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

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SUMMARY: We estimate how climate variables affect price and acreage of productive farmland using the Ricardian approach. Furthermore, we use our estimations to evaluate the joint effects of possible climate changes within the time horizon of 2010 and 2050. Our results show that the price of rainfed land in Spain tends to increase but rainfed acreage decreases. On the other hand, the effect on irrigated farmland price and acreage presents some mixed results, however, in the long run the dominant pattern is clearly increasing for both prices and acreage.

KEYWORDS: Climate change, agricultural land prices and acreage.

JEL classification: Q1, C2.

Relevancia económica de las variables climáticas en la agricultura: El caso de España

RESUMEN: Estimamos el efecto de varias variables climáticas en el precio y en el número de hectáreas cultivadas en España usando el enfoque Ricardiano. Asimismo utilizamos los modelos estimados para evaluar el efecto de posibles variaciones climáticas en el precio y en el número de hectáreas cultivadas durante el periodo 2010-2050. Nuestros resultados muestran que el precio de la tierra de secano incrementa pero la extensión disminuye durante el periodo considerado. En el caso del regadío, las previsiones no muestran una tendencia clara, pero en el largo plazo, tanto el precio como el número de hectáreas tienden a incrementar.

PALABRAS CLAVE: Cambio climático, precios y superficies de la tierra agrícola.

Clasificación JEL: Q1, C2.

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1. Introduction

Climate change and its potential consequences are high on the political agenda for environmental policy. 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. The realization that human activity is contributing to climate change has inspired abundant research, and this has resulted in the construction of several climate models to predict its effects[1]. The conclusions of these models are scenario dependent, however, some broadly accepted facts are emerging[2]. Scientists agree that the most severe drought effects will be felt in mid-latitude, inland continental areas, especially in the summer season, possibly leading to a loss of soil humidity and increased erosion. In this event, Spain will be among the regions most severely affected. Moreover, all these projections suggest that the agricultural sector will suffer the effects of climate change [see Intergovernmental Panel on Climate Change (IPCC, 2007) and European Commission (EC, 2005)]. The magnitude of the impact on this sector is as yet uncertain. Climate forecast, *per se*, is subject to error, but even if they were totally accurate, the reaction of the agricultural sector 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 (see EC, 2005 and 2007].

It is our aim to estimate the impact of climate on Spanish farmland value using the conceptual foundation of the Ricardian approach proposed by Mendelsohn *et al.* (1994) in their seminal paper. The Ricardian approach assumes that farmers continually adjust their production plans –by altering the types, combinations and amounts of inputs purchased and outputs produced adapting their agricultural production to the changing conditions and allocating land to its best possible use[3]. Production cost depends on factor prices as well as climatic conditions. Land is given a special consideration as a production factor in this approach. The hectares allocated to each crop depend on economic as well as climatic factors. Farmers adapt to climate and this adaptive process is reflected in farmland returns and land prices. Current farm value is based on present and expected returns. The price of an hectare of farmland depends on the discounted value of expected returns, and in turn, it depends on characteristics that determine these returns, among which we single out climate (see Mendelsohn *et al.*, 1996). Our goal is to estimate this relationship between climate variables and land prices for Spain. The Ricardian approach has been applied to a wide range of countries and regions such as Canada (Reinsborough, 2003 and Weber and Hauer,

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[1] Several climate models have been developed and are used for projections. For example, the ECHAM 4 that refers to a General Circulation Model designed by the Max Planck Institute for Meteorology; the HADCM3 GCM that was developed by the Hadley Centre in the UK, and the CGCM1 that was developed by the Canadian Climate Modelling Centre.

[2] See for example the list of robust findings presented in the IPCC Synthesis Report (2007).

[3] The theoretical developments for the Ricardian approach can be found in Mendelsohn *et al.* (1996) and Mendelsohn *et al.* (1999c).

2003), England and Wales (Maddison, 2000), India (Dinar *et al*., 1998 and Kumar and Parikh, 2001), Brazil (Sanghi, 1997) or China (Hui *et al*., 2004), among others. Also two continent-wide studies have been conducted, one for Africa (Dinar *et al*., 2008) and another for Latin America (Mendelsohn *et al*., 2007) using this methodology. However, it has not yet been applied to Spain. We are the first to estimate the impact of climate change on Spanish farmland value using the Ricardian approach[4]. Also, we estimate, together with the effect on land prices, the effect of climate change on acreage. Furthermore, we incorporate some of the recent contributions by Schlenker *et al*. (2005 and 2006), and Deschênes and Greenstone (2007) concerning the measurement of the climatic variables.

The production function or agronomic approach has been used to project the effect of climate change on Spanish agriculture [see Iglesias and Mínguez (1997), Rosenzweig and Tubiello (1997), Iglesias *et al*. (2000), Iglesias and Quiroga, (2007a), Iglesias (2009)]. It uses crop simulation models to predict yield variations and relies on experimental production functions to estimate the impacts of variations in input variables like temperature, precipitation, irrigation or fertilizer application on crop-yield. This agronomic approximation has the advantage of reliability in specific crop models, since it is based on controlled experiments, through which it is possible to predict outcomes in hypothetical conditions that have not yet occurred [see Adams (1989), Easterling *et al*. (1993), Rosenzweig and Parry (1994)]. With our article, we aim to help on ascertaining the possible climatic change effects on Spanish agriculture quantifying the impact of climatic, edaphic and socio-economic variables on Spanish farm prices and acreage. The organization of the article is as follows. The following section contains a description of the methodology, the econometric model and the data sets used to estimate the impact of climate change. The model is estimated in section three and the impact of climatic and non-climatic variables on Spanish agriculture is analyzed in this section. In section fourth we discuss the limitations of our results and compare them with other models. The article ends with a series of conclusions from our estimations.

2. Variables, data and the econometric approach

2.1. *The dependent variables*

We choose land price as the dependent variable. This variable may capture the long-term effects of climate and it is the best available representative for land value.

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[4] In a previous work, we have applied the Ricardian approach to estimate the effects of climate change on the agriculture in Castilla-La Mancha, a region of Spain, García and Viladrich-Grau (2009). Beyond the differences in the object of study –the Castilla La Mancha region versus the whole country of Spain– there are other methodological differences that are worth noting between the two works. In that case, we did not incorporate the recent contributions by Schlenker *et al*. (2005 and 2006), and Deschênes and Greenstone (2007) into our analysis, either with respect to the estimation technique or with respect to the definition of explanatory variables. Instead, we followed the methodology used in the seminal paper by (see Mendelsohn *et al*., 1994).

It is extremely difficult, however, to obtain data relating to the real sale price of a farm in Spain, mainly because of the infrequency of this type of transaction[5]. The variable that we will use to capture farm value, *i.e.* P_{it} corresponds to the average price of a hectare of farmland in province *i* during year *t*. In particular, for land prices, we used the results of the annual survey on agricultural land prices, which has been designed and coordinated since 1983 by the *Ministerio de Medio Ambiente, Medio Rural y Marino* (henceforth MARM) and conducted by the autonomous communities. Using this survey, average weighted prices per hectare for each province in each year can be calculated. This is based on the prices declared by the agents surveyed in each province[6]. The variable that represents farmland value, *i.e.* P_{it}, corresponds, therefore to the average price of a hectare of farmland in province *i* during year *t*. This price is obtained from the sum of the various land type prices in a given province weighted by the number of hectares of each type. That is, $P_{it} = \frac{\sum_{j=1}^{J} P_{jit} HA_{jit}}{HA_i}$ where P_{jit} is the price of land devoted to crop *j* in province *i* during year *t* and HA_{jit} is the number of hectares allocated to crop *j* in province *i* during year *t*.

Furthermore, an increase in this average price per hectare is just as likely to be associated with an increase as with a decrease in the number of hectares under cultivation. If climate change increases agricultural output and enables fallow land to be used for cultivation purposes, it will probably bring about an increase not only in price per hectare but also in the number of hectares being cultivated, and as a result, the average price would increase. However, an increase in the average price per hectare might also be due to a reduction in the number of hectares being cultivated, for example, if the least productive plots are the first to be left uncultivated. Therefore, to assess the impact of climate change in agricultural land value, we need to distinguish between these situations. Similar difficulties can be found in the interpretation of a decrease in the average price of a hectare of farm land[7].

Future returns will depend not only on changes in agricultural output prices or variations in crop mix but also on the size of the area under cultivation. In the Ricardian model the total amount of agricultural land farmed L_i is not a variable that can be chosen. Thus, if part of the land belonging to a farm were to turn fallow as a result of climate change, the farm would decrease in value. In our database, however, the land that is not cultivated would no longer intervene in the average price calculation, since it would ce-

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[5] This is the case in most of the Ricardian approach studies since Mendelsohn *et al.* 1994's seminal article. In most of these studies census data have been used as the dependent variable, where land values were obtained from farmer's evaluations, and not from market values. The only exception is Maddison (2000), who in his England and Wales study uses data from real market transactions.

[6] These agents, when assessing land, take into account 20 crop types and various usages (such as rainfed or irrigated cultivation, vineyards, stone fruit, pip fruit, olive groves, etc.). Once a price has been determined for land by usage, a representative price per hectare is calculated based on the percentage of each usage in each province. Sánchez (1986) describes the methodology used to obtain these prices.

[7] This average price could decrease even with an increase in the area under cultivation, if newly incorporated hectares were less productive than existing farm land. On the other hand, a reduction in the price of a hectare could coincide with a decrease in the number of hectares under cultivation if climate change were to severely reduce output.

ase to be farmland. Therefore, to assess the impact of climate change we also need to estimate its effect on the number of hectares of farm land. In order, therefore, to assess the impact of climate change on agricultural return and gauge the likelihood of a significant alteration on the agronomic map of Spain, we estimate two equations representing: i) the price per hectare of land for agricultural purposes in province i during year t, P_{it}, and ii) the number of hectares used for agriculture in province i during year t, HA_{it}.

