Research Papers
Issue RP0206
December 2013

CIP - Climate Impacts and Policy Division

Economic impacts of drought on agriculture

By **Jaroslav Mysiak**
Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), Fondazione Eni Enrico Mattei (FEEM)
phone: +39 0412700445
jaroslav.mysiak@cmcc.it

Maria De Salvo
Fondazione Eni Enrico Mattei (FEEM)

Silvia Santato
Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) Fondazione Eni Enrico Mattei (FEEM)

Mattia Amadio
Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) Fondazione Eni Enrico Mattei (FEEM)

SUMMARY Water security features prominently among the grand challenges of humanity in a quest for sustainable future. Southern European countries, Italy in particular, are highly vulnerable to droughts. In this article we estimate the drought-related losses in agriculture in terms of reduced yield and output for the selected, most important crops; and social impacts of droughts in the Po River Basin District (PRBD). To do this we first explore the regional impact assessment techniques based on production data collected or estimated at provincial (NUTS3) and lower (agricultural region, RA) spatial scale and then use partial equilibrium approach to modelling drought impacts in terms of yield, net revenue and employment.

Keywords: droughts, climate variability, agriculture, impact assessment, employment, Po River Basin

This report represents the Deliverable P80 developed within the framework of Work Package 6.2.15 of the GEMINA project, funded by the Italian Ministry of Education, University and Research and the Italian Ministry of Environment, Land and Sea.

1. INTRODUCTION

Water *security* features prominently among the grand challenges of humanity in a quest for sustainable future (Bakker, 2012). Repeatedly, the World Economic Forum (WEF) has placed water *supply* crises, in the 2014 report reclassified from societal to environmental risks, among the global risks of highest concerns (WEF, 2014). In terms of potential impacts, water crises are second only to systemic financial/fiscal risks and, only in recent editions, to climate change. The inspirational report of the 2030 Water Resource Group (2009), echoed by other studies, estimated that under fairly conservative assumptions (average economic growth and no efficiency gains), global water demand could exceed the currently *accessible* and *reliable* water supply by 40 per cent by 2030. Worse, extreme weather and climate events connected to water risks, already classified among the most likely global risks by WEF, are likely to be further exacerbated by human-induced climate change (IPCC, 2012), threatening to undermine economic growth and development.

Southern European countries, Italy in particular, are highly vulnerable to droughts. Beyond yield losses, droughts increase the risk of infestations, weeds and diseases. Moreover, droughts also affect soil functions, and play a role in desertification. Livestock's productions is affected by droughts through quantity and quality of forage. Assessment of drought-related agricultural losses is frequently conducted using *Computable General Equilibrium* (CGE) models (Gómez et al., 2004; Dixon et al., 2005; Diao et al., 2008; Schreider, 2009; Trnka et al., 2010 and 2011; Wittwer & Griffith, 2011; Pauw et al., 2011). These models offer several advantages, as they: i) capture economy-wide and global changes, such as those on input and output prices; ii) measure indirect impacts on other economic sectors besides agriculture. CGE models however are ill-suited for an analysis of farmers' adaptation to new climate scenarios. *Positive Mathematical Programming* (PMP) is a more recent approach (Quresh et al., 2010; Quresh et al., 2013; Howitt et al. 2012). This method overcomes the limits of linear programming, such as unknown relations between production factors and yields, considering only the costs of production function. PMP is suitable to simulate changes of use and availability of water. However, the PMP require knowledge, often not available, on the price of water, crops' water demand, and water availability. *Partial equilibrium* models have been used for estimating the impacts of climate change, (Mendelsohn and Dinar, 2009; Dinar and Mendelsohn, 2011), or for assessing losses caused by annual weather fluctuations (Kelly et al., 2005). Few studies consider farmers' expectations of changing climate (Deschenes and Kolstad, 2011), or weather risk management (Di Falco et al., 2011).

In this article we approximate the drought-related losses in terms of reduced yield and output for the selected, most important crops; and social impacts of droughts in terms of (labour and employment) in the Po River Basin District (PRBD). To this end, we *first* analyse the crop production data collected by Italian Statistical Bureau (*Istituto di Statistica*, ISTAT) at provincial (NUTS3[1]) level. *Second*, and to better account for climate variability within the provinces, we analyse the yield data disaggregated at the agricultural regions (*regione agraria*, RA). The RAs have been established by ISTAT back in 1950s as more disaggregated statistical accounting units characterised by similar environmental (including climate) conditions. However, the collection of the RA-disaggregated annual production data is not anymore pursued by most Italian regions.

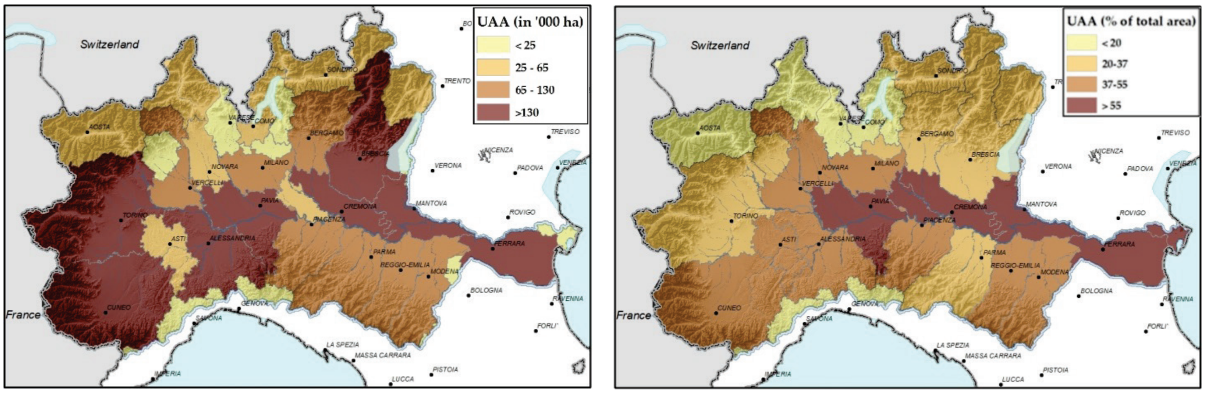
Third, we apply a complementary approach to the farm-level impact assessment (De Salvo and Mysiak, submitted) that uses the *Italian Farm Accountancy Data Network* (FADN) data. The latter offers a more reliable impact of drought not only on crop production but also on farm's income and viability. The partial equilibrium prospective is well-suited for analysing farmers' responses to droughts, and drought's impact on farm net revenue and labour demand. We have developed a fixed effect panel data model for each output variable (crop yield per ha; net revenue per ha; and labour hours per ha), using a set of explanatory time-variant and time-invariant variables such as the soil fertility; type, source and intensity of irrigation, the field location and dimension, and farm specialization, to quote but a few. The impacts of drought were simulated for a set of scenarios.

[1] NUTS - *Nomenclature of territorial units for statistics* is a hierarchical system for dividing up the economic territory of the EU for the statistical purposes, see for more detail http://epp.eurostat.ec.europa.eu/ portal/page/portal/nuts_nomenclature/introduction

2. AGRICULTURE AND DROUGHT RISK IN THE PO RIVER BASIN DISTRICT

The *Po valley*, major part of which is comprised in the Po River Basin District (P-RBD)[2], is Italy's largest contiguous agricultural land. The P-RBD accounts for nearly 21 per cent of the total agricultural area (TAA); 21.5 utilised agricultural area (UAA); almost entire national production of *rice* and about or more than a half of the national production of *soft wheat*, *rye*, *maize*, *sorghum,* and other cereals; and almost 30 per cent of the agricultural value added (see Annex SM Figure 1). The PRBD hosts over 260,000 agricultural holdings, mainly individual/family farms. Around 45 per cent of agricultural land in the P-RBD is irrigated or equipped for irrigation. Furrow (flood) irrigation is prevailing in the upstream part of the P-RBD whereas in the downstream the use of more efficient (sparkling and drip) irrigation techniques is more widespread (ISTAT 2013; Mipaaf 2009).

Agriculture in that area is prevalently devoted to specialised farming, especially breeding (~36 per cent); crop growing (~28 per cent), mostly cereals, protein and seed-oil crops; and arboreal cultivations (~19 per cent), in particular grape. Farmland is situated mainly in the low-laying plains (~61 per cent).



MAP 1: Utilised agricultural area (UAA) in the Po River Basin District (PRBD): (*left*) total extension of UAA (in thousands of ha) aggregated at the provincial (NUTS3) level, and (*right*) UAA proportion of the total district area (in per cent).

The OECD (2009) review acknowledged the atypical, with respect to the rest of Europe, character of Italy's rural areas. With few exceptions, the rural districts of the P-RBD are

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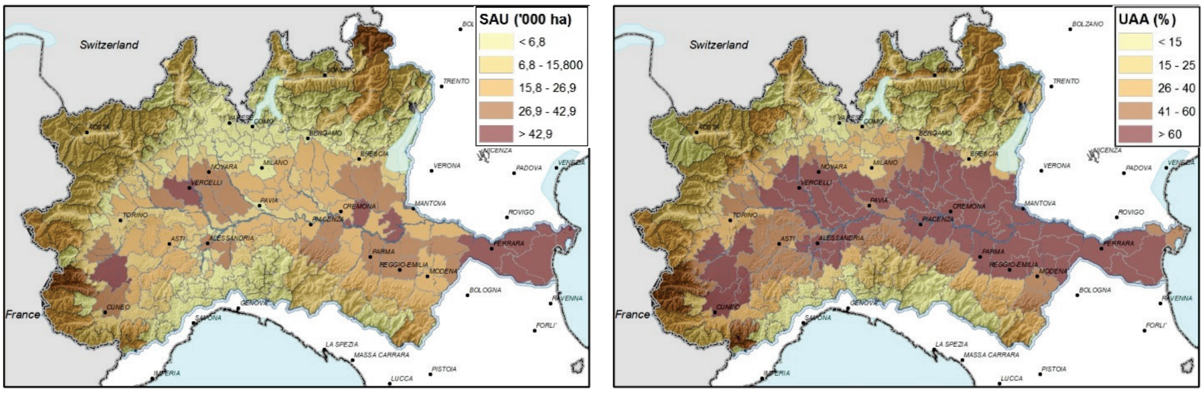
[2] The Po River Basin District (P-RBD) is one of the 8 river basin districts (RBDs) established under the EU Water Framework Directive (2000/60/EC) and the legislative decree 152/06 which transposes the WFD into national legislation (the so-called Environmental Code, ENC). It is the largest single river basin (RB) in Italy, one of the RBs of national importance (law 183/89 of 18th May 1989) (see also Annex SM MAP 1).

richer and more industrialised than the EU average. The gross national income (GDP) per capita at the provincial level (NUTS3) ranges from 90 to 160 per cent of the EU average (Eurostat 2010).



