# The economic relevance of climate variables in agriculture: The case of Spain *

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10th May 2005

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, July 24-27,2005

# 1 Introduction

Climate change and its potential consequences are high on the political agenda for environment. The relationship between climate change and economics is two-way. While climate change has repercussions on economic activity, economic activity also plays a role in climate change. In recent years, the realisation that human activity is contributing to climate change has inspired much research, which has resulted in the construction of climate models to predict the effects of climate change. [1] Although these models do not produce homogeneous meteorological forecasts, a reasonable consensus is emerging as to the impact of greenhouse gases on climate.

Scientists agree that the most severe drought effect will be felt in mid-latitude, inland continental areas, especially in the summer season, possibly leading to loss of soil humidity and increased erosion. In this event, Spain will be among the countries most badly affected. Even if there is no overall decrease in precipitation, the seasonal distribution is predicted to undergo a variation, resulting in an increase in winter rainfall and a decrease in summer rainfall. All these predictions suggest that both the agricultural and forestry sectors will suffer the effects of climate change.

The magnitude of the impact on the agricultural sector is as yet uncertain: because meteorological forecasts, *per se*, are subject to error, and, even if they were totally accurate, the reaction of the agents involved would also influence the degree of impact. The adaptive capacity of agents is fundamental when it comes to assessing the vulnerability of a sector to climate change. The better they are able to adapt to change, the lower the foreseeable impact. It is our aim in this study to analyse the economic effect of climate variables on the Spanish agriculture.

The economic return from an agricultural enterprise depends on the environmental, economic and social conditions facing the farmer at any given time. The current value of a farm is based on future land returns, assuming that land is allocated to its most profitable use. In a market economy, the current value of a given farm is based on its selling price. Our aim will be to quantify the impact of climatic, edaphic and socio-economic variables on this price. This in turn will give an approximation of the effect of climate on agricultural returns and thus measure the economic impact of a possible climate change.

[1] The models used by the Spanish Climate Variability and Prediction Service at the National Meteorological Institute are based on the HadCM3 version of the *Coupled atmosphere-ocean general circulation model(AOGCMs)*, developed in 1998 at the *Hadley Centre, UK*.

## 2 Specification of the model

Current farm value is based on expected future returns when the land is put to its best use. Future returns will depend, not only on changes in agricultural output but also on variations in crop mix and in the size of the area under cultivation. Thus, if part of the land belonging to the farm were to turn fallow as a result of climate change, the farm would decrease in value. The variable that we will use, *i.e.* $P_{it}$ , however, corresponds to the average price per hectare of land devoted to agricultural use in a particular province, which does not capture the effect of a variation in the number of hectares under cultivation. This price is obtained from the sum of the various crop prices in a given province weighted by the number of hectares devoted to each crop, that is, $P_{it} = \frac{\sum_{j=1}^{J} P_{jit} HA_{ji}}{HA_i}$. Note, however, that an increase in the average price per hectare can just as likely be due to an increase as to a decrease in the number of hectares under cultivation.

To assess the impact of climate change in the Spanish provinces, we need to distinguish between these different situations. To do so, we will begin by multiplying the average price of a hectare of farm land by the number of hectares devoted to agricultural uses in province $i$ in year $t$, and in this way obtain the current total value of the land devoted to agricultural uses in the said province during year $t$. Which can be expressed as:

$$VA_{it} = P_{it} \times HA_{it} \tag{1}$$

where $P_{it}$ is the average price of a hectare of farmland in province $i$ during year $t$; $HA_{it}$ is the total number of hectares under cultivation in the province during that period and $VA_{it}$ is the total current value of land devoted to agricultural uses in province $i$ that year.

From the observed climate-induced variation in $VA_{it}$ it is possible to find the total impact of climate change on the agricultural value of each province. To make comparisons across provinces, however, we need to find the impact per hectare. This can be done by dividing $VA_{it}$ by the number of hectares of total land surface in the province. Thus, we will define $VAH_{it}$, as *the agricultural value per hectare* (not the value of a hectare of agricultural land) in province $i$ during year $t$:

$$VAH_{it} = \frac{VA_{it}}{HT_i} = P_{it} \frac{HA_{it}}{HT_i} \tag{2}$$

where $HT_i$ is the total land surface of province $i$ in hectares, including all land whether it is devoted to agricultural or non-agricultural uses. The size of the province does not vary with climate change, therefore $HT_i$ is constant throughout the whole of the period considered.

The variation in agricultural value per hectare due to climate change, $CC$, can be written as:

$$\frac{\partial VAH_{it}}{\partial CC} = \frac{1}{HT_i}\left[\frac{\partial P_{it}}{\partial CC} \times HA_{it} + \frac{\partial HA_{it}}{\partial CC} \times P_{it}\right] \tag{3}$$

This expression allows us to see that the impact of climate change on agricultural value per hectare is reflected in changes both in the average price per hectare of land sold for agricultural purposes, and in the total number of hectares of farm land. By estimating these two effects, it is possible to tell whether an increase in agricultural value per hectare is the result of a decrease or an increase in the number of hectares used for agriculture. In order, therefore, to assess the impact of climate change on agricultural return and gauge the likelihood of a significant alteration in the agronomic map of Spain, we will estimate three equations representing: i) agricultural value per hectare $VAH_{it}$, ii) the price per hectare of land sold for agricultural purposes $P_{it}$, and iii) the number of hectares used for agriculture $HA_{it}$. We now present the model and the data needed to estimate the relationships.

## 2.1 Specification of the functional form of the model

In low temperatures, and with land that may be not be very productive, the farmer always chooses the most suitable crop. As temperatures rise, assuming that soil quality and edaphic conditions are suitable, output will also rise but at a decreasing rate. When the temperature increase is too high, crop output will begin to decrease. In excessively high temperatures, even if edaphic conditions are favourable, agricultural output will be low and agricultural value per hectare will decrease. As temperatures rise, farmers will switch crops in order to maintain or increase the productivity of their land. The new crop will reach its maximum output level within a certain temperature range and, once temperatures rise above that range, the farmer will again change crop to sustain the productivity of the land.

After conducting various tests, we find that the quadratic functional form is the best suited to the temperature variable, but not to the rainfall variable, for which a linear relationship is more suitable. A quadratic relationship allows, a priori, for the possibility of a concave relationship between the dependent variable and the climatic variable. This is not possible with a linear relationship. The existence of a positive linear relationship between rainfall and the variables $VAH_{it}$ and $P_{it}$ appears to suggest that Spain would increase its agricultural output if rainfall were more abundant and that the predicted increases in productivity are as yet far from reaching their maximum.

After conducting various additional tests, we decided to use the log-transformation of the dependent variable, since, econometrically, this was the model that provided the best fit.[2] The effect of climate change on agricultural value is therefore defined by the following equation:

$$\ln VAH_{it} = \beta_0^v + \sum_{s=1}^{4} \beta_s^v T_{its} + \sum_{s=1}^{4} \gamma_s^v T_{its}^2 + \sum_{s=1}^{4} \lambda_s^v PR_{its} + \sum_{n=1}^{N} \varphi_n^v RV_{itn} + \mu_{it}^v \quad (4)$$

where $i$ is the province under consideration, $t$ the year, and $s$ the season. Thus, $T_{its}$ is the temperature and $PR_{its}$ the amount of precipitation in season $s$ for the province and year in question, $RV_{itn}$ is the vector of $n$ independent variables and $\mu_{it}$ the error term.