2.2. *The econometric approach*

We have regionally disaggregated annual data from 47 Spanish provinces for the period 1983-1999[8]. Therefore, and in principle, the characteristics of our data set could suggest that it would be appropriate to estimate the parameters of our regression equations with a fixed effect model (FE). However, agricultural production is strongly related to the local climatic conditions, and the climatic variations have been small during our sample period. Temperature and precipitation are changing but they do so at a slow rate[9]. If we were to use a FE model to control for the location effects, we would also control for the climatic effects. A FE estimation would allow us to control for omitted and unmeasured time-invariant factors. However, if a FE model were estimated, the climatic variables would not be significant due to their small variation over time and their strong relationship with local factors. The Ricardian approach uses the variation in the climate variables across provinces (together with variation over time) to estimate the impact of these climate variables on farmland value. If we were to estimate a FE model we would not be able to identify these impacts[10].

Deschênes and Greenstone (2007) have presented an alternative approach where yearly profits are used as a dependent variable. However, this is a short-term variable and their use of it is controversial. Fisher *et al*. (2007) point out that climate scientists distinguish between climate change and weather change. For them, weather represents the atmospheric conditions that prevail at a particular moment in time and climate represents the long-run pattern of those weather conditions over time. As they are different phenomena, they may have different economic implications. For example, a negative weather shock can give rise to a decrease in harvest that results in an even larger increase in output price, revenue and profits during a short period of time. But these short lived weather shocks are not necessarily reflected in the long run land price or value, neither do they affect the number of hectares of farmland, because they are transitory. However, an adverse climate change could translate into a long-term effect that would lower the productivity of a region, the profitability of farming in that region and, therefore, land prices and the number of hectares devoted to farming. Moreover, we could not apply this approach because there is no agricultural profit data readily available from Spanish farms for the years and at the level of di-

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[8] Lack of data has led to the exclusion of the Autonomous Community of the Canary Islands.

[9] According to the National Oceanic and Atmospheric Administration's (NOAA) 2008 State of the Climate Report: The Earth's surface is currently warming at a rate of about 0.16ºC/decade or 1.6ºC/century. As published in http://www.ncdc.noaa.gov/sotc/index.php?report=global&year=2008&month=ann

[10] We estimate several fixed effect regression equations, and in most cases the climatic variables lost significance. The result of these estimations can be obtained from the authors.

saggregation that we need[11]. Further, if we were to use profit data we would encounter a measurement error in the sense that a year's revenues do not necessarily reflect the value of that year's production, at least in the case of storable crops, such as cereals[12]. Farmers and farmer's associations tend to store their production when the prices are low and increase sales when these are high. Therefore, yearly revenues do no necessarily reflect the value of that year's crop, at least in the case of storable crops. Therefore, and for these reasons, we keep using land price as a dependent variable and propose another strategy that we believe to be better suited to capturing local climatic conditions in our data set. We followed the convention in the Ricardian literature and estimated the climatic variables with linear and quadratic terms, but in addition, we introduced a new set of variables into our regression equations: the long term averages –or climate normals of our sample period that we present below.

The Ricardian approach uses temperature and precipitation as the main explanatory variables. However, we –following Schlenker *et al.* (2006), Deschênes and Greenstone (2007) and a broad body of agronomic literature– have included degree-days (DD_{it}) instead of temperature as an independent variable in our estimated regression equations. Plant growth depends on cumulative exposure to heat during the growing season and the variable degree-days measures the intensity of this exposure. Degree-days are the sum of the degrees of heat received by a plant during its growing season. Therefore, in addition to the linear and quadratic terms (e.g., DD_{it} and DD_{it}^2), we included in our regressions the long term average of degree-days ADD_i. We did the same for the variable precipitation, PR_i. These climate normals are calculated for each province over the 17 sample years, that is, $ADD_i = \sum_{t=1}^{17} DD_{it}/17$ for degree-days, and a similar calculation for precipitation (*i.e.*) $APR_i = \sum_{t=1}^{17} PR_{it}/17$ where i represents province, and t year and they capture the climatic characteristic of each province. They can be interpreted as representing the average or normal climate of each province. Their estimated parameters will represent the weight on land price of these persistent climatic characteristics. Additionally, we decided to use the log-transformation of the dependent variable, since, econometrically, this was the model that provided the best fit[13]. Therefore we represent the land price regression equation as:

$$\ln P_{it} = \beta_0^p + \beta^p ADD_i + \delta^p DD_{it} + \gamma^p DD_{it}^2 + \lambda^p APR_i + \phi^p PR_{it} + \eta^p PR_{it}^2 + \sum_{n=1}^{N} \varphi_n^p RV_{itn} + \mu_{it}^p \quad [1]$$

where RV_{itn} represent the vector of the n non-climatic independent variables such as income per capita and density among others. That is, RV_{itn} represents the value of a variable n (for example, density) in province i during year t. A detailed description of

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[11] We could have attempted to estimate the revenue side by multiplying the amount of each crop produced by its price. However, the *Encuesta sobre superficies y rendimientos de cultivos* does not include data from all provinces until the year 2000. Further we did not encounter cost data at the same disaggregation level.

[12] The output price *precio percibido* is defined by the MARM as the market price paid to the producer when the crops are sold.

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

these variables is given in Table 1 (Annex). μ_{it} represents the error term. This specification of the linear climatic variables captures the effect of climatic deviations around the sample mean. Likewise, we estimate the effect of climate change on the number of hectares of farm land. That is,

$$\ln HA_{it} = \beta_0^h + \beta^h ADD_i + \delta^h DD_{it} + \gamma^h DD_{it}^2 + \lambda^h APR_i + \phi^h PR_{it} + \eta^h PR_{it}^2 + \sum_{n=1}^{N} \varphi_n^h RV_{itn} + \mu_{it}^h \quad [2]$$

where HA_{it} represents the number of hectares used for agriculture in province *i* during year *t*.

Furthermore, we distinguish between irrigated and rainfed land[14]. A hectare of land is considered to be irrigated if it receives artificial irrigation at least once in the agricultural year. We therefore estimate two distinct models, one for rainfed agriculture and another for irrigated, after first assessing the need to do so. We performed a structural change tests and in all cases we could reject the null. The F-test were, for the price 214.73, and for the acreage 270.97. The provincial average values of rainfed and irrigated farmland are presented in Table 2. 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. In Spain more than 50% of the total value of final agricultural production is irrigation dependent, while occupying only 13% of the total area under cultivation (see *Ministerio de Agricultura*, *Pesca y Alimentación*, MAPA, 2000). Irrigation therefore has a decisive impact on agricultural return. In our country, the price of rainfed land is significantly lower than that of irrigated land (see Table 2). Therefore, we will estimate regression equations 1 and 2 for rainfed and irrigated land.

TABLE 2

Provincial average land prices per hectare and number of hectares of farmland

Province	Price Rainfed	Price irrigated	Ha. Rainfed	Ha. Irrigated
Coruña	13,961.01	13,228.89	231,219	13,295
Lugo	10,503.21	16,592.59	305,521	9,438
Orense	9,758.21	16,233.53	126,699	19,574
Pontevedra	18,734.89	32,264.59	119,049	15,795
Asturias	9,395.14	–	327,833	–
Cantabria	8,540.48	–	168,132	–
Guipúzcoa	13,126.25	–	52,052	–
Vizcaya	9,746.36	–	59,278	–
Álava	6,963.02	–	121,783	–
Navarra	5,156.48	12,673.37	528,706	87,243
La Rioja	8,170.24	12,707.11	227,449	44,328
Huesca	1,344.27	5,114.74	530,949	208,593
Teruel	1,188.29	9,389.04	805,605	37,975
Zaragoza	1,708.16	11,343.50	710,044	197,024

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[14] The need to estimate different models for rainfed and irrigated farmland was an early subject of discussion. The initial steps of this controversy can be found in Cline (1996), Darwin (1999), Quiggin and Horowitz (1999), and Mendelsohn and Nordhaus (1996 and 1999a and b).

TABLE 2 *(cont.)*

Province	Price Rainfed	Price irrigated	Ha. Rainfed	Ha. Irrigated
Barcelona	7,677.89	51,363.78	174,059	14,571
Gerona	4,694.52	9,905.49	125,026	34,651
Lérida	1,638.50	11,782.69	404,012	149,699
Tarragona	6,148.05	16,247.67	213,040	70,364
Baleares	10,923.40	18,344.64	172,41	20,788
Ávila	2,165.86	4,152.60	400,070	44,934
Burgos	4,284.54	9,810.26	744,322	28,532
León	1,655.20	7,463.62	482,557	166,815
Salamanca	3,207.80	10,030.03	733,175	45,530
Segovia	2,466.16	5,018.06	396,481	24,896
Soria	2,35420	–	453,487	–
Valladolid	3,943.43	7,673.61	536,009	94,472
Zamora	2,219.40	5,857.72	585,927	75,225
Madrid	3,503.10	8,772.46	336,663	32,274
Albacete	3,898.77	11,505.29	842,027	137,926
Ciudad Real	2,585.82	7,539.31	1,149,039	178,588
Cuenca	5,054.28	18,408.21	845,803	34,829
Guadalajara	1,486.98	7,325.64	396,054	20,547
Toledo	5,325.12	6,324.47	1,031,798	98,992
Valencia	11,129.38	38,957.91	196,729	171,536
Castellón	1,649.00	32,228.71	145,547	59,381
Alicante	4,220.71	23,026.19	145,182	134,390
Murcia	2,493.36	15,792.90	431,804	190,689
Badajoz	2,545.86	6,902.56	1,229,750	128,935
Cáceres	1,946.10	7,351.62	804,618	83,263
Almería	2,653.36	63,996.09	275,830	95,950
Huelva	3,949.23	–	264,864	–
Málaga	10,639.24	18,533.24	293,268	51,916
Cádiz	6,377.25	16,958.87	368,128	63,840
Córdoba	11,360.75	16,919.19	759,249	102,866
Granada	4,778.76	27,244.95	640,922	119,214
Jaén	11,897.23	16,092.86	678,622	159,968
Sevilla	9,270.45	20,414.62	771,316	257,081

Prices per hectare in euros, year 1999. Hectares in thousands.
The prices for Alava, Guipúzcoa and Vizcaya correspond to the year 1998.
There is no data on irrigated land prices during the sample years for Asturias, Cantabria, Guipúzcoa, Vizcaya, Álava, Soria and Huelva. It does not report prices for provinces that the surface allocated to reference crops represent less than the 5 per 1000 of the total Spanish surface.
Source: Own elaboration.