MAP 2: Utilised agricultural area (UAA) in the Po River Basin District (PRBD): (*left*) total extension of UAA (in thousands of ha) aggregated for the *agricultural regions* (RAs), and (*right*) UAA proportion of the total area of the RAs (in per cent).

Similar to elsewhere in Europe, agriculture has experienced substantial changes over the past decade (ISTAT 2011; OECD 2009). The TAA and UAA declined substantially, due to urbanisation and land abandonment, especially in mountain, disadvantaged areas. The agricultural sector generates an added value of about 7.7 billion Euro per annum (~1.2 per cent of the total added value produced in the district).

Although under average climate conditions water is sufficient for all water uses, including agriculture that accounts for around 80 per cent of consumptive water withdrawal, the recent period of prolonged droughts affecting parts or the whole P-RBD between 2003 and 2007 led to substantial harvested yield and economic losses. The P-RBD counts to a better water-endowed regions of Italy, but the drought spells during this period (Figure 1 and Annex SM Figure 2 and SM Map 2) had illustrated the District's vulnerability to drought and water scarcity.

During the spring and the summer of 2003, a severe and persistent drought afflicted Southern Europe, including the P-RBD. The Po river reached its absolute minimum at the closing section in Pontelagoscuro: -6.99 m or 270 m^3/s compared to an average of 1400 m^3/s. In 2006 and 2007, the Northern Italy experienced another anomaly in terms of precipitation. Scarce precipitation led to rainfall deficit of 200 mm by the end of 2006 and 30 per cent by April 2007. In 2007 rivers discharges were lower than in 2003, marking a decline of one fourth compared to historical minimum values. Since 2003, the state of (national) emergency (SoE) under the law 224/1992 has been declared three times (2003, 2006, 2007) for a total duration of 21 months. During the exceptional drought occurred in 2003, the River Basin Authority in collaboration with the Civil Protection Agency have initiated a new instrument, the so called *Drought Steering Committee* (DSC, in Italian *cabina di regia*) and *Protocol of Intent* (PoI, in Italian *protocollo d'intesa*). The agreement provided for the release of additional 3.7 million cubic meters a day from the Alpine reservoirs in order to reduce the water deficits downstream. It also provided for the reduction of water abstraction for agriculture.

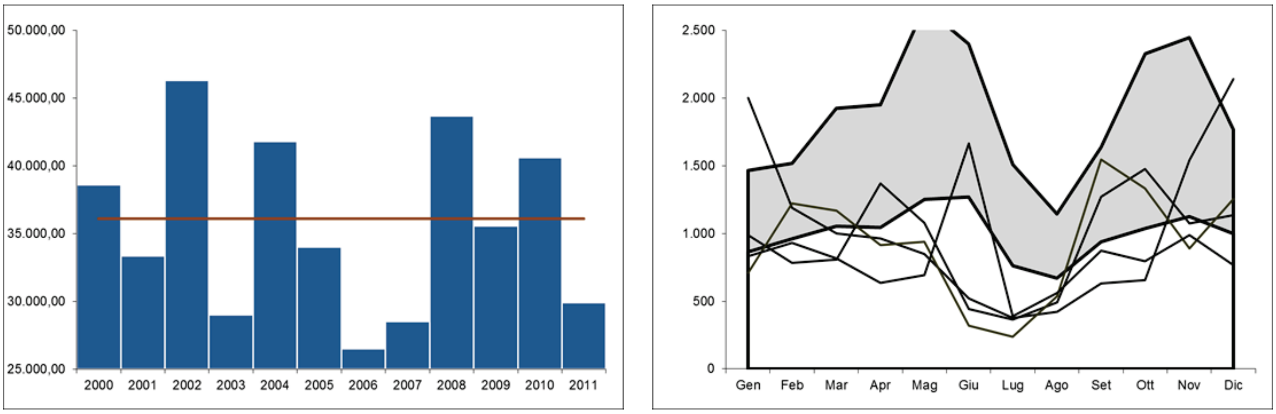
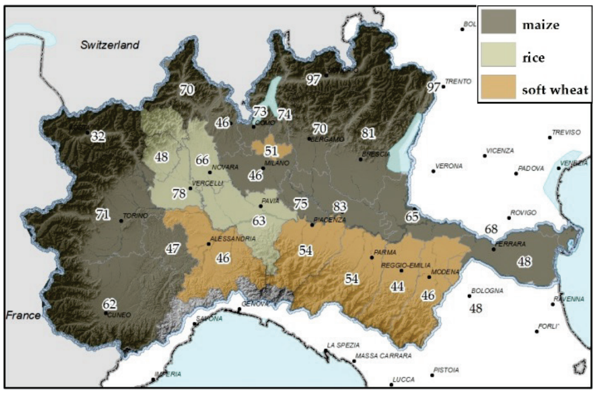


Figure 1 (left) Annual precipitation over the P-RBD in mil m^3 compared to the long-term average (red line) for the period 1971-2000; (right) The monthly average Po river discharge at the basin closure (Pontelagoscuro) in 2003, 2005, 2006, 2007, compared to the first $Q_{25\%}$ and third $Q_{75\%}$ quartiles of the distribution of monthly average value discharge volumes over the period 1917-2009. Based on ISTAT data, own elaboration.

3. MATERIAL AND METHODS

The P-RBD comprises territory of 33 provinces (see Annex SM Table 1), four of which only marginally[3]. The provinces differ considerably in many ways: the surface area ranges from 400 to almost 7,000 sq.km, the population density between 40 and over 2,000 inhabitants per sq.km, average altitude between 5 and over 950 meters above sea level (MASL). The climatic characteristics (temperature and precipitation) are equally diverse. The crop patterns and dominant cultivations (Map 3) on the other hand are relatively stable. Yet the utilised agricultural area (UUA) has declined substantially over the analysed period.

The agricultural yields for the period 2000-2012 have been obtained from ISTAT (ISTAT 2013). The data contains the extent of cultivated areas and the estimated/reported production of main crops by provinces.



MAP 3: Distribution of the dominant crops across the P-RBD, including the average (2000-2011) share of the UAA of the respective crops. Maize is the dominant crop in the western and northern part of the District, including the downstream low-plains. Rice is dominant in the central part of the District, in the provinces *Biella*, *Vercelli*, *Novara* and *Pavia*. Both rice and maize are irrigated crops. Soft wheat, which is usually not irrigated, is dominant in the southern part of the District.

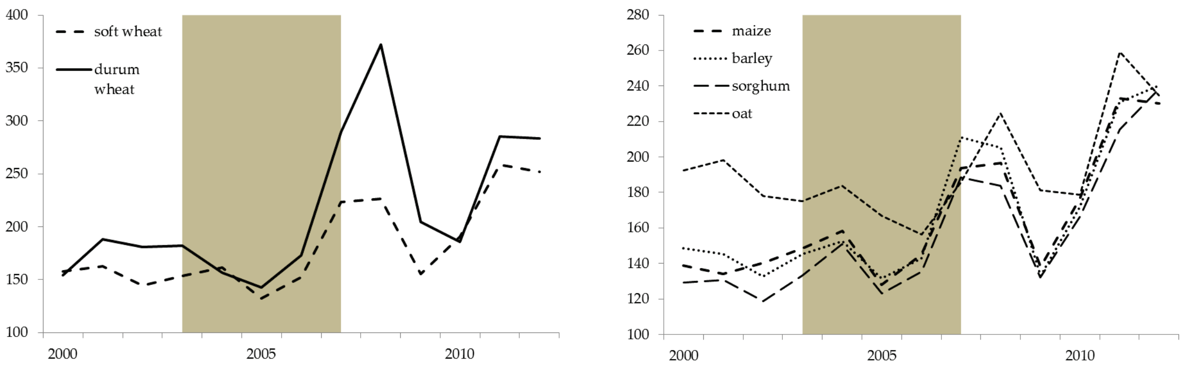


Figure 2: Average annual prices of the selected agricultural crops. The highlighted area demarcates the drought spells between 2003 and 2007. Source: *ISMEA* database.

[3] The provinces *Imperia*, *Genova*, *Savona* and *Verona* (situated in the *Liguria* administrative region) and *Verona* (*Veneto* region) have not been considered in the analysis.

The agricultural yield losses (section 3.1) were calculated as the difference between the reported per-hectare-yields during the years (2003, 2007) of the most intense drought-spell and the medium-term average yields over the period 2000-2011. The estimated yield losses are only approximations of the real drought-related losses as the average yields are influenced by management decisions such as the application rate of pesticides and fertilisers in addition to the climate variables (i.e. temperature and precipitation).

The *agricultural regions* (RA) is a statistical (rather than administrative) unit consisting by (2-5) neighbouring municipalities with similar environmental (i.e. geological, soil, climate and geographical) conditions (ISTAT 1958). The data on agricultural production at the RA level is collected by *regional administrations* but only few *regions* have maintained annual data collection campaigns. For the purpose of this study, we analysed the annual RA-data available only for the *Emilia Romagna Region* (RER) (ER Statistica 2013) and for fewer crops for *Lombardy* region. Both data was obtained from the regional statistical offices.

The agricultural prices were obtained from the database of the ISMEA[4] at the provincial, regional and national scale. Figure 2 shows the variation of the main crops, determined by the international markets and only to relatively small extent by the persistent drought in the Northern Italy. Especially the *durum wheat* price variation and to a lesser extent the price variation of the other crops show an upsurge that set-off in 2005-06 and culminated in 2007-08 (ISMEA 2010). A similar dynamics can be observed in the evolution of the production costs (see Annex SM Figure 3) over the same period. The dynamics of crop prices can counteract or reinforce the effects of drought, affecting the farm income and viability.

