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Research article

Extreme weather events and crop insurance demand

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A R T I C L E I N F O

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A B S T R A C T

Flood, drought, and frost may be disruptive events for agriculture. The subsidised crop insurance schemes are coping strategies that increase farms resilience to weather shocks and in fact the occurrence of extreme weather events and the level of subsidised crop insurance are correlated. Stronger evidence is found in Southern geographical areas, where drought (a major risking risk) is more frequent, and for spring-summer crops, that are less resilient to weather shocks. The article points at the need to reform extant policies to move toward a holistic approach for risk management.

1. Introduction

Extreme weather events are causing several disruptions in the agricultural sector (e.g., Refs. [1–5]). Participation in crop insurance scheme is a method to improve the resilience of farms to the adverse consequences of extreme events [6].

We analyse the co-occurrence of extreme weather events and the level of subsidised crop insurance. The aim is to investigate how flood, drought, and frost events' occurrence may correlate with changes in the share of production values covered by subsidised insurance contracts. We study this link within the Italian risk management framework, a relevant case study in terms of weather risk exposure (e.g., Ref. [7]), insurance market structures (e.g., Ref. [8]), and political interventions (e.g., Ref. [9]). In Italy, farmers may sign both subsidised and non-subsidised insurance contracts. However, non-subsidised insurance contracts represent a very small share of the total (about 10 percent) and are generally subscribed by farms under the threshold for access to subsidies[1]: our analysis only considers subsidised crop insurance. Whenever we mention 'insurance demand' we refer to 'subsidised crop insurance demand'.

A limited literature deepens on the linkage between extreme weather events and crop insurance demand. An example is the analysis by Ref. [10] who conclude that the insurance demand tends to increase in response to climatic conditions (i.e., the prevailing climate) and the use of insurance reduces the exposure to weather risks. We contribute to expand their results by investigating the relationship between extreme weather (i.e., flood, drought, and frost) events and the insurance demand.

The contribution of this study to the academic and policy debate is twofold. First, in the empirical model, we use *ad hoc* indicators identifying the occurrence of flood, drought, and frost events, built using triggering thresholds as defined by the literature on weather risks (e.g., Refs. [11–13]). This methodological approach allows us to better model the incidence of extreme weather events as

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[1] More information are available at: https://www.ivass.it/media/interviste/documenti/interventi/2023/sdp_26_05_2023_conventionventi23_lecce/SDP_CONVEGNOLECCE_26.05.23.pdf (accessed on January 05, 2024).

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compared to simple weather information (e.g., levels of temperature or precipitation). Second, we find regularities in the linkage between the occurrence of catastrophic events and the insurance demand, a relationship relatively unexplored. The value of insured production, as share of the total, tends to increase when severe events (flood and frost) are more frequent. This relationship is particularly strong in Southern geographical areas and for spring-summer crops, likely due to the structure of the Italian insurance market (e.g., Refs. [8,14]).

2. Materials and methods

2.1. Measuring extreme weather events

The Risk Management Plan in Agriculture 2023 (named 'Plan' hereinafter) provides definitions for extreme weather events (i.e., flood, drought, and frost, eligible for the public support). A flood event is described as "*a natural disaster resulting from torrential rains or flooding due to exceptional atmospheric events or from natural and artificial bodies of water invading surrounding areas, accompanied by transport and storage of solid and incoherent material*" [15]. A drought event is identified as "*an extraordinary precipitation scarcity as compared to the normal precipitation of the period, involving the lowering of soil water content below a critical moisture threshold and/or the impoverishment of water supply sources such that the implementing irrigation rescue interventions is not even possible*" [15]. A frost event is defined as "*a temperature drop lower than 0 °C due to the presence of cold air masses*" [15]. We use these precise definitions to calibrate our empirical analysis.

The Plan recognises these extreme weather events as potential sources of shortfalls in crop production and of variability in agricultural yields, recalling the vast literature that demonstrated the sensitivity of the agricultural sector to the occurrence of flood (e.g., Refs. [6,16]), drought (e.g., Refs. [17,18]), and frost (e.g., Refs. [19,20]). However, the thresholds triggering the compensation mechanism are not defined in the Plan for flood, drought, and frost events.

Relevant literature (e.g., Refs. [21–24]), reviewed in Table 1, identify the correlation between heavy daily precipitation and the occurrence of flood events, and indicates triggering thresholds ranging between 25 mm (e.g., Ref. [25]) and 122.6 mm (e.g., Ref. [26]) with an average of about 50 mm (e.g., Refs. [27–29]). While the accumulation of heavy precipitation is a necessary, although not sufficient, condition for inducing floods [30], the correlation between heavy precipitation and flood occurrence depends on soil moisture [31]. [11,27] suggest that precipitation cumulated on previous five days larger than 53 mm identify a saturated soil.

Among different indicators available in literature to monitor, predict, and assess the severity of drought [32], the Standardised Precipitation Evapotranspiration Index (SPEI) is a promising one. The SPEI, built at different timescale (i.e., 1-, 3-, 6-, or 12-months) on the basis of precipitation and temperature levels and of evapotranspiration demand assessed through the climatic water balance, allows to evaluate the severity of drought (e.g., Ref. [33]). According to Ref. [34], the SPEI is the difference between precipitation (*P*) and potential evapotranspiration (*PET*) in a month *i*, as in equation (1):

$$D_i = P_i - PET_i \quad where \quad PET = 16K\left(\frac{10T}{I}\right)^m \tag{1}$$

where *T* is the monthly mean temperature (in °C), *I* is a heat index, *m* is a coefficient depending on *I*, and *K* is a correction factor

Table 1
Measuring extreme weather events.

Event		Indicator	Threshold in literature		Reference	Threshold in this study
Flood						
	soil moisture	5-days cumulated precipitation		>53 mm	[11,27]	>53 mm
	heavy precipitation	daily precipitation				>50 mm
				>25 mm	[25]	
				>40 mm	[38]	
				>50 mm	[27–29]	
				>64.5 mm	[21]	
				>122.6 mm	[26]	
Drought		Standardised Precipitation Evapotranspiration Index		< −1	[12]	< −1
Frost		daily temperature				
			durum wheat	< −4 °C	[1]	< −4 °C
			almond	< −2.9 °C	[39]	< −2.9 °C
			apple	< −2.2 °C	[40]	< −2.2 °C
			grape wine	< −2 °C	[41]	< −2 °C
			pear	< −2 °C	[13]	< −2 °C
			peach	< −1.1 °C	[42]	< −1.1 °C
			apricot	< −1 °C	[43]	< −1 °C
			tomato	< −1 °C	[44]	< −1 °C
			maize	<0 °C	[45]	<0 °C
			orange	<0 °C	[46]	<0 °C
			kiwi	<1.5 °C	[37]	<1.5 °C

calculated as a function of latitude and month i.

The index D_i provides a simple measure of the water surplus or deficit for the analysed month. According to Ref. [35], D_i may be aggregated at different time scales, as in equation (2):

$$D_n^k \sum_{i=0}^{t=1} (P_{n-1} - PET_{n-1}), t \geq k \tag{2}$$

where t is the monthly time scale and n is the number of calculations.

In equation (3), a three-parameter log-logistic probability density function is used to fit the established data series:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{a}\right)^{\beta}\right]^{-2} \tag{3}$$

where α, β, and γ are scale, shape, and origin parameters, respectively, for D values in the range $[\gamma, \infty[$.

The cumulative distribution function of a given time scale is given by equation (4):

$$F(x) = \left[1+\left(\frac{a}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{4}$$

Following the classical approximation of [36], the SPEI can be calculated as the standardised values of $F(x)$, as in equation (5):

$$SPEI = \omega - \frac{c_0 + c_1\omega + c_2\omega}{1 + d_1\omega + d_2\omega + d_3\omega} \tag{5}$$

where $\omega = \sqrt{-2\ln(p)}$, p is the probability of exceeding a determined D value, $p = 1 - F(x)$. If $p > 0.5$, then p is replaced by $1 - p$ and the sign of the resultant SPEI is reversed [32]. define the constants as $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$.

In drought monitoring, a short timescale (e.g., 3 months) can be used to assess the meteorological drought in terms of intensity and frequency ([32,35]) [12]. classify drought into moderate (i.e., SPEI between −1.42 and −1.0), severe (i.e., SPEI between −1.82 and −1.43), and extreme (i.e., SPEI lower than −1.83) (Table 1).

While the Plan defines the occurrence of a frost event when the temperature falls below 0 °C, the literature (see Table 1) agrees that temperature thresholds triggering the occurrence of frost events tend to be crop-specific and ranging, for instance, between −4 °C for durum wheat [1] and 1.5 °C for kiwi [37].