2.3. *The climatic variables*

The data on climate were taken from the National Institute of Statistics (*Instituto Nacional de Estadística, INE*) Yearbook for each of the years included in the study period. The available information includes monthly data on temperatures and rainfall. Using the provincial data at our disposal, we have assigned each province the climatic data recorded at its main weather station. Weather data measured in the province's main weather station may not be the best representative of weather in agricultural areas. However, we had to choose a selection criterion, and to estimate the parameters of our model we chose the weather data measured in the main provincial weather station because most provinces only have one meteorological station. The degree-days required for full development differ among crops Agronomists postulate that plant growth has a linear relationship with temperature, but only between a lower and an upper threshold. Temperature must be above the lower threshold for plants to absorb heat; plants hardly grow if the temperature remains below this threshold. Further, plants cannot absorb extra heat when temperature is above the upper threshold, and hence there is a plateau above which additional degrees do not result in further growth. If temperature increases far beyond the upper threshold crops would be damaged. Therefore, they define degree-days as the sum of centigrade degrees of heat received by a plant between these two thresholds during its growing season[15]. Different crops may also have different growing seasons. Cauliflower in Navarra has a growing season that ranges from late Spring to late Fall. In Murcia, lettuce is the most extended irrigated crop with a year-long growing season. In most of Spain, almond trees flower in February and their fruits are collected in September and olive trees flower in spring and mature in December. There is a great variety of cereals with long and short growing periods[16]. Hence there could be as many different definitions of growing seasons, and of degree-days, as crops.

We present the estimated results associated with two of these definitions. First, we chose a full year growing season. A wide variety of crops are cultivated in most Spanish provinces and therefore choosing a year-long growing season allows us to capture the climatic characteristics that affect all of them. Second, we choose the growing season to be between the months of April and September (both included). This is the growing season of most fruits and vegetables, and it includes the spring months that are the most crucial for the development of most crops. In both cases we define the lower and upper bound to be 8° C and 32° C, respectively. These thresholds encompass most of the crops cultivated in Spain. In Table 3 we report the growing season's degree-days, actual and predicted. The actual degree-days were calculated from the temperatures collected in our sample. The Table shows the average degree-days across all Spanish provinces using the 17 years of data available. The predicted average degree-days reported in Table 3 were calculated by using the monthly predictions for future temperatures and precipitations provided by the Climate Variability Department of the Spanish Meteorological Agency (*Agencia Estatal de Metereología*, henceforth, AEMAT) between 2000 and 2099. They provided us with a grid of 203 points with associated estimated climate data, temperature and rainfall. This data

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[15] For example, if a crop has a lower threshold of 8ºC and an upper threshold of 32° C, a day with an average temperature below 8° C results in zero degrees and a day with a temperature of 12ºC results in 4 degree-days, that is, 4° C = 12° C – 8° C. Any day with a temperature equal to or above 32° C contributes 24 degrees. The variable degree-days is the sum of degrees contributed by each day over all days during the growing season.

[16] To determine the length of the growing seasons we followed the *Calendario de siembra, recolección y comercialización*, published by MAPA (2002).

TABLE 3
Summary statistics

Sample Statistics

Variables	**Mean**	**Maximum**	**Minimum**	**Std. Dev.**
DD_{it}, annual	2,620.62	4,498.60	1,146.40	811.83
PR_{it}, annual	578.09	2,401.90	64.90	350.89
DD_{it}, Abr-Sep	2,046.86	3,069.80	1,121.60	475.39
Pr_{it}, Abr-Sep	232.65	1,021.40	4.00	152.30
$Hoursun_{it}$	2,493.78	3,223.00	920.00	419.59
IPC_{it}*	10,443.57	14,616.10	7,325.13	1,751.71
$Density_{it}$*	105.95	63273	8.80	141.19
$Subsid_{it}$*	110.34	303.99	17.68	75.11
SQI_{it}	2.91	4.61	1.86	0.78
P_{it}*, rainfed	5,580.02	18,734.89	1,188.29	4,036.59
P_{it}*, irrigated	16,072.62	63,996.10	4,152.59	12,312.61
HA_{it}, rainfed	436,258	1,233,014	44,300	263,509
HA_{it}, irrigated	78,465	276,060	9,438	56,642

AEMET Climatic Variables Predicted Values

Variables	**Mean**	**Maximum**	**Minimum**	**Std. Dev.**
DD_{it}, annual	2,697.00	5,359.40	922.10	905.37
PR_{it}, annual	873.93	3,730.60	149.40	512.66
DD_{it}, Abr-Sep	2,019.00	3,690.10	866.65	539.66
Pr_{it}, Abr-Sep	360.95	1,403.90	48.4	218.16

* These monetary values correspond to the year 1999. The entries in the top panel report the statistics from our sample. The entries in the bottom panel report the statistics of the variables degree-days and precipitations as facilitated by the AEMET for 2000-2099.

Source: Own elaboration.

set corresponds to a regional projection of the HadCM3 GCM. The regional projection followed the methodology developed by *Agencia Estatal de Metereología* (AEMET, 1997). This scenario did not assume any emissions reduction due to technological change or behavioural changes. To calculate our variables we used the climate data corresponding to the point closest to the main weather station used in the estimation. In the case that there were several points equidistant from a main station, we calculate the average. We obtained monthly predictions for the future values of these temperature and rainfall variables for each Spanish province from the year 2001 until 2049[17].

Further, another climatic variable of great importance in determining the productivity of land is precipitation. We have included it in our model (PR_{it}), and we have defined it as total precipitation (in millimetres per square meter) during the corres-

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[17] We had data until 2099, but we did not used. The precision of the projections seems to decrease with time.

ponding growing season. It is measured as the sum of precipitation across the growing season months in the relevant years. In addition to degree-days and precipitation, we included a third climatic variable, hours of sunlight ($Hoursun_{it}$), since variations in the daily cycle affect crop output. However, we only have yearly measurements of this variable. The results of our estimations are presented in Tables 4 and 5. The definition of the climatic variables used to obtain Model *A* estimates consider a year-long definition of growing season. The definition of the variables used to estimate Model *B* consider an April-September growing season.

2.4. *The non-climatic variables*

In addition to the climatic variables, we have classified the independent variables into three groups: i) geographic, ii) socio-economic and iii) edaphic. Table 3 reports summary statistics from our database. The data on geographic-related variables were taken from the INE Yearbook. The geographic variables include $Latitude_i$ and $Longitude_i$[18]. We used a group of four socio-economic variables. First, the yearly income per capita, IPC_{it}[19]. The income level of a region influences consumer preferences and, therefore, 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. 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. We do, however, believe that the higher the income per capita in a province, the greater its investment capacity and the level of technology it will apply to agriculture, and therefore, the larger the agricultural returns. Under both interpretations, therefore, we expect IPC_{it} to have a positive and significant net effect on the value of land.

Demographic pressure and higher demand of land for housing can also play an important role in determining land prices, for this reason we include density among the explanatory variables in our model. In densely populated areas, urbanization is, at least potentially, an alternative or competing use for land resources. On the one hand, we expect greater population density to be linked to a higher demand for agricultural products and services, resulting in higher agricultural land prices. We therefore expect the coefficient of the $Density_{it}$ variable to be positive and significant.

Further, we included two socioeconomic variables related to agricultural subsidies. The first –which we have called $Subsid_{it}$– represents farm subsidies. This variable merits special attention; with it we aim to include only direct farm subsidies, ta-

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[18] These variables do not change over time and therefore we dropped the subscript t.

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

[20] 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 these types of subsidies means that they cannot be predicted by the farmer and included in his profit function. Moreover, indirect subsidies, in the form of fixed prices for agricultural products, are assumed to be included in the profit function.

king into consideration only those that are granted for the use of ordinary production factors[20]. With this variable 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. Secondly, we also included a dummy variable, which we refer to as DS_{it}. The Common Agricultural Policy (CAP) was reformed in 1992; before this reform, the CAP's subsidy policy was based on production subsidies, which proved to be an incentive for excess production. The greater the production, the greater the subsidy volume, with the result that the most productive lands received a greater volume of subsidies. Since the reform, subsidies are no longer linked to production, and instead became based on the so-called "historical yield". These new subsidies are independent of the level of production, and are given even where production falls. Given these two types of effects, we contrast whether the subsidies show a different type of influence before and after the reform of the CAP in 1992 (see Foro Agrario, 2000)[21]. Furthermore, to eliminate the nominal effect of an increase in monetary values, we have deflated all monetary variables using the consumer price index with 1983 as the base year, thus all variables are expressed in constant 1983 euros.

Finally, the edaphic variables were aggregated into a single Soil Quality Index (SQI_i) which depends on the productive capacity of the soil in each province[22]. This index classifies soils into five types[23]. 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 poorest quality soils and 5 for best 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– remains constant over time.

3. Analysis of the results

Next we present the results of our estimations. Our data set has cross sectional observations from 47 Spanish provinces during 17 periods of time. It is a panel data set that we estimate as a seemingly unrelated regression (SUR) system by a robust pooled ordinary least squares estimator. The result of the Wald statistic showed that we

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[21] Our data set does not include data from the latest CAP reform of 2003. If this dataset were available, we could have included another dummy variable to differentiate the effect of this new CAP reform on prices, but we could not.

[22] Many land uses can lead to soil degradation by altering edaphic conditions and thereby soil quality and productivity. However, as far as we are able to ascertain, there were no large changes in soil quality during the sample period, so we consider the SQI_i to remain constant throughout the study period and therefore we dropped the subscript t.

[23] We used the soil quality index constructed by N. Balti and A. Garrido of the Polytechnic University of Madrid in Balti (2001).

had a non-scalar residual covariance matrix. In particular, these results were, 1) $\chi^2 = 1{,}293$ and $\chi^2 = 2{,}573$ and for Model *A* rainfed land price and number of hectares respectively, 2) $\chi^2 = 988$ and $\chi^2 = 1{,}491$ for Model *A* irrigated land price and number of hectares respectively, 3) $\chi^2 = 1{,}104$ and $\chi^2 = 1{,}019$ for Model *B* rainfed price and number of hectares, and 4) $\chi^2 = 2{,}748$ and $\chi^2 = 1{,}524$ for Model *B* irrigated price and number of hectares. Our data are provincial averages and therefore prone to heteroskedasticity. To correct for this we premultiply the data with the inverse of the squared root of the number of hectares of agricultural land in each province. Still, we estimated the model as a robust pooled OLS model and used a robust estimation of the variance matrix to perform inference and hypothesis testing. The robust estimator is not efficient, but it gives us a lower bound for efficiency and significance. Following Wooldridge (2006), we chose to continue with this type of estimation to assure the consistency of estimated regression coefficients instead of estimating a specific structure for the residuals[24].

Additionally, our model did not show any symptom of multicollinearity. Most of the climate variables had significant estimated coefficients and these results did not contradict the jointly highly significant levels attained by the F-test and R-squared in the estimated regressions. Moreover, small changes in the data did not produce large swings in the parameters estimates[25]. In Table 4 we present the results of our estimations for rainfed and in Table 5 for irrigated land, respectively. Our estimations explain close to 60% of the variation in most regressions for both irrigated and rainfed land. In all cases, the tests of global significance of the model clearly show the set of selected independent variables to be significant. To study the robustness of our estimations, we have experimented with other definitions of degree-days on addition to the ones used to estimate Tables 4 and 5. For example, we modified our lower bound to be 5° C. However, the estimated results were similar and we chose not to report them. We also change the length of the growing season to be between January and September but, as before, the results were similar. The results of these estimations are available from the authors upon request.

With the Ricardian specification we do not estimate the behavioural equations that represent the farmers optimization process, but only a reduced form model. Therefore, the interpretation of the estimated parameters is not straightforward as we are not modelling the farmer's decision process and we cannot perfectly identify the different effects captured by each parameter. Hence, we will only briefly comment on the most relevant and straight forward results of our estimations. We analyze, first, the effect of non-climatic variables, and next we focus on the analysis of the climatic variables.

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[24] Specifying the structure of the covariance matrix implies that the properties of the estimated coefficients are conditional on the veracity of the chosen covariance matrix structure and therefore, if that specification is not accurate, the estimated regression coefficients could be biased and non-consistent.

[25] Following Novales (2000), we have estimated our models deleting the observations of some provinces from the sample and neither the significance nor the signs of the coefficients change much confirming the absence of multicollinearity. The results of these estimations can be obtained from the authors.

TABLE 4
Estimated rainfed models

Specification	Rainfed Price				Rainfed Hectares			
Model	A		B		A		B	
		P-value		P-value		P-value		P-value
Constant	5.682 (4.781)	0.000	5.731 (4.434)	0.000	13.519 (19.887)	0.000	10.597 (17.659)	0.000
ADD_i	3.36E-04 (2.488)	0.013	6.96E-04 (2.681)	0.007	–1.07E-04 (–1.179)	0.238	–2.87E-04 (–1.655)	0.098
DD_{it}	4.0E-04 (1.747)	0.081	–3.41E-05 (–0.063)	0.949	4.2E-04 (2.229)	0.026	1.16E-04 (0.280)	0.779
DD_{it}^2	–5.9E-08 (–1.599)	0.110	4.09E-08 (0.356)	0.721	–1.17E-07 (–4.146)	0.000	–5.49E-08 (–0.605)	0.545
APR_i	7.74E-04 (4.357)	0.000	1.23E-03 (2.842)	0.004	–1.21E-03 (–8.504)	0.000	–4.0E-03 (–12.082)	0.000
PR_{it}	2.7E-04 (0.787)	0.431	6.03E-04 (0.852)	0.391	6.13E-04 (2.392)	0.017	1.33E-03 (2.223)	0.026
PR_{it}^2	–2.7E-07 (–2.138)	0.032	–9.84E-07 (–1.472)	0.141	–3.0E-07 (–2.569)	0.010	–1.37E-06 (–2.210)	0.027
$Hoursun_{it}$	–5.03E-04 (–4.344)	0.000	–6.21E-04 (–5.372)	0.000	3.25E-04 (4.213)	0.000	2.62E-04 (3.501)	0.000
$Latitude_i$	1.71E-03 (3.790)	0.000	1.67E-03 (3.258)	0.001	–1.2E-04 (–0.438)	0.661	1.73E-03 (7.265)	0.000
$Longitude_i$	1.4E-03 (8.018)	0.000	1.89E-03 (10.502)	0.000	443E-04 (3.010)	0.002	–1.46E-04 (–0.798)	0.424
IPC_{it}	1.58E-06 (4.122)	0.000	1.82E-06 (4.257)	0.000	–181E-06 (–6.737)	0.000	–2.3E-06 (–7.627)	0.000
$Density_{it}$	3.79E-04 (1.990)	0.047	7.18E-04 (3.472)	0.000	–1.03E-03 (–7.091)	0.000	–1.07E-03 (–5.576)	0.000
$Subsid_{it}$	6.71E-05 (2.269)	0.023	5.89E-05 (1.905)	0.057	1.36E-04 (5.131)	0.000	1.48E-04 (5.055)	0.000
DS_{it}	–8.39E-05 (–3.026)	0.002	–8.28E-05 (–2.847)	0.004	–7.41E-05 (–3.723)	0.000	–7.63E-05 (–3.453)	0.000
SQI_{it}	0.1766 (4.746)	0.000	0.214 (5.442)	0.000	–0.0104 (–0.413)	0.679	–0.079 (–2.685)	0.007
R^2		0.645		0.605		0.699		0.667
N		551		551		551		551
Log likelihood		–379.54		–408.68		–276.92		–305.38
Akaike info criterion		1.4321		1.5378		1.0576		1.1608
Schwarz criterion		1.5494		1.6552		1.1749		1.2780

Values in parenthesis are *t-Statistics*.
Source: Own elaboration.

TABLE 5

Estimated irrigated models

Specification	**Irrigated Price**				**Irrigated Hectares**			
Model	**A**		**B**		**A**		**B**	
		P-value		**P-value**		**P-value**		**P-value**
Constant	8.631 (8.112)	0.000	11.309 (11.897)	0.000	–1.604 (–1.367)	0.172	–0.830 (–0.828)	0.408
ADD_i	3.66E-04 (3.127)	0.001	7.01E-04 (3.143)	0.001	6.66E-04 (5.444)	0.000	1.02E-03 (4.821)	0.000
DD_{it}	–5.88E-04 (–2.522)	0.012	–1.68E-03 (–3.642)	0.000	–5.91E-04 (–2.223)	0.026	–2.21E-03 (-4.75)	0.000
DD_{it}^2	1.34E-07 (3.927)	0.000	4.62E-07 (4.797)	0.000	7.38E-08 (1.920)	0.055	5.26E-07 (5.377)	0.000
APR_i	6.49E-04 (3.814)	0.000	2.47E-03 (4.894)	0.000	–1.08E-03 (–5.862)	0.000	–1.45E-03 (–3.633)	0.000
PR_{it}	–6.07E-04 (–2.302)	0.021	–1.19E-03 (–1.778)	0.076	–2.05E-04 (–0.795)	0.426	8.45E-04 (1.352)	0.176
PR_{it}^2	3.19E–07 (2.830)	0.004	1.83E-06 (2.079)	0.038	4.4E-07 (3.362)	0.000	–7.28E-07 (–0.888)	0.374
$Hoursun_{it}$	–2.43E-05 (–0.211)	0.832	2.35E-06 (0.020)	0.984	1.11E-03 (7.016)	0.000	1.08E-03 (6.674)	0.000
$Latitude_i$	2.01E-03 (5.213)	0.000	8.06E-04 (2.235)	0.025	4.47E-03 (10.093)	0.000	4.44E-03 (12.251)	0.000
$Longitude_{i,}$	–8.64E-04 (–4.811)	0.000	–4.22E-04 (–2.310)	0.021	–4.27E-04 (–2.178)	0.029	–4.29E-04 (–2.363)	0.018
IPC_{it}	–5.72E-07 (–1.853)	0.064	–1.94E-07 (0.640)	0.522	–2.41E-06 (–6.751)	0.000	–2.16E-06 (–6.289)	0.000
$Density_{it}$	1.03E-03 (4.942)	0.000	9.89E-04 (4.152)	0.000	–9.2E-04 (–3.953)	0.000	–1.04E-04 (5.018)	0.000
$Subsid_{it}$	2.56E-06 (0.102)	0.918	–1.76E-05 (–0.662)	0.508	7.38E-05 (2.921)	0.003	3.02E-05 (1.230)	0.219
DS_{it}	–4.95E-05 (–2.341)	0.019	–4.25E-05 (–1.905)	0.057	–3.37E-05 (–1.535)	0.125	–7.81E-05 (–0.365)	0.714
SQI_{it}	0.149 (4.260)	0.000	0.162 (4.255)	0.000	0.045 (1.889)	0.059	–3.71E-03 (–0.163)	0.870
R^2		0.662		0.633		0.480		0.511
N		453		453		453		453
Log likelihood		–239.79		–258.73		–339.32		–325.38
Akaike info criterion		1.1249		1.2085		1.5643		1.5028
Schwarz criterion		1.2612		1.3448		1.7006		1.6391

Values in parenthesis are *t-Statistics*.
Source: Own elaboration.

