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# A Ricardian Analysis of the Impact of Climate Change on European Agriculture

Steven Van Passel<sup>1,2</sup>; Emanuele Massetti<sup>2,3</sup> and Robert Mendelsohn<sup>2</sup>

## Abstract

This research estimates the impact of climate on European agriculture using a continental scale Ricardian analysis. Data on climate, soil, geography and regional socio-economic characteristics were matched for 37 612 individual farms across the EU-15. Farmland values across Europe are sensitive to climate. Even with the adaptation captured by the Ricardian technique, farms in Southern Europe are predicted to suffer sizeable losses (8% -13% per degree Celsius) from warming. In contrast, agriculture in the rest of Europe is likely to see only mixed impacts. Increases (decreases) in rain will increase (decrease) average farm values by 3% per centiliter of precipitation. Aggregate impacts by 2100 vary depending on the climate model scenario from a loss of 8% in a mild scenario to a loss of 44% in a harsh scenario.

**Keywords:** Ricardian analysis, climate change, European agriculture, climate change economics

**JEL:** Q54, Q51, Q15

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## **1 Introduction**

There is a large literature that uses crop models to estimate climate change impacts on the yield of major grains in Europe. These studies reveal that both negative and positive impacts are possible (EC, 2009). Iglesias et al. (2012b) and White et al. (2011) review many crop model papers that estimate the impact of climate change on agriculture. In general, the risks are higher in the Mediterranean and Continental regions than in the Alpine and Boreal regions. Iglesias et al. (2012a) confirms that warming causes crop productivity to increase in northern Europe and decrease in southern Europe. However, there are important limitations to these crop models. First, they are focused on major grains and do not cover all crops and so not cover livestock. Second at all, they do not incorporate decisions by farmers to change inputs or outputs as climate changes. That is, they do not capture efficient adaptations that farmers will likely make as climate changes over the century.

Mendelsohn et al. (1994) introduced the Ricardian method to estimate the impact of climate change on agriculture. The Ricardian model does not rely on complex crop-yield models, but rather is a cross-sectional technique that estimates the empirical relationship between land values and climate. Land values are regressed on climate, soil, geographic characteristics and other socio-economic control variables. The method relies on the assumption that agricultural land prices reflect the long-term productivity of land (Ricardo, 1817). One important advantage of this method is that it includes all of the agricultural activities of farms (not just major grains). Another important advantage is that it controls for adaptation. Current land values reflect all the adjustments that farmers currently make to current climate. The technique consequently captures the efficient adaptations that farmers currently make to their local climate. It assumes that future farmers will be as flexible to and aware of local climate as current farmers are.

The Ricardian technique has been demonstrated to be a practical tool for predicting the agricultural consequences of global climate change (Timmins, 2006). But there are limitations to the Ricardian technique. