Weather and their effect on crop yields in Scotland 1935-2012

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Abstract

The purpose of this paper is to analyse the effect that weather variables have on the mean and variance of the yields of barley, oats, potatoes and wheat in Scotland, during the period 1935-2012. Although theoretically grounded on the stochastic production function approach, the paper uses the generalised autoregressive conditional heteroskedastic (GARCH) to model the variance of the crop yields. Results indicate that temperature has a positive effect on the mean yield, whilst rainfall has a negative effect on it. In addition, both temperature and rainfall have differentiated results on the crop yields' variances.

Keywords: Scottish agriculture, climate change impact, weather, GARCH models.

1. Introduction

Climate change and its potential effects on agriculture make important to understand how weather affects agriculture, particularly crop yields. As pointed out by Gaupp (2013) yields can be influenced by many factors, for instance these could be divided into three groups: meteorological, technological and economic variables. Meteorological variables include temperature, rainfall, sunshine and incoming solar radiation, wind velocity, humidity, snowfall and storm. Technological denote the effect of use of fertilizers, pesticides, high-yielding variety seeds, weed control, plant density, planting date amongst others. Economic variables include the effect of input prices, financial resources or any other factor that may affect farmers' allocation of resources.

The purpose of this study is to measure the effect that weather variables have on the mean and variance of selected crop yields in Scotland. This is not the first study on the effects of weather on the Scottish agriculture (see Gaupp, 2013 for a literature review); however, it differentiates from those found in the literature in the sense that it is rooted on Just and Pope (1978) framework of a stochastic production function and also in its use modern time series econometrics, in particular generalised autoregressive conditional heteroskedastic (GARCH) processes to model the conditional variance of crop yields.

As regards the effect of weather on crops, it should be noted that the climate of the East of Scotland (where most of the cropping areas are located) is temperate without extremes of temperature or rainfall but, although meteorological catastrophes are rare, the success of agriculture is dominated by weather. Effects can be direct, such as the destructive influence of freezing temperatures, or indirect, through the vulnerability of wet land to compaction by heavy machinery. It is common for crop yield to be influenced by interactions between soil type and water relations, or temperature (Hay et al., p. 19).

The paper starts with a brief description of the data and methods. This is followed by a discussion of the results and ends offering some conclusions and some futures lines of research.

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2. Methods

Data

The dataset used for the analysis comprised time series information on the East of Scotland weather (area which concentrates most of the crop output in the country) and crop yields for the period 1935 to 2012. The weather variables used were mean temperature, rainfall and sunshine (total hours) on the East of Scotland and the studied crops were: wheat, barley, oats and potatoes. In addition, the aforementioned series trend representing changes in technology and area under the crop (to account for economic factors) were used. Table 1 presents the descriptive statistics of the variables used in the analysis.

Table 1. Descriptive statistics.

Variable	Period	Mean	Standard deviation	Skewness	Kurtosis	Normality	
						Jarque-Bera coefficient 1/	Sig 1/
Weather							
Rainfall (mm)	Jul - Jun	91.25	9.74	-0.17	3.41	0.96	0.62
	Apr-Jul	73.68	16.33	0.20	2.99	0.51	0.77
	Apr-Aug	77.46	16.85	0.10	3.08	0.14	0.93
	Apr-Sep	80.26	14.29	0.19	2.83	0.57	0.75
Sunshine (days)	Jul - Jun	103.38	7.07	-0.22	2.85	0.72	0.70
	Apr-Jul	155.46	15.57	0.15	3.37	0.75	0.69
	Apr-Aug	152.23	13.54	0.40	3.74	3.87	0.14
	Apr-Sep	145.00	11.71	0.37	3.75	3.62	0.16
Temperature (degrees C)	Jul - Jun	7.04	0.58	-0.01	2.91	0.02	0.99
	Apr-Jul	9.72	0.56	0.31	2.52	1.96	0.38
	Apr-Aug	10.36	0.57	0.12	2.48	1.04	0.60
	Apr-Sep	10.43	0.54	0.20	2.61	1.00	0.61
Yields							
Barley (t/ha)	Jul - Jun	4.22	1.25	-0.05	1.78	4.84	0.09
Oats (t/ha)	Jul - Jun	3.60	1.32	0.37	1.90	5.75	0.06
Potatoes (t/ha)	Jul - Jun	25.51	8.60	0.42	2.05	5.25	0.07
Wheat (t/ha)	Jul - Jun	5.41	2.20	0.18	1.46	8.10	0.02
Areas							
Barley (ha)	Jul - Jun	240.92	137.60	-0.21	1.57	7.21	0.03
Oats (ha)	Jul - Jun	161.60	152.22	0.53	1.60	10.02	0.01
Potatoes (ha)	Jul - Jun	47.13	20.33	0.86	2.60	10.25	0.01
Wheat (ha)	Jul - Jun	59.54	33.71	0.54	1.55	10.56	0.01