2.2. Empirical specification

We model the relationship between the insurance demand and the occurrence of extreme weather events as in equation (6):

$$lnSH_{pcy} = \alpha_c + \alpha_1\, {}_{ln}CY_{pcy} + \alpha_2 lnIP_{pcy} + \alpha_3 FL_{py} + \alpha_3 DR_{py} + \alpha_3 FR_{pcy} + \epsilon_{pcy} \tag{6}$$

where p, c, and y proxy province, crop, year, respectively. The annual crop-by-province share of insured value over the value of production (i.e., $lnSH_{pcy}$, in logarithm) is the insurance demand metric used in this analysis. It is a function of factors proxying the level of insured value of the produced value of each crop (i.e., α_c), of annual crop yield (i.e., $ln\ CY_{pcy}$, in logarithm) and insurance premium (i.e., $ln\ IP_{pcy}$, in logarithm) defined at the crop-province level, of province-specific daily extreme weather events aggregated at the annual level. Extreme weather events are modelled as three dummy variables proxying respectively the occurrence of flood (i.e., FL_{py}), drought (i.e., DR_{py}), and frost (i.e., FR_{pcy}) events. They take the value 1 when the event occurs in a province on at least one day in the considered year and are 0 otherwise. In line with [11,27], for the identification of soil moisture conditions, and [28,29], for the daily precipitation threshold, we consider flood a daily precipitation higher than 50 mm, following precipitations cumulated on previous five days larger than 53 mm. According to Ref. [12], we define a drought event occurring when the value of SPEI over 3 months is lower than −1.0. We model the occurrence of frost event using crop-specific thresholds of minimum temperature,[2] as identified in literature and reported in Table 1. The three indicators used in this study are synthesised in the last column of Table 1.

An empirical issue is the potential endogeneity between the insurance demand and its drivers, which we partially address by including drivers lagged of one period in a sensitivity analysis. However, lag identification may lead to incorrect inferences [47]. Consider a province characterised by particularly high insurance premium due to an above-average risk exposure (unobserved in our model) which may also lead to an increase in the insurance demand. For that province, both the premium in the current year and in the previous year are positively related with the unobserved factor (the time-invariant risk-exposure of the province). In this example, lag identification leads to an incorrect inference.[3] These endogeneity concerns do not allow us to identify the causal relationship between the occurrence of extreme weather events and the level of insurance demand, and hence we interpret the results as correlations rather than causal effects.

[2] We consider the entire year rather than the growing periods.
[3] We are grateful to an anonymous reviewer for the suggestion.

2.3. Data description

The analysis considers all the Italian provinces and eleven crops covered by Agri-CAT Fund (i.e., almond, apple, apricot, corn, durum wheat, grape wine, kiwi, orange, peach, pear, tomato), observed over the period between 2010 and 2020.

The variables indicating the occurrence of extreme weather events are built using province-specific daily weather data (i.e., precipitation in mm for flood; 3-months average minimum and maximum temperatures in °C and cumulated precipitation in mm for drought; minimum temperature in °C for frost), collected from the JRC MARS Meteorological Database. To ensure comparability between different sources of data, the obtained weather variables are aggregated at the annual level.[4]

To understand the potential correlation between the occurrence of extreme weather events and the insurance demand, we collected province- and crop-specific annual data on insured value (in EUR) and insurance premium (in EUR) from the '*Istituto di Servizi* per *il Mercato Agricolo Alimentare*' (ISMEA). From the same source we gathered annual data on prices of crops at the national level. This information, combined with data province-specific annual data on crop production (in t) from the '*Istituto Nazionale di Statistica*' (ISTAT), allowed us to build a proxy of the gross saleable production. By comparing the insured value and the gross saleable production, we obtained the share of insured value over the value of production, that is the insurance demand metric used in this analysis. It is consistent with metrics used in previous studies (e.g., Ref. [9]). The ISTAT also provided annual data on cultivated area (in ha) by province and crop.

