Response to the comments provided by anonymous reviewer 1

Title: " Risk of water scarcity and water policy implications for crop production in the Ebro Basin in Spain"

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AR: Authors responses

General comment

1. I found somewhat inconsistent the title of the paper and its more or less explicitly stated aims, with the content of the paper itself. Water policies are mentioned in the title; focus on the demand side is defined as very important in the introduction. Accordingly, the reader would then expect analyses/suggestions of optimal water management among different crops or of changes in crop mix to minimize losses in the presence of water scarcity, but both aspects are only marginally developed. What the paper does is in fact an (interesting) impact assessment exercise quantifying the implications on agricultural value added of water restrictions. I agree that this is the necessary first step to discuss then possible policies, but just the first step. I would suggest to state very clearly since the beginning the very goal of the work.

AR: We have modified the title following the reviewer advice and add some discussion on policy implications to the conclusions:
New title: “Crop yields response to water pressures in the Ebro basin in Spain: risk and water policy implications”
“Risk”: We present cumulative distribution functions of yield in response to water.

“Water policy implications”: We present crop responses to different policy scenarios of reductions on irrigated area. In a climate change context, more and more severe drought events are expected to happen in the Ebro basin. This could lead to the river basin management authority to reduce water availability. Although the national irrigation plan consider increases in irrigated land and some efforts are being made to make the irrigation systems more efficient, trying to reduce water consumption for agriculture, such an increase won’t be likely to occur. Instead of this, we have considered the consequences for crop production of three policy scenarios where irrigated area is reduced. We quantify the implications on crop productivity and agricultural value added. To assess optimal water management among different crops it is necessary to know the priorities of policy-makers, since the large loss of production is not the main economic loss. Some crops are linked to rural landscapes or customs that sometimes is important to maintain, water demand is different for each crop and also economic revenues, so there is not a unique crop mix that minimize losses, since the definition of loss depends on the objectives. A multicriteria analysis can be performed in a further step, but it has not been addressed here.

Specific comments -

2. Line 19 page 5898. The term “social capital” to describe labour and technology in a production function is not the most appropriate. It recalls and may confuse with the jargon of the sustainable development literature referring to institutional capacity, social safety nets and mutual trust among people. Also the use of the term “technology” as other from labour is ambiguous and partly imprecise. In standard economics, “technology” refers to factors of production (capital, labour etc.) and to how they are combined to produce. Thus saying “labour and technology” is not appropriate as labour is already incorporated in the concept of technology. I would rather use the words economic component (labour and capital) as opposed to the natural component. But this is just a suggestion. What is important is to be clear in the definitions.

AR: We agree with the reviewer and we have rewrite the sentence as: “The goal was to analyse economic component (labour and capital) as opposed to the natural component (water for irrigation and irrigated area components of the production function) together."

3. Lines 11 - 28 page 5899 and lines 1 - 5 page 5900. The extended theoretical justification of the choice of the production function is not really necessary. I would simply say that the functional specification developed thereafter is based on a Cobb Douglas specification with estimated elasticity of substitutions and address the reader directly to the following section for the description of the estimation procedure. Nevertheless, if authors feel necessary to explain in detail they should be more rigorous. For instance why if K tends to infinite R should tend to zero? I know the theory behind this, but this is not at all clear from equation (2). Some additional motivations should be provided.

AR: We have rewriten this discussion as follows: "Estimation of production functions is always controversial and each approach has strengths and limitations. In order to put our work in the viewpoint of the productivity literature we used the Solow-Stiglitz perspective. We follow Solow (1956) in the sense that we are modelling a production technology in order to identify productivity change. Some experts have criticized this function because of the assumption that R and K are substitutes, what is not true, since, they are complementary (Daly, 1997). However, nowadays it is extensively used to represent production processes (Stiglitz, 1997). Our approach differs from Solow's initial model from that we use more than two factors of production to obtain output. It is good to say that based in this model we specifically use the usual Cobb-Douglas specification, as it allows a simple estimation and the coefficients obtained have a very intuitive interpretation in terms of elasticities. There are empirical studies that have shown that in agriculture, statistical models of yield response have been proven useful to estimate input requirements at different locations for selected crops (Lobell et al., 2005; and Lobell et al., 2005, 2007; Parry et al. 2004)."

4. Line 8 page 5901. I found quite surprising that in the specification of the production function both fertilizer use and technological progress are missing. They are both essential components explaining yield performances. The role of fertilizers is also described as an important add up in the conclusions. And, the inclusion of a time trend to capture technological improvements in the production processes turns out to be usually highly statistically significant in those kind of regression. Their exclusion should thus be motivated. Is it a problem of data availability? Does it depends on weak explanatory power? Etc.

AR: We agree with the reviewer comment and we have added extended discussion and Figure 2 to the text: "Agricultural time series are nonstationary since they always present a trend. When variables are nonstationary, normal regression analysis requires a transformation of the data. When there is not enough information about the causes of a such trend, the transformation needed to generate a stationary variable may be attained by simply removing deterministic trends (that is by directly subtracting the trend value from the observations or "detrending"); by taking first-differences (that is the variable in year t (Yt) minus the variable in year t-1 (Yt-1); or by introducing and autoregressive term as a the independent or explanatory variable. (Iglesias, Quiroga, 2007). In our case, we assume that there is a causal relationship between yield increase and technological change, and therefore we consider a management variable, the farm equipment power (Mac), to explain yield trend. A range of management indicators such as farm equipment power (Mac), tractors (Trac), nitrogen fertilizer (Fert), pesticide consumption (Pest), or seeds improvement (Seed) have a high correlation (Quiroga, Iglesias, 2010) since they can be considered as a proxy variable for technology and investment in a farm or in the farming sector of a district or country. (See Figure 2)."

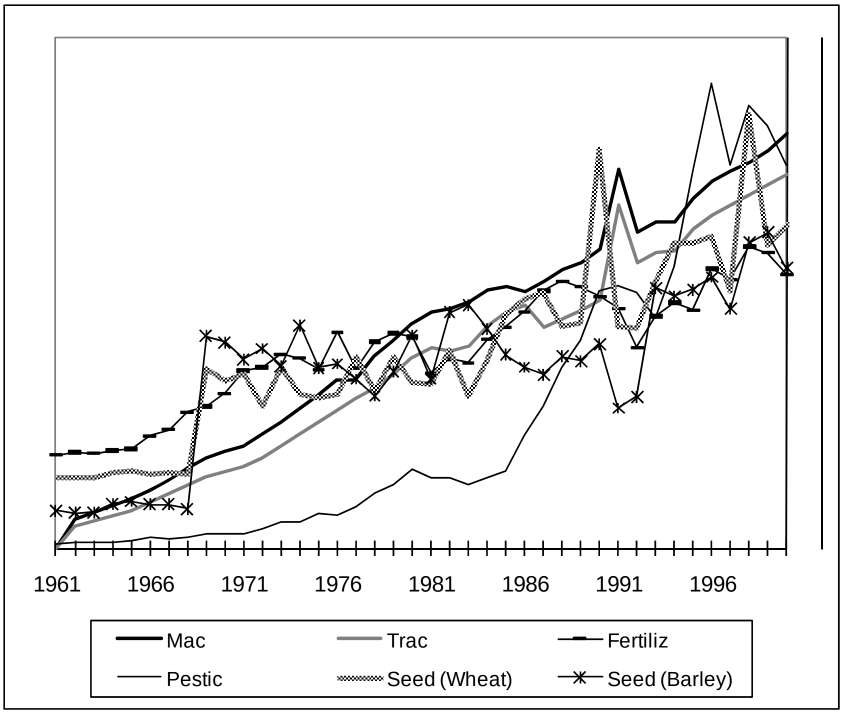

Figure 2. Evolution of management indicators: farm equipment power (Mac), tractors (Trac), nitrogen fertilizer (Fert), pesticide consumption (Pest), or seeds improvement (Seed). Source: Quiroga, Iglesias, 2010.

5. Lines 22 page 5902 to 2 page 5903. All rather messy. I would suggest to say simply that as usual the choice of the explanatory variables to include in the final specification follows a deductive approach based on the Akaike and Schwartz criteria. In that, please consider my comment above on fertilizers and technological progress.