Source: Own elaboration based on data from the MetOffice and the Scottish Government.

Notes:

1/ Normality test and its significance with null hypothesis that the data are normally distributed.

Methods

The theoretical approach followed in the paper is based on Just and Pope's stochastic production function (1978), which was also used by McCarl et al. (2008) to analyse the effect of weather on crop yields. It consists of modelling not only the mean yield but also its variance, which is not constant and assumed to be affected by exogenous variables. However, here the variance is estimated using Bollerslev (1986) generalised autoregressive conditional heteroskedastic process (GARCH) such as in Yang et al., (1992). The estimated model is given by (1)

$$y_t = \beta_0 + \beta_1 A_t + \beta_2 X^1{}_t + \beta_3 X^2{}_t + \beta_4 t + \beta_5 t^2 + \beta_6 t^3 + \varepsilon_t$$
$$h_t = \gamma_0 + \gamma_1 \varepsilon^2{}_{t-1} + \gamma_2 h_{t-1} + \gamma_3 X^1{}_t + \gamma_4 X^2{}_t \qquad (1)$$
$$\varepsilon_t \sim N(0, h_t)$$

Where the first equation explains the evolution of the conditional mean of the crop yields y_t and the second equation its conditional variance (h_t). In order to ensure stationarity for the variance the condition $\gamma_1 + \gamma_2 < 1$ needs to be satisfied. A_t is the total area under the crop, $X^1{}_t$ and $X^2{}_t$ are the temperature and the rainfall, t is a time trend, ε_t is the error term. The model was estimated by maximum likelihood.

3. Results and discussion

The empirical work started by testing the stationarity of the series. As shown in Table 2 all the weather series, crop yields and areas were found stationary.

Table 2. Phillips-Perron unit root test statistic

Variable	Period	Phillips-Perron statistic 1/	Probability 2/	Test critical values 1% level	Test critical values 5% level
Weather					
Rainfall (mm)	Jul - Jun	-8.35	0.00	-4.08	-3.47
	Apr-Jul	-7.42	0.00		
	Apr-Aug	-7.13	0.00		
	Apr-Sep	-7.42	0.00		
Sunshine (days)	Jul - Jun	-9.11	0.00		
	Apr-Jul	-8.93	0.00		
	Apr-Aug	-8.83	0.00		
	Apr-Sep	-8.95	0.00		
Temperature (degrees C)	Jul - Jun	-7.48	0.00		
	Apr-Jul	-7.17	0.00		
	Apr-Aug	-6.96	0.00		
	Apr-Sep	-6.63	0.00		
Yields					
Barley (t/ha)	Jul - Jun	-7.70	0.00		
Oats (t/ha)	Jul - Jun	-6.30	0.00		
Potatoes (t/ha)	Jul - Jun	-4.97	0.00		
Wheat (t/ha)	Jul - Jun	-4.86	0.00		
Area					
Barley (1,000 ha)	Jul - Jun	-4.33	0.00	-3.52	-2.90
Oats (1,000 ha)	Jul - Jun	-4.13	0.00		
Potatoes (1,000 ha)	Jul - Jun	-3.87	0.00		
Wheat (1,000 ha)	Jul - Jun	-5.79	0.00		

Source: Own elaboration based on data from the MetOffice and the Scottish Government.
Notes:
1/ All the test include an intercept and a deterministic trend.
2/ Probability of rejecting the hypothesis that the series do not have a unit root.