3.1. *The relevance of non-climatic variables*

Latitude shows a positive and significant impact on the price models of both rainfed and irrigated land. This significance suggests that more productive areas are to be found in the north of the Iberian Peninsula. Furthermore, the impact of latitude is also positive and significant in the number of hectares of irrigated land. Latitude is not significant in the rainfed acreage regression equation. Longitude is clearly significant and positive in the rainfed land price equations, which is an unequivocal confirmation of the lower agricultural value of the rainfed lands of the East. For a given latitude, rain is more abundant in the west than in the east, so productivity is higher in the west than in the east and this is reflected in land prices. However, the opposite is true in the case of irrigated agriculture. The longitude coefficient is negative in the regression equations for both price and irrigated acreage. Contrary to the case of rainfed agriculture, as one moves eastward across the Peninsula there is a gradual increase in expected agricultural returns from irrigated lands. The mild climate of the Mediterranean coast allows higher value added crops, such as fruits and vegetables, that are difficult to grow in the more extreme climate areas of the interior and west of the Peninsula.

The income per capita variable, IPC_{it}, is negative and significant, in the HA_{it} regression for rainfed and irrigated land. This indicates that higher income levels may be linked to farm abandonment. It is also significant but positive in the rainfed P_{it} regression equation. In the case of irrigated lands, however, the estimated parameters are not significant. $Density_{it}$ has a positive impact on the price model and a negative impact on the number of hectares model, for both rainfed and irrigated areas. It is also significant in all models. Density increases tend to increase the demand for land for non-agricultural uses. A higher demand for land for non-agricultural uses leads to increases in the selling price of land and to decreases in the number of farmland hectares.

The coefficient of the $Subsid_{it}$ variable is significant and positive in the rainfed price regression, indicating that, prior to the 1992 CAP reform, an increase in subsidies was linked to an increase in land prices. Subsidies were linked to production, the more productive the rainfed lands, the more subsidies they received. By contrast, the coefficient of variable DS_{it} is negative, significant, and higher in absolute value than the coefficient of $Subsid_{it}$ in the price regression equation. The effect of subsidies from 1992 onwards is given by the sum of these two coefficients (6.71E-5) – (8.39E-5) = –(1.68E-5), which turns out to be negative. This result suggests that –in the rainfed regime and after 1992 CAP reform– the highest subsidies were linked to the lowest priced land, even though this effect is very weak. The subsidies that came into force with the 1992 CAP reform were independent of the level of production and given even where production was low. In other words, the plots that benefited most from the 1992 CAP reform were the least productive. The coefficient of the $Subsid_{it}$ variable is positive and significant in the case of the rainfed acreage regression. However, and contrary to the price case, the effect of subsidies from 1992 onwards is positive. That is, an increase in subsidies generates an increase in the area of rainfed land used for agriculture. In other words, subsiding rainfed land prevented land abandonment both before and after the 1992 CAP reform. The coefficient of the $Subsid_{it}$ variable is not significant in the case of the irrigated price regression, but positive and significant in the number of hectares regression equation. Prior to 1992, the subsidy regime was not a relevant factor for price but it was relevant for the number of hectares of irrigated land. The dummy variable DS_{it}, meanwhile, is negative and significant in the price equation, as well as in the case of irrigated land Subsidies which are linked to the less productive areas are usually issued for cereal plots, which give a much lower return than irrigated land used for fruits and vegetables that are not usually subsidized.

The variable used to capture soil quality (SQI_i) behaves according to our expectations, it is significant and positive in the price equations. The better the soil quality, the higher the return and the higher the selling price for both rainfed and irrigated land. This variable has the highest coefficient of influence of all the independent variables associated with price, the coefficients for the latter being 0.17 and 0.15 for rainfed and irrigated land, respectively. Finally, we analyze the effect of the hours of sunlight variable ($Hoursun_{it}$). This is a climate variable, but we included it here as we do not have predictions from the AEMET regarding the value that this variable will take in the future. In the rainfed regressions, an increase in hours of sunlight leads to a decrease in price. In the case of irrigated land, hours of sunlight are not significant in the price regression equation. However, the impact on the number of hectares of irrigated land is significant and positive, suggesting that an increase in hours of sunlight would be positive.

3.2. *The effect of climatic variables*

We now analyze the effect of the climatic variables, rainfall and degree-days, using the results of our estimated model presented in Tables 4 and 5. There are three factors that make the interpretation of these estimated parameters difficult. First, as we have mentioned, we are estimating a reduced form model and therefore each estimated coefficient can summarize the effects of several variables that we cannot identify. Secondly, each of these estimated coefficients considered individually would only reflect partial effects. The weight of each of the climatic variables –degree-days and precipitation– is represented by three estimated coefficients in each regression equation. A single parameter taken individually will not usually have any lasting effect on the productivity of farmland, on its price or on its acreage, and therefore to evaluate the effect of possible climate change we need to evaluate their combined effect. Furthermore, even if all climatic variables changed simultaneously in a given year, the effect on the number of hectares of farm land and its price will be hardly noticeable. In order to be able to ascertain and measure the consequences of a steady change in the climatic variables we have to take into account not only the combined effect of these changes but also their evolution over time.

To quantify these changes, we first used the estimated models presented in Tables 4 and 5 to calculate the future expected value of each of the dependent variables for both rainfed and irrigated lands. From the models we obtained yearly predictions for each province and dependent variable. That is, for each province and for each dependent variable we obtain a series of predicted values from the year 2001 until 2049[26]. Before using these models to obtain predictions for the dependent variables, we contrasted their predictive capacity with the U-Theil statistic. We carried out several contrasts. First, ex-post, we compare the observed value of the dependent variable with our model's predicted value, evaluating the explicative climatic variables at their observed values. Second, ex-ante, we compared the observed values of the dependent variable with our model's predicted values using the estimated climatic data from the AEMET. We present these results in Table 6. We conclude that the estimations are reasonably reliable in all cases.

TABLE 6

Test of predictive capacity

	Rainfed Price		**Rainfed Hectares**		**Irrigated Price**		**Irrigated Hectares**	
Model	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
U (ex-post)	0.0517	0.0532	0.0312	0.0319	0.0407	0.0674	0.0380	0.0850
U (ex-ante)	0.0516	0.0533	0.0464	0.0511	0.0559	0.0852	0.051	0.102
n	46	46	46	46	39	39	39	39

Source: Own elaboration.

To obtain our predictions, we evaluated the degree-days and rainfall variables in our models at the corresponding values provided by the AEMET. We obtained monthly predictions for the future values of these temperature and rainfall variables for each Spanish province from the year 2001 until 2049. On the other hand, we substituted the non-climatic explanatory variables with their sample mean values. This is a drawback, as the validity of the predictions of our model would be limited when changes in economic structure occur, but we do not have predictions for the future values of these variables and we assume they are constant throughout the chosen period. Evaluating the non-climatic variables at the same value for the entire prediction period allows us to capture the changes in the dependent variables due only to climate factors. Furthermore, with the aim of reducing the variability of these series, we substituted each predicted value with its 10 year moving average

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[26] Recall that in all of the estimations carried out we have transformed the dependent variables logarithmically, and therefore in order to obtain the predicted value of the original variable, and not its logarithmic transformation, we must calculate the following transformation:

$$\hat{P}_{i,t+l} = \exp\left\{\ln \hat{P}_{i,t+l} + \frac{1}{2} Var\left[e_t(l)\right]\right\}$$

where, $\hat{P}_{i,t+l}$ represents the predicted value corresponding to the variable land price per hectare for province i in period $t+l$; $\hat{P}_{i,t+l}$ represents the value of the dependent variable obtained in our estimation, and $e_t(l)$ is the prediction error for the l periods after the sample period t.

value[27]. In this way, we avoid the excessive influence of possible extreme values that could distort the general trend of the variable. These predicted series reflect the evolution over time of each dependent variable for each province from the year 2001 until 2049. We present the results of our predictions in Figure 1 and 2. In particular, in Figure 1 we present the projected evolution of price and acreage of rainfed farmland obtained from models *A* and *B* of Table 4. The maps in the upper half of Figure 1 convey the results obtained using the estimated model *A*, the first row corresponds to the evolution of the price and the second to acreage for the years 2010, 2020, 2030, 2040 and 2050, respectively. In the lower half we present the predictions for rainfed price and acreage obtained using the estimated Model *B* and, as in the case of Model *A*, the first row corresponds to the evolution of the price and the second to acreage. We have coloured each Spanish province according to the degree of variation in the corresponding dependent variable with respect to its reference value. We took the 2006 moving average of each variable as the reference value. We coloured the increases in shades of red and the decreases in shades of blue. The more intense the colour, the larger the variation. We repeated the process for irrigated lands in Figure 2.