Next, the equation that captures the effect of climate change on the price per hectare of land sold for agricultural uses is written as:

$$\ln P_{it} = \beta_0^p + \sum_{s=1}^{4} \beta_s^p T_{its} + \sum_{s=1}^{4} \gamma_s^p T_{its}^2 + \sum_{s=1}^{4} \lambda_s^p PR_{its} + \sum_{n=1}^{N} \varphi_n^p RV_{itn} + \mu_{it}^p \quad (5)$$

To finish we will determine what will happen with the number of hectares used for agriculture. We need only estimate the following regression:

$$\ln HA_{it} = \beta_0^h + \sum_{s=1}^{4} \beta_s^h T_{its} + \sum_{s=1}^{4} \gamma_s^h T_{its}^2 + \sum_{s=1}^{4} \lambda_s^h PR_{its} + \sum_{n=1}^{N} \varphi_n^h RV_{itn} + \mu_{it}^h \quad (6)$$

Note that:

$$\frac{\partial \ln VAH_{it}}{\partial CC} = \frac{1}{VAH_{it}} \left[ \frac{\partial VAH_{it}}{\partial CC} \right] \quad (7)$$

Therefore, by substituting $\frac{\partial VAH_{it}}{\partial CC}$ with its value in equation 3, and $VAH_{it}$ with its value in equation 2 we have:

$$\frac{\partial \ln VAH_{it}}{\partial CC} = \frac{1}{P_{it} HA_{it}} \left[ \frac{\partial P_{it}}{\partial CC} \times HA_{it} + \frac{\partial HA_{it}}{\partial CC} \times P_{it} \right] = \quad (8)$$
$$= \frac{\partial P_{it}}{\partial CC} \frac{1}{P_{it}} + \frac{\partial HA_{it}}{\partial CC} \frac{1}{HA_{it}}$$

which can be written as:

$$\frac{\partial \ln VAH_{it}}{\partial CC} = \frac{\partial \ln P_{it}}{\partial CC} + \frac{\partial \ln HA_{it}}{\partial CC} \quad (9)$$

This expression allows us to identify the various factors that can cause a variation in agricultural value per hectare. Thus, if we have $\frac{\partial lnVAH_{it}}{\partial CC} > 0$, $\frac{\partial lnP_{it}}{\partial CC} > 0$ y $\frac{\partial lnHA_{it}}{\partial CC} > 0$, we can conclude that it is highly likely that climate change will bring about an increase in productivity in the area, since there

[2]We also tried the linear specification and the double-log specification.

will be an increase both in the price per hectare and the number of hectares used for agriculture. Land that was previously agriculturally unprofitable will now have become profitable.

If, on the other hand, an increase in agricultural value, $\frac{\partial lnVAH_{it}}{\partial CC} > 0$, and in the price of land $\frac{\partial lnP_{it}}{\partial CC} > 0$, were accompanied by a decrease in the number of hectares used for agriculture, $\frac{\partial lnHA_{it}}{\partial CC} < 0$, it would be reasonable to expect that climate change would induce farmers to cease cultivating the less productive hectares in the province. This reaction would not be reflected in the agricultural value of the province, however, since the reduction in the number of cultivated hectares would be offset by the increase in the average price of hectares still used for agriculture. If a large number of hectares were abandoned in this way, the price increase would not compensate for such a great decrease in hectares and therefore $VAH_{it}$ might even diminish. This kind of situation could occur, for example, in provinces with highly varied orography or a particularly large surface area, where the effects of climate change could vary from one area to another. A reduction in the number of hectares used for agriculture could also be linked to the reclassification of land for urban development, since the prospect of more lucrative allocations will create expectations that could trigger an increase in land prices.

However, if an increase in agricultural value per hectare, $\frac{\partial lnVAH_{it}}{\partial CC} > 0$, were accompanied by a decrease in the price per hectare of land sold for agriculture, $\frac{\partial lnP_{it}}{\partial CC} < 0$, and an increase in the number of hectares used for agriculture, $\frac{\partial lnHA_{it}}{\partial CC} > 0$, we could then conclude that climate change will increase the number of hectares used for agriculture, but that the output from the additional hectares will be lower than from the traditional agricultural areas. It would also suggest that possible alternative land uses will be less profitable than agriculture, since, if we assume land to be allocated to its best use, a result of this nature suggests that the best use is agriculture, albeit with ever decreasing output, and that there is no alternative use that would remedy the loss of output. A similar interpretation would apply if, with these same variations, that is, a reduction in price per hectare and an increase in the number of hectares used for agriculture, agricultural value per hectare were to decrease. The main difference would lie in the magnitude of the variations.

Finally, a decrease in agricultural value per hectare accompanied by a reduction in price and number of hectares used for agriculture would indicate a reduction not only in the area of land used for agriculture, but also in agricultural output. Such a scenario would suggest that there are few possible alternative uses or that those that exist are even less profitable than agriculture and that there will be a decrease in the expected value of the land in question. There is even some possibility that the land will be left fallow, since if it could be put to more productive use, this would eventually be reflected in the price.

## 2.2 Definition of the variables

We have regionally disaggregated annual data for the whole of Spain, which means a maximum of 48 observations, one for each province, for the period 1983-1999. This is the longest series of observations available (17 years).[3] We have classified the factors affecting agricultural productivity into four groups: i)climatic, ii) geographical, iii) socio-economic and iv) edaphic. Each of these groups is represented by several independent variables. The data on the main climate-related variables - temperature and precipitation regime- were taken from the National Institute of Statistics Yearbook (INE) for each of the years included in the study period.

Though the available information includes monthly data, for the purposes of our estimations we have used only January, April, July and October temperatures and rainfall, since this provides us with a representation of the four seasons and enables us to capture the effects of climate change in each.[4] The temperature variables are defined as monthly averages in degrees Celsius, while the precipitation variables represent the monthly accumulated precipitation, in millimetres, for the months to be analysed. In addition to temperature and precipitation, we included a third climatic variable, hours of sunlight, since variations in the daily cycle affect crop output. This variable, which we label "hoursun", measures the accumulated total number of hours of sunlight per year as recorded at the sample weather station.

The geographic variables were obtained from the INE Statistics Yearbook and include : i)"latitude", measured in degrees and minutes from the southernmost point of Spain in Las Palmas de Gran Canaria; and ii) "longitude", measured in degrees and minutes from the Easternmost point of Spain in Gerona.

We use a group of three socio-economic variables, first, income per capita (denoted by "ipc" in the tables) which isand estimated by dividing gross household income by the eligible population based on July 1st figures each

[3]Ceuta and Melilla are excluded from the analysis due to lack of continuity and reliability in the observations. Lack of data has also led to the exclusion of the Autonomous Community of the Canary Is.

[4]We found multicollinearity problems when using all twelve months of the year. We also performed a sensitivity analysis by estimating additional models, one based on February, May, August and November temperatures and another based on those of March, June, September and December, the results being similar in both cases.

year. Both these series were taken from "Renta Nacional de España" published by the BBVA Foundation.[5] The income level of a region influences consumer preferences and, thereby, local demand functions, which may affect farmers' production decisions. We expect a higher level of per capita income to result in increased demand for high value-added agricultural products. According to this interpretation, therefore, the sign of the coefficient on the per capita income variable "ipc" should be positive and significant, since land used to cultivate high value-added crops will be higher-priced. Income per capita can also be used to approximate the investment capacity of a province. We do not possess sufficient data to enable us to obtain specific estimations of investment in technology by the agricultural sector, uniformly for the whole Spain. We do, however, believe that the higher income per capita in a province, the greater its investment capacity will be and the greater the level of technology it will apply to agriculture. Under this second interpretation, therefore, we also expect "ipc" to a have a positive and significant net effect on the value of land, since investment in technology will tend to increase agricultural returns.

It is not only demand for agricultural products that affects land use and land prices, demographic pressure can also play an important role. In densely populated areas or provinces, urbanisation, is, at least potentially, an alternative or competing use for land resources. We include density among the explanatory variables of our model. The "density " variable represents provincial density measured in terms of the number of inhabitants per $Km^2$. To construct this variable, we used population, based on data taken from "Renta Nacional de España" published by the BBVA Foundation and provincial land surface, from the INE Statistical Yearbook.[6] On the one hand, we expect greater population density to be linked to higher demand for agricultural products and services, resulting in higher prices that will have a positive impact on the price of land. On the other hand, higher demand for urbanisable land will lead to an increase in the selling price of land and to an increase in farmers' potential profits. We therefore expect the coefficient on the "density" variable to be positive and significant.