The fixed effect panel data models (section 3.2) are based on the data from the Italian Farm Accountancy Data Network (FADN)[5]. Our analysis focusses on the prolonged drought period (2003-07) in the Emilia Romagna region inside the P-RBD. The study area encompasses the provinces of Piacenza, Parma, Reggio Emilia, Modena, Bologna and Ferrara. FADN data shed light on farm's physical and structural characteristics (location,

[4] Istituto di Servizi per il Mercato Agricolo-Alimentare (http://www.ismea.it)

[5] The Farm Accountancy Data Network (FADN) is a data collection tool established to evaluate the income of agricultural holdings in the EU. It consists of annual micro-economic surveys carried out by Liaison Agencies in each Member State on a rotating panel of "commercial" farms.

crop areas, livestock density index[6], labour force, etc.), and economic and financial data (value of crop production, stocks, sales and purchases, production costs, assets, liabilities, production quotas and subsidies etc.).

To separately account production, economic losses and employment losses different models was estimated considering as a proxy of these factors respectively:

1) The production quantity, measured in q/ha, considering as observation unit (*i*) a specific crop growing by a particular farm in a particular year (*t*).
2) The net Revenue, measured in €/ha, considering as observation unit a specific farm (*i*) in a particular year (*t*).
3) The employment level, measured in terms of total hour of labour/ha, considering as observation unit a specific farm (*i*) in a particular year (*t*).

Due to the panel nature of the database, for each model's specification both one-way and two-way fixed effects models was tested. In the first case fixed effects are associated with the farm only, while in the latter case the hypothesis is that effects are associated with each farm and each time period. In this case the model include also dummies variables related to years.

Variables used as regressors include both time-variant and time-invariant factors. The sample of farms extracted by the Italian FADN database for the studied area is unbalanced and data allows analysing effects of an independent variable when its value changes within farm, but also the effect of an explanatory variable when its value changes between farms, such as, for instance irrigation system and source.

However, the main characteristics of the fixed effects specification is the impossibility to consider among the independent variables factors that are time-invariant, because they are automatically excluded by the model. As suggested by Wooldridge (2002), these variables can be transformed in time-variant variables simply interacting their value with a trend variable that assumes a specific year as a base period. Given that our time-invariant regressors are prevalently dummy variables, we interact them values with dummy variables for the years 2003, 2006 and 2007 to isolate farms that present each specific characteristics in the above-mentioned drought years.

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[6] The livestock density index provides the number of livestock units (LSU) per hectare of utilized agricultural area.

Moreover, estimating the FE specification, the estimates of the standard errors obtained by the aid of the above estimators are consistent even if the residuals are heteroskedastic. To avoid this possibility, Huber and White's robust estimators have to be implemented (Huber, 1967; White, 1980). Again then, given the time nature of data, it is plausible that these estimates are biased also by autocorrelation.

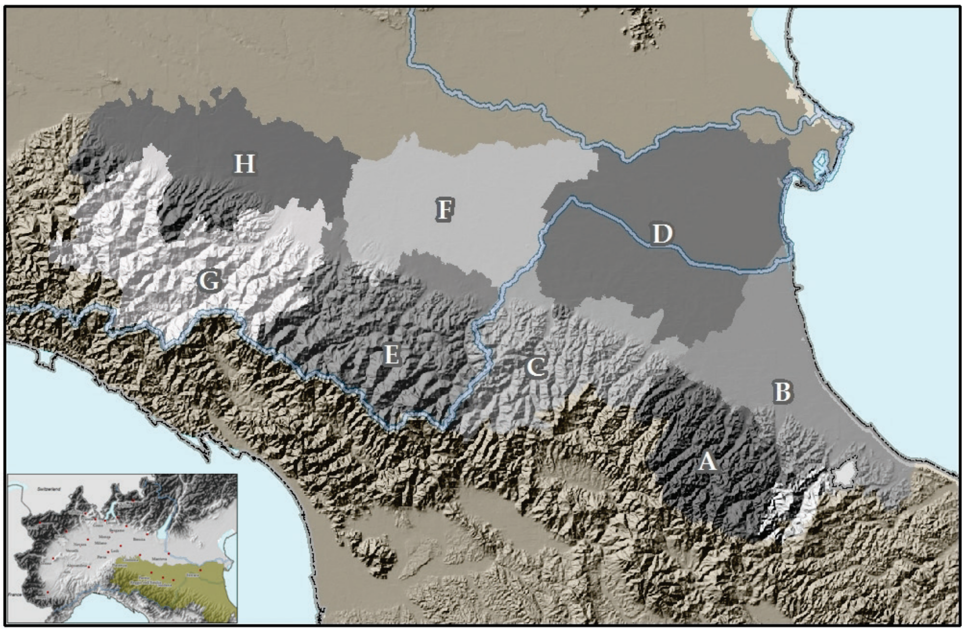
To avoid both sources of bias it is possible to implement the nonparametric technique of estimating standard errors suggested by Driscoll and Kraay (1998). According with this procedure, the error structure is assumed to be heteroskedastic, autocorrelated up to some lag and possibly correlated between the groups (panels). Consequently, these estimates of standard errors are robust to general forms of cross-sectional (spatial) and temporal dependence.

SM Table 1 reports, for each class of estimated models, the type of model (farm's vs. crop's specification) and the full list of factors hypothesized as independent variables, distinguishing between time variant vs. time-invariant ones.

To simulate the weather scenario and introduce into the analysis a proxy of drought severity ,we use the "*Hydro-Climatic Balance*" (HCB). HCB is calculated combines precipitations and potential evaporation, and is a good proxy of the soil humidity. The calculated sessional HCB make it possible to link temporal evolution of drought to yield losses. In each model we test a quadratic relationship between the dependent variable and the value of HCB:

$$y = \beta_0 + \beta_1 * HCB + \beta_2 * HCB^2 + \sum_{i=3}^{n} \beta_i x_i$$

The seasonal value of the HCB was estimated using data collected from the local meteorological stations by the Regional Nature Protection Agency of Emilia Romagna (ARPA-ER). The HCB has been calculated for the six hydro-climatic districts of the studied area. For each district, we aggregated the daily values of HCB for the periods September-November (Fall), December-February (Winter), March-May (Spring) and June-August (Summer), for rain season (Fall-Winter) and crops growing season (Spring-Summer). Drought sensitivity indexes were estimated for each year in the period 2003-2007 and for the baseline period 1992-2002.



Production and employment impacts for selected drought scenarios were simulated. To consider a different intensity of the simulated drought event we assumed a seasonal decline of HCB between 10 and 50 per cent respectively the corresponded average value accounted for the period 1992-2002, that we assume as benchmark period to represent the normal and "no-affected by drought" weather scenarios. Finally, using different levels of output prices and costs of production, we estimated economic losses for the simulated drought events. Hypotheses concern an increase of output prices (+5; +10 per cent) and an increase of the cost of production (+5 per cent; +10 per cent; +20 per cent; +30 per cent).

4 RESULTS

4.1 REGIONAL ANALYSIS

The yield losses are highly variable across the provinces but as shown in Figure 3, the average yields in the drought years 2003 and 2007 tend to be close to the minimum values observed over the period 2000-2011 in almost all altitude zones. This is more so in 2003. Notwithstanding, some provinces have benefited from higher temperature and display higher than average yields even in the drought years. The production gains are more pronounced in the upstream areas with higher water endowments and are representative of the fact that effects of droughts are unevenly distributed (Jaroslav Mysiak and Markandya 2009). In addition, Figure 3 and 4 display low (and statistically insignificant) correlation between the average altitude and yield which is little surprising given the highly variable environmental conditions within the district.

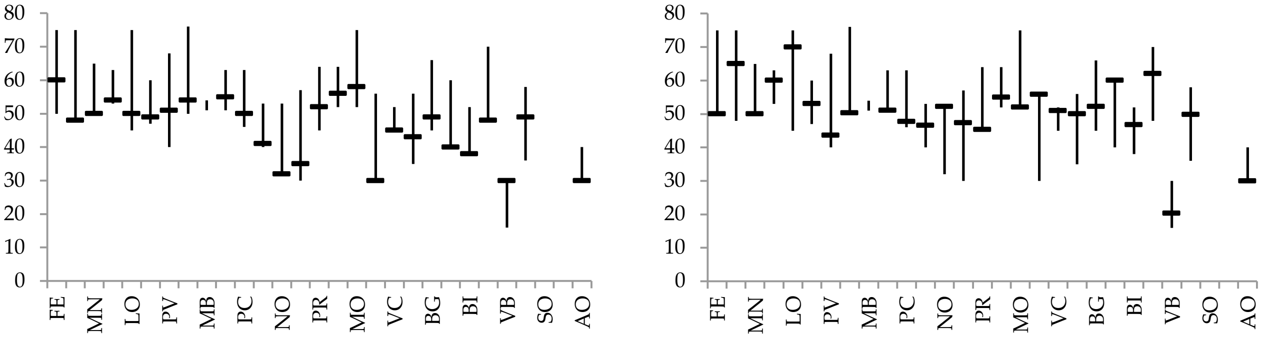


Figure 3: Variation of the *per-hectare* yields (in '00 kg) of the soft wheat across the 29 provinces over the period 2000-2011. Beside the range (min and max value), the figure display the average yield in 2003 (left) and 2007 (right). The provinces (x-axis) are ordered by average altitude, starting from lowland province Ferrara (FE) in the left up to the mountainous province Aosta (AO) in the right.

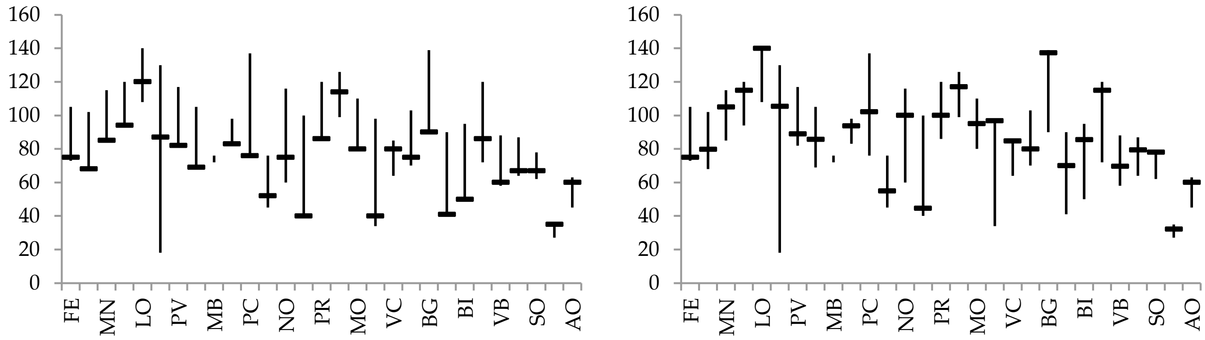


Figure 4: Variation of the *per-hectare* yields (in '00 kg) of the maize over 2000-2011. Middle point represents the 2003 (left) and 2007 (right) yields. The provinces are ordered as in the Figure 3.