The descriptive statistics of the main variables in 2010 (start year of the sample) and 2020 (end year of the sample) are in Table 2. Details are provided by geographical area and type of crop. We refer to the official Nomenclature of Statistical Territorial Units (NUTS) from Eurostat to classify hierarchies of regions (i.e., NUTS level I) into North and South. The North includes North-West and North-East of Italy, which comprise the following regions (i.e., NUTS level II): Valle d'Aosta, Liguria, Lombardia, Piemonte in the North-West, and Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Emilia-Romagna in the North-East. The South considers Centre (i.e., Toscana, Umbria, Marche, and Lazio regions), South (i.e., Abruzzo, Molise, Campania, Puglia, Basilicata, and Calabria regions), and Islands (i.e., Sicilia and Sardegna regions). We classify crops in autumn-winter or spring-summer crops on the basis of the phenological phase of flowering. Autumn-winter crops include almond [48] and apricot [49]. Spring-summer crops include apple [50], corn [51], durum wheat [52], grape wine, kiwi [53], orange [54], peach [55], pear [56], tomato [57].

The share of insured value per value of production tripled in a decade, from 0.46 in 2010 to 1.64 in 2020. This increase is mostly to be attributed to an increase in the share of insured value in Northern areas and of spring-summer crops (Table 2). This is consistent with evidence provided in recent studies (e.g., Refs. [9,14,58]) according to which the share of insured value is substantially higher in Northern than in Southern areas and the most insured crops (e.g., apple, corn, grapes, tomatoes) are spring-summer crops. The increase in the share of insured value is accompanied by a reduction both in insurance premiums (from 0.33 to 0.20 million EUR in 2010–2020) and crop yields (from 16.47 to 15.57 t/ha in 2010–2020). In a decade, the incidence of flood (non-existent in 2010) and of drought events has increased and the occurrence of frost events has reduced (Table 2), highlighting the worsening of the adverse effects of global warming (e.g., Refs. [6,7]).

The occurrence of extreme weather events is heterogeneous across Italy: for instance, flood and frost events are more frequent in Northern area whereas drought events are more common in Southern area. Their incidence is also related to the type of crops cultivated in these areas: for instance, drought events hit more frequently autumn-winter crops (Table 2), that are almond and apricot, highly spread in Southern area. The correlation between the share of insured value per value of production and the occurrence of extreme weather events is, as a consequence, heterogeneous across geographical areas (Fig. 1).

3. Results and discussion

Table 3 shows the Ordinary Least Square (OLS) estimates, not including (column 1) and including (column 2) extreme weather events, respectively.

The estimates indicate that the share of insured value per value of production exhibits a positive correlation with premium and a negative correlation with yield. The insurance demand is expected to increase by 5.6 percent with a 10 percent increase in premium and to decrease by 9.8 percent with a 10 percent increase in yield. The positive own-price elasticity of insurance demand is indicative of the prevalence of the insurance demand in a risky environment, consolidating the arguments, for instance, of [59–62], who conclude that high-risk participants tend to dominate the insurance market. Also, the results corroborate the recent findings of [63], indicating that the insurance demand is relatively more correlated (in absolute terms) to changes in yield than in premium.

Focusing on the interpretation of estimates in column (2), we find a positive correlation between the share of insured value per value of production and the occurrence of flood and frost events. The estimated semi-elasticities suggest that the insurance demand is relatively more correlated to the incidence of flood than of frost events. The results are robust to specifications that include, alternatively, single extreme weather events (see table S1of the Supplementary Material). We find no significant correlation between the occurrence of drought events and the insurance demand. Drought events are, in fact, hit more frequently the South (see Table 2), where the participation in insurance schemes tends to be lower.

The demand for crop insurance increase from 0.9 percent to 1.8 percent in response to the occurrence of extreme weather events. These figures are obtained by exponentiating the value of constant in the baseline specification (column 1) and the value of constant

[4] Annual weather variables take the value 1 when the corresponding weather variables are non-zero at least once in a certain year.

Table 2
Descriptive statistics of main variables in 2010 and 2020, details by geographical area and crop dimensions.

	Insured value/value of production		Premium (Million EUR)		Yield (t/ha)		Flood (%)		Drought (%)		Frost (%)	
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
All	0.46 (±0.90)	1.64 (±4.38)	0.33 (±2.35)	0.20 (±0.92)	16.47 (±14.58)	15.57 (±15.36)	0.00 (±0.00)	0.06 (±2.53)	2.49 (±15.60)	5.70 (±23.19)	10.81 (±31.05)	6.63 (±24.89)
North	0.51 (±0.92)	2.69 (±6.01)	0.71 (±0.35)	0.40 (±0.14)	18.65 (±14.68)	13.08 (±11.69)	0.00 (±0.00)	0.08 (±2.83)	0.00 (±0.00)	2.95 (±16.92)	20.27 (±40.21)	14.02 (±34.72)
South	0.42 (±0.87)	0.72 (±1.63)	0.38 (±0.18)	0.47 (±0.26)	14.83 (±14.29)	17.57 (±17.52)	0.00 (±0.00)	0.05 (±2.27)	4.37 (±20.44)	7.77 (±26.78)	3.70 (±18.88)	1.08 (±10.33)
Autumn-winter crop	0.42 (±0.84)	0.48 (±0.40)	0.01 (±0.02)	0.03 (±0.07)	9.98 (±4.38)	6.55 (±5.83)	0.00 (±0.00)	0.06 (±2.43)	1.69 (±12.88)	6.27 (±24.24)	9.37 (±29.14)	9.94 (±29.93)
Spring-summer crop	0.47 (±0.91)	1.69 (±4.48)	0.40 (±2.59)	0.21 (±0.96)	17.88 (±15.61)	16.43 (±15.71)	0.00 (±0.00)	0.06 (±2.54)	2.67 (±16.13)	5.65 (±23.09)	11.12 (±31.44)	6.33 (±24.36)

Notes: Descriptive statistics are mean and, in parentheses, standard deviation. The North includes North-West (i.e., Valle d'Aosta, Liguria, Lombardia, and Piemonte regions) and North-East (i.e., Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, and Emilia-Romagna regions) of Italy. The South considers Centre (i.e., Toscana, Umbria, Marche, and Lazio regions), South (i.e., Abruzzo, Molise, Campania, Puglia, Basilicata, and Calabria regions), and Islands (i.e., Sicilia and Sardegna regions) of Italy. Autumn-winter crops include almond and apricot. Spring-summer crops include apple, corn, durum wheat, grape wine, kiwi, orange, peach, pear, tomato.

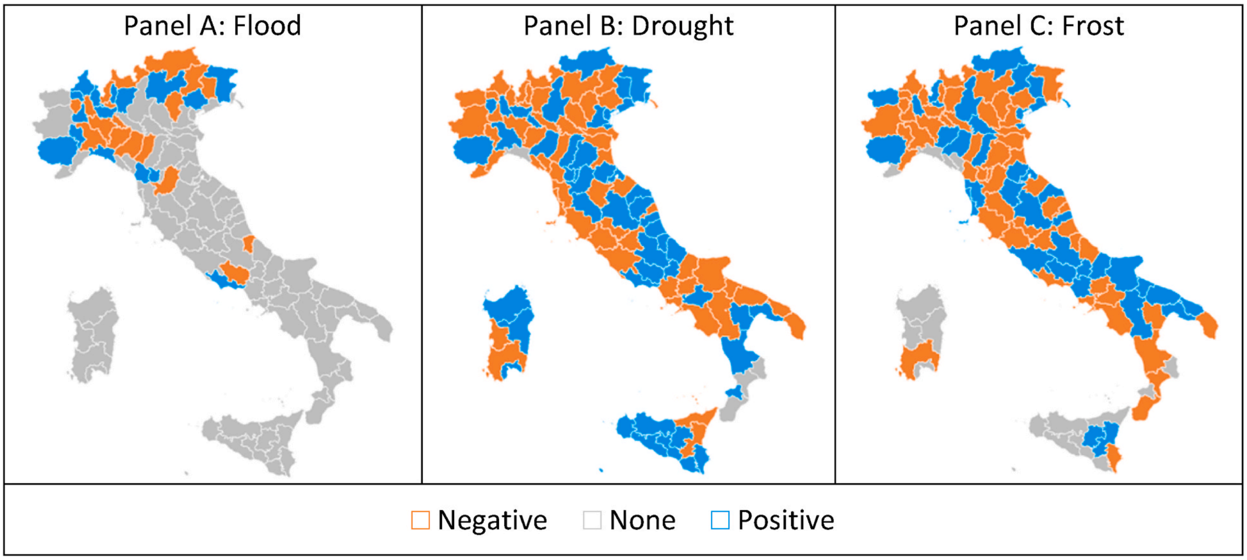

Fig. 1. Correlation between the share of insured value per value of production and extreme weather events.

Table 3
Drivers of insurance demand.