The last of the socio-economic variables to be analysed- labelled "subsid"- represents farm subsidies in pesetas per hectare.[7] This variable merits special attention; with it we aim to capture farm subsidies taking into consideration only those that are granted for the use of ordinary factors of

[5] Figures for the years with missing data were linearly interpolated from the observations immediately preceding and immediately following.

[6] We do not use Census data because, being updated only every ten years, they do not reflect the evolution of the population.

[7] Since the sample period stretched from 1983 to 1999, monetary figures are given in pesetas, although we analyse our findings in terms of euros.

production.[8] It should be pointed out that the only subsidies taken into consideration are direct subsidies, since indirect subsidies, in the form of fixed prices for agricultural products, are assumed to be included in the profit function. The subsidy variable was constructed by dividing the total amount paid in the type of subsidies considered by the total number of hectares of agricultural land in the province. The data for both these variables were obtained from the Agricultural Statistics Yearbook published by the MAPYA (Spanish Ministry of Agriculture, Fisheries and Food).[9] Based on the subsidy per hectare, we tried, at least partially, to isolate the effect of agricultural policy on farmers' production decisions and thereby on their profits. The fact that Spanish agriculture is so heavily subsidised means that this variable plays a very important role in determining land value.

To eliminate the nominal effect of an increase in variables , such as income per capita, that involve monetary values, they have all been deflated using the consumer price index (CPI) with 1983 as the base year, thus all monetary variables are expressed in constant 1983 pesetas.

Despite what might be expected judging from the theoretical model, we have not included among the socio-economic variables any to represent the vector of input prices. This is because, by assuming perfect competition in the factor market, we assume that this vector will be the same for all provinces and that its impact will therefore be equal across them all.

Finally, the edaphic variables are aggregated into a single Soil Quality Index(SQI) which depends on the productive capacity of the soil in each province.[10] This index classifies soils into five types on the CORINE map published by the "Institut National de Topographie".[11] This classification is based on soil suitability for agriculture, taking into account factors such as texture, percentage of organic matter or salinity. Soils are assigned a score from 1 to 5 according to their quality: 1 for poor quality soils and 5 for those of better quality, the provincial index is then constructed by weighting each type of soil according to its percentage in the provincial land surface, and summing the weightings. In this way we obtain an index for each province, and assume the result- a score between one and five - to remain constant

[8]This excludes subsidies for the purchase of capital goods and compensation for crop failure or damage due to meteorological phenomena, diseases, etc. because we consider that the extraordinary nature of this type of subsidies means that they can not be predicted by the farmer and included in his profit function.

[9]To find the subsidy figures, we also required the collaboration of the Departments of Agriculture in the various Autonomous Communities.

[10]We use the soil quality index constructed by N. Balti and A. Garrido of the Polytechnic University of Madrid.

[11]This map uses the French and English taxonomy of the FAO.

over time.[12]

Three dependent variables will be used in the estimation of the regressions, agricultural value per hectare, price per hectare, and number of hectares used for agriculture, $VAH_{it}$, $P_{it}$ and $HA_{it}$ respectively. Ideally, under competitive market conditions, the selling price of a hectare of land is a reflection of its true value. It is extremely difficult to obtain data relating to the real selling price of agricultural land in Spain, mainly because of the infrequency of this type of transaction. For land price, therefore, we use the results of the annual survey on potential agricultural land prices, designed and coordinated since 1983 by the MAPYA and conducted by the autonomous communities, each within its own boundaries.[13]

Through this survey, it is possible to obtain an average weighted price per hectare for each province in each year, $P_{it}$. This is based on the prices declared by the agents surveyed in each province, which take into account the type of crop cultivated in the region under evaluation. When valuing the land, 20 crop types and various usages (such as non-irrigated or irrigated cultivation, vineyards, stone fruit, pip fruit, olive groves, etc.) are taken into consideration. Once a price has been determined for the land according to usage, it is then possible to calculate a representative price per hectare, based on the percentage of each usage in each province. The data allow us to differentiate between non-irrigated crops and irrigated crops and therefore find the average provincial prices per hectare of non-irrigated and irrigated land.[14] As mentioned earlier, we work with deflated rather than nominal prices, which means that they can be considered real prices, that is, representative of purchasing power.

Finally, another dependent variable used in our regressions is the number of hectares used for agriculture in each province. This includes a distinction between irrigated and non-irrigated land. A hectare of land is considered to be irrigated if it receives artificial irrigation at least once in the agricultural year. Land used for agriculture includes both crop lands and also meadows, pasture and forest. The data for this variable were taken from the Agricultural Statistics Yearbook published by the MAPYA. Forests, meadows and pastures are all included in the number of non-irrigated hectares.

[12]Many land uses can lead to soil degradation by altering edaphic conditions and thereby soil quality and productivity. However, since, as far as we are able to ascertain, there were no great changes in soil quality during the sample period, we consider the SQI to remain constant throughout the study period.

[13]The prices disaggregated at the provincial level were supplied by the MAPYA and the autonomous communities themselves. In the case of the communities of Extremadura and Castilla La Mancha observations were available only for 1996-1999 and 1992-1999 respectively.

[14]See P. Sánchez Rodríguez.

From the price per hectare we are able, as described in the preceding section, to define the dependent variable "agricultural value per hectare". To do so we use the observations on price, number of hectares used for agriculture and number of hectares per province, as presented earlier, and from these we construct the quotient expressed in equation 2.

### 2.3 Differentiation between non-irrigated and irrigated land

Generally speaking, and particularly in our country, the price of non-irrigated land is significantly lower than that of irrigated land. We therefore estimate two distinct models, one for non-irrigated agriculture and another for irrigated, not without first assessing the need to do so.[15] The use of two independent models allows us to obtain a better fit between the dependent variables and climatic variations and therefore increases the reliability of the estimations.

The early models of this type, which were estimated for the United States (Mendelsohn *et al.* 1994) made no distinction between irrigated and non-irrigated land. In the US case this lack of distinction may be considered reasonable, since only 3% of the agricultural output of North America depends on artificial irrigation systems. In the Spanish case, however, more than 50% of the total value of final agricultural production is irrigation dependent, while occupying only 13% of the total area under cultivation.[16] Irrigation therefore has a much more decisive impact on agricultural return in Spain than in the US.

Thus, we will perform a simultaneous estimation of the three regressions presented above, this time one for each type of regime, $VAH_{it}^{sec}$ will denote the value per hectare of non-irrigated land; $P_{it}^{sec}$, the price per hectare of non-irrigated land and, finally, $HA_{it}^{sec}$, the total number of hectares of non-irrigated land per province. We will then repeat the same exercise with the irrigated lands.

By estimating these two models, we will be able to analyse not only whether it is worth turning some agricultural land over to non-agricultural uses, but also whether there is any benefit to be obtained from turning non-irrigated land into irrigated land. We will be able to distinguish, for example, between a reduction in the number of non-irrigated hectares due to the unavoidable need to cease agricultural activity, from a reduction due to conversion to irrigation. The first case will probably involve a reduction

[15] We performed a structural change test, which resulted in a score of 70.593, thus confirming the need to estimate two different models.

[16] See National Irrigation Plan.

in the total number of hectares used for agriculture, while the second will result in a net increase of hectares under irrigation.

The next section presents the estimations that will enable us to analyse the changes in the agronomic map of Spain.

## 3 Estimation of the model

In Table 1 we present the results of the estimations of equation 4 for non-irrigated and irrigated land. Contrary to our expectations, however, the coefficients of the temperature variables are non-significant in both models. In fact, the only significant coefficients are those of the temperature terms for January in the non-irrigated land and temperatures for April in the irrigated land. In light of the results of these estimations, we would have to conclude that the influence of the temperature regime on agricultural productivity is almost imperceptible, and, therefore, that a rise in temperatures as a result of global warming would have no impact on agricultural profitability. Since such conclusions would be inconsistent both with our expectations and with the empirical evidence,[17] we decided to investigate to see whether such counterintuitive results might be due to econometric problems.