Figure 5 and Maps 4, 5 show the pattern of average yield *gains* and *losses* observed during the drought years 2003 and 2007. In 2003, wheat (both soft and durum), maize, rye, sorghum and other cereals display yield losses across the whole territory only few exceptions mainly in the higher altitudes. Rice, oat and barley on the other hand show substantial variations of gains and losses. In 2007, the distribution of losses and gains (compared to average) is more complex and no unique pattern is detectable. Wheat and barley for example tend to display gains in the higher altitudes whereas the major losses are concentrated in the lower latitudes and the Po floodplains. Oat and sorghum show a weak gradient in west-east direction, while rice and maize display no clear pattern.

In 2003, the yield deviations from average are highly and positively correlated between wheat, barley and sorghum, while maize is significantly correlated with wheat and sorghum. In 2007, these correlations are preserved although in a weaker form. Besides the within-the-year variability, a between-year variability can be noted. There is significant negative correlation between wheat losses in 2003 and 2007; and between oat 2003 and 2007 sorghum losses. The complex pattern of losses cannot be explained without a detailed pattern of drought evolution in the respective years.

Consistent with the above discussion, the gross production losses (in current prices) estimated for the wheat, barley, oats, rice, maize and sorghum are larger in 2003 (~156 million Euro) than in 2007 (~97 million Euro). The largest losses are registered in both years for maize and soft wheat, the latter is typically not irrigated and hence more exposed to precipitation deficiency. In contrary, the gross gains are lower in 2003 (~ 44 million Euro) than in 2007 (~111 million Euro). Most of the gains are attributable to two crops, rice in 2003 and rice and maize in 2007. The net impacts estimated at the provincial level are negative for the 2003 (net loss of ~ 113 million Euro) and positive for 2007 (net gain of ~14 million Euro).

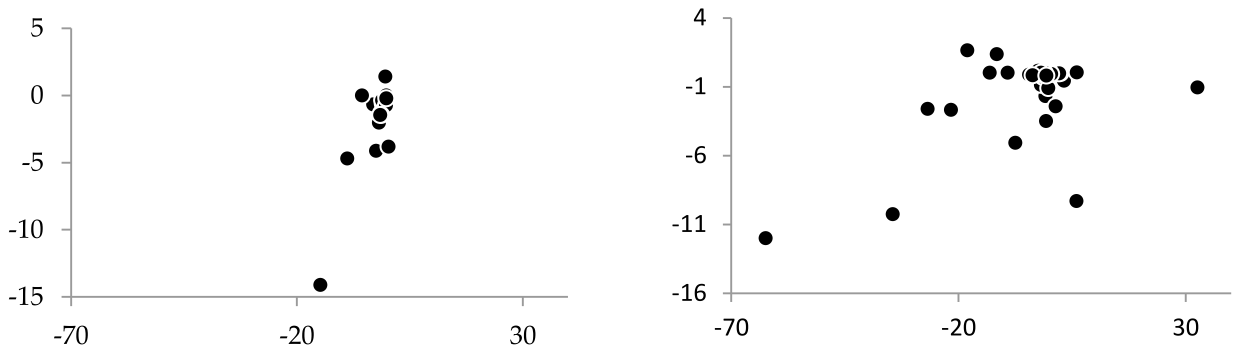


Figure 5: Comparison between the net losses (in million Euro) registered across six provinces of the Emilia Romagna Region for the eight crops using production data collected at RA level (x-axis) and province level (y-axis) in 2003 (*left*) and 2007 (*right*).

The analysis on the more detailed spatial scale (RA level) in Emilia Romagna (RER) allows a qualification of the above results[7] (Maps 6-7). Whereas the district level analysis for the 6 provinces of RER display net losses for both 2003 and 2007 (37 and 51,6 million Euro respectively), the net production losses estimated using the more detailed spatial

[7] Equivalent of the Figure 5 for the RA analysis is omitted in the paper as it is too large but is available upon request.

disaggregation of yield losses amounts to 46,9 and 170 million Euro respectively. The difference is particularly large for 2007 (factor 3.5). Wheat (both soft and durum) represent the largest net loss component driven by the sharp increase of wheat prices in that period. The largest differences between province and RA based estimates in RER refer to wheat in Ferrara and Piacenza, rice in Ferrara and maize in almost all provinces. The estimates of losses using the two different regional methods are both highly correlated and positive, but the estimates of gains are low (insignificant) and negative. The within-year correlation between losses show similar pattern as in the analysis using the district-level data: the yield losses are highly and positively correlated between wheat, barley and other cereals; and between barley and sorghum. Durum wheat losses in 2003 are moderately correlated with the maize 2007 losses. Importantly, the losses in wheat yields are negatively correlated between the two years also at the RA level of analysis.

Altitude zones	Provinces	sw 03	sw 07	dw 03	dw 07	ry 03	ry 07	ba 03	ba 07	oa 03	oa 07	ri 03	ri 07	co 03	co 07	so 03	so 07	ot 03	ot 07
Mountain > 600 MASL	AO	-	-		++	-	-	--	+++	--	+++			++	++				
	TN													++	-				----
Hill 300 to 600 MASL	SO					=	=							--	++				
	CN	=	+		++++	--	+	+	++	+	++++	++	--	--	+	--	-	--	+
	VB	++++	--			--	+++		---					--	+	++++	=	---	+
	TO	--	++		++	-	+	-	+++	++	+	++	+	--	+++		+	--	++
	BI	---	+			+++	++++	---	--	--	++++	++	++	----	++	+	---	--	-
	LC	---	++++					-	++	--	++			----	--			-	++
	BG	--	--		++++		+	-	---	--	+	----	+	---	+++		-		
	CO	-	++			-	++	----	++	--	+			--	-	++	--	-	++
	VC	--	+		---			--	-	+	=	++	+++	+	++				++
	VA	----	+++			--	++	----	+	----	++			----	+++	----	+++	----	-
	MO	--	---	-	--			--	-			++	++	---	-	----	--		
	BS	-	-	+	-		++	++	----	-	--			-	+		-		+
Plain < 300 MASL	PR	-	---	+	--			-	--	-	-			--	+	--	----	-	---
	AT	---	+	---	+		+	--	--	+++	++++			----	----	---	---	---	++++
	NO	----	++		+	---	+++	----	--	---	++	++	+++	---	++		+	---	++
	AL	--	=	-	--		-	-	---	++	++	++	++	--	--	+	=		=
	PC	-	--	-	+		=	--	-	--	++	--	----	---	++	-	--		+
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	MB																		
	BO	--	---	--	--		---	--	---	----	--	++	++	---	-	---	-		---
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	MI	--	-		-	--	=	--	-	----	+	+	+	--	++		+++	---	+
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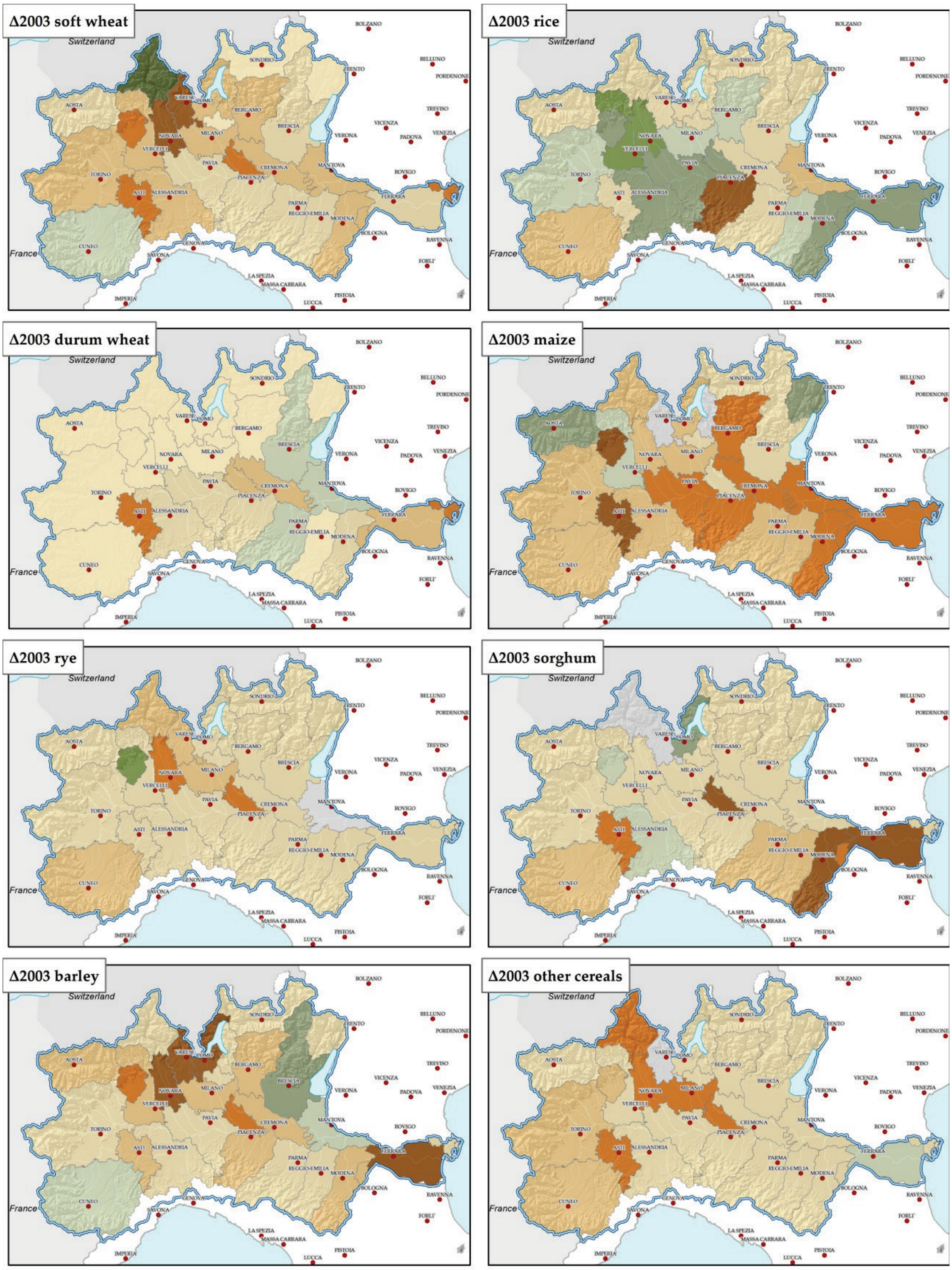
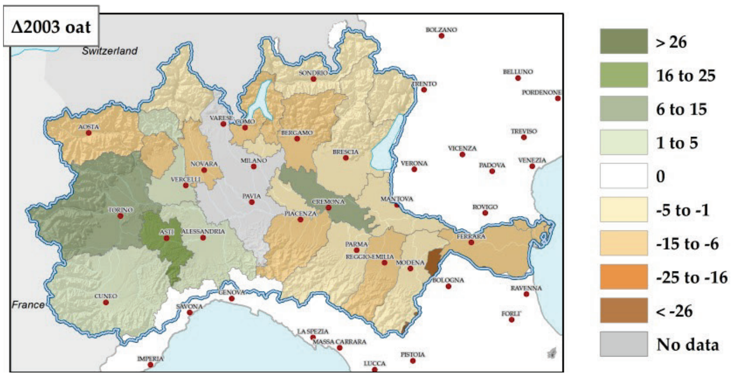
	MN	--	--	+	--	----	--	+	--		----	+++	--	---	-		--		--
	RO	---	+	---	+			--	+	--	++	++	++	---	--	-	+		
	FE	-	---	--	--		-	----	-	--	--	++	++	---	---	----	--	+	----

