Decreased drought sensitivity of major winter cereals in Spain revealed by remote sensing measures

David García-León

(with Sergio Contreras and Johannes Hunink)

Fondazione Eni Enrico Mattei (Venice, Italy)

Ispra, 22 September 2017

FutureWater
Investigación y consultoría en recursos hídricos para un futuro sostenible

Fondazione Eni Enrico Mattei

Before starting...

...my career and motivators in a nutshell

- Background: UMU, MMU, ESCP, CEMFI
  - Macroeconomics
  - Econometrics
- Bank of Spain: Research Department
  - Forecasting tools - Fiscal policy
  - Pursue a PhD on Climate Change: reconcile with social dimension of Economics
- PhD in Quantitative Economics (University of Alicante, Spain)
  - Climate Change economic impacts and adaptation
  - My transversal formation: not always a handicap
- Marie Curie IF (post-doc): 24 months (2016-2018.10)
  - Fondazione Eni Enrico Mattei (Venezia)
  - Drought impacts and adaptation to droughts (agriculture)

Motivation

Drought stress impacts on agriculture

- Droughts in Europe
  - Episodes more frequent in the last two decades
  - Erode the stability of agricultural production
  - Pose threats to Europe-wide food security
- Crucial to properly measure (economic) impacts and (possible) adaptation on agriculture
- Policy implications:
  - CAP implications
  - R&D on genomic research: Foster more drought-resistant varieties

Motivation

Drought stress impact on agriculture

- **Challenges**:
  1. Indicators: How to measure drought?
     - Meteorology, Hydrology, Soil moisture, etc
  2. Great spatial resolution: field-level data
  3. Insulate from irrigated crop varieties
- How we overcome these challenges? Features of our paper:
  1. We rely on remote sensing measures
     - High resolution
     - Easy and prompt access + Poorly accessible areas
     - No parametric assumptions
     - More sensors: new variables
  2. Field-level data set on cropland use, surface and productivity
  3. Analyse rainfed winter cereals

Objective of the paper

The objective of this paper is twofold:

- Determine whether remote sensing vegetation health (drought) indicators are good predictors of cereal yields
- Assess the evolution of Spanish cereals' productivity in response to drought stress (as measured by remote sensing indicators)

Closest to our work, Lobell *et al.*, 2014 (Science) study the US corn belt

- Yield data from USDA's Risk Management Agency (1995-2012)
- Measure drought stress via Vapour Pressure Deficit (VPD)
- Increased crop yields over the last years thanks to agronomic developments
- Maize shows greater sensitivity to drought

Data

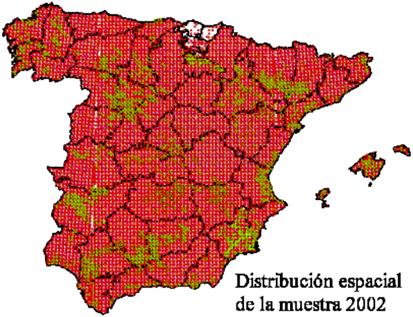
Yield and surface data

- ESYRCE (Spanish Survey on Surface and Crop Yields)
- Annual survey at field-level data. Stratified conglomerate sampling.
- Input of EC's Farm Accountancy Data Network (FADN) database

Data

Yield and surface data

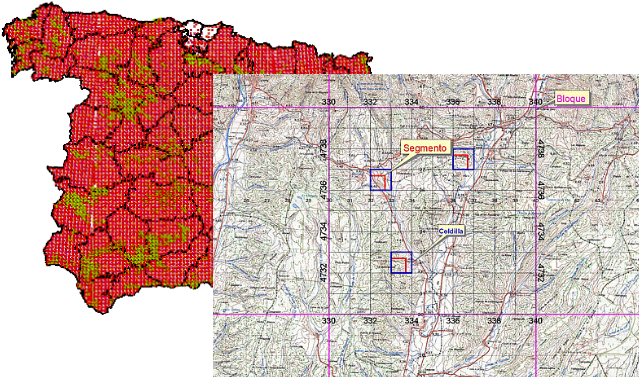
- ESYRCE (Spanish Survey on Surface and Crop Yields)
- Annual survey at field-level data. Stratified conglomerate sampling.
- Input of EC's Farm Accountancy Data Network (FADN) database



Data

Yield and surface data

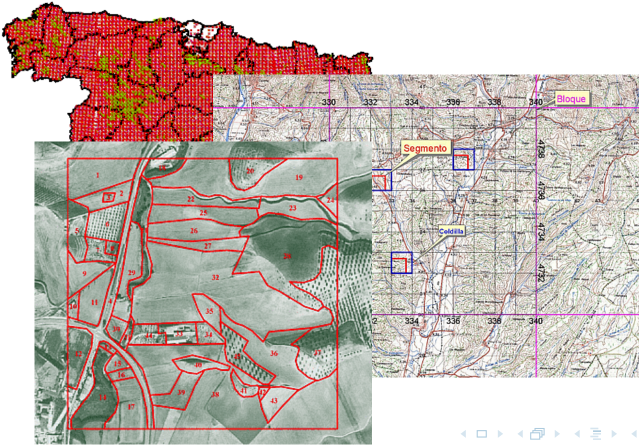
- ESYRCE (Spanish Survey on Surface and Crop Yields)
- Annual survey at field-level data. Stratified conglomerate sampling.
- Input of EC's Farm Accountancy Data Network (FADN) database



Data

Yield and surface data

- ESYRCE (Spanish Survey on Surface and Crop Yields)
- Annual survey at field-level data. Stratified conglomerate sampling.
- Input of EC's Farm Accountancy Data Network (FADN) database



Data

Cereals crops in Spain

- Wheat, barley, oat, rye (rainfed) represent 67% of Spain's cereal production
- Maize and rice (irrigated), 27%
- Barley: 5th largest world producer

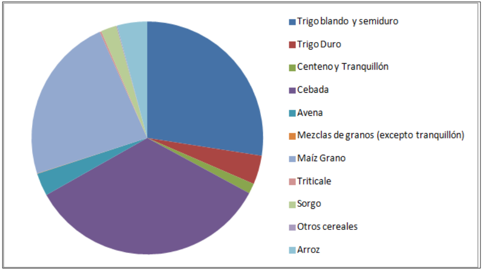
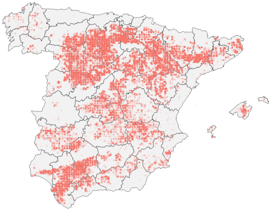


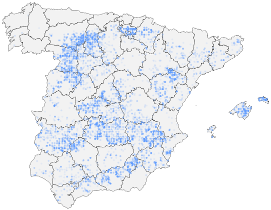
Figure: Spain's Cereal Production. Year 2014. Source: Ministry of Agriculture (Spain)

Data

Cereals crops in Spain: Production spatial distribution



(a) Wheat (b) Barley

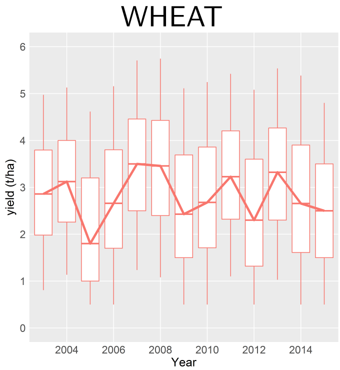


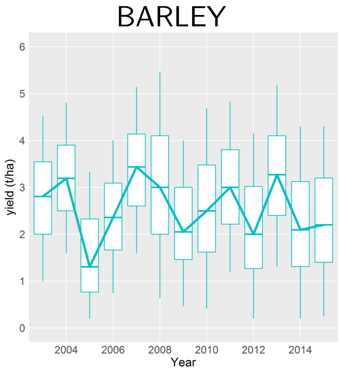
(c) Oat (d) Rye

Data

Cereal crops in Spain

- Yields measured in t/ha
- Predominantly flat yields over the period
- In line with Lobell and Moore (2014, 2015); Ceglar et al (2016, 2017)