On finding high coefficients of determination in our regressions, and since individual significance tests confirmed the null hypothesis, we began by testing for multicollinearity, for which we used the Condition Index, which gave a score of 711.52 in the non-irrigation context and 769.08 in the irrigation context. These values clearly confirm the presence of multicollinearity in both cases. Next, in order to identify which variables were involved in the multicollinearity, we constructed a correlation matrix with the independent variables. We found strong correlation between each of the linear temperature terms and its corresponding quadratic term.

Recall that the presence of multicollinearity in a model does not alter the efficiency or the non-bias of the least squares estimators, it simply prevents us from distinguishing the individual effect of each of the affected variables. The magnitude of the variance of the coefficients across the temperature variables, though minimal, too often leads us to accept their non-significance. A further problem with multicollinearity is that it makes estimations highly sensitive to slight changes in the information captured by the independent variables, leading to loss of accuracy in the estimation. To distinguish between the linear and quadratic effects of the temperature variables, we constructed an additional quadratic variable, $\tilde{T}^2_{its}$, that captures only that part

[17] which we tested with the likelihood ratio test.

Table 1: Agricultural value per hectare

| Model | VAH Non-irrigated | | VAH Irrigated | |
|---|---|---|---|---|
| Variables | Parameter | Sig. | Parameter | Sig. |
| Constant | 15.738 | .000 | 4.190 | .159 |
| TJanuary | 0.103 | .010 | 0.110 | .059 |
| $TJanuary^2$ | -6.505E-03 | .011 | -1.714E-03 | .641 |
| TApril | 3.841E-02 | .540 | -.175 | .059 |
| $TApril^2$ | -2.693E-03 | .316 | 1.055E-02 | .007 |
| TJuly | -7.782E-02 | .590 | .254 | .250 |
| $TJuly^2$ | 2.770E-03 | .367 | -4.020E-03 | .387 |
| TOctober | 0.102 | .171 | 8.977E-02 | .405 |
| $TOctober^2$ | -9.445E-04 | .697 | -2.324E-03 | .507 |
| PRJanuary | 1.165E-03 | .015 | 3.426E-04 | .650 |
| PRApril | 1.836E-03 | .002 | 3.591E-04 | .724 |
| PRJuly | 7.480E-05 | .949 | 3.970E-03 | .048 |
| PROctober | 1.250E-03 | .001 | 7.635E-04 | .209 |
| Hoursun | -8.575E-04 | .000 | 8.624E-04 | .000 |
| Latitude | 8.579E-04 | .055 | 3.021E-03 | .000 |
| Longitude | 1.274E-03 | .000 | -1.198E-03 | .000 |
| IPC | 1.133E-06 | .000 | -1.226E-06 | .016 |
| Density | 7.498E-04 | .000 | 3.192E-04 | .329 |
| Subsid | -1.594E-05 | .060 | -7.092E-05 | .000 |
| CPI | .228 | .000 | .241 | .000 |
| | $\bar{R}^2$= .583 n=529 | | $\bar{R}^2$.553 n=435 | |

Sig: p-value

of the information from the original quadratic variable that is not already included in the corresponding linear term. For the construction of this new variable we estimated the following model:

$$T^2_{its} = \xi_s + \theta_s T_{its} + \epsilon_{its} \tag{10}$$

where s=January, April, July, October, for each province $i$ in year $t$. From this estimation we obtained the following results:

$$\hat{\theta}_{ja} = 14,513 \qquad \hat{\theta}_a = 24,542 \qquad \hat{\theta}_j = 46,059 \qquad \hat{\theta}_o = 31,09$$

for January, April, July and October, respectively. The corrected determination coefficients ($\bar{R}^2$) given by the above estimations for the four months are:

$$\bar{R}^2_{ja} =,949 \qquad \bar{R}^2_a =,980 \qquad \bar{R}^2_j =,996 \qquad \bar{R}^2_o =,986$$

thus confirming the high correlation between the linear and quadratic terms of the temperature variables. From these estimations we constructed $\tilde{T}^2_{its}$ such that:

$$\tilde{T}^2_{its} = T^2_{its} - \hat{\theta}_s T_{its} \tag{11}$$

Note that, by construction, each $\tilde{T}^2_{its}$ is orthogonal to the corresponding linear term and therefore the introduction of these two variables into the model does not result in multicollinearity. Using these new variables, to replace the original quadratic terms, we can rewrite model 4, which is estimated as follows:

$$\begin{aligned} lnVAH_{it} = \alpha^v_0 + \sum_{s=1}^{4} \alpha^v_s T_{its} + \sum_{s=1}^{4} \psi^v_s \tilde{T}^2_{its} + \sum_{s=1}^{4} \lambda^v_s PR_{its} + \\ + \sum_{n=1}^{N} \varphi^v_n RV_{itn} + \eta^v_{it} \end{aligned} \tag{12}$$

From the results of these estimations we find that most of the temperature variables are significant and we can therefore conclude that the lack of significance found in the estimation of model 4 was due to the presence of multicollinearity.

Having estimated these coefficients, we can calculate the values of the coefficients of the original variables by substituting them with $\tilde{T}^2_{its}$. That is:

$$\begin{aligned} lnVAH_{it} = \hat{\alpha}^v_0 + \sum_{s=1}^{4} \hat{\alpha}^v_s T_{its} + \sum_{s=1}^{4} \hat{\psi}^v_s \left( T^2_{its} - \hat{\theta}_s T_{its} \right) + \\ + \sum_{s=1}^{4} \hat{\lambda}^v_s PR_{its} + \sum_{n=1}^{N} \hat{\varphi}^v_n RV_{itn} + \hat{\eta}^v_{it} \end{aligned} \tag{13}$$

thus we have:

$$\begin{aligned} lnVAH_{it} = \hat{\alpha}^v_0 + \sum_{s=1}^{4} \left( \hat{\alpha}^v_s - \hat{\psi}^v_s \hat{\theta}_s \right) T_{its} + \sum_{s=1}^{4} \hat{\psi}^v_s T^2_{its} + \\ + \sum_{s=1}^{4} \hat{\lambda}^v_s PR_{its} + \sum_{n=1}^{N} \hat{\varphi}^v_n RV_{itn} + \hat{\eta}^v_{it} \end{aligned} \tag{14}$$

The linear effects of the temperature variables are denoted by $\left( \hat{\alpha}^v_s - \hat{\psi}^v_s \hat{\theta}_s \right)$, which, together with the strictly linear effect of the term $\alpha^v_s$, includes some of the effect of the quadratic term denoted by $\psi^v_s \theta_s$. Note that this term also affects agricultural value per hectare through $\psi^v_s$, hence there is high correlation between the linear and quadratic terms. Therefore, the effect of a variation in temperature in any climatic season will be written as:

$$\frac{\partial lnVAH_{it}}{\partial T_{its}} = \left( \hat{\alpha}^v_s - \hat{\psi}^v_s \hat{\theta}_s \right) + 2\hat{\psi}^v_s T_{its} \tag{15}$$

Note that this is the final relevant effect that includes all the other effects of a temperature change, both linear and quadratic, and that we resorted to the above analysis only in order to find the differentiated significance of the linear and quadratic terms and to ensure that both were relevant in the regression. To analyse the effect of climate change on Spanish agriculture, however, we need to consider the two coefficients jointly.

