On the relationships among durum wheat yields and weather conditions: evidence from Apulia region, Southern Italy

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On the relationships among durum wheat yields and weather conditions: evidence from Apulia region, Southern Italy

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Abstract

The weather index-based insurances may help farmers to cope with climate risks overcoming the most common issues of traditional insurances. However, the weather index-based insurances present the limit of the basis risk: a significant yield loss may occur although the weather index does not trigger the indemnification, or a compensation may be granted even if there has not been a yield loss. Our investigation, conducted on Apulia region (Southern Italy), aimed at deepening the knowledge on the linkages between durum wheat yields and weather events, i.e., the working principles of weather index-based insurances, occurring in susceptible phenological phases. We found several connections among weather and yields and highlight the need to collect more refined data to catch further relationships. We conclude opening a reflection on how the stakeholders may make use of publicly available data to design effective weather crop insurances.

Keywords: climate change, farming system, phenological phase, risk, weather insurance

JEL codes: G22; Q14; Q18; Q54

Introduction

Farming activities are exposed and vulnerable to several risks, among which the weather risks are increasingly frequent and impactful due to climate change (Conradt et al., 2015). Among the several strategies available to reduce the weather impacts on farming systems, e.g., pest control, financial saving, agricultural and structural diversification (Vroege and Finger, 2020), the crop insurance programs can play an important role (Di Falco et al., 2014). In recent years, the attention for the weather index-based insurances (WIBIs) has been growing mainly because these tools may help to overcome some of the challenges associated with traditional indemnity-based insurances, e.g., asymmetric information, high transaction costs, moral hazard, and adverse selection (Norton et al., 2013; Dalhaus and Finger, 2016; Belissa et al., 2019; Ceballos et al., 2019). Differently from the traditional insurances, which provide pay-outs depending on actual yield losses, WIBIs indemnify the farmers when an index, computed on rainfall or temperature and highly correlated with farms performance (e.g., yields), is triggered (Conradt et al., 2015; Dalhaus and Finger, 2016). Therefore, farmers will be indemnified when the index exceeds a pre-determined threshold (Belissa et al., 2019). Moreover, WIBIs can be manipulated neither by the insurers or the insured because they are collected from historical and current dataset provided by recognized bodies (Belissa et al., 2020; Vroege et al., 2021). However, WIBIs present a limit, namely basis risk: a significant yield loss may occur even if the weather index does not trigger the payment (Conradt et al., 2015; Dalhaus et al., 2018) or a compensation may be granted even if there has not been a yield loss (Heimfarth and Musshoff, 2011). The contribution of our study is at least twofold: first, we provide empirical evidence on how yields and weather conditions are correlated, more specifically, we deepen the knowledge on the linkages between durum wheat yields and weather events occurring in susceptible phenological stages; second, we start a reflection on how stakeholders may make use of publicly available data to design an effective crop insurance scheme. We focused on the Apulia region (Southern Italy) which is the main national producer of durum wheat: almost a thousand of tons of production, i.e., accounting for 25%

of the Italian durum wheat production, and about 344 thousand cultivated hectares, i.e., accounting for 28% of the Italian area utilized to grow durum wheat (ISMEA, 2020).