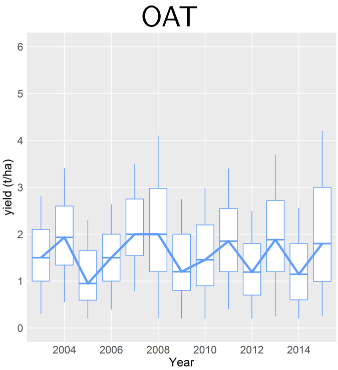


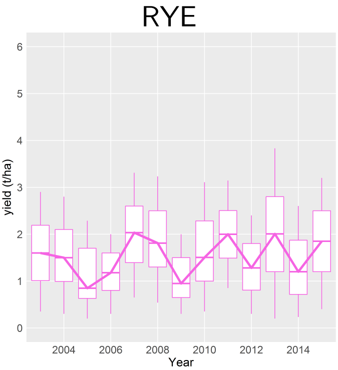


Data

Cereal crops in Spain

- Yields measured in t/ha
- Predominantly flat yields over the period
- In line with Lobell and Moore (2014, 2015); Ceglar et al (2016, 2017)





Data

(Remote sensing) Drought indices: the VCI and the TCI

- VCI: Vegetation Condition Index
- Measures NDVI anomalies
- Characterises moisture and thermal condition of vegetation

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{VIS}}{\mathrm{NIR} + \mathrm{VIS}}$$

NIR is acquired in the near-infrared regions
VIS is acquired in the visible regions

$$\mathrm{VCI} = \frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}}}{\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}}$$

Data

Drought indicators: the NDVI

- Available from 2002.
- Resolution: 1km x 1km
- NDVI shows values $\in (0, 1)$, where 0 (green) indicates higher stress

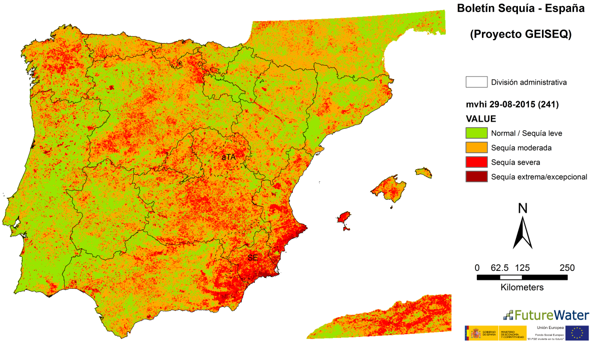


Figure: NDVI. August 2015. Source: www.InfoSequia.es

Data

(Remote sensing) Drought indices: the VCI and the TCI

- TCI: Temperature Condition Index
- Measures LST anomalies
- LST: Land Surface Temperature

$$\mathrm{TCI} = \frac{\mathrm{LST}_{\mathrm{max}} - \mathrm{LST}}{\mathrm{LST}_{\mathrm{max}} - \mathrm{LST}_{\mathrm{min}}}$$

Methods

Multiple Linear Regression Model

- Multiple linear regression models have been already used in the literature to address the role of *drought indicators* with respect to *yields*: Quiring and Papakryiaokou, 2003 (Agr For Meteo)
- The combo VCI-TCI, e.g. Singh, Roy and Kogan (2003)
- For all crops, we estimate the following equation

$$\mathrm{yield} = \alpha + \beta * \mathrm{province} + \delta * \mathrm{year} + \mathrm{X}'\gamma + \mathrm{u}$$

  where X describes vegetation stress at different stages of the growing period. Specifically, we distinguish three phases of growing period (Month of sowing: Oct):
  - Oct-Dec
  - Jan-Mar
  - Apr-Jun