To estimate the effect of the annual variation in temperatures on agricultural value, we need to calculate:

$$\sum_{s=1}^{4}\left(\frac{\partial lnVAH_{it}}{\partial T_{its}}\right)=\sum_{s=1}^{4}\left(\hat{\alpha}_s^v-\hat{\psi}_s^v\hat{\theta}_s\right)+2\sum_{s=1}^{4}\hat{\psi}_s^v T_{its} \quad (16)$$

The effect of a change in annual precipitation, meanwhile, can be derived by solving the following expression:

$$\sum_{s=1}^{4}\left(\frac{\partial lnVAH_{it}}{\partial PR_{it}}\right)=\sum_{s=1}^{4}\hat{\lambda}_s^v \quad (17)$$

And similary we can obtain the effect of the annual variation in temperatures and precipitation on price per hectarea and on the number of hectares used for agriculture.

## 3.1 The impact of subsidies

Subsidies are highly significant and negative. This negative coefficient indicates that subsidised plots command a lower price. There is nothing unusual in finding a negative relationship in the irrigation models, since subsidies are usually granted to farmers producing low-return crops, such as cereals, for example, while non-subsidised irrigated land is used mainly for fruit and vegetable production; that is, higher value-added crops. The negative coefficient in the models for non-irrigated land is surprising, however. It suggests, as in the previous case, that the highest per hectare subsidies are issued to the lowest-priced and agriculturally least valuable lands. This appears to indicate a contradiction, since, unlike irrigated land, much of the non-irrigated land would be unprofitable if it were not for the subsidies, and farms are supposed to increase their value through the subsidies they receive. We must therefore seek an alternative explanation for this result.

The Common Agricultural Policy underwent reform in 1992; prior to this, CAP policy was to link subsidies to production, which encouraged surplus production. The more a farmer produced the higher the subsidy he received, which meant that the most productive plots were the most highly subsidised. Thus, up until 1992, subsidies should correlate positively with agricultural output. Since the 1992 reform, however, instead of being linked to production, subsidies have been based on what are known as "historical returns", which do not depend on the output level and are sustained even if output falls. Given the existence of these two different effects, we tested to see whether the impact of subsidies per hectare does in fact present a different sign before and after the CAP reform of 1992.

To verify whether a structural change does in fact take place from 1992 onwards, we introduce a dummy variable, $DS$, into the estimation of our non-irrigated models, this variable takes a value of 0 for all observations between 1983 and 1991, and the value of variable *subsid* for the rest of the sample period, 1992-1999. In this way we aim to differentiate between the influence of the subsidy system before and after 1992.

The recalculated coefficients of model 14, non-irrigated and irrigated, are shown in Tables 2 and 3 respectively. Coefficient $\left(\hat{\alpha}_s^v - \hat{\psi}_s^v \hat{\theta}_s\right)$ in equation 14 corresponds to the linear coefficient of the temperature variable in Tables 2 and 3.

# 4 The implications of the greenhouse effect

## 4.1 The effect of climatic variables

The results of our regressions, shown in Tables 2 and 3, confirm our expectations regarding the dependence of agricultural performance on climatic variables. Our estimations explain 59.1% of the variation in the agricultural value per hectare of non-irrigated land, and somewhat less, only 55.9%, of the variation in the case of irrigated land. In both cases, the tests of global significance of the model clearly show the set of selected independent variables to be relevant.[18] With respect to the land price variable, our model explains a slightly higher percentage of variation in both non-irrigated and irrigated land, that is, 59.5% and 58%, respectively. Finally, the percentages of variation explained on the number of hectares variable are 55.2% for non-irrigated and 47.7% for irrigated areas. Again, the global significance tests confirm the relevance of the selected variables.[19]

[18] The F statistic is 39.264 for the non-irrigated case and 28.525 for the irrigated case.

[19] The F statistic values for the global significance tests of the non-irrigated and irrigated price models are 39.808 and 30.997, respectively; while those for the number of hectares models are 33.611 and 20.807.

Table 2: Estimation of the non-irrigated models with analysis of subsidies

| Model | VAH | Price | hectares |
|---|---|---|---|
| Variables | Parameter | Parameter | Parameter |
| Constant | 15.474** | 8.256** | 14.416** |
| TJanuary | 9.760E-02 | 7.939E-02* | 1.645E-02** |
| $TJanuary^2$ | -6.375E-03** | -3.954E-03* | -3.131E-03* |
| TApril | 4.750E-02 | 3.002E-02 | 3.153E-02 |
| $TApril^2$ | -2.706E-03 | -1.530E-03 | -9.258E-04 |
| TJuly | -6.149E-02* | -6.603E-02 | -.319** |
| $TJuly^2$ | 2.095E-03 | 2.035E-03 | 7.777E-03** |
| TOctober | .113** | .112** | -4.453E-02** |
| $TOctober^2$ | -1.163E-03 | -1.390E-03 | 1.843E-04 |
| PRJanuary | 1.065E-03* | 8.012E-04* | -2.552E-04 |
| PRApril | 1.684E-03** | 1.177E-03* | -4.923E-04 |
| PRJuly | -3.795E-04 | -6.710E-04 | -1.431E-03* |
| PROctober | 1.246E-03** | 1.113E-03** | -5.290E-04* |
| Hoursun | -8.538E-04** | -7.207E-04** | 3.331E-04** |
| Latitude | 8.336E-04* | 1.132E-03** | 8.986E-04** |
| Longitude | 1.342E-03** | 1.144E-03** | 2.859E-04* |
| CPI | 1.241E-06** | 1.082E-06** | -9.471E-07** |
| Density | 7.863E-04** | 8.455E-04** | -1.112E-03** |
| Subsid | 7.323E-05** | 7.435E-05** | 1.115E-05 |
| DS | -8.081E-05** | -8.409E-05** | 2.308E-06 |
| SQI | .209** | .195** | 7.945E-02** |
|  | $\bar{R}^2 = 0.591$ | $\bar{R}^2 = 0.595$ | $\bar{R}^2 = 0.552$ |
|  | n=529 | n=529 | n=529 |

*: Sig. al 95%; **: Sig. al 99%

Thus, in the case of the agricultural value of non-irrigated land, all the coefficients of the linear terms of the temperature variables are significant except spring temperature and winter temperature. The quadratic term for the latter is significant, however. In the irrigation model, the significant coefficients are those that correspond to the linear temperature terms for winter, spring and summer, and also the coefficient of the quadratic spring term. This suggests that the relationship between the temperature regime and agricultural value per hectare is represented by a very smooth curve. The same can be said of the regression of land price and the number of hectares, where most of the coefficients of the temperature variables are significant.

This model enables us to perform three types of analysis. First, an anal-

Table 3: Estimation of the irrigated models with subsidy analysis

| Model | VAH | Price | Hectares |
|---|---|---|---|
| Variables | Parameter | Parameter | Parameter |
| Constant | 3.767 | 12.393** | 4.868* |
| TJanuary | .104** | 5.935E-02** | 2.152E-02 |
| $TJanuary^2$ | -1.617E-03 | -7.331E-04 | -1.356E-03 |
| TApril | -.159** | -6.600E-02 | -.136** |
| $TApril^2$ | 1.037E-02** | 3.188E-03 | 9.463E-03** |
| TJuly | .275* | -2.503E-02 | -.288** |
| $TJuly^2$ | -4.839E-03 | 3.490E-04 | 7.951E-03* |
| TOctober | .102 | .138** | -.031** |
| $TOctober^2$ | -2.576E-03 | -3.166E-03 | -5.929E-04 |
| PRJanuary | 2.439E-04 | 1.178E-04 | 1.857E-04 |
| PRApril | 2.710E-04 | 7.405E-04 | -2.611E-04 |
| PRJuly | 3.216E-03 | 6.198E-04 | 2.629E-03* |
| PROctober | 7.313E-04 | 8.212E-04* | -5.729E-04 |
| Hoursun | 8.625E-04** | -7.531E-05 | 1.183E-03** |
| Latitude | 3.038E-03** | 1.402E-04 | 3.218E-03** |
| Longitude | -1.147E-03** | -5.798E-04** | -9.053E-04** |
| IPC | -1.149E-06* | -1.151E-07 | -2.231E-06** |
| Density | 3.500E-04 | 8.978E-04** | -9.487E-04** |
| Subsid | 2.418E-05 | -1.986E-06 | 3.735E-05 |
| DS | -8.558E-05** | -5.209E-05** | -2.479E-05 |
| SQI | .216** | .159** | 6.961E-03 |
| | $R^2 = 0.559$ | $R^2 = 0.580$ | $R^2 = 0.477$ |
| | n=435 | n=435 | n=435 |

*: Sig. al 95%; **: Sig. al 99%

ysis of the impact of individual seasons, which enables us to calculate, for example, the impact of a variation in average temperature in a particular season on the agricultural value of a province. For this analysis, we will evaluate the expression 15 at the average temperature for the season and province that concern us. Thus, the effect of the January temperature in province $i$ on $VAH_{it}^{non-irr}$, for example, will be calculated from the expression $0.0976 - 2(0.0063)TJanuary_i$.