Variables	(1) Baseline	(2) Under extreme weather events
Premium	0.5651***	0.5636***
	(0.0249)	(0.0249)
Yield	−0.9818***	−0.9821***
	(0.1235)	(0.1229)
Flood		0.3772**
		(0.1595)
Drought		0.0341
		(0.0683)
Frost		0.3093***
		(0.0549)
Constant	−4.7213***	−4.7309***
	(0.3332)	(0.3312)
Dep. var.	Share of insured value	Share of insured value
Fixed effects	Crop	Crop
Observations	283,167	283,167
R-squared	0.68	0.68

Notes: Ordinary Least Square estimates. The dependent variable is the natural logarithm of the share of insured value over the value of production. All specifications include the natural logarithm of yield and premium, crop-specific fixed effects, and a constant. The specification under extreme weather events includes dummy variables proxying the occurrence of flood, drought, and frost. Standard errors, clustered at province-crop level, are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

increased by the values estimated for extreme weather events (column 2).

We conduct robustness checks to assess the sensitivity of the correlation between the insurance demand and extreme weather events to alternative model specifications: they are reported in the Supplementary Material. First, we run a variance analysis using different sets of fixed effects (table S2). When year fixed effects are included jointly with crop fixed effects, the estimates still suggest a significant correlation between the insurance demand and the occurrence of flood and frost events. The specification based on crop and province fixed effects allows to detect a significant correlation also with the occurrence of drought events.

Second, we estimate additional specifications including drivers lagged of one period (table S3) to partially control for potential endogeneity between the insurance demand and its drivers. In fact, the participation in crop insurance schemes may be an optimal adaptation strategy to the adverse consequences of extreme weather events due to climate change [10]. However, the decision to uptake crop insurance may reduce the adoption of other preventive measures, such as crop diversification, and as a consequence increase the exposure to weather risks. The results confirm the main findings of Table 3.

Third, we test the hypothesis that the insurance demand is correlated both with past and expected extreme weather events. The literature suggests that farmers form their weather expectations based on weighted averages of the past (e.g., Refs. [64,65]). We estimate the model including, alternatively, the occurrence of flood, drought, and frost events lagged of one, two, and three periods, and forwarded of one period[5] (table S4). To achieve an effect similar to partial correlation we also estimate the model adding progressively lagged terms for weather variables (table S5). As expected, we find that the share of insured value per value of production is sensitive both to past and expected flood and frost events.

To evaluate the degree of heterogeneity in the correlation between the crop insurance demand and the occurrence of extreme weather events across geographical area and crop dimensions, we replicate the analysis focusing on various subsets of our sample. Specifically, we compare Northern and Southern geographical areas (Table 4) and autumn-winter and spring-summer crops (Table 5).

As for the heterogeneity analysis across geographical areas, we find that the insurance demand in Southern geographical areas is correlated with the occurrence of extreme weather events. The share of insured value per value of production in the South tends to increase by 8.4 percent with the occurrence of flood events and by 3.6 percent with the occurrence of frost events (Table 4). Accordingly, participants in the insurance market in the South may be more willing to insure their crops as compared to their counterparts in the North. This evidence is consistent with the literature (e.g., Refs. [8,14,58]) demonstrating that the insurance demand is widespread in Northern Italy rather than in other parts of the country. In terms of insurance values, Northern regions account for 81.4 percent of the total [66].

This suggests that the increasing frequency of extreme weather events may create an incentive to improve the participation in the insurance market in geographical areas not traditionally devoted to the insurance instrument.

Considering the crop dimension, we find that only the insurance demand for spring-summer crops is correlated with the occurrence of flood events (Table 5). Also, spring-summer crops tend to be relatively less correlated than autumn-winter crops to the occurrence of frost events. This is likely due to the timing of the occurrence of extremes throughout the year (i.e., the growth phase may be different between spring-summer crops and autumn-winter crops when the weather extreme hits). The exposure to critically cool temperatures has relevant ecological and economic impacts on the agricultural sector and is a particular threat to fruit, vegetable, and grape wine during reproductive growth stages ([7,20]). Under climate change, reproductive growth stages tend to occur earlier in the season increasing, as a consequence, the exposure to frost risks of spring-summer crops [6].

4. Conclusions

We investigated the correlations between the incidence of weather risks and uptakes in subsidised crop insurance schemes. These two dynamics are correlated. The coverage (i.e., the share of production values covered by insurance) is higher where flood and frost events are more frequent. This confirms and adds on previous findings (e.g., Ref. [10]).

The heterogeneity in our evidence deserves attention. The South, where crop insurance is less common, is more sensitive to the incidence of extreme weather events, likely due to the incidence of cover crops [67]. The correlation between uptake and events is also greater for the (higher valued) spring-summer crops (e.g. grape wine). Our findings, based on precise and granular indicators of catastrophic events' occurrence (*cfr*. [11–13,29]), are clear: the catastrophic events shape uptake and dynamics of the (subsidised) insurance market. This is an important result insofar the extreme events have been by far (and for long time) been neglected in the (publicly subsidised) Italian crop insurance scheme, and only recently have been under the spotlight with the introduction of the AGRI-CAT. The numerous and myopic reforms have had negligible effects [9], due to the low response of the uptake to changes in subsidies level [68]. A different path could be traced if major risks are seriously considered. This is not only valid for Italy, but also for sister countries such as France and Spain [69].

Our results are not causal and future research is needed insofar the climate change (and the higher frequency of extreme weather events) requires building a more resilient agriculture, promoting the adoption of synergic risk-reducing management practices (e.g., drought resistant crops), and moving toward a holistic approach [70].

Data availability statement

The data supporting the findings of this study are publicly available:

CRediT authorship contribution statement

Fabio Gaetano Santeramo: Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Emilia Lamonaca:** Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis. **Irene Maccarone:** Visualization, Data curation. **Marco Tappi:** Writing – original draft, Software, Resources, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Fabio Gaetano Santeramo reports financial support was provided by Government of Italy Ministry of Education University and

[5] The introduction of a forwarded variable allows us to test for the presence of potential reverse causality [9].

Table 4
Drivers of insurance demand, Northern *versus* Southern geographical areas.

Variables	(1) North	(2) South
Premium	0.4023***	0.6650***
	(0.0283)	(0.0352)
Yield	−1.1734***	−1.1569***
	(0.1487)	(0.1667)
Flood	−0.1075	0.8386***
	(0.1334)	(0.2845)
Drought	0.0855	−0.0004
	(0.0648)	(0.0844)
Frost	0.0763*	0.3640***
	(0.0439)	(0.0623)
Constant	−2.3068***	−5.4960***
	(0.3889)	(0.4939)
Dep. var.	Share of insured value	Share of insured value
Fixed effects	Crop	Crop
Observations	135,745	147,421
R-squared	0.79	0.71

Notes: Ordinary Least Square estimates. The dependent variable is the natural logarithm of the share of insured value over the value of production. All specifications include the natural logarithm of yield and premium, dummy variables proxying the occurrence of flood, drought, and frost, crop-specific fixed effects, and a constant. The North includes North-West (i.e., Valle d'Aosta, Liguria, Lombardia, and Piemonte regions) and North-East (i.e., Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, and Emilia-Romagna regions) of Italy. The South considers Centre (i.e., Toscana, Umbria, Marche, and Lazio regions), South (i.e., Abruzzo, Molise, Campania, Puglia, Basilicata, and Calabria regions), and Islands (i.e., Sicilia and Sardegna regions) of Italy. Standard errors, clustered at province-crop level, are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

Table 5
Drivers of insurance demand, autumn-winter *versus* spring-summer crops.

Variables	(1) Autumn-winter	(2) Spring-summer
Premium	0.4625***	0.5777***
	(0.0556)	(0.0267)
Yield	−0.8646***	−1.0324***
	(0.2295)	(0.1360)
Flood	−0.3206	0.4631***
	(0.2425)	(0.1676)
Drought	0.0446	0.0354
	(0.1618)	(0.0727)
Frost	0.4891**	0.2930***
	(0.2085)	(0.0567)
Constant	−4.0133***	−4.7389***
	(0.5368)	(0.3624)
Dep. var.	Share of insured value	Share of insured value
Fixed effects	Crop	Crop
Observations	27,649	255,518
R-squared	0.58	0.69

Notes: Ordinary Least Square estimates. The dependent variable is the natural logarithm of the share of insured value over the value of production. All specifications include the natural logarithm of yield and premium, dummy variables proxying the occurrence of flood, drought, and frost, crop-specific fixed effects, and a constant. Autumn-winter crops include almond and apricot. Spring-summer crops include apple, corn, durum wheat, grape wine, kiwi, orange, peach, pear, tomato. Standard errors, clustered at province-crop level, are in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

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Appendix A. Supplementary data

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