The Italian crop insurance system

The Italy boasts a long tradition of public subsidies for agricultural risk management. The "Fondo di Solidarietà Nazionale" (FSN) was instituted in 1974 to finance both insurance policies and ex-post payments (Enjolras et al., 2012). Moreover, the EU Common Agricultural Policy allocated funds for agricultural insurances (art. 37 of EU Reg. 1305/2013) to cope economic losses due to adverse weather conditions, plant diseases, epizooties, and parasitic infestations (Santeramo et al., 2016; Rogna et al., 2021). Despite the public interventions, the participation level to insurance programs remains low (i.e., around 15 percent) mainly due to high costs of bureaucracy (i.e., complexity of procedures), delays in payments, lack of experience with crop insurance contracts or lack of high-quality information on existing insurance tools (Santeramo, 2019). The role of Defense Consortia, introduced both to facilitate the match of insurers and farmers in the subsidized crop insurance market and to reduce the asymmetric information, is not negligible. It emerges a North-South territorial dualism that affects farmers participation: Defence Consortia are more effective in Northern Italy than in the Southern Italy and, also, the strong presence of producer organizations and cooperatives aggregates the crop insurance's demand in the Northern Italy (Santeramo et al., 2016). Moreover, farmers who trust more in the intermediaries assisting them are inclined to adopt insurance tools to cope the risk of production loss, while risk averse farmers tend to implement other risk management strategies as crop or financial diversification (Trestini et al., 2018). In Italy, only the 9.9 percent of Utilised Agricultural Area is covered by insurance contracts and 20.9 percent of production value is insured (ISMEA, 2021). According to a survey conducted by ISMEA in 2018 on low participation to the subsidized agricultural insurance systems, most Italian farmers renounce to subscribe insurance contracts due to economic reasons, highlighting the high costs of policies. The share of farmers who believe that their farms are not exposed to specific risks or who have had negative experiences when receiving compensation, losing trust on insurance market systems, is also not negligible. Indeed, Giampietri et al., 2020 found that the trust affects the decision-making process: under uncertainty, the trust may substitute the knowledge also overcoming the lack of experience, therefore, strong communication campaigns to improve farmers' participation are recommended. Moreover, focusing on the WIBIs, also subsidized by the Measure 17 of National Rural Development Program 2014-2020, a lack of knowledge emerged among big insured farmers, i.e., WIBIs were unknown to 93 percent of them (ISMEA, 2020). Furthermore, some farmers believe that index-based insurances are inadequate to manage the weather risks due to the distrust of the objectivity of the indexes and parameters used, also showing an aversion to any future subscriptions. Clearly, it is necessary to improve the appeal and communication of these innovative risk management tools, also considering that any intervention aimed at promoting farmer participation should improve the competition among insurance providers, also reducing at the same time the asymmetric information and opportunistic behaviour (Menapace et al., 2016; Rogna et al., 2021; Santeramo and Russo, 2021). In this complex scenario, we estimate the yield response equation to investigate the responsiveness of yield to climate, deepening the working principles of weather index-based insurance, through a case study on durum wheat crop in the Apulia region, also animating the debate on the use of publicly available data to the development of an effective and attractive tool to manage climatic risk in agriculture.

Data and research methodology

An agronomic review on durum wheat allowed us to identify sensitive phenological stages of durum wheat in Apulia region and those critical weather events occurring in certain phenological stages that may cause significant production losses (Table 1).

Table 1. Phenological stages, weather events and critical limits of durum wheat in Apulia region

Phenological stage	**Weather event**	**Time interval**	**Critical limit**	**Reference**
Sowing	Cold	From the first decade of November to the first decade of December	Temperature < 0 °C	Baldoni and Giardini, 2000; Angelini, 2007; Disciplinare di produzione integrata della Regione Puglia, 2021
Germination	Cold	From the second decade of November to the second decade of December	Temperature < 0 °C	
Stem elongation	Cold	From the second decade of March to the third decade of April	Temperature < 0 °C	Baldoni and Giardini, 2000; Angelini, 2007
Flowering	Cold	From the second decade of May to the first decade of June	Temperature < 0 °C	Angelini, 2007; Disciplinare di produzione integrata della Regione Puglia, 2021
	Heat, drought		Temperature > 30-31 °C	Angelini, 2007; Rezaei et al., 2015
Grain filling	Heat, drought	From the second decade of June to the first decade of July	Temperature > 34 °C	Angelini, 2007; Asseng et al., 2011; Rezaei et al., 2015; Zampieri et al., 2017; Makinen et al., 2018
All phases	Excessive rainfall	From first decade of November to the first decade of July	Rainfall > 40 mm/day	Makinen et al., 2018

Cold sensitivity is higher during the germination phase that occurs 10-15 days after sowing in which temperatures of few degrees centigrade below zero may cause considerable damages (Baldoni and