Nevertheless, climate change will alter the whole annual temperature regime- not just that of one season- it will therefore be necessary to evaluate the effect of this annual variation in temperatures on the agricultural value of a province, for which we will use expression 16, which takes into consideration all the variations in the temperature regime over the period of one year. This can be done in two ways (the second and third of the three analyses mentioned above). First, as can be seen from the expression, we can evaluate this expression using monthly temperatures for each province. The expression then becomes a four-variable function, that is, one for each of the temperatures considered. In order to calculate the impact of a change in the temperature regime, we will substitute the temperature values from the previous expression and calculate the value of the relevant variable $VAH_{it}$ in each case. In this type of analysis it is necessary to calculate $VAH_{it}$ for each year and each province and then analyse the evolution of these values.

The second possibility is to use the average annual temperature in each province, which we denote by $TM_{it}$. This is a less accurate and less detailed analysis than the one above, but it does allow us to treat the expression 16 as a single-variable function, the properties of which are easier to examine.[20]

There is generally little point in considering any of the seasonal coefficients in isolation, since the output of a plot does not depend on the climatic regime of one particular season but on climatic variations throughout the whole year. We will therefore calculate the effect of the annual variation in temperatures and evaluate equation 16 on the annual average temperature in each province, $TM_{it}$. For non-irrigated land the expression is equal to $0.1972 - 0.0163TM_{it}$, where $TM_{it}$ is the annual average temperature in province $i$ during period $t$. This is a concave function that reaches its maximum value at $12^oC$. It shows that, whereas increases in the annual average temperature up to $12^oC$ will increase the value of non-irrigated arable land, excessive increases (above $12^oC$) may reduce it. We repeat the same operation for the "price per hectare" and "number of hectares" regressions. In the first of these, the expression is equal to $0.1558 - 0.00967TM_{it}$ with the maximum value occurring at $16.1^oC$. The number of hectares has a decreasing function with respect to the temperature variables in the whole range of relevant temperatures in Spain, which clearly suggests that increases in annual average temperatures will lead to a reduction in the number of hectares of non-irrigated land used for agriculture across all Spanish provinces. The results can be observed in Figure 1

[20]Expression 16 can now be rewritten as:

$$\frac{\partial lnVAH_{it}}{\partial TM_{it}} = \sum_{s=1}^{4} \left(\hat{\alpha}_s^v - \hat{\psi}_s^v \hat{\theta}_s\right) + 2\sum_{s=1}^{4} \hat{\psi}_s^v TM_{it}$$

Note that the log function is a monotonic transformation of $VAH_{it}$ and both reach their maximum value at the same point.

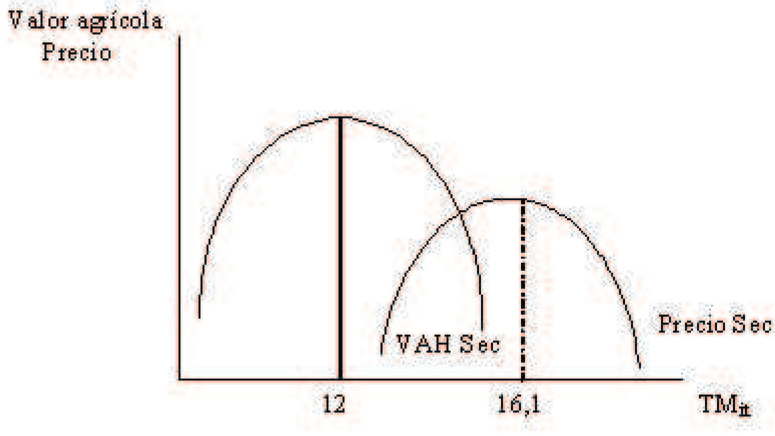


Figure 1: Effect of variation in the annual temperature regime

This reveals that the Spanish provinces can be divided into three types according to the trend followed by the independent variables, agricultural value, price per hectare, and number of hectares used for agriculture, shown in Figure 1. In provinces with an annual average temperature below 12°C, a temperature increase will bring about an increase in agricultural value and the price of land. A rise in temperatures will also cause an increase in the price of land in provinces with an average temperature between 12°C and 16.1°C, but there will be a decrease in agricultural value. Finally, in provinces with annual average temperatures above 16.1°C there will be a decrease in both agricultural value and the price of land. In all three cases, the number of hectares of non-irrigated land is a decreasing function for the relevant range of temperatures in Spain, it therefore is not included in the graph.

The effect of the annual variation in temperatures on the agricultural value of irrigated land is equal to $0.306 + 0.0032TM_{it}$. This is an increasing function for any range of temperatures. There is a similar effect on the price per hectare of irrigated land, which also increases for any reasonable range of temperatures. When it comes to the number of hectares, however, the resulting equation is $-0.4355 + 0.0308TM_{it}$, a convex function that reaches its minimum value at $14.1^{o}C$. This suggests that the expansion of the irrigated areas will require a minimum annual average temperature of $14.1^{o}C$ and that such an expansion will only be worth undertaking at average temperatures above that level.

Taking the evolution of non-irrigated and irrigated areas together, we are left with the picture that appears in Figure 2, which shows four different zones, one shown in red, where, in both non-irrigated and irrigated areas, there is an overall reduction in the area used for agriculture, together with increases in both price per hectare and agricultural value. This zone includes the provinces of the Community of Castilla y León - with the exception of Valladolid and Zamora - and also Guadalajara, Álava, Lugo and Teruel. These are provinces with a particularly low average temperature, such that an increase will not be entirely detrimental, since, the reduction in the number of hectares used for cultivation will be accompanied by an increase in the price per hectare, which will help to sustain the agricultural value of these provinces.

A second zone, shown in violet, differs from the first only in the fact that this time, the increase in price per hectare of non-irrigated land does not compensate for the loss in the number of hectares and so there is a reduction in the agricultural value of non-irrigated land in these provinces. In the case of the irrigated areas, the number of hectares is reduced but not their price or value. This zone includes part of the region of Cantabria, the upper Ebro - with the exception of Zaragoza - the rest of Castilla y León, Albacete and Cuenca. The provinces of this zone, like those of the previous one, are characterised by a reduction in the number of hectares of both non-irrigated and irrigated land and can be said to be the worst-affected by the climate change phenomenon.

In the zones shown in light and dark blue, it is possible to observe an increase in the number of hectares, the price and the value of irrigated land. Those shown in dark blue - such as Gerona, Lérida, Zaragoza and Madrid - also register an increase in the value of non-irrigated land. This is not the case with the those shown in light blue, which include the southern half of Spain and practically all of the Mediterranean coast, where there is a marked difference between irrigated and non-irrigated land. Thus, while a rise in average temperature will lead to increases in the area, price and value of irrigated land, it will result in quite the opposite in non-irrigated areas; that is, a decrease in area, price and agricultural value. The map shown in Figure 2 provides further evidence of the existence of two zones, one shown in shades of red indicating the provinces that stand to suffer as a result of climate change, the other in shades of blue showing those that will benefit.