AR: We have added the following explanation to the choice of the explanatory variables: “As usual the choice of the explanatory variables to include in the final specification follows a deductive approach based on the Akaike (1973) and Schwarz (1978) criteria and adjusted R squared criteria, which are widely used to describe the goodness of model parameterization. A full description of the methods can be found in Greene (2003). To complete this process of variable selection, we observe a strong relationship between some of the explanatory variables which might be a source of collinearity problems. To detect a potential problem in each regression, we calculated the variance inflation factor (VIF) for each of the explanatory variables:

$$VIF(x_k) = \frac{1}{1 - R_k^2}$$

VIF represents the squared standard error (or sampling variance) of $\hat{\beta}_k$ in the estimated model divided by the squared standard error that would be obtained if x_k were uncorrelated with the remaining variables (Chatterjee and Hadi, 2006). So we have a VIF factor for each variable. Then, we follow the following criteria: (i) values larger than 10 give evidence of collinearity and, (ii) a mean of the VIF factor considerably larger than one suggests collinearity. We then proceed to eliminate variables which have a VIF value larger than 10. The criteria for elimination of variables when collinearity exists have been to eliminate the variable presenting lower impact on the goodness of model. We proceed in an iterative way when collinearity persists.”

6. The role of the value added equation is not completely clear to me. If it is meant to be explanatory, its specification should be much richer including at least crop prices among the independent variables. If it is just a way to link value added and yields, thus it is manly a descriptive device, it could be acceptable. But this should be clearly stated.

In addition, even under the descriptive view point the explanatory power is extremely weak. Justification should be provided both on the specification used and on its use within the study.

AR: Crop prices does not vary across the Ebro basin, so cannot be used as explanatory variables. So, we agree with the reviewer that the role of the value added equation is just a way to link value added to yields in order to suggest that yields reduction and economic losses are different concepts but in some way they are related.

7. Lines 14 to 16 page 5907 not needed. They are just a repetition of what already stated.

AR: We removed lines 14 to 16 as suggested.

8. Line 11 page 5910. Not clear that and why the loss is larger when irrigation is reduced the 10 20% than when it is reduced the 30%. In fact as far as yields are concerned (table 8) this is not the case. And because of the positive relationship between yields and value added this should be also true in monetary terms. Perhaps I'm missing some point, but further explanations could be useful.

AR: Changes shown on Table 8 in general shows a slightly smaller decrease between 20-30% than between 10-20% in almost all the cases.

9. In table 5 apparently the use of machineries has a negative impact on alfalfa and wheat yield, whereas labour has a negative impact on maize and barley production. Am I wrong? If not this is quite surprising and important explanation for this should be provided.

AR: We have added the following interpretation to the results section: "The quantity of machineries has a possitive effect after one period (Mac(-1)) or even two periods (Mac(-2)). That can respond to a lag in the investments on machinery. In the case of agricultural labour, the variable is at macro level and the negative effect is responding to the decreasing returns to scale when additional labour force move to agricultural sector."

Minor comments:

10. I suggest numbering all the equations in the text.

AR: We have numbering all the equations as suggested.

11. There are some typos to correct. In general the paper would benefit from an English revision.

AR: We have revised the paper edition.

Crop yields response to water pressures in the Ebro basin in Spain: risk and water policy implications

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Abstract

The increasing pressure on water systems in the Mediterranean enhances existing water conflicts and threatens water supply for agriculture. In this context, one of the main priorities for agricultural research and public policy is the adaptation of crop yields to water pressures. This paper focuses on the evaluation of hydrological risk and water policy implications for food production. Our methodological approach includes four steps. For the first step, we estimate the impacts of rainfall and irrigation water on crop yields. However, this study is not limited to general crop production functions since it also considers the linkages between those economic and biophysical aspects which may have an important effect on crop productivity. We use statistical models of yield response to address how hydrological variables affect the yield of the main Mediterranean crops in the Ebro river basin. In the second step, this study takes into consideration the effects of those interactions and analyzes gross value added sensitivity to crop production changes. We then use Montecarlo simulations to characterize crop yield risk to water variability. Finally we evaluate some policy scenarios with irrigated area adjustments that could cope in a context of increased water scarcity. A substantial decrease in irrigated land, of up to 30 % of total, results in only moderate losses of crop productivity. The response is crop and region specific and may serve to prioritise adaptation strategies.

Keywords: crop productivity, water production function, water policy, Montecarlo simulations

1 Introduction

Water conflicts in the Mediterranean have been extensively reported, and many of the studies have analysed the costs for governments to maintain or even increase water supply (Smith, 2002). In the past, studies have focused on the supply side through cost-benefit analyses. However, with the new water-related problems, such as climate change, droughts and floods, focus on the demand side is needed. For this kind of analysis physical, political and socioeconomic components must be integrated for an optimal management of activities to increase the basin's output.

It is crucial for the Mediterranean region, where irrigation represents as much as 90% of total water consumption (Gómez-Limón and Riesgo, 2004), to measure the risks associated with climate variability in agriculture and to implement water demand policies that promote an efficient allocation and use of resources in the region's farms. According to the OECD, agriculture is the major user of water in most countries, since about 70% of total available water is used for irrigation. It also faces the enormous challenge of producing almost 50% more food by 2030 and doubling production by 2050. This will likely need to be achieved with less water, mainly because of growing pressures from urbanisation, industrialisation and climate change (OECD, 2010). Agriculture is also the main user of other environmental and natural resources and therefore has an important role to play in global ecosystem sustainability. Therefore, small changes in agricultural water use (in planting, crop management or crop production) can have significant economic and hydrological impacts.

In Spain, irrigated agriculture accounts for 80% of national consumption of water (Gómez-Limón and Riesgo, 2004) and only 40% of the land area is suitable for cultivation (Iglesias et al. 2000). This paper focuses on the Ebro basin, where agriculture can reach up to 90% or more of water consumption. In fact, more than 354,245 ha of irrigated land are projected to be added according to the National Irrigation Plan (2001) for the nine regions in the Ebro basin. This represents an increase of 2,110 hm3/year of water demand and an expected increase of 44% in the irrigated area, raising the total mean to 1,128,653 hectares. This increase imposes significant additional pressure on aquatic ecosystems and has serious environmental implications, such as the maintenance of environmental flows and water quality in rivers. Although some efforts are being made to make the irrigation systems more efficient, trying to reduce water consumption for agriculture, such a huge increase on irrigated land is not likely to occur in a climate change context since more and more severe drought events are expected to happen. In addition, it will be difficult to make this compatible with the water framework directive environmental restrictions. So we have consider three policy scenarios where irrigated area is reduced.

The Ebro Basin is located in the Northeast of the Iberian Peninsula with a total area of 85,362 km2. This watershed is the largest in Spain, accounting for 17.3% of the total national area. It is made up of 347 major rivers, including the Ebro River, which drains the basin. It rises in the Cantabrian Mountains and ends in the Mediterranean and has a total length of 910 km and 12,000 km of main river network (CHEBRO, 2009).

The climate in the Ebro basin is primarily Continental Mediterranean, with hot, dry summers, cold, wet winters and short, unstable autumns and springs. In the middle of the basin, the climate is semi-arid and in the northwest corner it is oceanic. Consequently, there is a wide heterogeneity in temperature. In 2007, for example, the province of Tarragona reached a maximum temperature of 43 °C, while Burgos had a minimum of -22 °C. Our methodological approach deals with these differences since links bio-physical and socio-economic factors.

In this paper, we focus on the evaluation of hydrological risk and water policy implications for agricultural production in the Ebro basin in Spain. We link bio-physical and socio-economic factors by the introduction of environmental, hydrological, technological, geographical and economic variables to characterize crop yield for the main Mediterranean crops in this basin. The results provide information about the best crop to minimise risk. Later, these models are used to address a simulated policy to assess some policy scenarios with irrigated area adjustments that could cope in a context of increased water shortage. We observe how a reduction in irrigated land results in moderate or significant losses of crop productivity. The response is crop specific and may serve to prioritise adaptation strategies.

The article is organized as follows: The second section provides general and detailed information on the methodological steps. The third section describes the results of the estimates crop-water production functions for 8 main crops in the basin. This section shows also the estimates of agricultural added value function, Montecarlo risk analysis and virtual policy scenarios. The final section presents the conclusions of the paper.

2 Methods

2.1 Steps on methodology

The methodology developed in this study is applied to selected crops in Ebro basin. Models are obtained for each of 8 crops in order to estimate the risk of water variability and policy scenarios. The methodology includes the following 4 steps: [1] we estimate linear regression models by ordinary least squares (OLS). Statistical models of yield response have proven useful to estimate the water requirements at different locations for selected crops and have also proven useful to evaluate the effects of extreme contingencies and other socioeconomic variables. Extensive literature exists about the estimation of crop production functions to compute the climate effects over crop production (Lobell et al., 2005; Lobell et al. 2006; Parry et al. 2004; Iglesias et al., 2000; Hussain and Mudasser, 2007). Some papers focus specifically on the crop-water relationship for irrigated yields (Al-Jamal, 2000; Alcalá and Sancho-Portero, 2002; Echevarría, 1998; Acharya and Barbier, 2000). Socio-economic factors have also been included as explanatory variables (Iglesias and Quiroga, 2007; Quiroga and Iglesias, 2009; Griliches, 1964). In this paper, we have linked bio-physical and socio-economic factors introducing environmental, hydrological, technological, geographical and economic variables to characterize crop yield for the main Mediterranean crops in the Ebro river basin. The goal was to analyse economic component (labour and capital) as opposed to the natural component (water for irrigation and irrigated area components of the production function) together. Literature on this specific area includes Acharya and Barbier, 2000; Alcalá and Sancho-Portero, 2002; Echevarría, 1998; and Hussain and Mudasser, 2007. [2] In a second step, we try to understand the interactions between agricultural production and profit functions focusing on water demand. To do so, we analyze the total agricultural gross added value (GAV) of the region and its interaction with the aggregate crop yield. [3] We use the Montecarlo method to characterize statistical properties of crop yield in response to water patterns or policy adjustments. This method is a powerful and commonly used technique for analyzing complex problems and conducting experiments to evaluate probabilistic risk (Rubinstein, 1981). In agriculture, this method is used to characterize statistical properties of crop yield in response to climatic variables and other inputs (Lobell & Ortiz-Monasterio, 2006; Iglesias and Quiroga, 2007). [4] Finally, we simulate the structural adjustments, in this case a decrease in irrigated area (ha) that could allow the agricultural sector, to cope with increased water restrictions for the agricultural sector. See Figure 1.

[FIGURE 1 NEAR HERE]

In our approach, the estimation of the crop production function plays a fundamental role, since it is then used to evaluate the added value as well as the risk and policy implications. Estimation of production functions is always controversial and each approach has strengths and limitations. Here we have followed the Solow-Stiglitz perspective (Solow, 1974; Stiglitz 1979, 1997), as specified below. According to Solow (1956), there are two factors of production to obtain output, capital (*K*) and labour (*L*). Where its technological possibilities are represented by a production function:

$$Y = F(K, L)$$

[1]

It is assumed that production shows constant returns to scale. Therefore the production function is homogeneous to the first degree. This is equivalent to assuming no scarcity of non-augmentable resources such as land. If we assume scarce-land, this would lead us to decreasing returns to scale in capital and labor and the model would become more Ricardian. Nowadays, it is well known that natural resources are very important to economic growth and environmental sustainability. In this context we find an extended production function named the Solow-Stiglitz model (Solow, 1974; Stiglitz 1979), which includes natural resources (*R*).

$$Y = K^{\alpha_1} L^{\alpha_3} R^{\alpha_2} \qquad \text{with } \alpha_1 + \alpha_2 + \alpha_3 = 1 \text{ y } \alpha_i > 0$$

[2]

Where: K is capital, L is labour, R is natural resources and $\alpha_1, \alpha_2, \alpha_3$ are parameters and represent the elasticity of substitution among the factors.

Estimation of production functions is always controversial and each approach has strengths and limitations. In order to put our work in the viewpoint of the productivity literature we used the Solow-Stiglitz perspective. We follow Solow (1956) in the sense that we are modelling a production technology in order to identify productivity change. Some experts have criticized this function because of the assumption that *R* and *K* are substitutes, what is not true, since, they are complementary (Daly, 1997). However, nowadays it is extensively used to represent production processes (Stiglitz, 1997). Our approach differs from Solow's initial model from that we use more than two factors of production to obtain output. It is good to say that based in this model we specifically use the usual Cobb-Douglas specification, as it allows a simple estimation and the coefficients obtained have a very intuitive interpretation in terms of elasticities. There are empirical studies that have shown that in agriculture, statistical models of yield response have been proven useful to estimate input requirements at different locations for selected crops (Lobell et al., 2005; and Lobell et al., 2005, 2007; Parry et al. 2004).

2.2 Data

To characterize our model we use regional, national and international sources of data. Table 1 describes the variables included in this study and the source of data. We have included observed historical data about crop yield, water and climate requirements and socio-economic and geographic characterization of eight representative crops in the 18 regions in the Ebro basin from 1976 to 2002. Crop yield (Y) is defined as the ratio between production (t) and agricultural total area (ha) and data were obtained from the Spanish Ministry of Environment (MARM). Economic and geographic variables were mainly obtained from the Spanish Institute of Statistics (INE) while technological variables were taken from FAOSTAT and Food and Agriculture Organization (FAO). To build a proxy variable for irrigation, we used Ebro basin management authority local data, (CHEBRO, 2004) about net water needs of crops. Finally, climatic data such as total precipitation, maximum and mean temperatures, and number of days below 0ºC degrees were taken from the Spanish Meteorological Agency (AEMET) to characterize the impact of climate.

[TABLE 1 NEAR HERE]

2.3 Crop-water production function

We have estimated a crop-water production function that establishes the relationship between crop yield and water applied for a range of crops that represent irrigated agriculture in the Ebro basin. The crop-water production function is linear in the deficit irrigation section because all the applied water is used for evapotranspiration, and the production function is equal to the evapotranspiration production function. Nevertheless, non-linear responses indicate that not all water is used by the crop, since some goes to deep drainage and the evapotranspiration production function is really a production function. The function becomes curvilinear as more of the applied water goes to deep drainage. Generally, a curvilinear function is expressed as a second order polynomial (Al-Jamal, 2000). This function is not unique and varies among crops and zones.

The specified model is:

$$\ln Y_t = \alpha \ln Y_{t-1} + \beta_0 + \beta_1 L_t + \beta_2 Mac_t + \beta_3 Mac_{t-n} + \beta_4 Altitude_t + \beta_5 Area\_ebro_t + \beta_6 Irrig\_area_t + \\ + \beta_7 Irrig_t + \beta_8 Irrig_t^2 + \beta_9 \Pr ec_{it} + \beta_{10} T\_Max_{it} + \beta_{11} T\_Mean_{it} + \beta_{12} Fr_{it} + \beta_{13} Dro_t + \varepsilon_t \quad [3]$$

Where the dependent variable ($\ln Y_t$) is the natural logarithm of the crop yield for a site in year t. The explanatory variables were described on Table 1. The subscript *i* on climate and some water variables refers to the three months periods (*i* = *def* (Dec, Jan, Feb), *mam* (Mar, Apr, May), *jja* (Jun, Jul, Aug) and *son* (Sep, Oct, Nov)).

Agricultural time series are nonstationary since they always present a trend. When variables are nonstationary, normal regression analysis requires a transformation of the data. When there is not enough information about the causes of a such trend, the transformation needed to generate a stationary variable may be attained by simply removing deterministic trends (that is by directly subtracting the trend value from the observations or “detrending”); by taking first-differences (that is the variable in year t (Yt) minus the variable in year t-1 (Yt-1); or by introducing and autoregressive term as a the independent or explanatory variable. (Iglesias, Quiroga, 2007). In our case, we assume that there is a causal relationship between yield increase and technological change, and therefore we consider a management variable, the farm equipment power (Mac), to explain yield trend. A range of management indicators such as farm equipment power (Mac), tractors (Trac), nitrogen fertilizer (Fert), pesticide consumption (Pest), or seeds improvement (Seed) have a high correlation (Quiroga, Iglesias, 2009) since they can be considered as a proxy variable for technology and investment in a farm or in the farming sector of a district or country. (See Figure 2).