Rainfed land

The maps portrayed in the first row of Figure 1 show that the price for rainfed farmland tends to increase throughout Spain during the considered period. In particular, in the case of model *A*, this upward trend is generalized with the only exception being Almeria and Pontevedra for 2010. In the long run, prices for rainfed farmland rise with more intensity in the center and southwest of Spain, in particular, with increases that in some areas reach the 25%. The maps in the second row of Figure 1 show that rainfed acreage decreases in most of Spain. The changes in weather patterns may make rainfed agriculture more vulnerable and less viable, reducing its already low productivity. This reduction in productivity, instead of leading to a decrease in land prices, leads, in the case of Spain to a decrease in rainfed acreage, and therefore the increase in land prices can be due to the abandonment of less productive land. This analysis holds for all regions, with differences in intensity.

On the other hand, the predicted patterns obtained from model *B* are similar to the patterns from model *A*. The price for rainfed land shows an upward trend and the acreage shows a downward trend throughout Spain during the period considered. However, there are some differences. For example, for the year 2010 model *B* forecasts a decrease in the rainfed land price on the Mediterranean coast and the Duero river valley that model *A* does not, although by the year 2020 model *B* has already returned to the increasing trend. Furthermore, the rainfed price increases predicted by model *B* are slightly smaller than those predicted by model *A*.

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[27] In particular, we substituted the predicted values for province i and year $t+l$ with the result of the expression: $\hat{P}_{i,t} = \sum_{l-5}^{l+5} \hat{P}_{i,t+l} / 11$.

FIGURE 1

Evolution of rainfed farmland price and acreage, 2010-2050

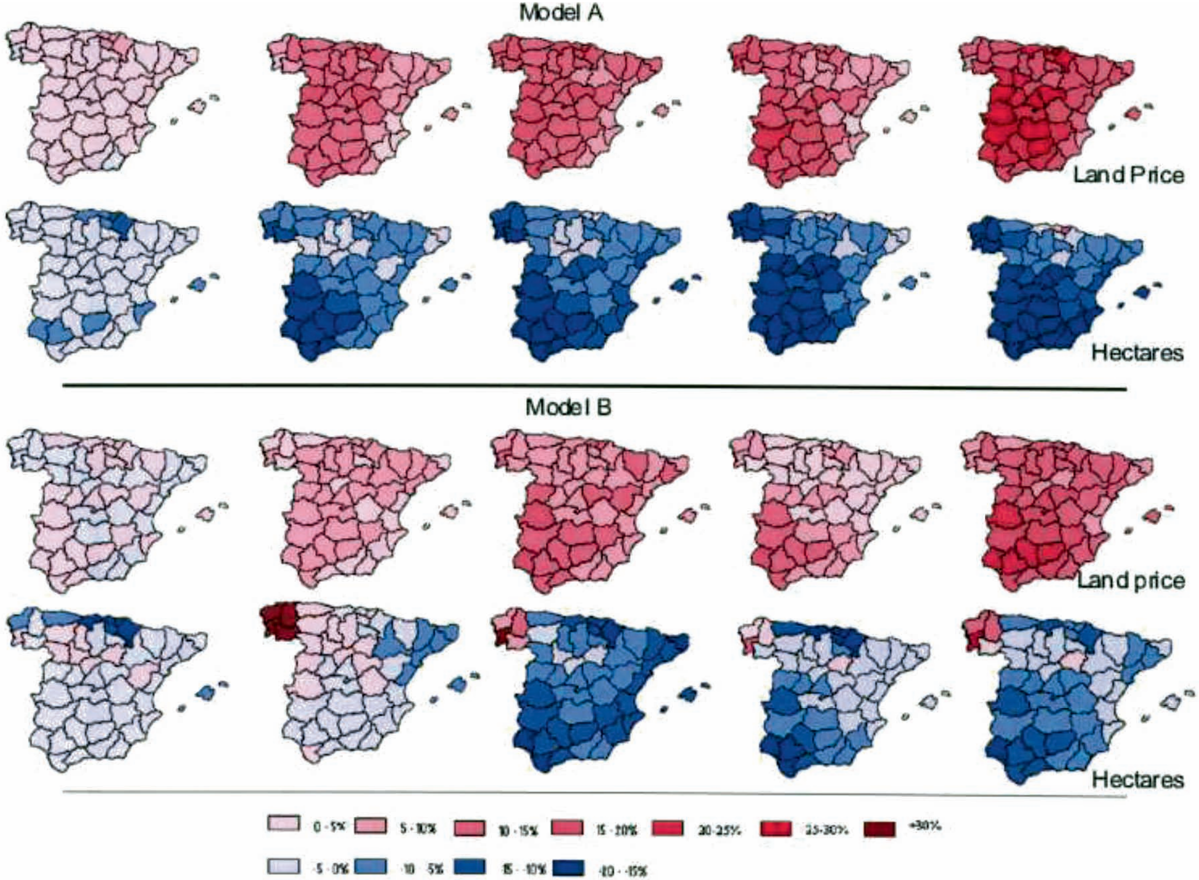
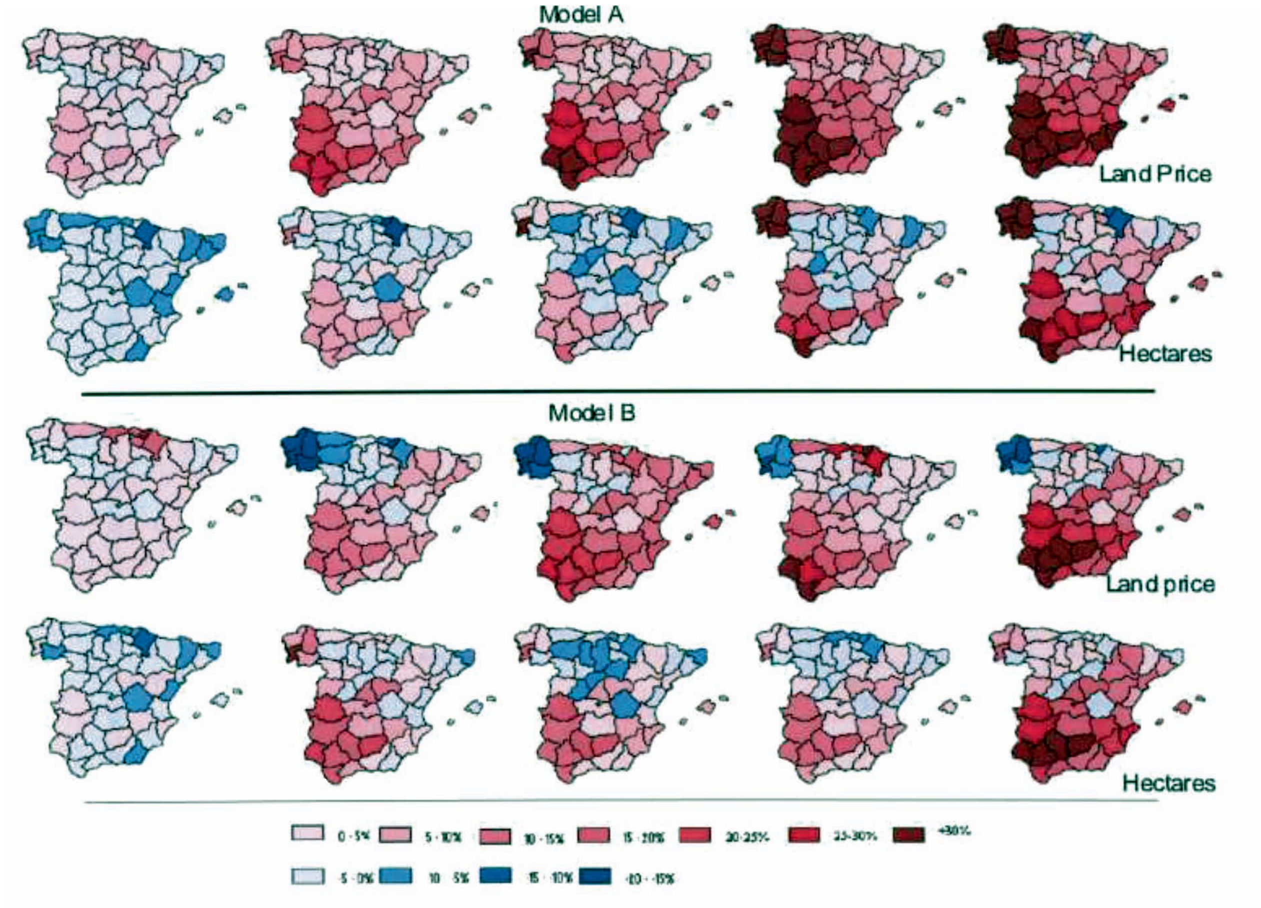


FIGURE 2

Evolution of irrigated farmland price and acreage, 2010-2050



In both models the rainfed acreage diminishes. In fact, the evolution of acreage is similar with the exception of the north-western region of Galicia[28]. Both models also coincide in showing that rainfed acreage will decrease at a significantly slower rate in the northern half than in the southern half of the Peninsula, revealing that the acreage in the north will be less affected by climate change. As in the case of rainfed prices, the major difference between the evolution of the acreage predicted by model *A* and that predicted by model *B* is not so much the pattern but the rate of change being larger in model *A*.

Irrigated land

Model *A* predicts a clear and sustained upward trend in the price of irrigated land from 2010 onwards, as can be seen in Figure 2. Only some provinces show a slight decrease in irrigated land prices for the year 2010 and they are colored in light blue indicating that the decrease in the prices of irrigated land would be of limited size. In particular, in all these cases the price reductions represent a less than 1% change. As we move south, land price increases become more pronounced, reaching their highest values in the Southwest by 2050. Irrigated land and warm temperatures can produce crops that provide great added value. Even though prices on the Mediterranean coast for irrigated land are extremely high already, they will keep increasing, but at a lower rate than in the Southwest. The increases in irrigated land prices are lower in the north of the Peninsula through out all the studied period. Model *B* also predicts a general increasing tendency of the irrigated land price. However, as in the case of model *A*, there are a few exceptions, and most of these coincide in both models. In particular, there are only three provinces where land price decreases in model *B* but not in model *A*, Pontevedra, León and Toledo. The colouring of these provinces indicates that the reduction in the price of irrigated land is very small. Also, as we commented earlier, the evolution of irrigated land prices in Galicia is clearly different between the two models. By the end of the studied period, both models predict a generalized increased in the price of irrigated land in Spain, but that this increase would be more limited in the North. In fact, model *B* predicts that the price of irrigated land is expected to decrease in a few provinces mainly located in the Northern Meseta. However, the percentage reductions in these prices are very small.

