of Law and Economics 54*(S4), S329–S345.

Galor, Oded and Ömer Özak (2015). Land productivity and economic development: Caloric suitability vs. agricultural suitability. *Brown University Working Paper*.

Galor, Oded and Ömer Özak (2016). The agricultural origins of time preference. *American Economic Review 106*(10), 3064–3103.

Galor, Oded, Ömer Özak, and Assaf Sarid (2016). Geographical origins and economic consequences of language structures. *Brown University Working Paper*.

Ganteaume, Anne, Andrea Camia, Marielle Jappiot, Jesus San-Miguel-Ayanz, Marlène Long-Fournel, and Corinne Lampin (2013). A review of the main driving factors of forest fire ignition over Europe. *Environmental management 51*(3), 651–662.

Giglio, Louis, Luigi Boschetti, David P. Roy, Michael L. Humber, and Christopher O. Justice (2018). The Collection 6 MODIS burned area mapping algorithm and product. *Remote sensing of environment 217*, 72–85.

Giglio, Louis, Wilfrid Schroeder, and Christopher O. Justice (2016). The collection 6 MODIS active fire detection algorithm and fire products. *Remote Sensing of Environment 178*, 31–41.

Goldammer, J. G., G. Xanthopoulos, G. Eftychidis, G. Mallinis, I. Mitsopoulos, and A. Dimitrakopoulos (2019). Report of the independent committee tasked to analyze the underlying causes and explore the perspectives for the future management of landscape fires in Greece (available at: https://gfmc. online/wp-content/uploads. *FLFM-Greece-Committee-Report-07-February-2019. pdf*.

Goldstein, Markus and Christopher Udry (2008). The profits of power: Land rights and agricultural investment in Ghana. *Journal of political Economy 116*(6), 981–1022.

Graff Zivin, Joshua and Matthew Neidell (2012). The impact of pollution on worker productivity. *American Economic Review 102*(7), 3652–73.

Hall, Troy E. and Megan Slothower (2009). Cognitive factors affecting homeowners' reactions to defensible space in the Oregon Coast Range. *Society and Natural Resources 22*(2), 95–110.

Hanna, Rema and Paulina Oliva (2015). The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City. *Journal of Public Economics 122*, 68–79.

Hazarika, Gautam, Chandan Kumar Jha, and Sudipta Sarangi (2019). Ancestral ecological endowments and missing women. *Journal of Population Economics 32*(4), 1101–1123.

He, Guojun, Tong Liu, and Maigeng Zhou (2020). Straw burning, PM2. 5, and death: Evidence from China. *Journal of Development Economics 145*, 102468.

Henderson, Martha, Kostas Kalabokidis, Emmanuel Marmaras, Pavlos Konstantinidis, and Manussos Marangudakis (2005). Fire and society: A comparative analysis of wildfire in Greece and the United States. *Human Ecology Review*, 169–182.

Holman, Adam Truman (1946). *Fire Fighting on Farms*. Number 612. US Department of Agriculture.

Jayachandran, Seema (2009). Air quality and early-life mortality evidence from Indonesia's wildfires. *Journal of Human resources 44*(4), 916–954.

Jones, S. W. (1943). Fire Fighting Equipment for the Farm and Home.

Justice, C. O., Louis Giglio, S. Korontzi, J. Owens, J. T. Morisette, D. Roy, J. Descloitres, S. Alleaume, F. Petitcolin, and Y. Kaufman (2002). The MODIS fire products. *Remote sensing of Environment 83*(1-2), 244–262.

Kabubo-Mariara, Jane, Vincent Linderhof, and Gideon Kruseman (2010). Does land tenure security matter for investment in soil and water conservation? Evidence from Kenya. *African Journal of Agricultural and Resource Economics 4*(311-2016-5544), 123–139.

Kapotas, Panagiotis and Efpraxia Aithra Maria (2017). Livestock grazing, forest protection and law in Greece. *Management of Environmental Quality: An International Journal*.

Karali, A., M. Hatzaki, C. Giannakopoulos, A. Roussos, Gavriil Xanthopoulos, and V. Tenentes (2014). Sensitivity and evaluation of current fire risk and future projections due to climate change: The case study of Greece. *Natural Hazards and Earth System Sciences 14*(1), 143–153.

Karanikola, Paraskevi P., Stilianos A. Tampakis, Evangelos I. Manolas, and Ioannis I. Papalinardos (2011). The 2007 forest fires in the prefecture of Ilia: The views of citizens with regard to the actions taken before, during and after the fires. *International journal of environmental studies 68*(5), 687–701.

Kizos, Thanasis and Maria Koulouri (2006). Agricultural landscape dynamics in the Mediterranean: Lesvos (Greece) case study using evidence from the last three centuries. *Environmental science & policy 9*(4), 330–342.

Kolios, Stavros and Chrysostomos D. Stylios (2013). Identification of land cover/land use changes in the greater area of the Preveza peninsula in Greece using Landsat satellite data. *Applied Geography 40*, 150–160.

Kousky, Carolyn and Sheila M. Olmstead (2010). Induced development in risky locations: Fire suppression and land use in the American West. *Resources for the Future Washington, DC Working paper*.

Kousky, Fire Policy Carolyn, Sheila Olmstead, and Roger Sedjo (2013). In harm's way: Homeowner behavior and wildland fire policy. In *Wildfire Policy*, pp. 194–215. Routledge.

Lagouvardos, Kostas, Vasiliki Kotroni, Theodore M. Giannaros, and Stavros Dafis (2019). Meteorological conditions conducive to the rapid spread of the deadly wildfire in eastern Attica, Greece. *Bulletin of the American Meteorological Society 100*(11), 2137–2145.

Langpap, Christian and JunJie Wu (2021). Preemptive Incentives and Liability Rules for Wildfire Risk Management. *American Journal of Agricultural Economics*.

Liacos, L. G. (2015). Present Studies and History of Burning in Greece. *Fire Ecology 11*(3), 3–13.

Libecap, Gary D. and Dean Lueck (2011). The demarcation of land and the role of coordinating property institutions. *Journal of Political Economy 119*(3), 426–467.

Lin, Justin Yifu (1992). Rural reforms and agricultural growth in China. *The American economic review*, 34–51.

Lithourgidis, A. S., C. A. Damalas, and A. A. Gagianas (2006). Long-term yield patterns for continuous winter wheat cropping in northern Greece. *European Journal of Agronomy 25*(3), 208–214.

Lueck, Dean and Jonathan K. Yoder (2016). *Clearing the Smoke from Wildfire Policy: An Economic Perspective*, Volume 22. PERC.

Malesky, Edmund J. and Markus Taussig (2009). Where is credit due? Legal institutions, connections, and the efficiency of bank lending in Vietnam. *The Journal of Law, Economics, & Organization 25*(2), 535–578.

Mancilla-Leytón, J. M., R. Pino Mejías, and A. Martín Vicente (2013). Do goats preserve the forest? Evaluating the effects of grazing goats on combustible Mediterranean scrub. *Applied Vegetation Science 16*(1), 63–73.

Martin, Ingrid M., Holly Bender, and Carol Raish (2007). What motivates individuals to protect themselves from risks: The case of wildland fires. *Risk Analysis: An International Journal 27*(4), 887–900.

McCaffrey, Sarah (2004). Thinking of wildfire as a natural hazard. *Society and Natural Resources 17*(6), 509–516.

McCaffrey, Sarah M., Melanie Stidham, Eric Toman, and Bruce Shindler (2011). Outreach programs, peer pressure, and common sense: What motivates homeowners to mitigate wildfire risk? *Environmental Management 48*(3), 475–488.

McFarlane, Bonita L., Tara K. McGee, and Hilary Faulkner (2011). Complexity of homeowner wildfire risk mitigation: An integration of hazard theories. *International Journal of Wildland Fire 20*(8), 921–931.

McGee, Tara K. (2005). Completion of recommended WUI fire mitigation measures within urban households in Edmonton, Canada. *Global Environmental Change Part B: Environmental Hazards 6*(3), 147–157.

McGee, Tara K. and Stefanie Russell (2003). "It's just a natural way of life…" an investigation of wildfire preparedness in rural Australia. *Global Environmental Change Part B: Environmental Hazards 5*(1), 1–12.

Moeltner, Klaus, M.-K. Kim, Erqian Zhu, and Wei Yang (2013). Wildfire smoke and health impacts: A closer look at fire attributes and their marginal effects. *Journal of Environmental Economics and Management 66*(3), 476–496.

Molina-Terrén, Domingo M., Gavriil Xanthopoulos, Michalis Diakakis, Luis Ribeiro, David Caballero, Giuseppe M. Delogu, Domingos X. Viegas, Carlos A. Silva, and Adrián Cardil (2019). Analysis of forest fire fatalities in southern Europe: Spain, Portugal, Greece and Sardinia (Italy). *International journal of wildland fire 28*(2), 85–98.

Monroe, Martha C. and Kristen C. Nelson (2004). The value of assessing public perceptions: Wildland fire and defensible space. *Applied Environmental Education and Communication 3*(2), 109–117.

Morehouse, Barbara J., Martha Henderson, Kostas Kalabokidis, and Theodoros Iosifides (2011). Wildland fire governance: Perspectives from Greece. *Journal of Environmental Policy & Planning 13*(4), 349–371.

Moreira, Francisco, Olga Viedma, Margarita Arianoutsou, Thomas Curt, Nikos Koutsias, Eric Rigolot, Anna Barbati, Piermaria Corona, Pedro Vaz, and Gavriil Xanthopoulos (2011). Landscape–wildfire interactions in southern Europe: Implications for landscape management. *Journal of environmental management 92*(10), 2389–2402.

Morello, Thiago Fonseca, Rossano Marchetti Ramos, Liana O. Anderson, Nathan Owen, Thais Michele Rosan, and Lara Steil (2020). Predicting fires for policy making: Improving accuracy of fire brigade allocation in the Brazilian Amazon. *Ecological Economics 169*, 106501.

Morisette, Jeffrey T., Jeffrey L. Privette, and Christopher O. Justice (2002). A framework for the validation of MODIS land products. *Remote sensing of environment 83*(1-2), 77–96.

Mouflis, George D. and Ioannis Z. Gitas (2007). Analysis of the causality of fires (1985-1997) in Macedonia, Greece. *TOWARDS AN OPERATIONAL USE OF REMOTE SENSING IN FOREST FIRE MANAGEMENT*, 218.

Neill, Sean P. and David R. Lee (2001). Explaining the adoption and disadoption of sustainable agriculture: The case of cover crops in northern Honduras. *Economic development and cultural change 49*(4), 793–820.

North, Malcom P., Scott L. Stephens, Brandom M. Collins, James K. Agee, Gregory Aplet, Jerry F. Franklin, and Peter Z. Fule (2015). Reform forest fire management. *Science 349*(6254), 1280–1281.

OECD (2018). *OECD Economic Surveys: Greece 2018.*

Padilla, Marc, Stephen V. Stehman, Ruben Ramo, Dante Corti, Stijn Hantson, Patricia Oliva, Itziar Alonso-Canas, Andrew V. Bradley, Kevin Tansey, and Bernardo Mota (2015). Comparing the accuracies of remote sensing global burned area products using stratified random sampling and estimation. *Remote sensing of environment 160*, 114–121.

Palaiologou, Palaiologos, Kostas Kalabokidis, Alan A. Ager, and Michelle A. Day (2020). Development of comprehensive fuel management strategies for reducing wildfire risk in Greece. *Forests 11*(8), 789.

Palaiologou, Palaiologos, Kostas Kalabokidis, Andreas Troumbis, Michelle A. Day, Max Nielsen-Pincus, and Alan A. Ager (2021). Socio-Ecological Perceptions of Wildfire Management and Effects in Greece. *Fire 4*(2), 18.

Papakostas, Apostolis (2018). Building State Infrastructural Capacities: Sweden and Greece. In *Bureaucracy and Society in Transition.* Emerald Publishing Limited.

Parresol, Bernard R., John I. Blake, and Andrew J. Thompson (2012). Effects of overstory composition and prescribed fire on fuel loading across a heterogeneous managed landscape in the southeastern USA. *Forest Ecology and Management 273*, 29–42.

Rangel, Marcos A. and Tom S. Vogl (2019). Agricultural fires and health at birth. *Review of Economics and Statistics 101*(4), 616–630.

Rasmussen, Patricia E. and W. J. Parton (1994). Long-term effects of residue management in wheat-fallow: I. Inputs, yield, and soil organic matter. *Soil Science Society of America Journal 58*(2), 523–530.

Rehm, Ronald, David Evans, William Mell, Simo Hostikka, Kevin McGrattan, Glenn Forney, Charles Bouldin, and Elisa Baker (2003). 5th Symposium on Fire & Forest Meteorology, Orlando, Florida, 16-20.

Rice, Charles W. and Fernando O. Garcia (1994). Biologically active pools of carbon and nitrogen in tallgrass prairie soil. *Defining soil quality for a sustainable environment 35*, 201–208.

Rioux, J. and M. G. San Juan (2016). Soil fertility and climate benefits of Conservation Agriculture adoption in the highlands of Tanzania. *Nature & Faune 30*(1), 90–93.

Rokos, Dimitris (2018). Recent developments in the context of the Hellenic Cadastre. *Proceedings of the Tufe2018-Economy, Society and Climate Change–The impact of mega trends in the Built Environment, Construction Industry and Real Estate, Athens, Greece*, 7–10.

Rokos, Dimitris, Konstantinos Kyriazis, Panos Lolonis, and Ktimatologio SA (2010). Setting up the infrastructure for improving the development of Cadastre in Greece. *Population 11*, 000.

Ruiz-Mirazo, J., A. B. Robles, and J. L. González Rebollar (2009). Pastoralism in natural parks of Andalusia (Spain): A tool for fire prevention and the naturalization of ecosystems.

Shafran, Aric P. (2008). Risk externalities and the problem of wildfire risk. *Journal of Urban Economics 64*(2), 488–495.

Sheldon, Tamara L. and Chandini Sankaran (2017). The impact of Indonesian forest fires on Singaporean pollution and health. *American Economic Review 107*(5), 526–29.

Statheropoulos, M. and S. Karma (2007). How to be shield against forest fire and smoke impacts: A list of recommendations for local community and population.

Stolle, F. and E. F. Lambin (2003). Interprovincial and interannual differences in the causes of land-use fires in Sumatra, Indonesia. *Environmental Conservation 30*(4), 375–387.

Thornes, John B. and John Wainwright (2004). *Environmental Issues in the Mediterranean: Processes and Perspectives from the Past and Present.* Routledge.

Timmins, Merrill Sylvester (1976). *Safeguard Your Farm Against Fire.* Number 2150. Department of Agriculture, Science and Education Administration.

Tsigarida, Aikaterini (2019). *Evolution of the Cadastral System in Greece: Investigation of Attitudes and Perceptions of Citizens (in Greek).* Ph. D. thesis, Hellenic Open University.

Turco, Marco, Sixto Herrera, Etienne Tourigny, Emilio Chuvieco, and Antonello Provenzale (2019). A comparison of remotely-sensed and inventory datasets for burned area in Mediterranean Europe. *International Journal of Applied Earth Observation and Geoinformation 82*, 101887.

Twerefou, Daniel Kwabena, Eric Osei-Assibey, and F. Agyire-Tetteh (2011). Land Tenure Security, Investment and the Environment in Ghana.

Vogltance, Bob, Larry Wiles, and Jeff Bassett (2007). Fire Prevention on the Farm and Ranch What every country homeowner needs to know about fire!

World Bank (2019). Doing Business in the European Union 2020: Greece, Ireland and Italy.

Xanthopoulos, Gavriil (1998). Forest fires in Greece: Past, present and future. *WILDLAND FIRES: AWorldwide REALITY*, 141.

Xanthopoulos, Gavriil (2004). Who should be responsible for forest fires? Lessons from the Greek experience. In *Proceedings of the "II International Symposium on Fire Economics, Planning and Policy: A Global View", April 19e22*, pp. 189e202. Citeseer.

Xystrakis, Fotios, Thomas Psarras, and Nikos Koutsias (2017). A process-based land use/land cover change assessment on a mountainous area of Greece during 1945–2009: Signs of socio-economic drivers. *Science of the Total Environment 587*, 360–370.

Yoder, Jonathan (2013). Fuel for the Fire: Liability and the Economics of Wildfire Risk. In *Wildfire Policy*, pp. 66–86. Routledge.

Zirogiannis, Nikolaos (2009). Wildfire prevention and mitigation: The case of southern Greece.

Zivin, Joshua Graff, Tong Liu, Yingquan Song, Qu Tang, and Peng Zhang (2020). The unintended impacts of agricultural fires: Human capital in China. *Journal of Development Economics 147*, 102560.

Appendix A: Robust Checks for Main Results

For this paper, each observation is a regional unit-year cell $(s, t) \in \{1, \ldots, S\} \times \{1, 2, ...9\}$ where the 9 periods correspond to the years from 2011 to 2019. $D_{s,t}$ be an indicator of treatment. Let $Y_{s,t}$ be the outcome of interest (e.g., fire events or burned areas). For any $\ell \in \{0, \ldots, 7\}$ and $t \in \{\ell + 2, \ldots, 9\}$, let $N^1_{t,\ell} = \sum_{g:F_{g,1}=t-\ell} N_{g,t}$ be the number of observations in groups treated for the first time at period $t - \ell$, and let $N^{nt}_t = \sum_{g:F_{g,1}>t} N_{g,t}$ be the number of observations in groups untreated from period 1 to t. Let

$$\begin{aligned}\mathrm{DID}_{+,t,\ell} = &\sum_{g:F_{g,1}=t-\ell} \frac{N_{g,t}}{N^1_{t,\ell}} \left(Y_{g,t} - Y_{g,t-\ell-1}\right) \\ &- \sum_{g:F_{g,1}>t} \frac{N_{g,t}}{N^{nt}_t} \left(Y_{g,t} - Y_{g,t-\ell-1}\right)\end{aligned} \tag{3}$$

The DID_M estimator for ℓth year effect is then defined as: $\mathrm{DID}_{+,\ell} = \frac{\sum_{t=\ell+2}^{NT} N^1_{t,\ell} \mathrm{DID}_{+,t,\ell}}{\sum_{t=\ell+2}^{NT} N^1_{t,\ell}}$

Table A1 displays the year-by-year estimates using two-way fixed effect and $\mathrm{DID_M}$ methods. Compared to the coefficients in column 1 under two-way fixed effects method, the $\mathrm{DID_M}$ estimates in column 2 shows similar results with some coefficients becoming statistically insignificant, because $\mathrm{DID_M}$ estimates tend to have larger variances than the two-way fixed-effect estimates. To examine whether heterogeneous treatment effects is a serious issue, De Chaisemartin and d'Haultfoeuille (2020) suggests computing the ratio of the coefficients of the two-way fixed-effect estimates divided by the standard deviation of the weights. If the ratio is less than $\sqrt{3}$, the issue is a serious concern. In our case, the standard deviation of the weights is 0.27, which makes most ratios post the second year larger than $\sqrt{3}$. The large ratios along with comparable results across different estimators suggest that heterogeneous treatment effects are unlikely to be a serious concern for fire incidences.

A similar pattern is observed when using agriculture burned areas as the dependent variable in columns 3 and 4. The $\mathrm{DID_M}$ estimates in column 4 shows somewhat larger effects, with 94 percent reduction in the second year and 95 percent reduction in the fifth year. In this case, the standard deviation of the weights of the two-way fixed-effect treatment effects is 0.37, which makes most ratios post the second year larger than $\sqrt{3}$, again suggesting heterogeneous treatment effects are unlikely to be a serious concern for fire incidences.

Table A1: Land Registry on Fires under DID_{M} estimators

	Log, Fire Events		Log, Burned Area	
	(1)	(2)	(3)	(4)
	Two-way	DIDm	Two-way	DIDm
same year effect	-.0395	.027	-.202	-.259
	(.118)	(.14)	(.221)	(.218)
1st year effect	.0224	-.171	-.326	-.352
	(.131)	(.168)	(.324)	(.325)
2nd year effect	-.654**	-.493	-.968	-1.01*
	(.297)	(.462)	(.595)	(.596)
3rd year effect	-.481	-.456	-1.38***	-1.39***
	(.5)	(.541)	(.423)	(.418)
4th year effect	-.477**	-.511	-1.62***	-1.62***
	(.21)	(.329)	(.414)	(.413)
5th year effect	-.523	-.883*	-1.79**	-1.73***
	(.355)	(.482)	(.675)	(.648)
Mean of Dep. Var.	4.76	4.76	5.62	5.62
Weather Controls	X	X	X	X
Year FE	X	X	X	X
Regional Unit FE	X	X	X	X
Observations	531		531	

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the natural log of fire incidences in columns (1) and (2), and the natural log of burned areas in columns (3) and (4). Odd columns present the two-way fixed effects estimates. Even columns present the estimator DID_{M} proposed by De Chaisemartin and D'Haultfœuille 2020. Weather controls include the average temperature and the total rainfall during the fire season. *Mean of Dep. Var.* shows the average number of fire events and the average burned areas in km^2 (without natural log). Standard errors are clustered at the region unit level.

Table A2: Land Registry on Fires under a Smaller Sample

	Log, # of Fire Events		Log, Burned Area	
	(1)	(2)	(3)	(4)
	Two-way	DIDm	Two-way	DIDm
same year effect	.0797	.179	-.276	-.346
	(.12)	(.152)	(.242)	(.24)
1st year effect	.149	-.0423	-.294	-.331
	(.131)	(.175)	(.372)	(.371)
2nd year effect	-.576*	-.558	-.984	-1.04*
	(.293)	(.421)	(.597)	(.605)
3rd year effect	-.447	-.535	-1.45***	-1.42***
	(.503)	(.529)	(.437)	(.427)
4th year effect	-.423*	-.536*	-1.66***	-1.66***
	(.216)	(.268)	(.417)	(.416)
5th year effect	-.512	-.855*	-1.96***	-1.77***
	(.367)	(.504)	(.67)	(.648)
Mean of Dep. Var.	4.3	4.3	4.3	4.3
Weather Controls	X	X	X	X
Year FE	X	X	X	X
Regional Unit FE	X	X	X	X
Observations	450		450	

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The sample is restricted to the regional units that receive land registry in the same year for more than 90% of areas. The dependent variable is the natural log of fire incidences in columns (1) and (2), and the natural log of burned areas in columns (3) and (4). Odd columns present the two-way fixed effects estimates. Even columns present the estimator DID_M proposed by De Chaisemartin and D'Haultfœuille 2020. Weather controls include the average temperature and the total rainfall during the fire season. *Mean of Dep. Var.* shows the average number of fire events and the average burned areas in km^2 (without natural log). Standard errors are clustered at the region unit level.

Table A3: Land Registry on Fires with Additional Controls

Dependent Variable:	Log, # of Fire Events		Log, Burned Area	
	(1)	(2)	(3)	(4)
same year effect	-.0395	-.0301	-.202	-.202
	(.118)	(.113)	(.221)	(.218)
1st year effect	.0224	.0304	-.326	-.256
	(.131)	(.134)	(.324)	(.327)
2nd year effect	-.654**	-.68**	-.968	-.73
	(.297)	(.297)	(.595)	(.695)
3rd year effect	-.481	-.504	-1.38***	-1.17**
	(.5)	(.49)	(.423)	(.451)
4th year effect	-.477**	-.414**	-1.62***	-1.46***
	(.21)	(.206)	(.414)	(.373)
5th year effect	-.523	-.633**	-1.79**	-1.65***
	(.355)	(.274)	(.675)	(.493)
# of Agri. Machinery		7.04e-06		-.0000101
		(9.28e-06)		(.0000141)
Population Density		.0000186		.0000324
		(.000205)		(.000222)
Crop Area		.00113		-.000459
		(.00202)		(.0044)
Mean of Dep. Var.	4.76	4.76	5.62	5.62
Year FE	X	X	X	X
Regional Unit FE	X	X	X	X
Observations	531	413	531	413

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the natural log of agricultural fire incidences in columns (1) and (2), and the natural log of agricutural burned areas in columns (3) and (4). *Mean of Dep. Var.* shows the average number of fire events and the average burned areas in km^2 (without natural log). Standard errors are clustered at the region unit level.

Table A4: Relationship between Land Registry and pre-trend Fire Events

Dependent Variable:	# of Agri. Fire Events, Log				
	Δ14-11	Δ17-11	Δ17-14	Δ19-14	Δ14-11
	(1)	(2)	(3)	(4)	(5)
year of land registry	.0000273	-2.65e-06	-.0000195		
	(.0000244)	(.0000302)	(.0000289)		
land registry by 2019 (0/1)				-.0359	-.218
				(.148)	(.195)
Mean Dep. Var.	-.33	-.28	.05	-.1	-.33
P-value of F-test	.27	.93	.5	.8100000000000001	.27
Adj. R-squared	0	-.02	-.01	-.03	0
Observations	55	49	49	34	55

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Linear Regressions. The regressions only include regional units have not received land registry. The dependent variable is the change of the natural log of agricultural fire events from 2011 to 2014 in Columns 1 and 5, from 2011 to 2017 in column 2, from 2014 to 2017 in column 3, and from 2014 to 2019 in column 5. The explanatory variables are the year for land registry and a binary indicator for whether a regional unit has received land registry by 2019.

Table A5: Relationship between Land Registry and pre-trend Burned Areas

Dependent Variable:	Agri. Burned Areas, Log				
	Δ14-11	Δ17-11	Δ17-14	Δ19-14	Δ14-11
	(1)	(2)	(3)	(4)	(5)
year of land registry	.0000479	.0000623	.0000169		
	(.000047)	(.0000537)	(.0000464)		
land registry by 2019 (0/1)				-.171	-.382
				(.276)	(.375)
Mean Dep. Var.	-.58	-.65	-.07	-.4	-.58
P-value of F-test	.31	.25	.72	.54	.31
Adj. R-squared	0	.01	-.02	-.02	0
Observations	55	49	49	34	55

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Linear Regressions. The regressions only include regional units have not received land registry. The dependent variable is the change of the natural log of agricultural burned areas from 2011 to 2014 in Columns 1 and 5, from 2011 to 2017 in column 2, from 2014 to 2017 in column 3, and from 2014 to 2019 in column 5. The explanatory variables are the year for land registry and a binary indicator for whether a regional unit has received land registry by 2019.

Table A6: Land Registry on other Measures of Fires

Dependent Variable:	# of Agri. Fire Events		Agri. Burned Area	
	(1) Arcsinh	(2) Normalize	(3) Arcsinh	(4) Normalize
same year effect	-.0424	.000165	-.238	.000406
	(.145)	(.000382)	(.275)	(.000708)
1st year effect	.0302	.000838	-.396	.00122
	(.157)	(.00067)	(.389)	(.00212)
2nd year effect	-.733**	-.00248**	-1.2*	-.00104
	(.35)	(.00121)	(.7)	(.00261)
3rd year effect	-.535	-.00205	-1.64***	-.00332**
	(.586)	(.00171)	(.515)	(.0016)
4th year effect	-.473*	-.00368***	-1.91***	-.0042**
	(.246)	(.00116)	(.501)	(.00162)
5th year effect	-.531	-.00245**	-2.14***	-.00459
	(.4)	(.00121)	(.799)	(.00295)
Mean of Dep. Var.	1.162	.002	.834	.002
Weather Control	X	X	X	X
Year FE	X	X	X	X
Regional Unit FE	X	X	X	X
Observations	531	531	531	531

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the number of agricultural fire events in columns (1) and (2), and agricultural burned areas in columns (3) and (4). Odd columns present the hyperbolic sine transformation (arcsinh) of the dependent variable. Even columns normalized the dependent variable by the area of regional units. Weather controls include the average temperature and the total rainfall during the fire season. *Mean of Dep. Var.* shows the average number of fire events and the average burned areas in km^2 (without hyperbolic sine) in columns 1 and 3. *Mean of Dep. Var.* shows the average number of fire events and burned areas divided by the area of regional units in columns 2 and 4. Standard errors are clustered at the region unit level.

Appendix B: Supplement Tables and Figures

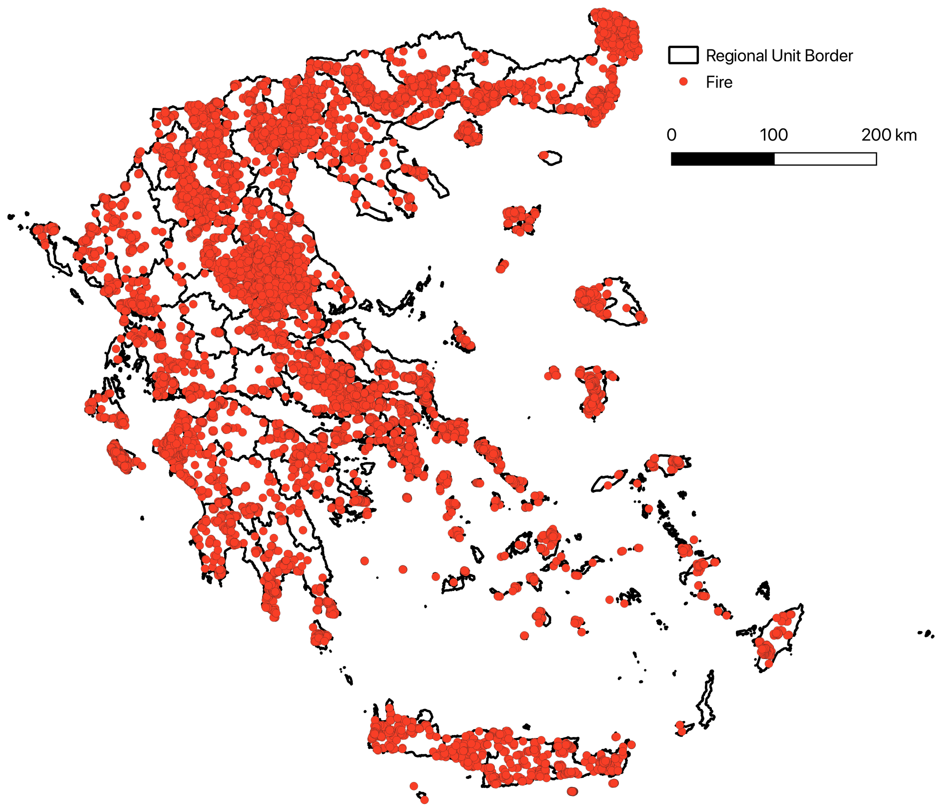


Figure B1: Distribution of Fires from 2011 to 2019

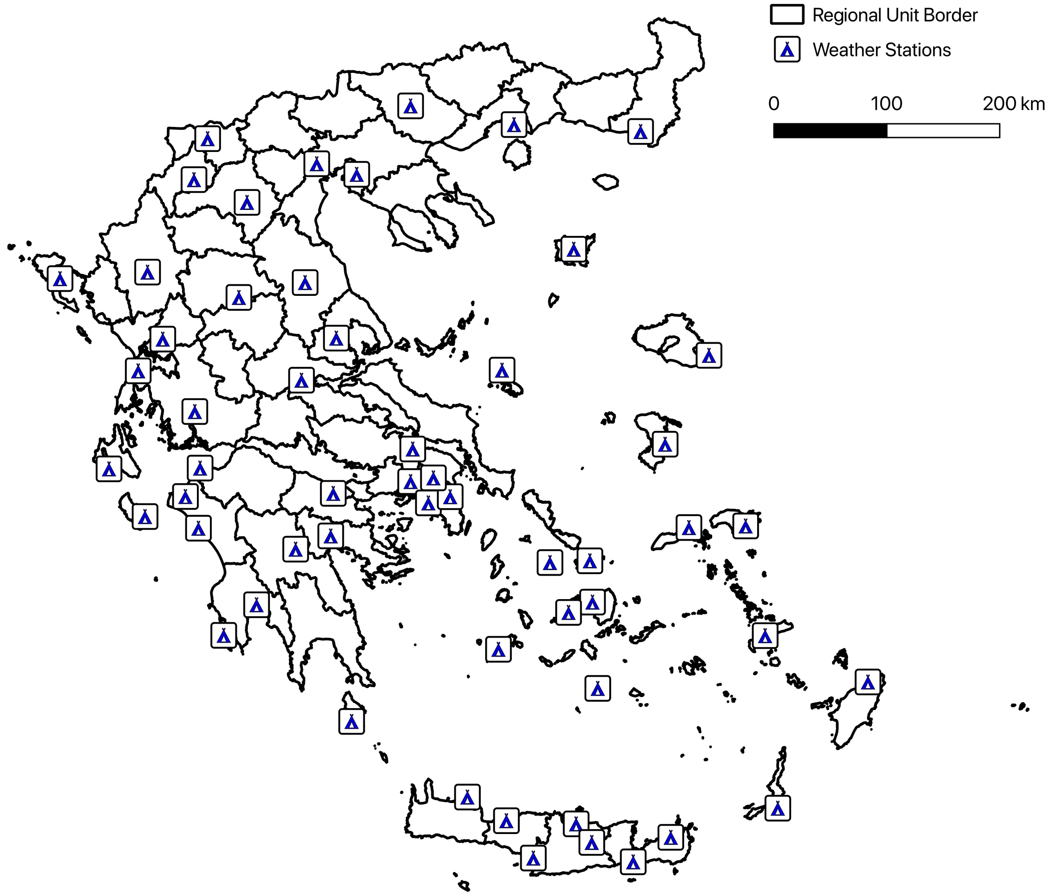


Figure B2: Distribution of weather stations across Greece

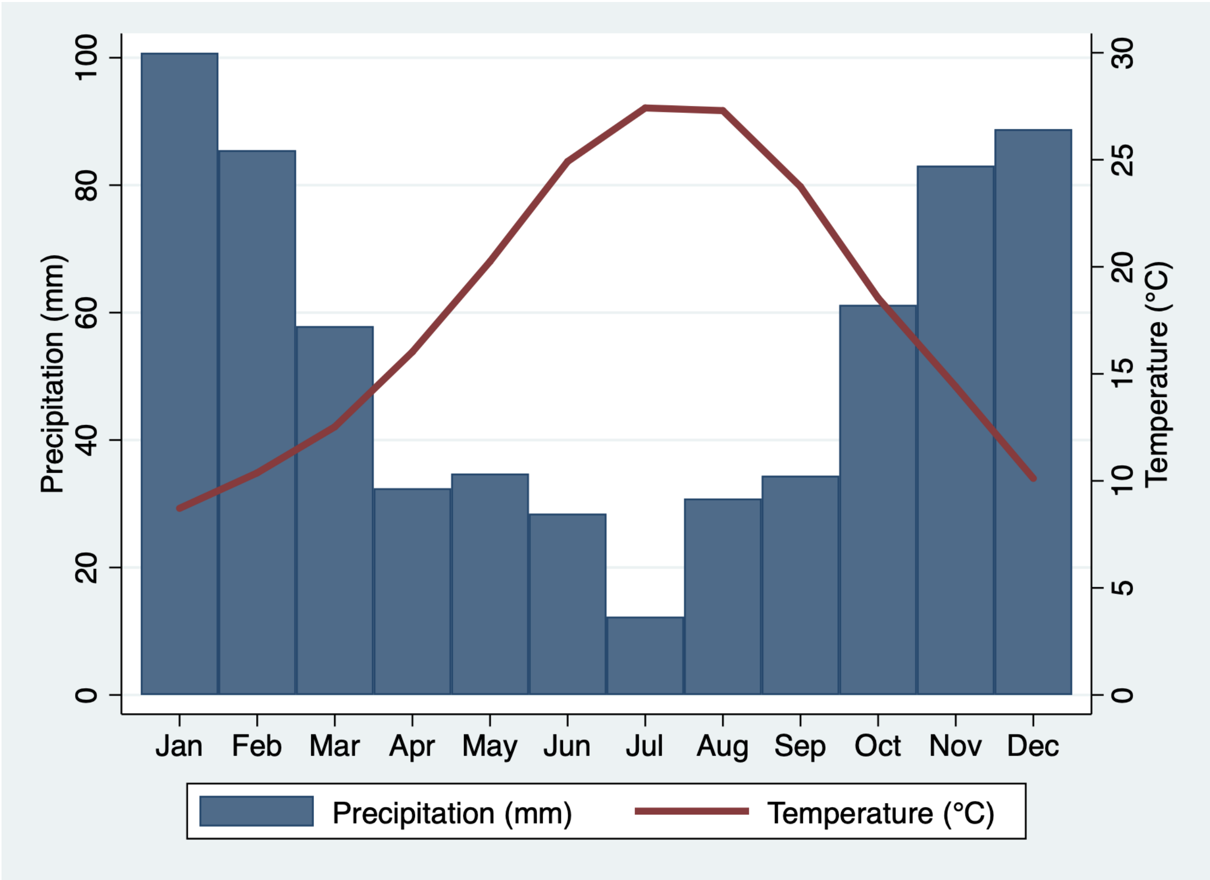
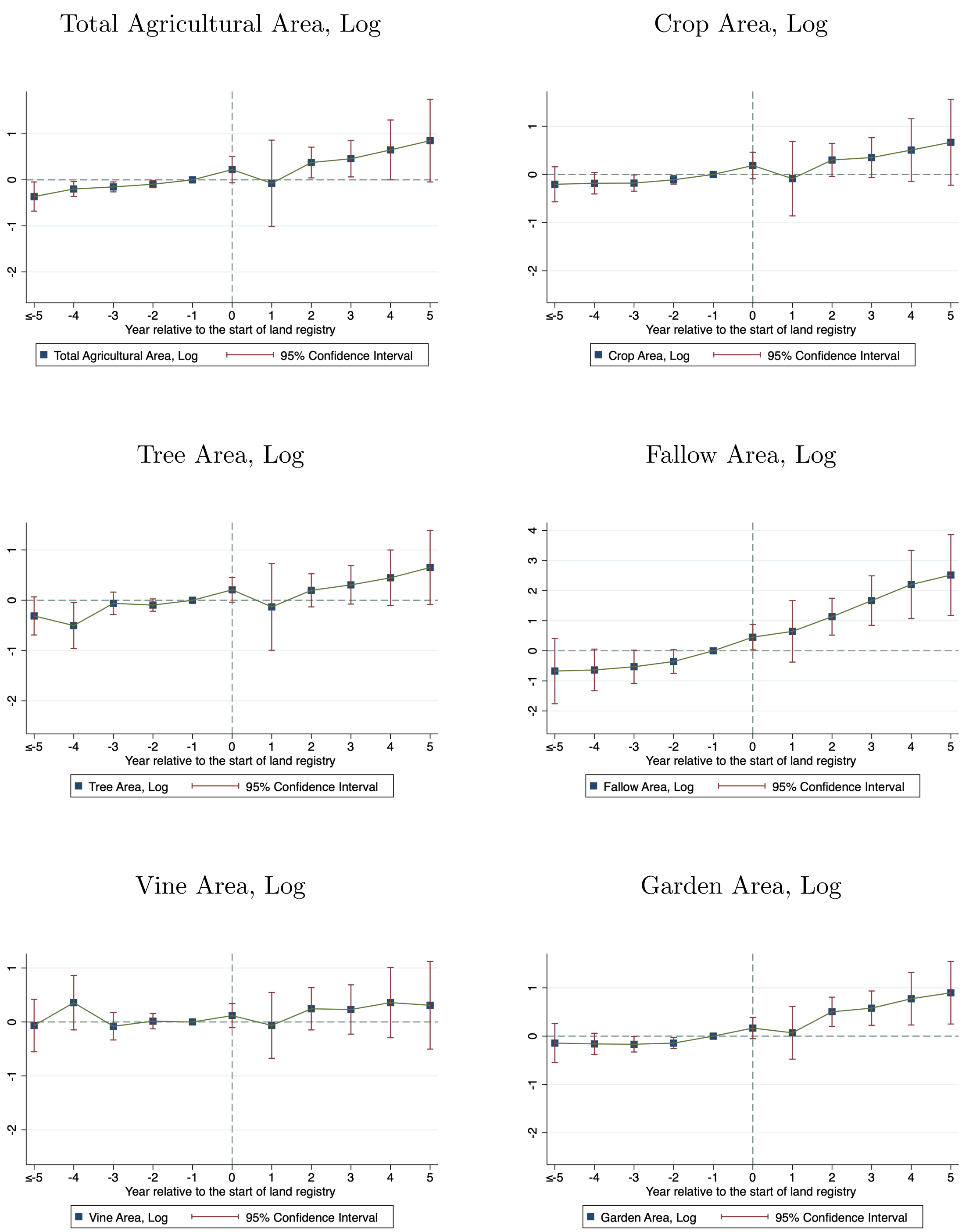


Figure B3: Average rainfall and temperature of Greece

Figure B4: A farmer's truck participating in fire suppression efforts. Source: Zirogiannis (2009)

Figure B5: Land Registry on Farming Area



Number of Sprayers, Log

Number of High Pressure Power Sprayers, Log

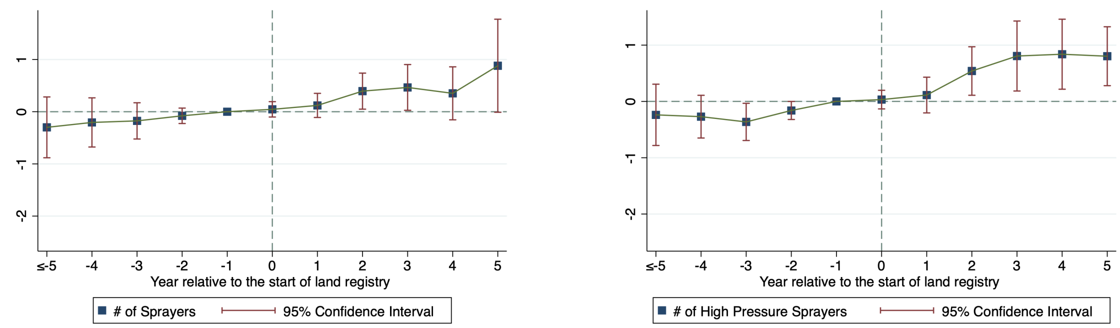


Figure B6: Trends of Agricultural Equipment