We used OLS to estimate the coefficients. To facilitate the improvement of particular model estimation for each crop, 95% confidence intervals were estimated assuming normality of the residuals, and significant relations were considered into the estimated model. White's general test (White, 1980) was used to check conditional heteroscedasticity under null hypothesis (Ho) of homoscedasticity (Johnston and Dinardo, 2001). Durbin-Watson statistics are used to check autocorrelation existence (Durbin and Watson, 1950).

When the parameters β_i are estimated, the marginal effect of a change in the explanatory variables is given by:

$$\frac{\partial E[\ln Y | X_i]}{\partial X_i} = \beta_i \qquad [4]$$

The signs and magnitude of the marginal effects indicate the effect of a particular input variable X_i over the crop yield. In this case, the coefficients of the model have to be interpreted as semi-elasticities because the model presents a semi-logarithmic transformation. The interpretation is that semi-elasticity is responsible for the percent increase of yields produced by a unit change in the input variable.

In the Ebro basin there exists a very high variability in precipitation and it is common to observe that recurrent drought periods affect agricultural production. To date, it is difficult to characterize droughts because of their spatial and temporal properties and the lack of a universally accepted definition (Tsakiris et al., 2007; Hayes 2002, Keyantash and Dracup 2002; Bradford 2000). In this work, we use the frequently used Standardized Precipitation Index (SPI, McKee et al 1993). This index, based on the probability of precipitation for any time scale, calculates the difference in accumulated precipitation between a selected aggregation period and the average precipitation for that same period, it is an index. The calculation of the SPI for any location is based on the long-term precipitation record for a desired time. This long-term record is fitted to a probability distribution, and is then transformed into a normal distribution, implying values that vary around 0. This allows areas with different climates to be relatively compared (McKee et al 1993; Steinmann et al., 2005). We have selected 12 months as the aggregated period for calculation. To define the criteria for a drought event we follow McKee et al.'s (1993) table where a drought event occurs when SPI values are -1.0 or less (see Table 2). This criterion was followed in previous detailed works in Spain (Iglesias et al 2007; Garrote et al., 2007). We, then, construct a dummy variable that equals 1 if the year t is a drought year (with SPI smaller than -1) and 0 in other cases.

[TABLE 2 NEAR HERE]

Due to the large number of correlated variables the selection of explanatory variables for model specification is important. Greene (2003) shows two alternatives to follow: (a) an inductive approach, which consists in starting with a reduced model and amplifying it by including more variables to a general model. The main problem associated with this approach is that the computed statistics can be biased and inconsistent if the hypothesis is incorrect. (b) A deductive approach, which consists in starting with a given general model to set up a correct fitted model. This approach is frequent in recent analyses since, although inefficient, the estimates and test statistics computed from this over-fitted model are not systematically biased. We therefore, we use the second approach in this paper. As usual the choice of the explanatory variables to include in the final specification follows a deductive approach based on the Akaike (1973) and Schwarz (1978) criteria and adjusted R squared criteria, which are widely used to describe the goodness of model parameterization. A full description of the methods can be found in Greene (2003). To complete this process of variable selection, we observe a strong relationship between some of the explanatory variables which might be a source of collinearity problems. To detect a potential problem in each regression, we calculated the variance inflation factor (VIF) for each of the explanatory variables:

$$VIF(x_k) = \frac{1}{1 - R_k^2}$$

[5]

VIF represents the squared standard error (or sampling variance) of $\hat{\beta}_k$ in the estimated model divided by the squared standard error that would be obtained if x_k were uncorrelated with the remaining variables (Chatterjee and Hadi, 2006). So we have a VIF factor for each variable. Then, we follow the following criteria: (i) values larger than 10 give evidence of collinearity and, (ii) a mean of the VIF factor considerably larger than one suggests collinearity. We then proceed to eliminate variables which have a VIF value larger than 10. The criteria for elimination of variables when collinearity exists have been to eliminate the variable presenting lower impact on the goodness of model. We proceed in an iterative way when collinearity persists.

2.4 Agricultural added value

Agricultural added value variations are characterized as a function of crop yields as follows:

$$\ln GAV_t = \alpha_0 + \alpha_i \ln Y_{it} + + \varepsilon_t \qquad [6]$$

Where the dependent variable ($\ln GAV_t$) is the natural logarithm of agricultural gross added value for a site in year t and the subscript *i* refers to the different crops considered and α_0, α_i are parameters.

In this case, the coefficients of the model can be understood as elasticities because the model presents a logarithmic transformation. The interpretation is that elasticity is responsible for the percent increase of yields produced by a one percent increase in the input variable.

The coefficients have been estimated by OLS and diagnostic tests were conducted as in the crop-water production function estimation process.

2.5 Montecarlo risk analysis

Risk analysis bridges the gap between impact evaluation and policy formulation by focusing policy's interest on consequences (i.e. crop yield) rather than agents (i.e. rainfall or irrigation). There are many definitions of risk but, in a wide sense, risk can be defined as the capacity of a system to suffer losses when it is exposed to an external stressor.

In this paper, the probability distribution of production functions for each crop is estimated using the Montecarlo method, which is a key component of uncertainty and probabilistic risk evaluation, since it allows us to generate random samples of statistical distributions to measure risk (Robert and Casella, 2004; Iglesias and Quiroga, 2007; Hammersley and Handscomb, 1975). The approach consists of generating a synthetic series of yield variables using the Monte Carlo method and Latin Hypercube sampling (Just, Weninger 1999; Atwood et al. 2003.).

In agriculture, Montecarlo simulation offers a flexible and accurate approach for investigating and understanding statistical properties of crop yield in response to inputs like irrigation and rainfall (Lobell & Ortiz-Monasterio, 2006). In terms of to water policy, we analyze marginal effects on the statistical model to calculate how a reduction in irrigated area could affect crop yield (Iglesias and Quiroga, 2009; Llop, 2008). Using Montecarlo simulations we obtain 10,000 random values of statistical distributions of every crop yield and then analyze the distribution of probabilities to obtain a certain yield (risk level).

2.6 Water policy scenarios

We have evaluated three policy scenarios considering a reduction of agricultural irrigated land of 10%, 20% and 30%. These scenarios are consistent with a perspective of increased water scarcity and reflect the policy implications of environmental concerns. The European Water Framework Directive states that it is necessary to restore and conserve the ecological health of rivers, thus the Hydrological Plan of the Ebro Basin must accommodate the irrigated land area, review current concessions and seriously consider the removal of salinised irrigated areas as well as those that consume too many resources due to their low profitability.

On the other hand, the establishment of environmental flows in some sections of the Ebro Basin Rivers means that current irrigation areas will have to be reduced. Currently, there is a provisional minimum flow of between 5% and 10% of current annual average flow which is made by sections. It is important to observe that the minimum ecological flow in the Ebro river mouth has been set at 100 m^3 seg^{-1}. This amount is practically arbitrary, due to the absence of more detailed studies. At this moment, some complementary actions are being taken in order to improve the systems' basin efficiency. For instance, existing or future infrastructure needs to respect the minimum ecological flow required downstream (Herranz, 2008; CHEBRO 2004).

Also, it is well known that irrigated area is a crucial element when talking about agricultural water demand. In Table 3, we can observe a summary of irrigated areas by Community. These are grouped by large and small irrigation systems for each of the nine Autonomous Communities contained within the basin. According to the CHEBRO, the existing concessional irrigated areas' demand, in the current situation of distribution by crop, is 6310 hm^3 $year^{-1}$ while the current concessional irrigable area is 783,948 ha. Here, Aragón and Cataluña account for more than 77% of this area. It is important to say that this demand does not coincide with the annual supplied volume, which depends on the actually irrigated area, and the actual of annual crops among other factors (CHEBRO normative).