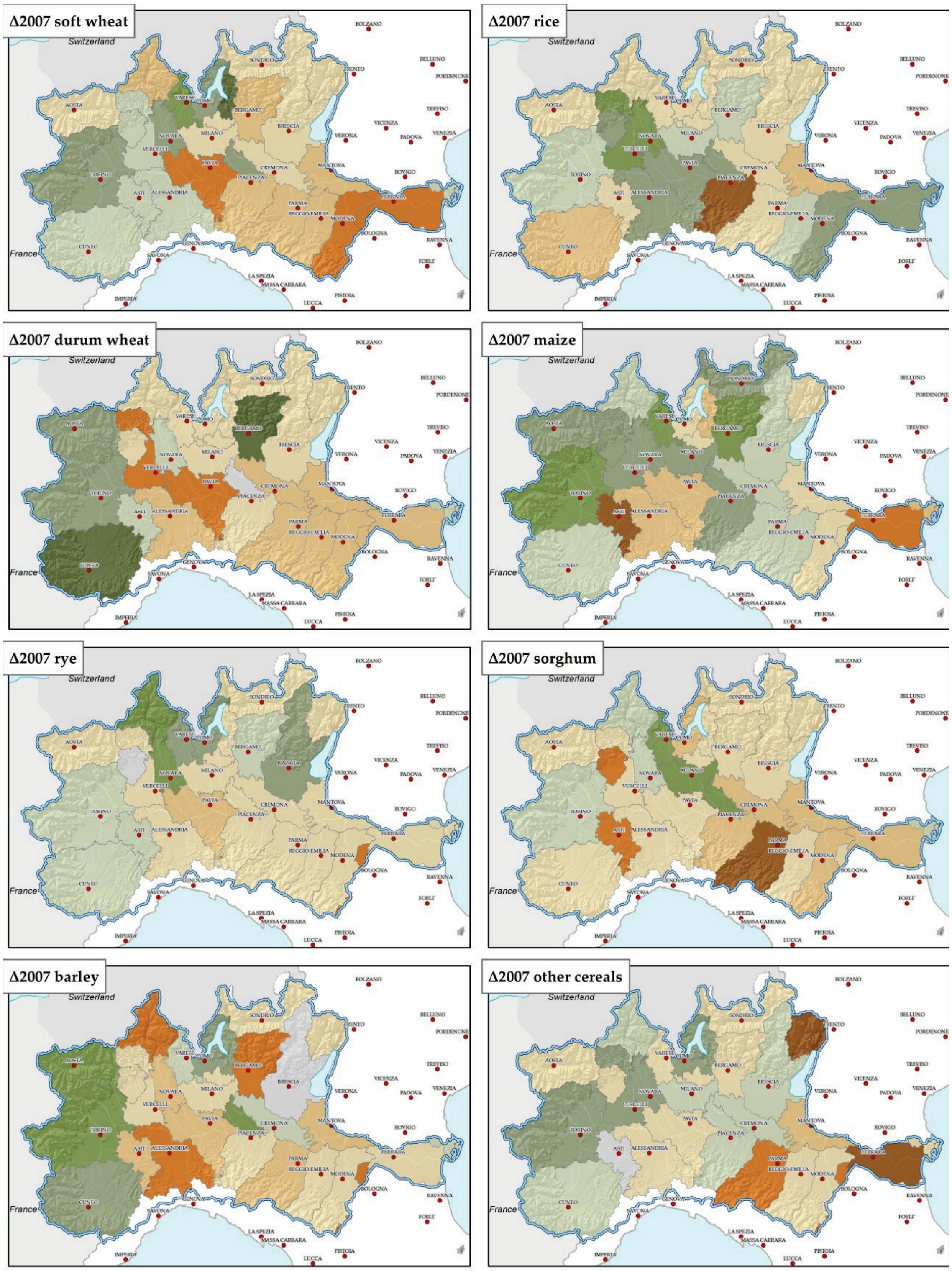
Figure 6: Comparison of the 2003 and 2007 relative deviations from the 2000-2011 average yields for the major crops (soft what *sw*, durum wheat *dw*, rye *ry*, barley *ba*, oat *oa*, rice *ri*, maize *ma*, sorghum *so*, other minor cereals *ot*)

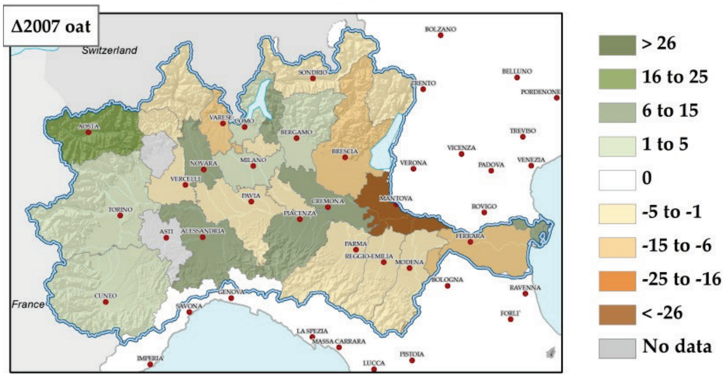
++++	Over +26	+++	+16 to +25	++	+6 to +15	+	+1 to +5	=	0
----	Below -26	---	-16 to -25	--	-6 to -15	-	-1 to -5	n.d.	No data



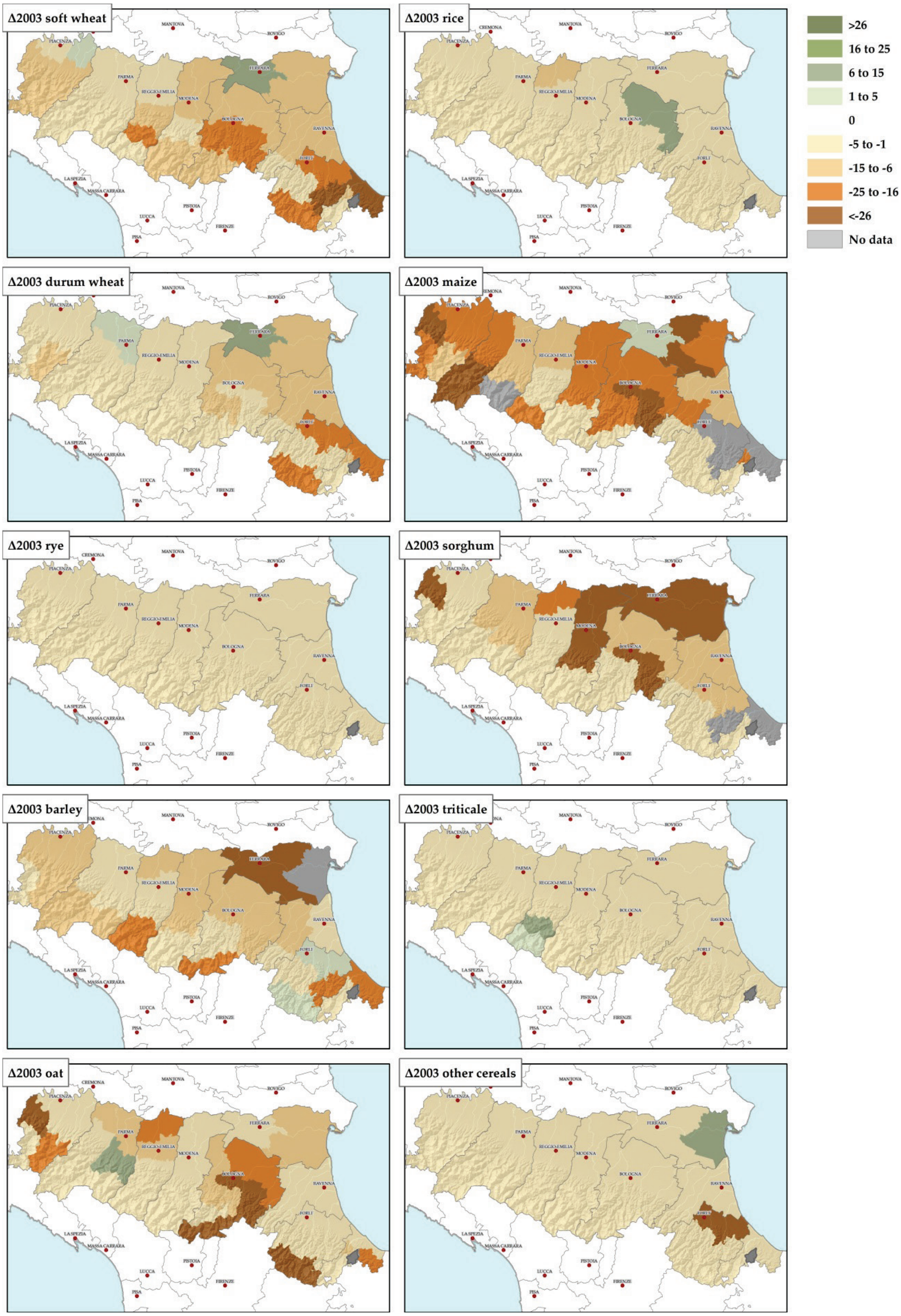


MAP 4: Relative difference of the *per-hectare* 2003 yields of major crops from the 2000-2011 average yields. Based on data from ISTAT, own elaboration.