Results

The role of VCI-TCI as determinants of yields

	Wheat	Barley	Oat	Rye
VCI_{Q1}	0.086	0.083*	−0.147*	0.060
	(0.053)	(0.044)	(0.061)	(0.102)
VCI_{Q2}	0.234***	0.486***	0.371***	0.330***
	(0.058)	(0.049)	(0.071)	(0.116)
VCI_{Q3}	0.986***	1.123***	0.631***	0.840***
	(0.063)	(0.051)	(0.074)	(0.114)
TCI_{Q1}	0.380***	0.376***	0.300***	−0.206
	(0.082)	(0.068)	(0.096)	(0.151)
TCI_{Q2}	0.055	0.052	−0.110	0.294***
	(0.067)	(0.054)	(0.079)	(0.110)
TCI_{Q3}	1.296***	1.538***	1.028***	0.299*
	(0.081)	(0.064)	(0.095)	(0.157)
N	22256	26307	7220	2635
R^2	0.283	0.283	0.411	0.286

Notes: In all regressions, the dependent variable is the average annual yield at the cell level (tonnes/hectare). All specifications include time and provincial fixed effects. * denotes significance at 10 pct., ** at 5 pct., and *** at 1 pct. level.

Results: Measuring drought sensitivity

the Environment Index (Lobell et al, 2014)

- Stress levels are often quantified as the average yield across all cultivars grown at a given site and season: the **Environment Index**
- Using the models estimated in the previous section,

$$\mathrm{EI} = \hat{\mathrm{yield}} - \hat{\alpha} - \hat{\beta} * \mathrm{province} - \hat{\delta} * \mathrm{year} = \mathrm{X}'\hat{\gamma}$$

- A plot of yields versus environment index is then used to measure the sensitivity of that cultivar's yield to stress
- We study the response of yields to different stress levels along time to test for changes in sensitivity
- We look in particular at
  - the time trends of yields according to different drought stress (EI quintiles)
  - the contribution of each indicator

Results: Measuring drought sensitivity

the Environment Index for **Wheat**

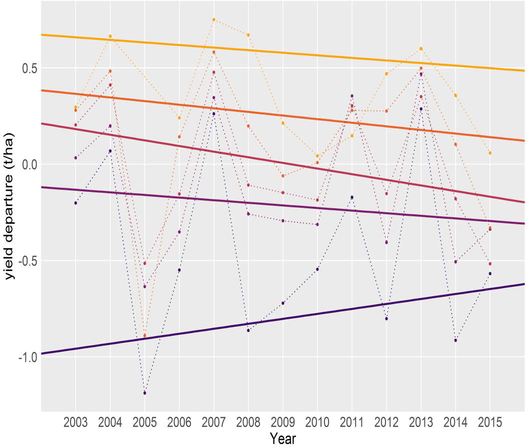
Yield anomalies quintiles of wheat for the period 2003-2015

Additional results for wheat More results

Results: Measuring drought sensitivity

the Environment Index for **Barley**

Yield anomalies quintiles of barley for the period 2003-2015

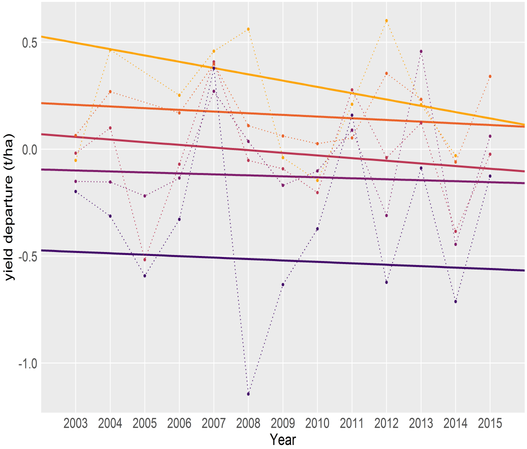


Contribution of indicators More results

Results: Measuring drought sensitivity

the Environment Index for **Oat**

Yield anomalies quintiles of oat for the period 2003-2015



Results: Measuring drought sensitivity

the Environment Index for **Rye**

Yield anomalies quintiles of rye for the period 2003-2015

Discussion of our results

- We confirm the stagnation of rainfed cereal yields in Spain over the last 15 years
- Positive, significant relation between VCI-TCI and cereal yields
- For VCI, this relation gets intensified over the growing period: Values close to anthesis are critical to determine yields
- In the case of temperature anomalies (TCI), except from rye, they only affect early and last stages of growth
- For wheat and barley, evidence from 2002-2015 suggests decreased sensitivity of yields under relatively worse drought conditions (convergence in yield anomalies)