Giardini, 2000, Angelini, 2007; Disciplinare di Produzione Integrata della Regione Puglia, 2021). Likewise, temperatures of few degrees centigrade below zero during the stem elongation phase may cause stems death and serious damages to the tissue of the internodes (Baldoni and Giardini, 2000; Angelini, 2007; Disciplinare di Produzione Integrata della Regione Puglia, 2021). Flowering stage occurs in late May and lasts about 10 days in which wheat crop is highly sensitive to cold stress that may cause death of flowers (Angelini, 2007; Baldoni and Giardini, 2000; Disciplinare di Produzione Integrata della Regione Puglia, 2021). Heat and drought stress during susceptible flowering and grain filling stages (i.e., after flowering, until the first decade of July) may cause considerable reductions in wheat yield and quality, leading the acceleration of leaf senescence process, reducing photosynthesis, causing oxidative damage, pollen sterility, also reducing physiological and metabolic imbalances, photosynthesis, grain numbers and weight (Angelini, 2007; Asseng et al., 2011; Li et al., 2013; Farooq et al., 2014; Rezaei et al., 2015; Zampieri et al., 2017; Makinen et al., 2018). Heavy rainfall during the entire crop cycle may cause significant production losses due to the proliferation of pathogens, nutrient leaching, soil erosion, inhibition of oxygen uptake by roots (i.e., hypoxia or anoxia), waterlogging and lodging (Zampieri et al., 2017; Makinen et al., 2018).

Furthermore, we collected yearly total production (tons) and area harvested (hectares) data for durum wheat crop from the National Institute of Statistics (ISTAT), from 2006 to 2019, for each province of Apulia region, also calculating the respective yields (tons/hectare). Then, for the same time-period, we collected 10-days frequency weather data from six synoptic weather stations of the Institute for Environmental Protection and Research (ISPRA), one for each province of Apulia region: Bari (BA), Barletta-Andria-Trani (BT), Brindisi (BR), Foggia (FG), Lecce (LE), Taranto (TA). Weather data include 10-days average minimum temperature (°C), i.e., the average of daily minimum temperatures, 10 days average maximum temperature (°C), i.e., the average of daily maximum temperatures, and 10-days cumulative precipitation (mm), i.e., the average of daily precipitation.

Details on collected variables are shown in Table 2 below:

Table 2. Details on collected variables

Variable (unit)	Frequency	Time-period	Province	Weather station - province (no. of obs, SR in km^2)	Source
durum wheat yield (tons/hectares)	Yearly			-	ISTAT
average minimum temperature (°C) average maximum temperature (°C) cumulative precipitation (mm)	10-days	2006-2019	Bari (BA) Barletta-Andria-Trani (BAT) Brindisi (BR) Foggia (FG) Lecce (LE) Taranto (TA)	Bari - BA (501, 5.138) Trani - BT (144, 1.543) Brindisi - BR (471, 1.839) Monte Sant'Angelo - FG (504, 7.008) Lecce - LE (471, 2.799) Marina di Ginosa – TA (471, 2.437)	ISPRA, UCEA, ARPA

Notes: missing data have been integrated including Research Unit for Climatology and Meteorology (UCEA) and Regional Agency for the Protection of the Environment (ARPA) datasets. Table includes no. of observations and spatial resolution (SR) of weather stations.

Our empirical approach is based on a panel data model that includes fixed effect (i.e., it is a major advantage of the panel rather than cross-sectional regression) both to control for unobservable variables such as seed varieties or soil quality that may vary across the space, i.e., provinces, and to catch the variation across the time within the Apulian provinces (Tack et al., 2015; Blanc and Schlenker, 2017; Kolstad and Moore, 2020).

The relationship between durum wheat yields and weather events is synthesized as follows:

$$y_{it} = f(w_{it}) + \mu_i + \theta_t + \epsilon_{it}$$

where y_{it} is the yield over the space ($_i$) and time ($_t$) as function (*f*) of weather (w_{it}), also including fixed effects over space (μ_i) and time (θ_t), error term and "controls" refers to other relevant exogenous variables (ϵ_{it}) (Kolstad and Moore, 2020). More specifically, we conducted temporal and spatial autocorrelation identifying those contiguous provinces having a larger shared borders for a twofold check: (i) verify if the weather events occurring in a province may affect durum wheat yields in the contiguous province; (ii) control if the yields may be affected by weather events occurring at time t-1. Undoubtedly, both environmental and agronomic factors may justify the extreme variability of the durum wheat yield across the Apulian provinces: Foggia shows the highest average durum wheat yields while Lecce shows the lowest average yields, although it is characterized by lower yield variability than other provinces as Brindisi that, on the contrary, is more affected by environmental and agronomic factors, reason why it may benefit of crop insurance programs more than other provinces to cope yields fluctuations (Table 3).