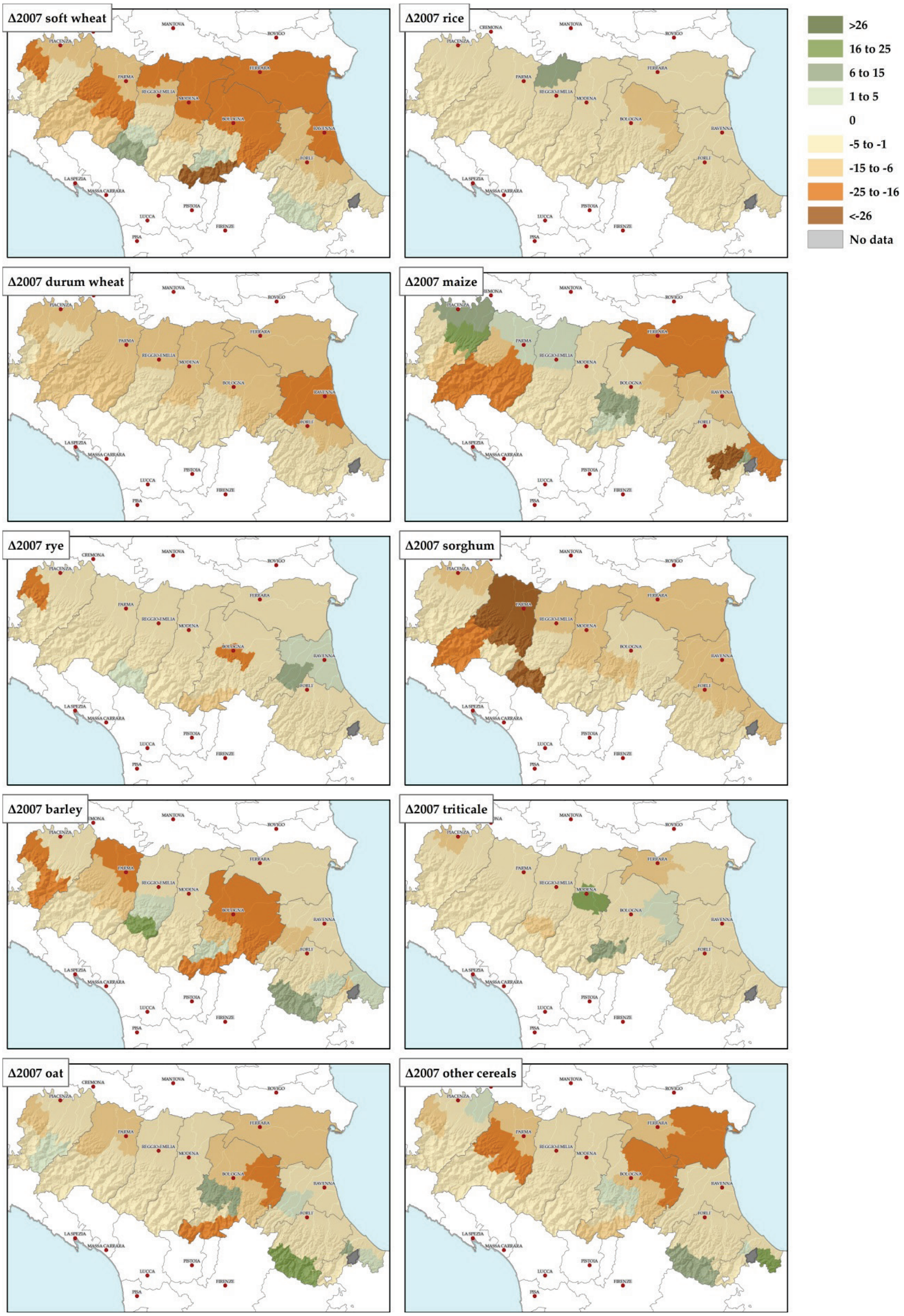




MAP 5: Relative difference of the *per-hectare* 2007 yields of major crops from the 2000-2011 average yields. Based on data from ISTAT, own elaboration



MAP 6: Relative difference of the *per-hectare* 2003 yields of major crops across the agricultural regions (RA) in the Emilia Romagna Region (RER) from the respective 2000-2011 average yields. Based on data from the RER *Statistical Bureau*, own elaboration.



MAP 7: Relative difference of the *per-hectare* 2007 yields of major crops across the agricultural regions (RA) in the Emilia Romagna Region (RER) from the respective 2000-2011 average yields. Based on data from the RER *Statistical Bureau*, own elaboration.

4.2 PARTIAL EQUILIBRIUM PERSPECTIVE

In line with the previously discussed results, the analysis of the FADN data confirm higher wheat yield losses in 2007 than in 2003, even if limited to around 1.38 q/ha. Oppositely, the maize yield losses were higher in 2003 (-6.58 q/ha) than in 2006 and 2007 (respectively -4.75 q/ha and -5.38 q/ha). The evolution of maize prices compensated the yield losses, resulting in improved crop profitability (in 2003 155 Euro/ha, in 2006 133 Euro/ha, and in 2007 893 Euro/ha). Similar compensation was not observed for soft wheat for which the drought resulted in net economic losses. In terms of total farm production, the largest economic losses were recorded in 2006 and 2007 (-795 and -891 Euro/ha, compared to baseline average level). The drought resulted in increased labour demand on average 22 and 42 hours/ha respectively.

Simulations of HCB regimes show high sensibility of wheat yields to even moderate reduction of water. In case of maize, generally irrigated, the sensibility is lower but depends on the availability of substitutes. The simulation of drought intensity, price variations and production costs reveal that wheat price increase of 5 per cent compensates moderate drought yield losses as well as moderate (10 per cent) increase of production costs. In case of maize, profitability is reduced by Fall-Winter droughts. An increase of maize price equal to 5 per cent compensate production losses and an increase of the cost of production if lower than 20 per cent; whereas higher price increases (10 per cent) is able to compensate much higher (30 per cent) production costs.

Crop production

SM Table 2 shows the results of the estimated models for soft wheat and maize. As for wheat, the results confirm positive and significant relationship between crop yields and farms' structural and time-invariant environmental characteristics such as altitude (lowland vs. others), soil fertility, and farm's location (internal zone vs. others). Yield is also positive associated with farming practices such as the costs for the pests and pathogens control and fertilization, level of mechanization and labour hours (per ha). Because wheat is generally non-irrigated in PRBD, variables associated with irrigation do not explain the yield variability.

This is different for maize, being one of the principal irrigated crops in the PRBD. Not only the irrigation system but also water source are help to explain the yield of maize. The crop productivity depends also from the farm's structural characteristics (field' position, soil fertility, farm's location) but to a lesser extent from technology and farming practice, except for pests and pathogens control. Yields of farms specialized on maize production are generally higher.

Depending from the drought intensity, time-invariant variables play a different role in explaining the crop yields, both in terms of sign and magnitude of impacts, explaining to some extent the high spatial variability in the loss data. The variability of rainfall (in terms of HCB) influences the wheat losses only in the fall-winter session, i.e. during the growing period of the crop in the PRBD (estimated coefficient 0.014). Contrary to wheat, HCB influences maize production mainly during spring-summer. The estimated relationship between yield and HCB for maize is positive and hill-shaped for the fall-winter season and positive and U-shaped for the growing (spring-summer) period. Estimated β_1 coefficients for these seasons equal respectively to 0.036 and 0.138.

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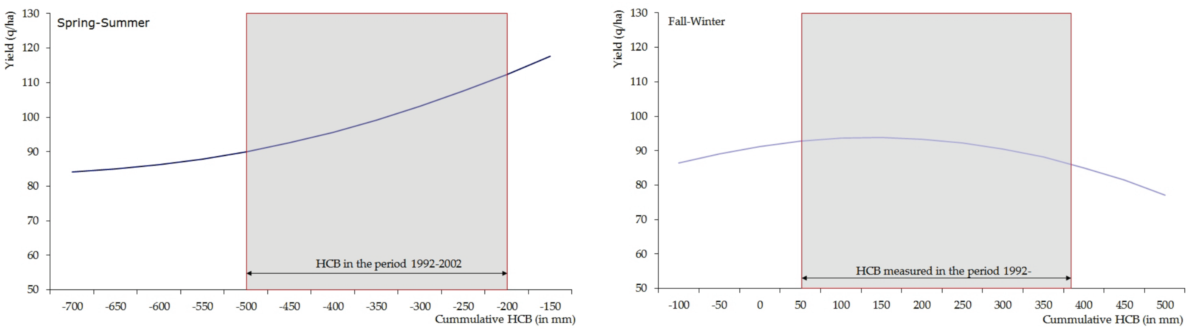


Figure 7: Maize yields (q/ha) as a function of cummulative seasonal (*left*: Spring-Summer, *right*: Fall-Winter) HCB values (in mm).

Farm revenues

The model explaining farm's net revenues (NR) pinpoints lower income for collective (rather than individual) water provision, and if the farm is located in a less favoured areas. The former effect is associated with internal community rules of water re-allocations during drought spells, not necessarily satisfying water demand of crops with highest value. In contrary, the individual water provision implies higher costs due to energy demand of water pumping and suffers lesser restrictions.

Variable positively influencing net-revenue include level of mechanization, labour input, type of specialization (livestock vs. others), and irrigation system (pressurized vs. others).

Weather variables are also important. The relationships between net revenue and seasonal value of HCB are positive and hill-shaped for winter; negative and hill-shaped for spring; positive and U-shaped for summer; and negative and U-shaped for fall. Estimated β_1 equal respectively to 15.340, -9.097, 37,761 and -8.341.