Contrary to the predictions for rainfed acreage –where a reduction was a clear conclusion for the whole period– the evolution of the irrigation acreage is less conclusive. Both models predict that the number of irrigated hectares would decrease in most of the country, that this tendency would prevail until 2030, and that after this date irrigated acreage would recover. The number of irrigated hectares (3,664,920) in Spain is much smaller than the number of rainfed hectares (21,400,751), therefore the same percentage change results in a smaller variation in terms of the actual change in

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[28] Galicia is the only region where the predictions clearly differ between the two models. Recall that the only difference between model *A* and model *B* is the definition of the growing season. This suggests that the definition of the climatic variables is more crucial for forecasting the consequences of climate change in this region than in the rest of the country.

the number of hectares. By the end of the period, irrigated farmland tends to increase in most of the Peninsula. There are a few exceptions, however, mostly located in the north, where irrigated acreage would slightly decreases. These reductions in most cases are very small.

In panels *a* and *b* of Figure 3 we present the evolution of the average Spanish price predicted by our model. A price is predicted separately for each province, year and model. Then, for each year and model, we calculate the weighted mean of these provincial prices to obtain the national average. We use as weights the participation share of each province's farmland acreage in the total national acreage, as predicted by our acreage models in the corresponding years. We calculate these weights separately for rainfed and irrigated land.

The average rainfed land price for our 1983 sample was 1,773 euro/ha, and the predicted average rainfed land prices for 2010 are 1,687 euro/ha and 1,662 euro/ha (evaluated in constant 1983 euro) for models *A* and *B*, respectively. These prices are equivalent to 5,112 euro/ha and 5,036 euro/ha, respectively, in 2007 prices. The average irrigated land price for our 1983 sample was 6,112 euro/ha. The predicted 2010 average irrigated land prices are 5,798 euro/ha and 6,470 euro/ha (evaluated in constant 1983 euro) for models *A* and *B*, respectively. These prices amount to 18,275 euro/ha and 20,391 euro/ha, respectively, in terms of 2007 prices. Therefore, in real terms, land prices have changed little since 1983, even though in monetary terms they have increased almost 200%. These results confirm the general expected pattern of land price increases for both, rainfed and irrigated land. In panel *c* of Figure 3 we show the expected evolution of farmland acreage. This is the total acreage calculated adding up across all provinces the acreage predicted by our models the corresponding year. We can see in both cases, the already commented decrease in the rainfed acreage and the increase in the number of irrigated hectares.

4. Discussion of our results

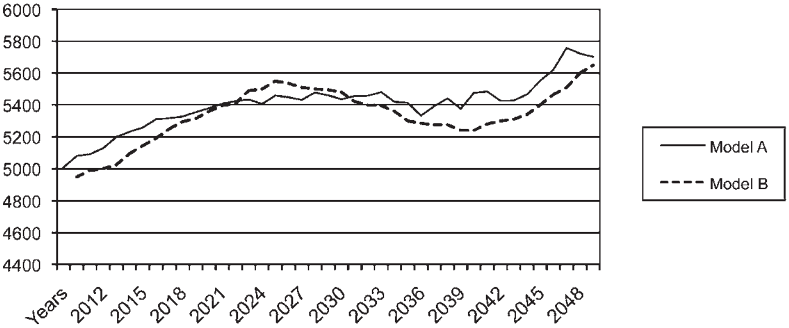
In any prospective work results should be interpreted with care, but this caution should be applied particularly with regard to the impacts of climate change on agriculture, as these are subject to many unknowns. The effects of climate change on crop yields are subject to high uncertainties due to complex interactions between natural and economic factors, technical progress, and policy measures. In this section, first, we comment on the uncertainties present in our model; second, we compare our results with those obtained by other studies; and finally, we discuss some of the caveats remaining in our work.

4.1. *Uncertainties*

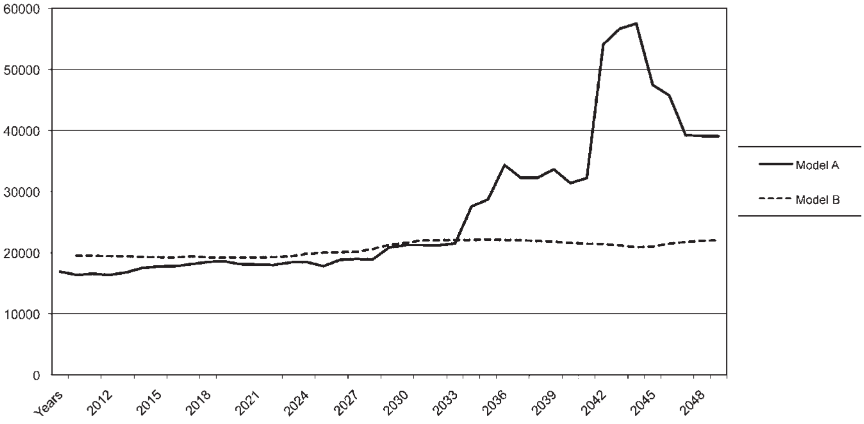
The projections obtained from these circulation models present at least three sources of uncertainty, first, the associated with, the general circulation model used; second, the related to the regional downscaling process applied and third, the linked to the emission scenario chosen. As we said before we are using data from a regional

FIGURE 3

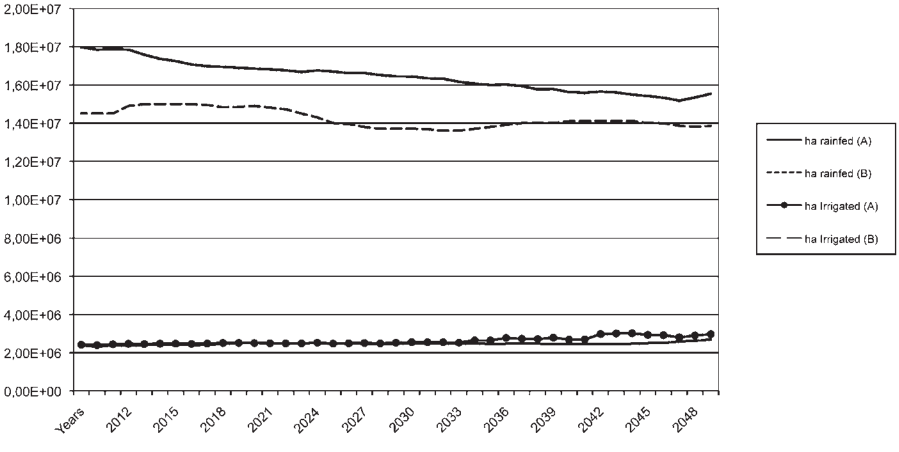
Evolution of the dependent variables



Panel a: Expected evolution of the Spanish average rainfed price.



Panel b: Expected evolution of the Spanish average irrigated price.



Panel c: Expected evolution of Spanish acreage

Source: Author's own elaboration.

projection of the HadCM3 GCM. Any projection error that affects the climate variables will affect our predictions. There are still significant gaps in scientific knowledge with regard to both, the working of natural systems and the possible social responses (IPCC, 2007). Climate models differ in measuring the strength of the different feedback effects in the climate system such as cloud and carbon cycle feedbacks. There are also differences in ascertaining the oceanic heat up take, or in measuring changes in the ice sheet maps. Any variation in these natural phenomena could generate variations in the climate change projections. Furthermore, there is also a lot of variability due to the regionalization model and to the scenario chosen (see AEMET, 2009). The relationship between global and regional climate variables does not need to be stable if climate changes and therefore the quality of the regional predictions could be affected. The change in soil use adds another source of uncertainty for the local projection. Likewise, projections are also scenario dependent, the studies differ in ascertaining the evolution and the consequences of the interaction of the socio-economic variables. Estimation of the consequences of climate change depends on assumptions about economic growth; technological change and its implementation; the diffusion, performance and cost reduction of the new technology; and also in consumption patters and changes in lifestyles and in behaviour. Therefore, the adaptive capacity of society to these biological and economic changes and how this adaptive process is implemented are important issues for determining the final effect on climate.

Nevertheless, the IPCC (2007) report, also presents a long list of robust findings on which most prospective models agree. There is a consensus, for example, in that the on going process of climate change would cause further temperature increases, with inland areas warming more than oceans; in that the sea level would rise; and in that the frequency and the intensity of some extreme weather events will increase. Additionally, robust findings show that ecosystems like the Mediterranean would become very vulnerable and that Southern Europe is expected to become more exposed to climate change with increase temperatures, more frequent drought episodes and a reduction on water availability. Regardless of these robust findings our projection cannot be isolated from the consequences of uncertainty and our results should be interpreted only as one of the possible outcomes resulting from the process of climate change.