Table 3. Durum wheat yields (tons/hectare) among Apulian provinces

	Average	Minimum	Maximum	Standard deviation
Bari	0.234	0.170	0.306	0.045
BAT	0.224	0.200	0.260	0.020
Brindisi	0.285	0.180	0.420	0.071
Foggia	0.314	0.200	0.420	0.047
Lecce	0.189	0.160	0.220	0.018
Taranto	0.244	0.100	0.350	0.057

Notes: data include yearly durum wheat yield from 2006 to 2020.
Source: ISTAT, 2020

Results

Our results clearly show that a relationship links weather conditions and production yields in the Apulia region. More specifically, precipitation seem to have a negative effect on durum wheat yields (Table 4).

Table 4. Effects of weather variables on durum wheat yield

VARIABLES	Panel prov FE time trend	Panel temporal correlation prov FE time trend	Panel spatial correlation prov FE time trend	Panel temporal correlation spatial correlation prov FE time trend
Temperature (min)	-0.00764	-0.00124	-0.46909***	-0.45553**
	(0.10641)	(0.11715)	(0.17058)	(0.18731)
Temperature (min) sq.	0.00049	-0.00023	0.00892*	0.01384**
	(0.00296)	(0.00320)	(0.00490)	(0.00544)
Temperature (max)	0.22572	0.28286*	0.61165**	0.66801**
	(0.14125)	(0.15378)	(0.25587)	(0.27703)
Temperature (max) sq.	-0.00523*	-0.00612**	-0.01530***	-0.02022***
	(0.00278)	(0.00299)	(0.00515)	(0.00568)
Precipitation	-0.01646**	-0.01625*	-0.03939**	-0.04670**
	(0.00799)	(0.00844)	(0.01819)	(0.01954)
Precipitation sq.	0.00008	0.00007	0.00019	0.00024
	(0.00006)	(0.00006)	(0.00017)	(0.00018)
Yield (lag)	-	0.10464***	-	-0.09290***
		(0.02153)		(0.03579)
Temperature (min) contig.	-	-	0.23065***	0.18642***
			(0.06565)	(0.07019)
Temperature (max) contig.	-	-	0.00822	0.04557
			(0.10765)	(0.11545)
Precipitation contig.	-	-	0.00537	0.00771
			(0.00704)	(0.00837)
Observations	1,837	1,638	914	833
Number of id	6	6	4	4

Notes: panel regression model was processed in STATA software. It includes provincial fixed effect, time trend, temporal (i.e., yield lag), and spatial (contiguous weather variables) autocorrelation.
Standard errors in parentheses.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

However, controlling by spatial and temporal autocorrelation, the effects of temperatures have been caught. Minimum temperatures negatively affect durum wheat yields, while maximum temperatures positively affect the yields, both in a non-linear way. Indeed, we included the squares of weather variables to catch the nonlinearity, in other terms, the trade-off between weather and yields (Blanc and Schlenker, 2017). Our results clearly highlight that the weather affects the yields in a nonlinear way, therefore, variables have a statistically significant inverted-U shape relationship (Schlenker and Roberts, 2009; Lobell et al., 2011). Last but not least, minimum temperatures may affect the contiguous provinces. According to the scientific literature, any excess (or deficit) of temperature and precipitation (or their combinations) may cause severe yield losses on durum wheat (Baldoni and

Giardini, 2000; Angelini, 2007; Asseng et al., 2011; Li et al., 2013; Farooq et al., 2014; Rezaei et al., 2015; Zampieri et al., 2017; Makinen et al., 2018). Furthermore, we estimated the model for each phenological phase of durum wheat to capture the potential heterogeneity in the effect of weather variables, also controlling by spatial and temporal autocorrelation. Our results show that the relationship between weather variables and yields is valid only for some weather variables in certain phenological phases. More specifically, the maximum temperatures and precipitation positively affect durum wheat yield in a nonlinear way when occur in the germination and grain filling stages, respectively (Table 5).

Table 5. Effects of weather variables on yield by phase.