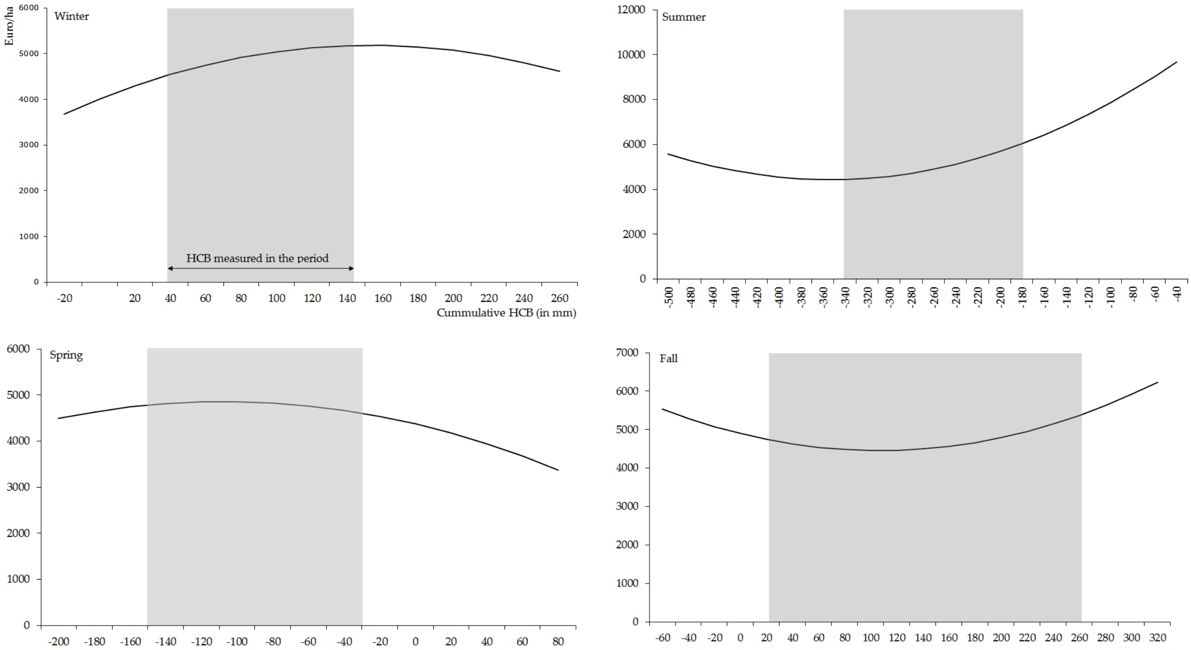
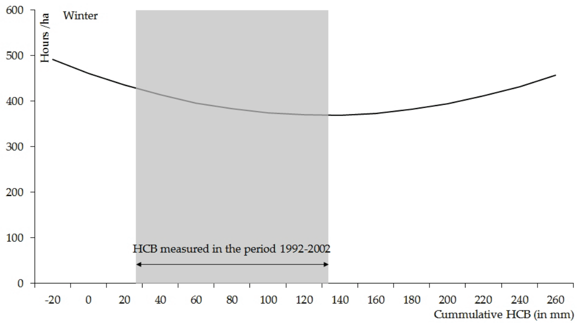
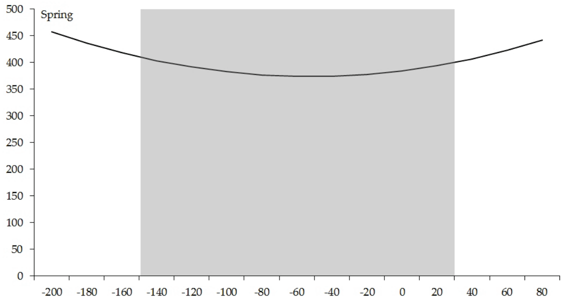


Figure 8: Predicted farm's net revenue (NR, Euro/ha) as a function of the seasonal values of HCB (in mm)

Employment

The labour demand (hours/ha) declines as a result of environmental constrains, soil fertility, farm size, and presence of advanced (pressurised) irrigation systems. On the other hand, labour input increases with farm specialisation; if farms are located in disadvantaged areas, constrained by irrigation quota; in cases of collective water provision, and with increasing livestock density. As for the climate variability (approximated through HCB), labour input increases (estimated coefficient 0.40) in spring with progressively declining HCB decrease. In summer, drought conditions result in decline of labour input (on average equal to -1.4). The estimated labour demand curves are U-shaped for winter and spring and a hill-shaped for summer.





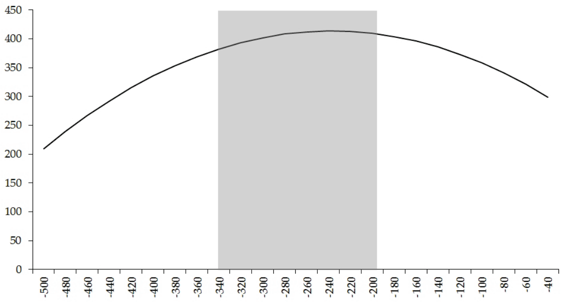


Figure 9: Predicted labour demand (hours/ha) as a function of the seasonal values of HCB (in mm).

5. CONCLUSIONS

A better understanding of drought-related losses in agriculture is an imperative for designing effective and equitable agricultural insurance schemes as well as for appropriate allocation of water access and use (restrictions) entitlements in a way that produces highest social benefits. In the PRBD the latter is prompted by declining trend of harvestable water resources (J. Mysiak, Puma, et al. 2013).

In this paper we first explored the regional impact assessment techniques based on production data collected or estimated at provincial (NUTS3) and lower (*agricultural region*, RA) spatial scale. The former is pursued by the Italian Statistical Bureau (ISTAT) and represents the only consistent data base available for the whole national territory. The latter is more precise and suitable for the scope of the paper but no more maintained in all but a few regions. Overall, we found that the provincial data substantially underestimates the production losses, depending on the type of crop up to the factor 3, and overestimates the gains. Still it may find limited use is corrected by crop, climate, and soil distributional factors. However, it is more advisable to return to the previous practice of annual production accounts at RA level.

Second, the partial equilibrium approach to modelling drought impacts in terms of yield, net revenue and employment, here based on the farm-level FADN database, offers additional insights. Model results confirm that relevance, sign and magnitude of impacts varies with the seasonal pattern of the drought. It is also useful to capture on-farm strategies to cope with drought. The impacts of deficient precipitation in the PRBD affects differently farms cultivating wheat and maize, affecting more the latter. Over the studied period, the interplay of climate variability and crop prices, especially later stage of the 2003-2007 drought, led to partial compensation of yield losses. The increased maize prices were sufficiently high make maize cultivation profitable despite the drought. In terms of farm's profitability, taking into account both growing and breeding activities, the droughts on 2006 and 2007 led to comparable results.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the GEMINA project, funded by the Italian Ministry of Education, University and Research and the Italian Ministry of Environment, Land and Sea as well as from the European Union Seventh Framework Programme under the grant agreement no. 265213.

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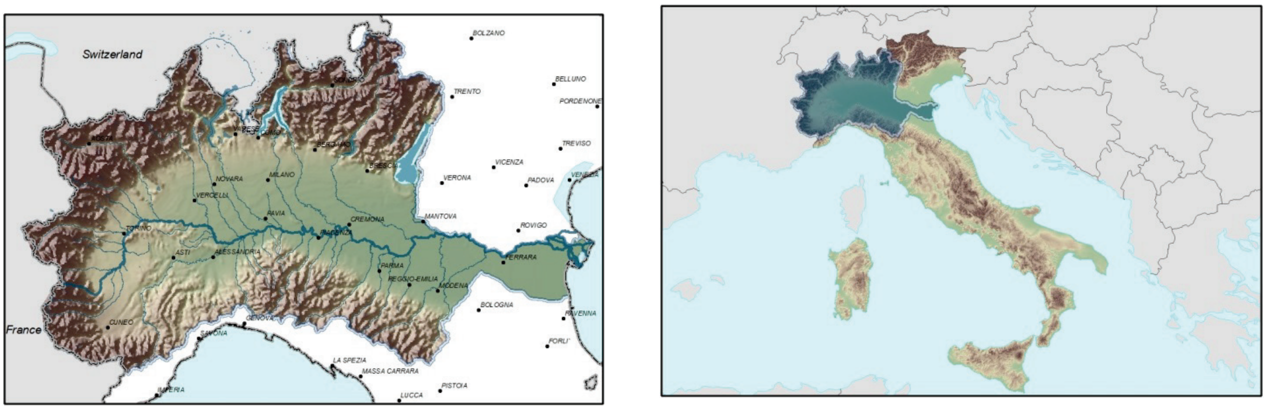
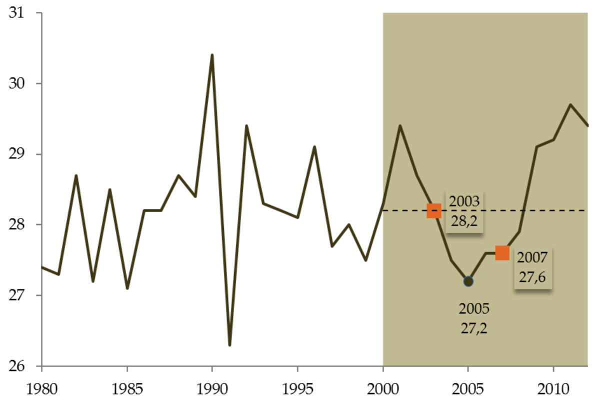
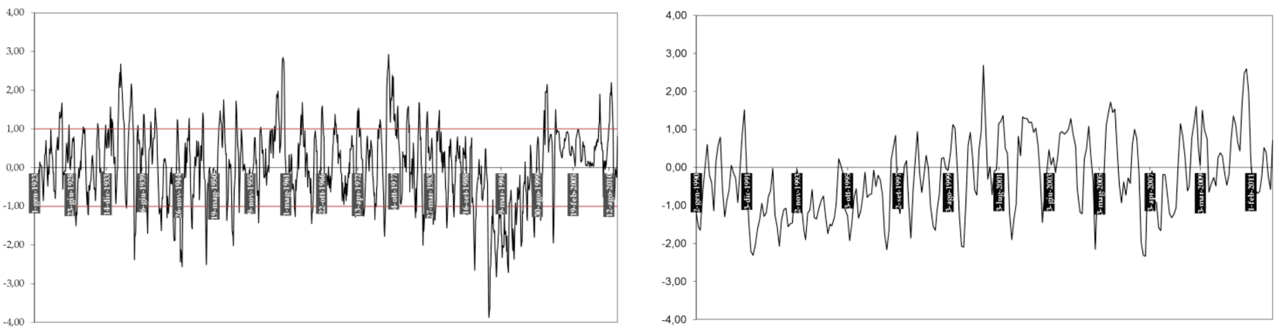
7 ANNEX – SUPPLEMENTARY MATERIAL