Under a hydrologic-hydraulics point of view and according to the regulation and concessional guidelines' adaptations, the maximum possible irrigation area in the future will reach 985,999 ha, corresponding to a demand of 8,213 hm^3. Under the same assumptions, it would expand to a maximum irrigated area of 1,271,306 ha with a demand of 9,879 hm^3. This represents a partial increases of 202,051 ha and 285,307 ha for each of the two horizons. However, the effective development of these areas will depend on agricultural policy decisions taken by competent institutions. Nevertheless, the COAGRET Report (2007) says that the establishment of future environmental flows on some river sections will imply cuts in current irrigation extensions in order to follow the statements of the Water Framework Directive. It is therefore difficult to think about an increase in those ha.

[TABLE 3 NEAR HERE]

Relative to the total agricultural area in the Ebro basin, alfalfa, wheat, grapevine, olive, potato, maize and barley are the seven most representative crops in the Ebro basin since they account for almost 60% of the total agricultural area in this region. Rice does not represent a large percentage of the total cultivated area in the overall basin, but it is the most important crop in the Ebro delta area and it is an intensively irrigated crop. Alfalfa, maize, potato and rice are mainly irrigated while wheat, barley, grapevine and olive are primarily rainfed crops (Table 4).

[TABLE 4 NEAR HERE]

3 Results

3.1 Crop-water production functions and agricultural added value

The relationship between crop yields and amount of water for irrigation in the six representative crops varies with crop and location (Figure 3). The relationship between crop yield and irrigation is obviously positive in an initial phase but the marginal decrease to scale. For alfalfa, potato and maize, the most irrigated crops considered, the decreasing phase is not observed within the range of irrigated values considered in this study. For wheat, barley and grapes, optimization of the amount of water is essential. In these crops, additional water beyond a threshold results in reduced output. Rice is not shown since it is always irrigated nor are olives since the amount of irrigated land in this region is relatively small compared to the irrigated land of the other crops. Irrigated land has evolved differently for each crop and area considered (Figure 4). In the upper basin (Burgos province) the proportion of irrigated area for the cereals crops increases during the period of analysis. This increase is a result of the lack of water scarcity problems in this part of the basin during the period of analysis. In contrast, in the middle basin (Zaragoza province) and the lower basin (Tarragona province) the trend is clearly downward, except in the case of maize in Zaragoza, where the tendency is almost constant. This reflects an increased limitation of irrigation due to prioritization of water for the environment.

[FIGURE 3 NEAR HERE]

[FIGURE 4 NEAR HERE]

We estimated crop-water production functions that explain the influence of water on crop productivity and also incorporate a wide range of variables (Table 5). The increasing trend in crop productivity is explained largely by technological and management variables. We assume that yield increases due to improved varieties are linked to more intensified management. We tested the adequacy of the functions to represent crop-water production functions as outlined in the methods section; in the cases where regressions present heteroskedasticity the regressions are estimated with the White method (1980) to obtain robust estimates (following Wooldridge, 2003).

In general the eight crop-water production functions present the expected signs according to the agricultural processes. Irrigation for alfalfa, wheat, rice, potato, maize and barley present a positive impact on the crop yield but this decreases after a given amount of water. Irrigation is not statistically significant for grapevine and olive yield. This may be due to the small area of these crops under irrigation and to the fact that irrigation in these crops is "deficit irrigation" used only to maintain yield during drought periods. Irrigation area also has an important impact on alfalfa, wheat, grapevine, potato, maize and olive. For this last crop, the effect of irrigation area is the largest. In contrast, drought does not show significant impacts for all crops. Only wheat, barley, and grapevine have negative significant impacts in this variable probably because these crops are rainfed. In other words, except for olives, irrigated crops do not show evidence of significant impact of drought on their yield. The quantity of machineries has a positive effect after one period (Mac(-1)) or even two periods (Mac(-2)). That can respond to a lag in the investments on machinery. In the case of agricultural labour, the variable is at macro level and the negative effect is responding to the decreasing returns to scale when additional labour force move to agricultural sector.

Table 6 shows the estimated profit function for each crop yield. The estimation of this function has been considered for all crops; however, we only took into account those that are significant. In other words the effects may be poorly specified for crops that are not represented in the entire geographic area. We note that when yields of alfalfa, maize, potatoes and wheat increase by 1 unit, the agricultural gross added value increases. A strictly economic analysis might suggest the desirability of a stronger orientation of production towards wheat and maize, because an increase in the yield of these crops has a major impact on the region's agricultural GAV. However, this does not take into account the cost of virtual water. Even though today the Ebro Delta does not present problems of availability of water the problems associated with the necessity of large amounts of irrigation water that are caused due to factors such as the crop's characteristics, natural ground permeability and capillary rise of salt water should not be ignored. Therefore, an analysis of water risk management is necessary. In the next section, we analyze the water risk of the selected crops and the impacts of potential changes in water policy.

It is important to note that the contribution to the gross added value includes direct payments linked to crop productivity during the period of analysis (before 1986 from the agricultural policy in Spain and since 1986 from the EU Common Agricultural Policy). The recent decupling of productivity and payments, since 2008, may change the relative contribution of each crop to the gross added value.

[TABLE 5 NEAR HERE]

[TABLE 6 NEAR HERE]

3.2 Montecarlo risk analysis

Statistical properties of crop yield in response to water patterns were derived using Montecarlo simulations in order to asses risk levels. Figure 5 shows the cumulative density probability functions where significant differences in risk levels between crops can be observed. According to these cumulative distribution functions, the probability of having low yields is higher for olive, barley and wheat and lower for alfalfa and potato.

[FIGURE 5 NEAR HERE]

Table 7 provides the detailed statistical properties from Figure 5. Rice and alfalfa present a low variation coefficient (CV) while olive and grapevine have a high variability. On the other hand, we observed that the skewness coefficient is above +1 in potato, olive, alfalfa and barley, indicating that they have an elevated probability of obtaining results above the mean. Also, the skewness coefficient is greater than 0, indicating that there is no large probability of having a low yield. The kurtosis coefficient for every crop yield is lower than 3, and we have a platykurtic distribution that indicates that the probability distribution functions of the crop yields have a wide peak (a lower probability than a normally distributed variable of values near the mean) and thin tails (a lower probability than a normally distributed variable of extreme values). Figure 6, presents the distribution function for rice, which is practically normal.

[TABLE 7 NEAR HERE]

[FIGURE 6 NEAR HERE]

3.3 Water policy scenarios

Although irrigation contributes to social welfare in many regions, it cannot be rural development's the sole concern. As we mentioned before, nowadays there are no explicit restrictions on the irrigation area in the Ebro basin. However, within the context of increases of water demands and policy developments such as the Water Framework Directive restrictions context, it is necessary that the Basin Plan consider adaptation measures such as changes in irrigated land to cope with environmental and sustainability constraints. Thus, we propose three possible scenarios, in which we assume a reduction of the irrigated area by 10%, 20% and 30%. Table 8 shows the yield changes responding to these scenarios.

[TABLE 8 NEAR HERE]

A substantial decrease in irrigated land, of up to 30 % of total, results in only moderate losses of crop productivity. The response is crop specific, wheat is the least affected and alfalfa is the most affected. These results contrast with the relative importance of the crop as measured by the gross added value (Table 6). Both indicators, the gross added value and the changes in crop productivity, are useful to choose adaptation strategies. For example, the contribution of maize to the gross added value is large and the yield is highly reduced as result of irrigated land reduction. Therefore the economic losses of irrigated land reduction in a maize producing area are significant. In contrast, although the yield reduction of alfalfa is comparable to that of maize, the resulting economic loss due to limitation in irrigated land is smaller because alfalfa's contribution to the gross added value is low.

The reductions are consistent given the uncertainty of future policy and our purpose is to show the implications in terms of production risk. Using the models presented in Table 8, we note that these scenarios imply yield losses, ranging from 1% to more than 15%. Regardless of the extent of the reduction in irrigated land imposed by the policy, we see that wheat and grapevine do not suffer major losses in yield performance, whereas alfalfa, potato and maize would be affected considerably given that they are mostly irrigated crops. Since the irrigation area was not significant for rice (which is 100% irrigated), we cannot observe, using this technique, the amount of decrease in its yield would most likely decline. One important factor to consider is the fact that the losses are not proportional. Therefore, the loss is larger when the irrigation area is reduced from 10%-20% scenarios than when it is reduced from 20%-30% scenario.

Finally, the reductions in crop yields can be used to estimate the necessary incentives for the implementation of environmental goals (Iglesias and Quiroga, 2009).

4 Conclusions

Given the pressure, mainly from agriculture, on water in the Mediterranean, this paper presents an analysis of the factors that affect eight major crops in the Ebro river basin including latent risks as well as policies that could be implemented. We analyzed the marginal effects on the statistical model to calculate the effect of a potential reduction in irrigated area on crop yield. This study was based on an analysis of demand.

Extended water production functions by crop were estimated. These show the expected signs for most of the variables. Focusing on the hydrological variables, our results show that an increase in irrigation and in the irrigated area has a positive impact on crop yields. However, the impact of irrigation is not always positive given that after a certain quantity of water supplied to the crop, yield begins to decrease (negative sign in irrigation elevated to square). The precipitation also shows a positive impact on crop yields, except for maize in the *son* quarter (Sep, Oct, Nov), which might be due to excessive water from irrigation, given the usual humidity of this time of the year.

A strictly economic analysis might suggest that production could be oriented to wheat and maize, given their impact on agricultural gross value added of the area. However, this does not consider the cost of virtual water. Maize is a major crop in the Ebro Delta, in the low basin, that could suffer a reduction on water availability. An analysis of water risk management is needed. Rice and potatoes show a low variation coefficient, implying low variability. Olive shows low yield and high variability in this area, although under a reduction in irrigated area scenario, this crop is not severely affected. Potato, maize and alfalfa are the ones most affected by a reduction in irrigated area, because they are mainly irrigated crops.

We present crop responses to different policy scenarios of reductions on irrigated area. In a climate change context, more and more severe drought events are expected to happen in the Ebro basin. This could lead to the river basin management authority to reduce water availability. Although the national irrigation plan consider increases in irrigated land and some efforts are being made to make the irrigation systems more efficient, trying to reduce water consumption for agriculture, such an increase won’t be likely to occur. Instead of this, we have considered the consequences for crop production of three policy scenarios where irrigated area is reduced. We quantify the implications on crop productivity and agricultural value added. To assess optimal water management among different crops it is necessary to know the priorities of policy-makers, since the large loss of production is not the main economic loss. Some crops are linked to rural landscapes or customs that sometimes is important to maintain, water demand is different for each crop and also economic revenues, so there is not a unique crop mix that minimize losses, since the definition of loss depends on the objectives. A multicriteria analysis can be performed in a further step, but it has not been addressed here.

Finally, the methodology presented here can be extended to examine additional factors that affect crop yield and interact with water demand, such as climate change, irrigation systems, and fertilizer application.

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Table 1. Description of variables

Type of variable	Name	Definition	Unit	Source of Data
Economic	Y_t	Crop yield at a site in year t	t / ha	MARM
	GAV_t	Gross added value of agriculture a site in year t	K€ current prices	MARM and INE
	L_t	Total employment of agricultural sector at a site in year t	People (thousands)	Labour Force Survey (LFS). INE
Water	$Irrig_{it}$	Net water needs of crops in the ith month in year t	m / month	Planning Hydrographic Office - CHEBRO
	$Prec_{it}$	Total precipitation in the ith month/ 3 month period in year t	mm / month	AEMET
Managment	Mac_t	Machinery in year t	Nº (thousands)	FAO
	I_t	Irrigated area by crop type	ha	MARM
Geographic	$Altitude_t$	Variables indicating 0-600, 601-1000 and more than 1000 meters		INE
	$Area\_ebro_t$	Dummy variables indicating the 3 main areas of the basin: Northern, Central and Low Ebro		Own elaboration
Climate	T_Max_{it}	Maximum temperature in the ith month / 3 month period in year t	° Celsius	AEMET
	T_Mean_{it}	Average temperature in the ith month / 3 month period in year t	° Celsius	AEMET
	Fr_{it}	No. of days with temperatures below 0° C in the ith month/ 3 month period in year t		AEMET
	Dro_t	Dummy variable indicating drought years	1 or 0 as a function of SPI critical value	SPI calculated from AEMET precipitation data

Table 2. SPI Values and drought intensities

SPI Values	
2.0 o more	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
−0.99 to 0.99	near normal
−1.0 to −1.49	moderately dry
−1.5 to −1.99	severely dry
−2 and less	extremely dry

Table 3. Irrigated area by irrigation systems

Region	**Irrigation Area and Porcentages**					
	Large systems		**Small systems**		**Total**	
	ha	**%**	**ha**	**%**	**ha**	**%**
Aragón	237,813	52.2	161,721	49.1	399,045	50.9
Cantabria	0	0.0	553	0.2	553	0.1
Cataluña	160,625	35.3	46,316	14.1	207,036	26.4
Castilla - La Mancha	0	0.0	241	0.1	241	0.0
La rioja	17,584	3.9	34,864	10.6	52,448	6.7
Castilla - León	0	0.0	8,913	2.7	8,913	1.1
Navarra	39,359	8.6	48,407	14.7	87,766	11.2
Valencia	0	0.0	275	0.1	275	0.0
País Vasco	0	0.0	27,277	8.3	27,277	3.5
Total land area	**455,381**	**100.0**	**328,568**	**100.0**	**783.948,69**	**100.0**

Table 4. Percentage of agricultural area for selected crops

Crop	Percentage of the total agricultural area			Total cropland (Ha)			Percentage of cropping system	
	Rainfed	**Irrigation**	**Total**	**Rainfed**	**Irrigation**	**Total**	**Rainfed**	**Irrigation**
Wheat	18.97	9.55	17.00	774864	102720	877584	88.30	11.70
Barley	29.90	13.04	26.38	1221483	140156	1361639	89.71	10.29
Rice	–	0.87	0.69	–	35379	35379	0.00	100.00
Maize	0.16	9.94	2.20	6700	106874	113574	5.90	94.10
Potato	0.07	1.04	0.27	2868	11191	14059	20.40	79.60
Alfalfa	0.95	13.01	4.39	38758	139837	179180	21.63	78.04
Grapevine	4.36	3.72	4.22	177957	39975	217932	81.66	18.34
Olive	5.13	2.64	4.61	209595	28413	238008	88.06	11.94
Total	**59.53**	**53.80**	**59.77**	**2432225**	**604545**	**3037355**	**80.53**	**19.45**

Table 5. Estimated coefficients of crop-water functions, robust t-statistics and R^2

	Alfalfa	**Wheat**	**Rice**	**Grapevine**	**Olive**	**Potato**	**Maize**	**Barley**
Ln($Y_{t-1)}$				0.4441				
				[4.73]***				
L							-0.0116	-0.0118
							[3.66]***	[3.66]***
Mac	-0.0067	-0.0103			0.0022	0.0013	0.0010	0.0007
	[2.05]**	[3.19]***			[4.74]***	[9.62]***	[5.61]***	[3.25]***
Mac_{t-1}	0.0069	0.0109		0.0010				
	[2.16]**	[3.39]***		[3.39]***				
Mac_{t-2}			0.0005					
			[1.73]*					
$Altitude_{(0-600)}$		-4.80E-05		-6.20E-05				
		[4.24]***		[4.41]***				
$Altitude_{(601-1000)}$	-2.06E-05	2.58E-05						2.66E-05
	[4.05]***	[1.69]*						[1.86]*
$Altitude_{(+1000)}$	-1.49E-05	-8.94E-05		-6.57E-05			-1.38E-05	-6.53E-05
	[3.36]***	[6.54]***		[4.01]***			[2.16]**	[4.89]***
Cent_ebro	-0.0412	-0.1006		-0.0781			-0.2954	-0.2646
	[1.28]	[1.69]*		[1.56]			[6.32]***	[4.15]***
Northern_ebro	0.2226	-0.4780		-0.3589			-0.3249	-0.6043
	[4.53]***	[2.97]***		[3.08]***			[5.22]***	[4.07]***
Irrig_area	0.8531	0.5964		0.9993	1.6479	0.5693	0.7691	
	[9.65]***	[3.75]***		[4.53]***	[4.22]***	[11.41]***	[9.00]***	
Irrig	0.0963	0.2024	0.1543			0.0355	0.0766	0.2496
	[7.10]***	[4.73]***	[2.08]**			[2.08]**	[3.35]***	[5.19]***
Irrig$^{\wedge 2}$	-0.0083	-0.0447	-0.0213			-0.0002	-0.0027	-0.0649
	[5.69]***	[6.59]***	[1.89]*			[0.08]	[1.38]*	[6.24]***
$Prec_{def}$					0.0015		0.0006	
					[2.41]**		[3.49]***	
$Prec_{mam}$	0.0010							
	[6.52]***							
$Prec_{jja}$					0.0017		0.0006	
					[2.58]**		[2.88]***	
$Prec_{son}$		0.0005					0.0000	0.0004
		[3.30]***					[0.20]	[2.33]**
$Prec_{year}$						0.0001		
						[1.80]*		
T_Max_{def}							0.0059	
							[2.17]**	
T_Max_{mam}		-0.0098						-0.0133
		[3.39]***						[4.33]***
T_Max_{jja}				-0.0099	-0.0273			
				[3.10]***	[3.34]***			
T_Max_{son}		0.0092					0.0069	0.0187
		[2.35]**					[1.88]*	[5.03]***
T_Mean_{year}	0.0474	-0.0879	0.0377			-0.0685	-0.0602	-0.1394
	[4.12]***	[3.00]***	[2.24]**			[10.02]***	[2.95]***	[5.40]***
Fr_{def}		-0.0022						-0.0019
		[1.67]*						[1.41]
Fr_{mam}		-0.0090			-0.0297			-0.0117
		[1.66]*			[2.80]***			[2.53]**
Fr_{son}					0.0303	-0.0120	-0.0069	
					[2.79]***	[4.06]***	[2.11]**	
Dro		-0.1281		-0.1328				-0.1737
		[2.22]**		[1.97]*				[3.75]***
Adj R-squared	0.65	0.63	0.17	0.84	0.41	0.62	0.77	0.55
White test: p-value	0.0008	0.4362	0.3695	0.038	0.6504	0	0.0154	0.5003

t statistics and robust t statistics in brackets, * significant at 10%; ** significant at 5%; *** significant at 1%

Table 6. Estimated coefficients of profit function (logarithm of the gross added value), robust t-statistics [in brakets] and R^2

	Coefficients
Yield_Alfalfa	0.04
	[4.58]***
Yield_Maize	0.11
	[3.56]***
Yield_Potato	0.02
	[2.49]**
Yield_Wheat	0.20
	[2.80]***
Constant	9.31
	[22.08]***
Observations	133
R-squared	0.31

Robust t statistics in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7. Statistical properties of yield simulations

	Alfalfa	**Wheat**	**Rice**	**Grapevine**	**Olive**	**Potato**	**Maize**	**Barley**
Mean	42.149	3.092	5.343	3.973	0.970	21.602	6.352	2.814
Median	40.472	3.083	5.222	3.555	0.744	20.293	6.184	2.671
SD	12.565	0.995	1.157	2.300	0.781	7.705	2.648	0.933
CV	29.810	32.196	21.661	57.893	80.457	35.668	41.692	33.171
Maximun	183.797	7.150	13.232	11.513	7.307	162.001	13.075	9.475
Minimum	8.909	0.175	2.188	0.167	0.039	4.661	0.542	0.777
Skewness	1.547	0.088	0.668	0.678	1.843	2.984	0.216	1.029
Kurtosis	9.759	2.736	3.859	2.771	7.786	28.900	2.246	4.908

Table 8. Yield changes for irrigated area policy scenarios

Decrease in irrigated land	**Changes in crop productivity**					
	Alfalfa	**Wheat**	**Grapevine**	**Olives**	**Potatoes**	**Maize**
-10%	- 4.8	- 0.7	- 1.5	- 2.2	- 4.3	- 4.8
- 20%	- 11.2	- 1.4	- 2.9	- 4.4	- 8.4	- 9.4
- 30%	- 15.5	- 2.0	- 4.3	- 6.6	- 12.3	- 13.7

Yield decrease

□ 0 to -5%
▒ -5% to -10%
▓ < -10%

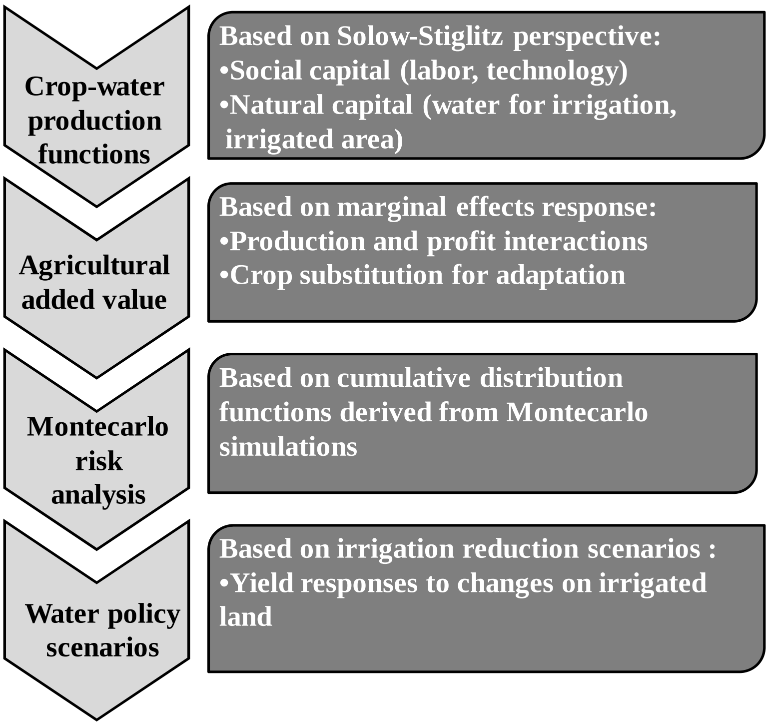


Figure 1. Steps on methodology

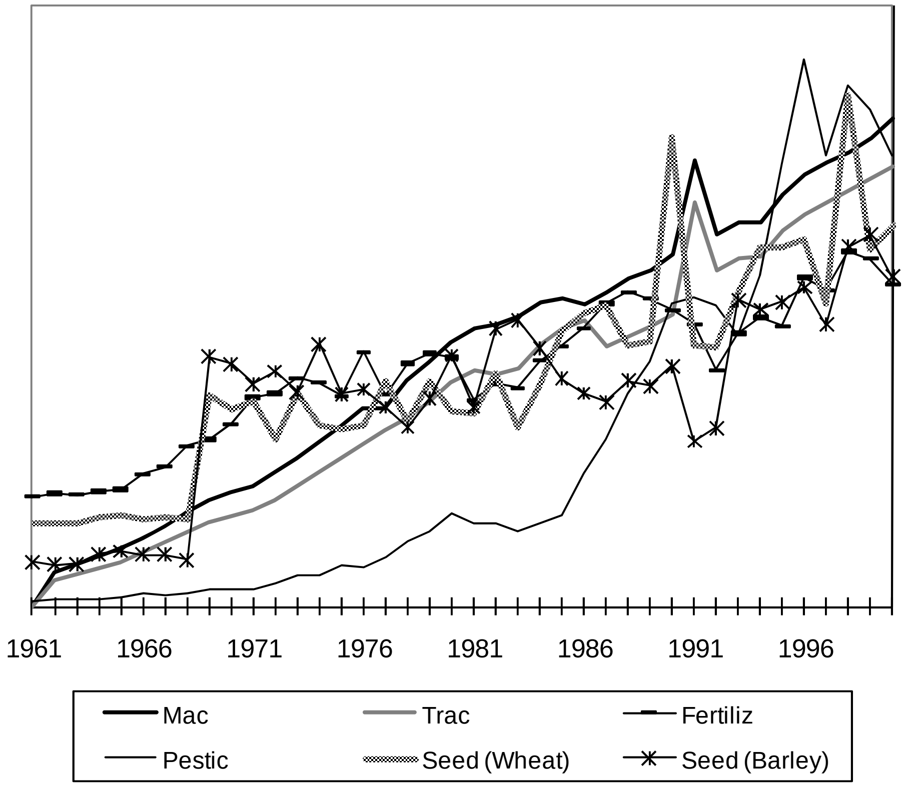
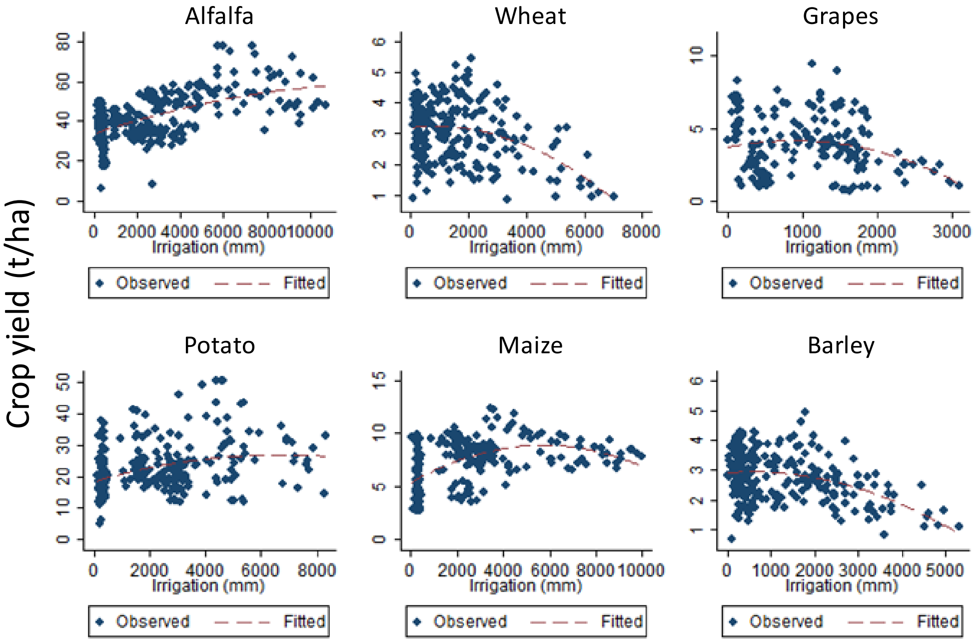
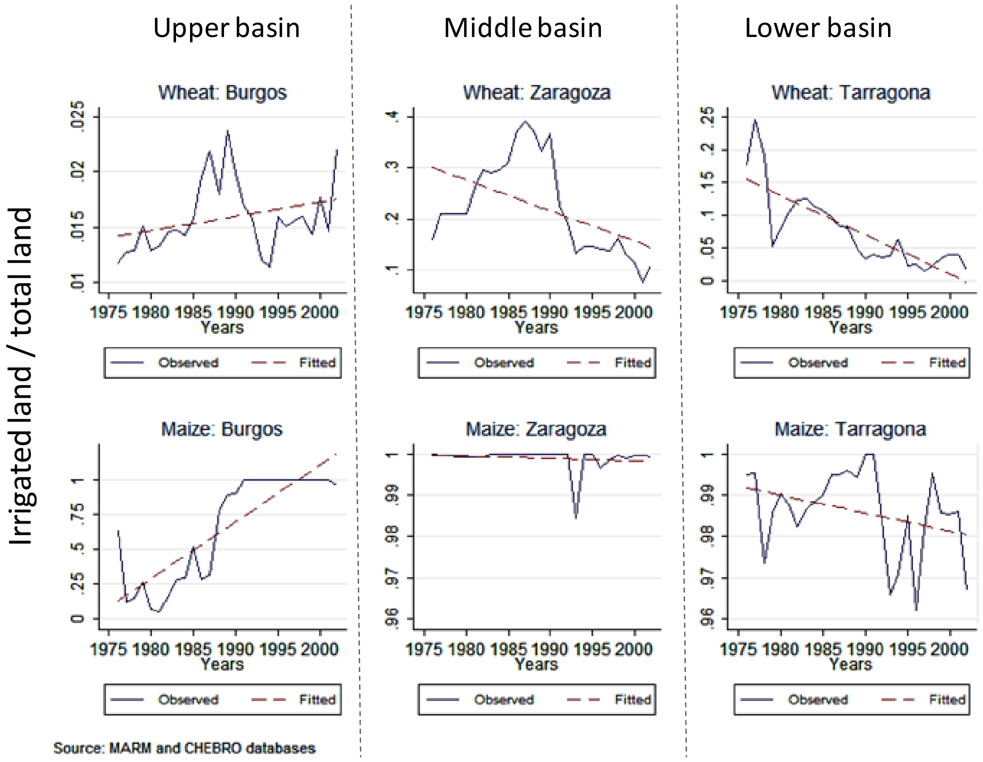


Figure 2. Evolution of management indicators: farm equipment power (Mac), tractors (Trac), nitrogen fertilizer (Fert), pesticide consumption (Pest), or seeds improvement (Seed). Source: Quiroga, Iglesias, 2009.



Source: MARM and CHEBRO databases

Figure 3. Observed crop response to irrigation water applied



Source: MARM and CHEBRO databases

Figure 4. Irrigated land for wheat and maize at representative areas of Upper (Northern, Central and Low Ebro: Burgos, Zaragoza and Tarragona.

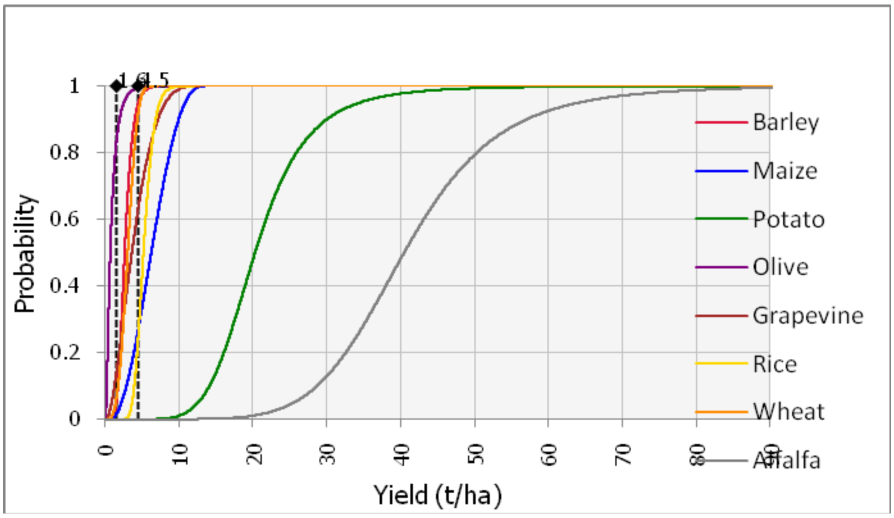


Figure 5. Cummulative density probability function of crop yield

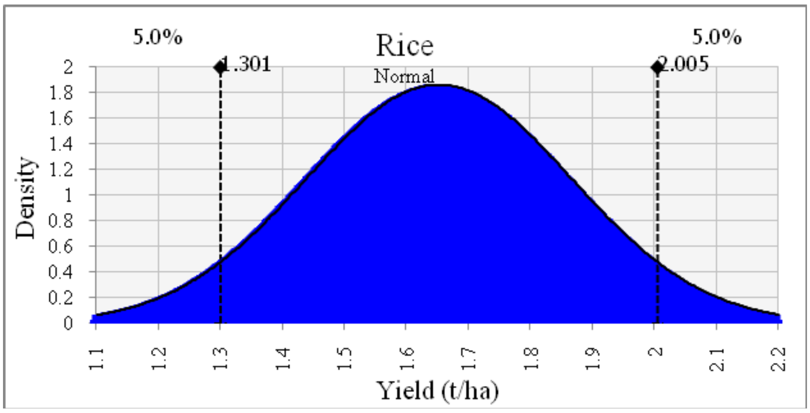


Figure 6. Distribution function of simulated rice yield in the low Ebro. Normal distribution with mean=1.62 and SD=0.21.