4.2. *Comparison of our results*

Our results show that rainfed acreage diminishes but land prices increase. Further, our models show that the south of Spain is expected to be more negatively affected by a reduction in rainfed acreage than the north. However, on the other hand, the evolution of rainfed land prices indicates that increases will be largest in the southwest of the Peninsula. As we have commented before, the likely reduction in rainfed crop productivity, due to the consequences of climate change, seems to lead to an abandonment of less productive land rather than a decrease in land prices. Average prices may rise because only the more valuable land would remain productive. To measure the reliability of our results we compare them to the ones obtained by other methodologies. The reduction in rainfed crop productivity is also suggested by other models. The results obtained from the application of the production function methodology to Spanish crops seem to coincide on this point. In particular, Iglesias and Mínguez (1997) and Iglesias *et al.* (2000), using the CERES crop simulation model for seven representative Spanish sites[29], obtained corn and wheat yield functions for each of these sites and analyzed the impact of climate change on these cereals. They show that the greatest negative effects on wheat yields are seen in southern regions, while the regions in the center of Spain do not experience great yield changes. Additionally, the European Environmental Agency (EEA, 2004) suggests that wheat yields could decrease as much as 3 t/ha in southern Spain, the critical factor being the uncertainty of precipitation. All models seem to agree that the magnitude of these effects is uncertain and that they are scenario dependent. However, all models indicate that the north of Spain would be better off than the south for these crops.

Another critical issue depends on the availability of water. Our results indicate that irrigated agriculture is less vulnerable to climate change than rainfed agriculture. However, although the dominant pattern is clearly increasing for both irrigated land prices and acreage, this result should not lead us to envisage large areas of irrigated land providing a buffer against the consequences of changing climatic conditions, because the conversion of rainfed farmland to irrigation would only be viable if there were sustained water availability. Our results suggest that the availability of water will be crucial for farming and would help to reduce the abandonment of farmland. Unfortunately, most studies agree that the frequency of water shortages will increase in southern Europe, mainly in spring and summer months, increasing the need for irrigation (see Iglesias and Medina, 2009; EEA, 2004; IPCC, 2007). In particular, the IPCC (2007) concludes that the frequency of dry spells, which are likely to reduce the yield of some crops, would increase in southern Europe. For irrigated crops such as corn, Iglesias and Mínguez (1997) affirm that the problems related to water availability may force this crop out of production in some regions. Iglesias *et al.* (2000) predict that the need for irrigation will increase in all regions. Moreover, Iglesias and Quiroga (2007b), using a computable general equilibrium model for European agriculture, conclude that the competition for the use of water would play a vital role in future agricultural decisions in all Mediterranean countries. Therefore, the conclusion that the availability of water will be crucial for farming emerges from all studies.

The agronomic approach uses crop simulation models to predict yield variations due to climate change (see Adams, 1989; Easterling *et al.*, 1993; Rosenzweig and Parry, 1994). The latter relies on experimental production functions to estimate the impacts of variations in temperature, precipitation or fertilizer application on the yields of specific crops. It has been applied principally to two Spanish crops: corn and wheat. This methodology allows precisely calculating crop returns under several conditions. Iglesias and Quiroga (2007a) estimate the risk of climatic variability on

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[29] CERES stands for Crop Environment Resource Synthesis and is a simulation model that describes the development and growth of crops in response to environmental and managerial factors.

wheat production using this methodology and evaluate the probability of low yields as a consequence of climatic changes. They show that rainfed yields are likely to be negatively affected by climate change. These types of specific predictions about the evolution of some type of harvest are difficult to translate into the terms of our model. The Ricardian approach cannot capture the consequences of a single crop yield reduction on land prices and acreage, as it assumes that farmers would adapt to climate change by switching crops if actual crop yields are reduced. However, the general pattern of adaptations that stems from our work shows decreasing acreage, suggesting a reduction in crop yields and that the adaptation process may require abandonment of less productive lands.

4.3. *The results of other Ricardian models*

From a different perspective, the Ricardian approach has been applied to a wide range of countries, as mentioned in the introduction. The studied countries, Canada, the United States, England and Wales, India, Brazil and China, among others, are extremely different with regard to both climatic and socio-economic characteristics, and therefore the conclusions of these studies are not homogeneous. Most of these studies use temperature and rainfall as climatic explanatory variables, as did the seminal article by Mendelsohn *et al*. (1994). However, they differ in the set of non-climatic explanatory variables and the units of analysis used, which mainly depend on the type of political administrative unit in each country. Furthermore, not all countries are equally vulnerable to climate change and therefore the conclusions that emerge from these studies are very different. However, one point on which all these studies coincide is that the losses produced by climate change are less devastating than the conclusions reached using other methodologies. The Ricardian approach assumes that farmers will adapt to conditions affecting their productive activity, including climatic factors, and therefore the amount of losses would be smaller. In general, these studies show that the hotter, drier and less developed a country is, the more vulnerable it seems to be to climate change. In the case of Canada, climate change is expected to bring an improvement for the agricultural sector (see Weber and Hauer, 2003 and Reinsborough, 2003). Dinar *et al*. (1998) conclude that the effect of climate change can present significant regional variations in India, where some eastern districts can benefit slightly while most others suffer. Similarly, rainfed farmland seems to be more vulnerable than irrigated agriculture. Further, it seems that where water is available, moving from rainfed to irrigated agriculture not only increases net returns but also the resilience of agriculture to climate change.

4.4. *Additional caveats*

There are several additional caveats that apply to our analysis, along with much of the rest of this literature. First, some climatic models predict changes in extreme events that would represent an increase in climate variability. If this were the case, neither our approach nor that of others, such as Deschênes and Greenstone (2007), could inform us about the consequences of such changes. The costs and welfare effects of such extreme climate events would have to be added to our predictions. Second, our estimates rely on the set of existing relative prices for both agricultural inputs and outputs. If global changes were to imply a relative change in these commodity prices, it would be difficult for our model to capture these effects. The same could be said about agricultural subsidy programs. If there were large variations our model would be unable to fully capture the consequences of these changes. Third, 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 would also have major implications with respect to the demand for water, since irrigation infrastructure requires a substantial investment, which will only be made if there is a reasonable return on water used for irrigation. And fourth, higher concentrations of CO_2 are known to increase the fertility of crops. Our model does not capture the likely increases in yield that would result from such an increase in CO_2 concentration. We believe, however, that this is a necessary first step in approaching the important issue of measuring the economic consequences of climate change and that there is a great deal of room for additional research into the application of this and other methodologies on the evaluation of the consequences of climate change on Spanish agriculture.

5. Conclusions

We have estimated, using the conceptual foundation of the Ricardian approach, the potential impacts of climate change on Spanish farmland prices and acreage through 2050. Accordingly, we have measured the effect of climate on Spanish land using values from a reduced-form hedonic model. We estimated two separate models, one for rainfed and another for irrigated agriculture, as evidence suggests that the economic effects of climate change on rainfed and irrigated farmland differ. We are able to conclude that rainfed farmland prices increase in all of the Peninsula during the evaluated period. This result is accompanied by an important reduction in rainfed acreage under cultivation. There is some heterogeneity in the predicted impact across provinces. The south of Spain is expected to suffer from a larger loss in rainfed farmland acreage than the north. On the other hand, the evolution of prices establishes that the increases will be largest in the southwest of the Peninsula. The evolution of irrigated farmland prices and acreage presents some mixed results. Although the dominant pattern is clearly increasing for prices and acreage, in several provinces, in the short run, the irrigated farmland prices and acreage tend to decrease. Our results indicate that rainfed agriculture is more vulnerable to climate change than irrigated agriculture. Despite the limitations of our work that have been commented in the previous section, we believe that this is a necessary first step in measuring the economic consequences of climate change and that there is much room for additional research in the evaluation of the consequences of climate change on Spanish agriculture as more data becomes available.

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Anexo

TABLE 1

Definition of variables

Variable	Definition
P_{it}	Average weighted land price per hectare in province *i* and year *t**.
HA_{it}	Number of hectares of farmland, from Agricultural Statistics Yearbook by MAPA. It includes forest, meadows and pastures in its definition of rainfed farmland. We have excluded the hectares occupied by forest and kept those devoted to meadows and pastures in our definition.
ADD_i	Sample average degree-days in province *i*, degrees Celsius.
DD_{it}	Degree-days in province *i* during the growing season of year *t*.
DD_{it}^2	Degree-days during the growing season, squared.
APR_i	Sample average of accumulated precipitation in province *i* during the growing season, millimetres per square meter.
PR_{it}	Accumulated precipitation in province *i* during the growing season of year *t*, millimetres per square meter.
PR_{it}^2	Accumulated precipitation in province *i* during the growing season of year *t*, squared.
$Hoursun_{it}$	Accumulated hours of sunlight per year.
$Latitude_i$	Latitude measured in degrees and minutes from southernmost point in Spain, Las Palmas de Gran Canaria.
$Longitude_i$	Longitude measured in degrees and minutes from the easternmost point in the Spanish Peninsula, Girona.
IPC_{it}	Annual personal income, estimated by dividing gross household income by the eligible population based on July 1st figures of each year. Both series were taken from "Renta Nacional de España" by *Fundación Banco Bilbao Vizcaya Argentaria* (FBBVA, 1999 and 2001).
$Density_{it}$	Number of people per square kilometre, estimated by dividing population (obtained from the "Renta Nacional de España") by provincial land surface from the INE Statistical Yearbook.
$Subsid_{it}$	Direct farm subsidies in pesetas per hectare, estimated by dividing the total amount paid in subsidies during year *t* by the total number of hectares of agricultural land in the province *i* during that year. Both series were obtained from the Agricultural Statistics Yearbook by MAPA. To find the subsidy figures, we also required the collaboration of the Departments of Agriculture in the various Autonomous Communities.
DS_{it}	Dummy variable: It is given the value 0 for all observations between 1983 and 1991 and the value of the variable $Subsid_{it}$ for the rest of the sample period.
SQI_{it}	Soil Quality Index.

* All observations refer to province *i* and year *t* except for *ADD*, *APR*, *Latitude*, *Longitude* and *SQI* that do not change over time.

Source: Own elaboration.