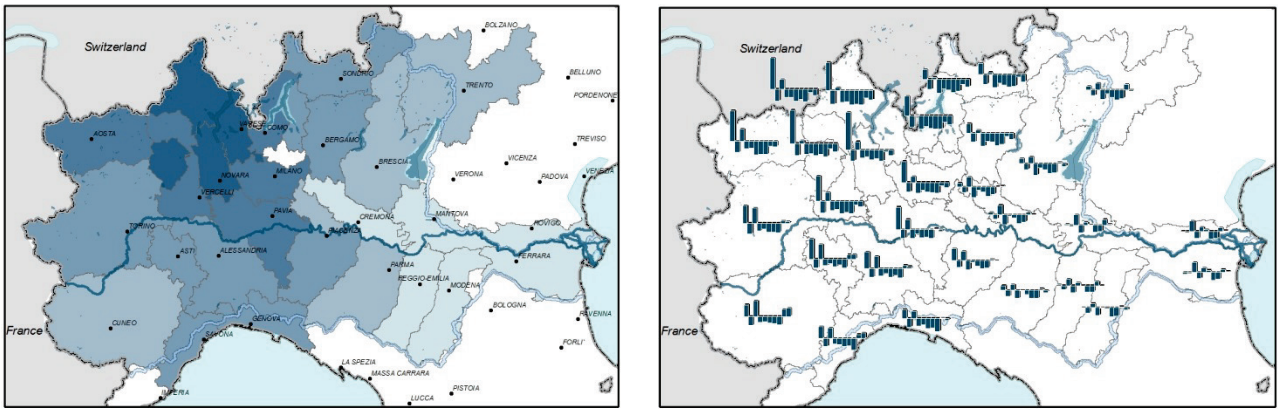
SM MAP 1: Situation map of the Po River Basin District (P-RBD): (left) elevation and altimetry zones of the District, and (right) map of Italy with the P-RBD highlighted.



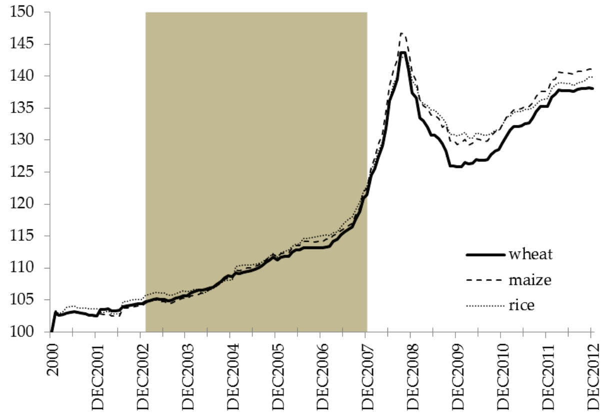
SM Figure 1: Evolution of the value-added of *crop and animal production, hunting and related service activities* (based on ISTAT national accounts break-down) in the regions Piedmont, Valle d’Aosta, Lombardi, Emilia Romagna, Veneto, and the autonomous province Trento, in per cents of the national production. Shaded area highlights the period 200-2012.



SM Figure 2: Standardized Precipitation Index SPI for the P-RBD: (left) SPI-6 month for the period 1923-2011; (right) SPI-3 months for the period 1990-2012 (data elaboration by S. Pecora, ARPA-ER)



SM MAP 2: Precipitation in the P-RBD: (left) Average annual precipitation (2000-2009) by provinces; (right) difference between annual precipitation in each year over 2000-2010 compared to the long term average precipitation (1971-2000). Based on data from ISTAT (2010) own elaboration



SM Figure 3: Evolution of the agriculture production cost index (2000 = 100) over the period 2000-2012. Source: ISMEA, own elaboration.

SM Table 1: Models' description

Models of	**Type of model**	**Explanatory variables**	
		Time variant	***Time invariant***
Production losses	Crop's specification	- Intensity of irrigations; - Intensity of fertilizations; - Intensity of pest and pathogens control's; - Farm's specialization; - Farm's physical and economic dimensions; - Irrigation regime; - Weather scenario.	- Soil's fertility; - Field's position; - Constrains in the fields; - Irrigation system; - Water sources; - Field location; - Farm's location.
Economic losses	Farm's specification	- Farm's specialization; - Physical dimension, - Irrigation regime; - Farmer's agreement to cooperative or other forms of farmers association; - Extra-source of income; - Aids and contribution; - Mechanization level; - Employment level; - Market aspects; - European single area payment scheme (saps); - Weather scenario.	- Soil's fertility; - Field's position; - Constrains in the fields; - Irrigation system; - Water source - Farm's location.
Employment impact	Farm's specification	- Farm's management typology; - Farm's specialization; - Physical dimension, - Irrigation regime; - Mechanization level; - Market aspects; - Weather scenario.	- Crop's category; - Farm's management typology; - Soils fertility; - Field's position; - Constrains in the fields; - Irrigation system; - Water source; - Farm's location.

SM Table 2: Estimated model on soft wheat and maize yield

	Soft wheat		Maize	
	Coefficient	p-value	Coefficient	p-value
Year: 2004	9.854	0.000	-3.991	0.045
Year: 2005	12.225	0.000	-6.271	0.000
Year: 2006	14.896	0.000		
Year: 2007	12.368	0.000		
Mechanization level (in HP/ha)	0.085	0.000		
Hours of labor per hectare	18.018	0.003		
Fields' position in 2003: prevalently flat	5.782	0.000		
Fields' position in 2006: prevalently flat	-2.297	0.000		
Fields' position in 2007: prevalently flat	-8.212	0.000	-8.487	0.000
Soil fertility in 2003: high	-3.867	0.000		
Soil fertility in 2006: high	4.337	0.000	7.480	0.000
Soil fertility in 2007: high	2.306	0.006	15.296	0.000
Farm's location in 2003: internal zone			-5.229	0.000
Farm's location in 2006: internal zone	2.607	0.000	-6.605	0.000
Farm's location in 2007: internal zone	-1.174	0.005	-2.853	0.003
Pest and pathogens control costs (in €/ha)	0.015	0.006	0.033	0.000
Fertilization costs (in €/ha)	0.008	0.000		
Irrigation system 2003: pressurized			-3.944	0.074
Irrigation system 2006: pressurized			-2.194	0.056
Irrigation system 2007: pressurized			3.359	0.005
Irrigation source 2003: collective			-4.456	0.007
Irrigation source 2007: collective			-5.069	0.000
Farm specialized on crop cultivation			5.014	0.077
Cumulate HCB for Fall and Winter	0.014	0.000	0.036	0.000
Cumulate HCB for Fall and Winter squared			-0.000	0.000
Cumulate HCB for Spring and Summer			0.138	0.000
Cumulate HCB for Spring and squared			0.000	0.009
Constant	43.531	0.000	133.854	0.000

SM Table 3: Estimated model on farm's net revenue

Variable	Coefficient	P-value
Fields' position in 2006: prevalently flat	-309.416	0.066
Fields' position in 2007: prevalently flat	453.291	0.053
Less favored area in 2003: yes	-1030.054	0.000
Less favored area in 2007: yes	-401.480	0.014
Irrigation system in 2003: pressurized	-454.536	0.057
Irrigation system in 2006: pressurized	163.992	0.006
Irrigation system in 2007: pressurized	611.579	0.000
Source of water in 2006: collective companies	-280.800	0.043
Source of water in 2007: collective companies	-149.300	0.000
Irrigated surface	5.167	0.002
Irrigated surface squared	-0.004	0.003
Farm's specialization: livestock (not herbivorous)	1954.314	0.003
Mechanization level (in HP/ha)	257.978	0.000
Hours of labor per hectare	3.189	0.000
Cumulate HCB for Winter	15.340	0.000
Cumulate HCB for Spring	-9.097	0.000
Cumulate HCB for Summer	37.761	0.000
Cumulate HCB for Fall	-8.341	0.000
Cumulate HCB for Winter squared	-0.050	0.000
Cumulate HCB for Spring squared	-0.043	0.000
Cumulate HCB for Summer squared	0.053	0.000
Cumulate HCB for Fall squared	0.039	0.000
Constant	6099.554	0.000

SM Table 4: estimated model on hours of labour per hectare

Variable	Coefficient	P-value
Farm's specialized on vegetable and fruit cultivations	51.4388	0.0000
livestock density index	14.9229	0.0000
Farmland	-0.8101	0.0000
Farmland squared	0.0003	0.0000
irrigation quota	15.4852	0.0000
Farm's economic dimension	-50.9508	0.0000
Price input index	-6.1394	0.0210
Cumulate HCB for Winter	-1.4021	0.0000
Cumulate HCB for Spring	0.4048	0.0030
Cumulate HCB for Summer	-1.4026	0.0000
Cumulate HCB for Fall	-0.3656	0.0040
Cumulate HCB for Winter squared	0.0053	0.0000
Cumulate HCB for Spring squared	0.0039	0.0000
Cumulate HCB for Summer squared	-0.0030	0.0000
Farm's location in 2003: internal zone	82.8431	0.0000
Farm's location in 2006: internal zone	68.6577	0.0000
Farm's location in 2007: internal zone	121.4065	0.0000
Environmental constrains in 2006	-59.2846	0.0000
Soil fertility in 2003: high	-66.0246	0.0000
Irrigation system 2003: pressurized	-51.1532	0.0000
Irrigation system 2006: pressurized	-52.9925	0.0020
Irrigation system 2007: pressurized	-103.1444	0.0000
Irrigation source 2006: collective	-23.4807	0.0000
Irrigation source 2007: collective	-24.3466	0.0010
Fields' position in 2003: prevalently flat	38.1970	0.0000
Fields' position in 2006: prevalently flat	24.9008	0.0000
Constant	1214.0790	0.0000

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