Table 3 presents the crop yields equations (conditional mean and variance). As regards the results for the mean of the crop yields, the weather variables, temperature showed a positive impact on yields (although the coefficient was statistically significant only for potatoes and wheat). Precipitation affected negatively the yields of barley, oats and potatoes (the effect on wheat was negative but not significantly different than zero). The variable sunshine was not found statistically significant in any of the cases.

Table 3. Yields equations

	Yields (tonnes/ha)							
	Barley		**Oats**		**Potatoes**		**Wheat**	
	Coeff.	Sig. 1/	Coeff.	Sig. 1/	Coeff.	Sig. 1/	Coeff.	Sig. 1/
Mean equation 2/								
Intercept	2.578	*	1.916	*	14.875	*	1.963	*
Std. error	(0.447)		(0.325)		(3.089)		(0.384)	
Area	0.000		0.001	*	-0.007		0.006	*
Std. error	(0.000)		(0.000)		(0.013)		(0.002)	
Mean temperature	0.080		0.047		0.996	*	0.133	*
Std. error	(0.043)		(0.032)		(0.313)		(0.040)	
Mean rainfall	-0.008	*	-0.004	*	-0.051	*	-0.003	
Std. error	(0.003)		(0.001)		(0.020)		(0.003)	
Trend (t)	0.017	*	-0.024	*	-0.126	*	-0.055	*
Std. error	(0.004)		(0.003)		(0.040)		(0.008)	
t^2	0.001	*	0.002	*	0.010	*	0.005	*
Std. error	(0.000)		(0.000)		(0.001)		(0.000)	
t^3	0.000	*	0.000	*	0.000	*	0.000	*
Std. error	(0.000)		(0.000)		(0.000)		(0.000)	
Variance equation 2/								
Intercept	-0.057		-0.001	*	(5.718)	*	0.188	*
Std. error	(0.053)		(0.000)		0.130		(0.085)	
ε^2_{t-1}	-0.160	*	-0.103		-0.169		0.319	*
Std. error	(0.084)		(0.133)		(0.117)		(0.105)	
h^2_{t-1}	1.070	*	0.683	*	1.080	*	0.768	*
Std. error	(0.098)		(0.230)		(0.103)		(0.064)	
Mean temperature	0.028	*	--		--		-0.027	*
Std. error	(0.007)						(0.012)	
Mean rainfall	-0.001	*	--		-0.062	*		
Std. error	(0.000)				(0.000)			
Trend (t)	--		0.001	*	0.010	*		
Std. error			(0.000)		(0.004)			
Statistics								
Adjusted R-squared	0.93		0.938		0.898		0.952	
Log likelihood	-13.00		4.459		-167.003		-30.998	
Durbin-Watson stat	2.04		2.104		1.586		2.131	
Jarque-Bera	1.28		1.888		1.487		1.987	

Notes
1/ Statistically significant at 5 per cent.
2/ Standard errors are the Bollerslev-Wooldridge robust errors.

The effect of the area on yield normally hypothesised as having a negative effect on average yield, showed the opposite sign. However, note that the Ricardian hypothesis of the effect of marginal lands on average yields refers to a situation at a micro level and not at a macro level like in the data used in the study. Following Yang et al., (1992) a cubic trend to represent technological changes was used. All the trend coefficients were statistically significant.

The variance equation showed that the GARCH process fitted well the data and all the equations were within the unit circle (i.e., were stationary). The effect of temperature on the variance was significant only on barley and wheat but with opposite sign, showing that a higher average temperature would increase the variance of barley yields and decrease wheat crop yields variance. Rainfall was found to (ceteris paribus) to decrease the variance of barley and potatoes. It should be mentioned that the variance of oats and potatoes showed a positive trend coefficient, indicating that these variances were growing over time.

4. Conclusions

The purpose of this paper has been to explore the effect of weather variables on the yields of selected crops in Scotland. The estimated models allowed obtaining the effects on the mean and variance of crop yields.

Of particular importance are the results for the conditional variance because they indicate that changes on the weather variables affect not only the yield levels but also their predictability. Either temperature or rainfall or both affect three out of four studied crops; however, note that although no effect was found for oats, the variance equation includes a positive trend coefficient.

The above results should not be considered definitive but only indicative as additional research is needed on the effect of weather on yields; in particular, relaxing the assumption that effects are linear.

5. References

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