Next steps

...to complement this project

- Alternatives to VCI-TCI: other remote sensing measures (Svoboda and Fuchs, 2016)
  - FAPAR, LAI
  - SMOS products (soil moisture)
- Combined measures: CSI (Zampieri et al, 2017)
- Copernicus products
- Control for regional heterogeneity
  - Yield anomaly and Yield heterogeneity by region/province (Lobell and Azzari, 2017)

Next steps

Short-term Projects

- Drought impacts in agriculture
  - Case study: Po river basin. Compare performance with other indicators/methods
  - Enlarge the scope to Europe mainland (using FADN database)
  - Integration of Northern Africa
  - Study/compare remote sensing measures available
- Combine satellite imagery and machine learning techniques to improve yield forecasts: ASAP (Meroni et al, 2017)
- Integrate with biophysical models
- Other climate extremes: heat-cold waves, floods...

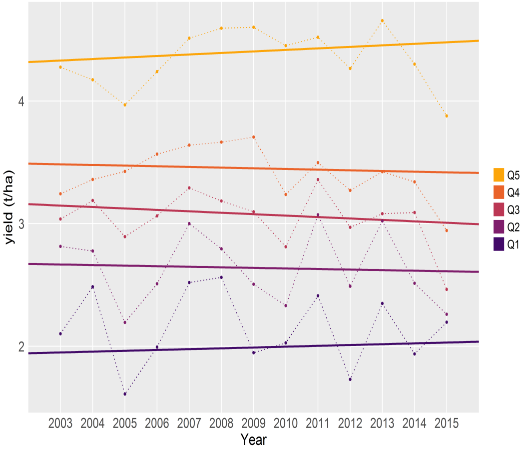
Thanks for your attention

European Commission | Horizon 2020 European Union funding for Research & Innovation

This research is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 705408.

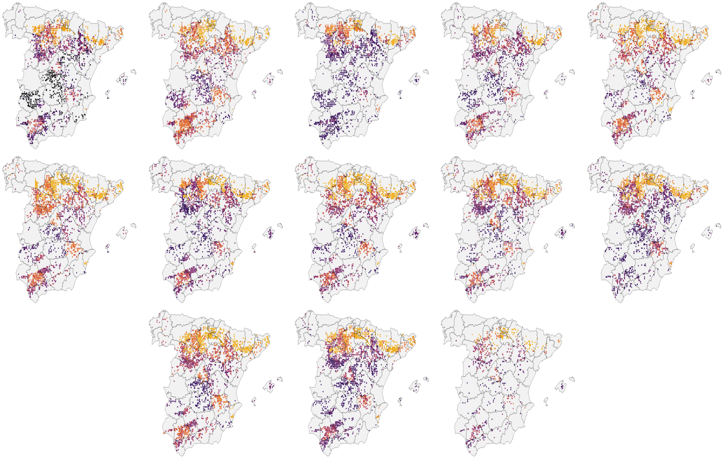
Supplementary material

Yield quintiles of wheat for the period 2003-2015



Supplementary material

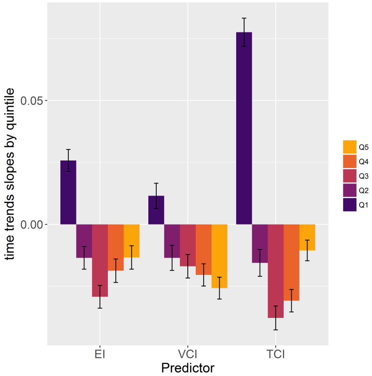
Yield quintiles of wheat for the period 2003-2015



Back to Results

Supplementary material

Contribution of drought indicators to yield trends for each drought environment



Back to Results