VARIABLES	sowing	germination	stem elongation	flowering	grain filling
Yield (lag)	-0.11883	0.05952	0.17798*	-0.04474	0.09403
	(0.20660)	(0.20523)	(0.09219)	(0.18593)	(0.14041)
Temperature (min)	0.95845	-0.00051	0.50020	-1.32087	-0.65587
	(2.53724)	(1.74362)	(1.26379)	(4.06620)	(3.83238)
Temperature (min) sq.	-0.01783	0.01530	-0.01201	0.03550	0.02171
	(0.11363)	(0.08655)	(0.05223)	(0.10882)	(0.08353)
Temperature (max)	3.15220	23.00804**	-2.73726	7.62398	-1.65011
	(12.35641)	(10.88917)	(2.21349)	(8.51643)	(6.74553)
Temperature (max) sq.	-0.15964	-0.76330**	0.06023	-0.15868	0.01396
	(0.35336)	(0.33477)	(0.05582)	(0.15987)	(0.11320)
Precipitation	0.04601	-0.07450	-0.03735	-0.43463	0.42332*
	(0.12015)	(0.11228)	(0.07473)	(0.42173)	(0.24351)
Precipitation sq.	-0.00034	0.00054	0.00049	0.01188	-0.00826*
	(0.00088)	(0.00084)	(0.00101)	(0.01680)	(0.00463)
Temperature (min) contig.	1.05294**	0.86957**	0.62187***	0.52210	0.55304**
	(0.41397)	(0.35021)	(0.17188)	(0.35845)	(0.23765)
Temperature (max) contig.	0.38942	0.17524	-0.06474	0.22627	0.00512
	(1.25128)	(1.33537)	(0.34861)	(0.52741)	(0.37530)
Precipitation contig.	-0.05370	0.01278	-0.01394	-0.10017	-0.05635
	(0.05168)	(0.04199)	(0.03275)	(0.11446)	(0.04998)
Observations	42	44	125	43	67
Number of id	4	4	4	4	4

Notes: panel regression model was processed in STATA software. It includes provincial fixed effect, time trend, temporal (i.e., yield lag), and spatial (contiguous weather variables) autocorrelation.
Notes: standard errors in parentheses
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Moreover, minimum temperatures may affect the contiguous provinces. Clearly, ten-days data we have collected does not highlight the dynamics between weather events occurring in certain phenological stages and durum wheat yields mainly because the impacts of daily weather are not captured. Moreover, most variables are not statistically significant: this limit opens a reflection on data disaggregation level and on the need to collect more spatially and temporally refined data, also laying the foundations for the development of an effective index that reflects the responsiveness of the yields to climatic conditions to be implemented in the WIBIs. The evidence resulting from our econometric model on phenological stages is also in contrast with the literature: germination stage is highly sensitive to cold stress (Baldoni and Giardini, 2000, Angelini, 2007; Disciplinare di Produzione Integrata della Regione Puglia, 2021), while there are not evidences on heat stress during this stage. However, our study may help the debate suggesting precise directions for the future research.

Conclusions

Participating in index-based crop insurance schemes is a key challenge to improve the resilience of farming systems and adopting effective subsidies to enhance participation in the schemes is a pressing goal for policymakers. In this complex scenario, we investigated how temperatures and precipitation are correlated with yields data to reflect on potential designs for the index-based insurance schemes. While not novel (e.g., Chen et al., 2014), we found that weather changes affect durum wheat yields in a nonlinear way and some weather events occurring in certain phenological phases may have an impact on the yields. Our results are important to show that even with aggregated data the evidence is striking. However, focusing on phenological stages, our findings are in contrast with the literature highlighting the complexity of the phenomenon and the need to rely on more temporally and spatially disaggregated data. Although we provided clear evidence on the weather-yield relationship, it is impossible to design a WIBI using 10-days weather data. Therefore, our contribution may help the debate suggesting precise directions for the future research: first, a major effort should be devoted to the collection of weekly or daily weather observations, also identifying empirical damage thresholds that can be verified at farm-level, as well as the collection of production area or municipal data; a promising approach could be the Growing Degree Days tool so as to calibrate the more precisely the growing stages in a view to a better explanation of weather risks on crop performances (Conradt et al., 2015; Dalhaus et al., 2018; Lollato et al., 2020); last but not least, the design of the index-based insurance schemes needs of further investigation because establishing a triggering index is a major challenge for the *stakeholders* involved in the implementation of the insurance schemes. The debate on crop insurance schemes is still vivid, and it will be so also in the next decade due to the central role that the risk management (old and novel) tools will have in the new CAP (Meuwissen et al., 2018; Severini et al., 2019; Cordier and Santeramo, 2020).

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