Climate change affects not only the temperature regime but also the precipitation regime, however. By observing the results of the estimations obtained in Tables 2 and 3 we can check that, as expected, irrigated agriculture is less vulnerable than non-irrigated agriculture to change in the rainfall regime. The differences are reflected mainly in the significance of the precipitation variables. Indeed, the coefficients of the precipitation variables in the regression on the agricultural value of irrigated land can be seen to be

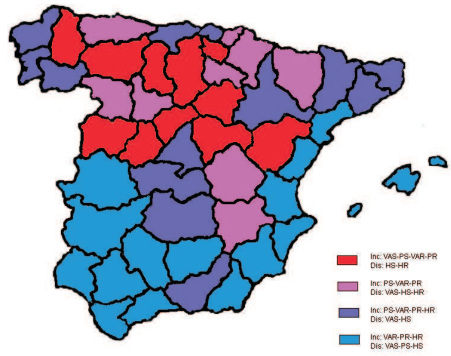


Figure 2: Joint Evolution Non-irrigated/Irrigated

non-significant. In the regression on the agricultural value of non-irrigated land, however, the same coefficients are clearly significant and positive, indicating that the agricultural value of non-irrigated land will suffer a negative effect from a reduction in precipitation.

If we repeat this analysis for the price per hectare variable, we can see that the coefficients of the precipitation variables are also significant and positive for non-irrigated lands. The differences emerge when these results are compared with those obtained in the irrigated models. None of the precipitation coefficients in the agricultural price per hectarea model prove to be significant, as can be seen in the second column of Table 3. These results show that changes in precipitation levels will have no significant effect on the agricultural value of irrigated land.

The results of the regression on the number of hectares suggest a similar interpretation. In the case of non-irrigated land, the summer and autumn precipitation coefficients are significant and negative, suggesting that increases in precipitation would lead to a reduction in the number of non-irrigated hectares. In the case of irrigated land, only the summer precipitation coefficient is significant, at 2.692E-03.[21] These values confirm our hypothesis that long periods of drought, particularly in the summer season, could lead to water shortages that would threaten crop viability. Given the higher profitability of irrigated crop production, together with the rainfall indices registered in Spain, the extent of the area under irrigation is subject to the availability of water for irrigation purposes. An increase in precipitation would therefore reduce uncertainty in this matter and encourage investment to convert dry land to irrigation.

Finally, it should be mentioned that the "hours of sunlight" variable is highly significant in both models, though the nature of its impact is radically

[21] Tables 2 and 3, column 3.

different in each case. While in the non-irrigated regressions an increase in hours of sunlight would lead to a reduction in both price per hectare and agricultural value, in the case of irrigated land, a similar increase would improve agricultural value, with a coefficient of 8.625E-04. These are the signs expected in the north of Spain, where almost all agricultural output is rainfed. Artificial irrigation is unnecessary thanks to the high precipitation index, which permits the cultivation of high value added products that in other areas of the country would require artificial irrigation and therefore form part of the irrigated agriculture data. The price per hectare of non-irrigated land in this part of Spain is therefore higher than in the rest of the country. This, meanwhile, is an area with a considerably lower annual total of hours of sunlight than are registered in the center or south of the peninsular. Econometric estimation suggests that an increase in hours of sunlight would leave these non-irrigated lands in the same state as those of southern Spain. In the case of irrigated land, as long as water availability is ensured, an increase in hours of sunlight will increase output, since it is on the Mediterranean coast that irrigation produces the highest return. As predicted, therefore, the impact on the number of hectares, of either non-irrigated or irrigated land, is clearly significant and positive.

### 4.2 The relevance of non-climatic variables

Agricultural value per hectare, $VAH_{it}$, increases with the latitude variable. Indeed, latitude shows a positive and significant impact, in both the non-irrigated and irrigated model, indicating that the further north one goes in the peninsular, the higher the return on agricultural production. With non-irrigated agriculture the case is clear, since the most productive cereal-producing areas are to be found toward the north. The positive impact on irrigated land can be explained by the high agricultural value of the irrigated areas in the Ebro valley and around Barcelona. It could be argued, however, that both north and south along the whole of the Mediterranean coast, we find high value added irrigated agricultural production, though our model captures the East-West effect through the longitude variable.

We expected the longitude variable to have a negative sign, in both the $VAH_{it}$ and the $P_{it}$ regressions, for irrigated agriculture. The empirical results corroborate these predictions, indicating that as one moves westward across the peninsular, there is a gradual decrease in expected agricultural returns from irrigated lands. This shows that the lands on the Mediterranean coast perform better in this type of production. Indeed, the coefficient of the longitude variable for irrigated lands is negative and highly significant. In the case of non-irrigated lands, longitude is also significant but positive, which is unequivocal confirmation of the high agricultural value of the north-east of the peninsular. The results of the models estimated for number of hectares confirm these trends.

The income per capita variable, $IPC$, is significant, both in the non-irrigated agricultural value regression, and in the irrigated regression ($VAH_{it}$). In the case of non-irrigated lands the impact is positive as expected, though quite small (with an estimated parameter of $1.241E-06$). In the case of irrigated lands, however, the estimated parameter also exhibits little impact, but this time it is negative and significant, $-1.149E-06$. An initial interpretation might lead us to suspect a relationship between higher per capita income and a decrease in expected returns from irrigated agriculture, an idea that is surprising to say the least.

The negative impact of per capita income ($IPC$) on the agricultural value of irrigated land, $VAH_{it}$, is conditioned by the decrease in the number of hectares under irrigation. The $IPC$ variable is non-significant in the irrigation price regression, $P_{it}$, but significant in the regression on number of hectares used for agriculture, $HA_{it}$. This indicates that higher income levels may be linked to farm-abandonment, even in irrigated areas, to give way to other more profitable land uses. Note that the reduction in the number of hectares used for agriculture also affects non-irrigated areas, hectares used for non-irrigated agriculture decrease with increases in this variable - the coefficient of which,$-9.471E-07$, is significant and negative. In this case, however, both the price and agricultural value of non-irrigated land increase as per capita income rises.

While the density variable is significant in all the non-irrigated models, it is significant only in price and number of hectares in the irrigated models. It has a positive impact in the price and agricultural value models, both for non-irrigated and irrigated areas. This may be due to the fact that density tends to increase the demand for land for non-agricultural uses. This would explain the negative sign in the regressions on number of hectares of both non-irrigated and irrigated land. The coefficient is $-1.112E-03$ for non-irrigated output and somewhat lower but also negative, $-9.487E-04$, for irrigated output. Two effects are present in this process, on the one hand, the number of hectares decreases in response to the rise in demand for land for other uses and, on the other, it is likely that land of poorer quality or less output will be the first to be abandoned for agriculture, and this will lead to an increase in the average output of the remaining hectares and subsequently to a rise in the price per hectare. Both effects, therefore, cause a price increase.

The coefficient of the *subsid* variable in the value and price regressions is significant and positive, indicating that, prior to the 1992 CAP reform, an increase in subsidies was linked to an increase in land price and land value. By contrast, the coefficient of variable $DS$ is negative, significant, and higher in absolute terms than the *subsid* variable. Note that the effect of subsidies from 1992 onwards is given by the sum of these two coefficients, $(7.323E-5)-(8.081E-5)=-(0.761E-5)$. This result suggests that -in the non-irrigated regime- the highest subsidies are linked to the lowest priced land; note, however, that the effect is very weak. The subsidy system that came into force with the 1992 CAP reform therefore was to reward the plots with the lowest value and lowest price, in other words, the plots that were to benefit most from the 1992 CAP reform were the least productive. Moreover, the coefficient on the subsidy variable is positive when it is regressed on the number of non-irrigated hectares,[22] that is, an increase in subsidies generates an increase in the area of non-irrigated land used for agriculture.

For the case of irrigated land, the variable *subsid* shows a positive sign but no significant, which shows that, prior to 1992, the subsidy regime was not a relevant factor in the value of irrigated land. The dummy variable $DS$, meanwhile, is negative and significant, showing - as mentioned earlier- that in the case of irrigated lands, subsidies are issued for cereal plots, which give a much lower return than irrigated land used for fruit and vegetable cultivation. This time the positive coefficient on the subsidy variable, when it is regressed on the number of hectares indicates that an increase in subsidies generates an increase in the area of irrigated land under cultivation.

Finally, the variable used to capture soil quality behaves according to our expectations, in other words, it is highly significant and positive. The better the quality of the soil, the higher the return and the higher the selling price and agricultural value, both of non-irrigated and irrigated lands. It is striking, moreover, to find that this variable has the highest coefficient of influence of all the independent variables on price and agricultural value, the coefficients for the latter being 0.209 and 0.216 for non-irrigated and irrigated land, respectively.

## 5 Conclusions

In this article, we have examined the impact of climate change on agricultural profitability, assuming that farmers adjust to changing climatic conditions by modifying their production decisions. We use a model that, in addition to quantifying the impact on agricultural value per hectare, also allows us to differentiate the effect of global warming on the price per hectare

[22] Table 2, column 3.

of land sold for agricultural uses and on the number of hectares used for agriculture.

We estimate two separate models, one for non-irrigated and one for irrigated agriculture. From the estimated coefficients we are able to conclude that, given the average annual temperatures recorded in Spain, the number of hectares allocated to the cultivation of rainfed crops is likely to decrease, while the number allocated to irrigated crop production, in southern and eastern Spain should increase. It should be pointed out, however, that this increase would not compensate for the loss in the number of non-irrigated hectares. It is likely, therefore, that most of the non-irrigated hectares will be abandoned for agriculture if, as forecasts suggest, climate change in our country involves an increase in average temperatures.

Our results are a clear indication that non-irrigated agriculture is more vulnerable to climate change than is the case with irrigated agriculture. This result should not lead us to envisage large areas of irrigated land providing a buffer against the consequences of changing climatic conditions, however, because, as our model shows, this solution is not feasible in all regions of Spain. If we take into account the predicted variation in the temperature regime, the conversion of non-irrigated lands to irrigation only appears viable in the coastal regions, and then only as long as there is sustained water availability. Our model does not consider, for example, the loss in the profitability of irrigated agriculture that would take place if the price of water for irrigation purposes were to increase. This also has major implications with respect to the demand for water, since irrigation infrastructure requires substantial investment, which will only be made if there is a reasonable chance of relying on sufficient supplies of water for irrigation. Under this perspective, the increase in profitability achieved by converting non-irrigated land for irrigation might be considered a fair approximation of the economic value of water for agricultural uses.

Our analysis also excludes other factors, such as external competition, that could also have a relevant impact on our agricultural map. Finally, we should also bear in mind that predicted climate change is not restricted to a rise in temperatures. Forecasters also predict much greater variabilty and a much higher frequency of extreme events, which will have a greater impact on non-irrigated than on irrigated agriculture. We have not considered either climatic variability or the likelihood of extreme events, because predictions for these are much less reliable than for average conditions.

## References


[1] Adams, R. M. 1989. Global Climate Change and Agriculture: An Economic Perspective. *American Journal Agriculture Economics* : 1272-1279.

[2] Balti, N. 2001. Evaluación Económica de los Efectos del Cambio Climático sobre la Agricultura de Tünez y España.Tesis Master.

[3] Cline, W.R. 1996. The Impact of Global Warming on Agriculture: Comment. *The American Economic Review* 86(5): 1309-1311.

[4] Darwin, R. 1999. The Impact of Global Warming on Agriculture: A Ricardian Analysis: Comment. *The American Economic Review* 89(4): 1049-1052.

[5] Dixon, B.L. y Segerson, K. 1999. Impacts of Increased Climate Variability on the Profitability of Midwest Agriculture. *Journal of Agricultural and Applied Economics* 31(3): 537-549.

[6] Easterling, W., Crosson, P.R., Rosenberg, N.J., McKenney, M.S., Katz, L.A. y Lemon, K.M. 1993. Agricultural impacts of and responses to climate change in the Missouri-Iowa-Nebraska-Kansas (MINK) Region. *Climatic Change* 24: 23-61.

[7] Foro Agrario. La reforma de la PAC de la agenda 2000 y la agricultura española. 2000. Ed. Mundi-prensa

[8] Fundación BBVA. Renta Nacional de España

[9] Hatch, U., Jagtap, S., Jones, J. y Lamb, M. 1999. Potential effects of climate change on agricultural water use in the southeast U.S. *Journal of the American Water Resources Association* 35 (6): 1551-1561.

[10] Iglesias, A. y Mínguez, M.A. 1997. Modelling crop-climate interactions in Spain: Vulnerability and adaptation of different agricultural systems to climate change. *Mitigation and adaptation strategies for global change* 1 (3): 273-288.

[11] Iglesias, A., Rosenzweig, C. y Pereira, D. 2000. Agricultural impacts of climate change in Spain: developing tools for a spatial analysis. *Global Environmental Change* 10: 69-80.

[12] Instituto Nacional de Estadística. Anuario Estadístico 1984-2000.

[13] Intergovernmental Panel on Climate Change. Climate Change 2001: Impacts, adaptation and vulnerability.

[14] Kaiser, H. M. y Crosson, P. 1995. Implications of climate change for U.S. agriculture. *American Journal of Agriculture Economics* 77: 734-740.

[15] Kaufmann, R.K. 1998. The impact of climate change on U.S. agriculture: a response to Mendelsohn et al. (1994). *Ecological Economics* 26: 113-119.

[16] Mendelsohn, R., Nordhaus, W. y Shaw, D. 1994. The impact of global warming on agriculture: A Ricardian Approach. *American Economic Review* 84(4): 753-771.

[17] Mendelsohn, R., Nordhaus, W. y Shaw, D. 1996. Climate impacts on aggregate farm value: accounting for adaptation. *Agricultural and Forest Meterology* 80: 55-66.

[18] Mendelsohn, R. y Nordhaus, W. 1996. The impact of global warming on agriculture: Reply. *The American Economic Review* 86(5): 1312-1315.

[19] Mendelsohn, R. y Nordhaus, W. 1999. The Impact of Global Warming on Agriculture: A Ricardian Analysis: Reply. *The American Economic Review* 89(4): 1046-1048 y 1053-1055.

[20] Mendelsonh, R. Neumann, J.E. Ed. 1999. The Impact of Climate Change on the United States Economy.

[21] Ministerio de Agricultura, Pesca y Alimentación. Anuario de Estadística Agraria 1984-2000.

[22] Ministerio de Agricultura, Pesca y Alimenatción. Boletín Mensual de Estadística Agraria.

[23] Ministerio de Agricultura, Pesca y Alimentación. Plan Nacional de Regadíos.

[24] Novales, A. 2000. Econometría. Ed. McGraw-Hill.

[25] Quiggin, J. y Horowitz, J.K. 1999. The Impact of Global Warming on Agriculture: A Ricardian Analysis: Comment. *The American Economic Review* 89(4): 1044-1045.

[26] Reilly, J. 1995. Climate Change and global agriculture: recent findings and issues. *American Journal of Agriculture Economics* 77: 727-733.

[27] Rosenberg, N.J. 1993. Towards an Integrated Impact Assessment of Climate Change: The MINK Study. *Climatic Change* 24: 1-173.

[28] Rosenzweig, C. y Parry, M.L. 1994. Potential Impact of Climate Change on World Food Supply. *Nature* 367: 133-138.

[29] Rosenzweig, C. y Tubiello, F.N. 1997. Impacts of global climate change on Mediterranean agriculture: Current methodologies and future directions. An introductory essay. *Mitigation and adaptation strategies for global change* 1: 219-232.

[30] Sánchez Rodríguez, P. 1986. La encuesta de Precios de la tierra del Ministerio de Agricultura, Pesca y Alimentación. *Agricultura y Sociedad* 41(octubre-diciembre): 187-207.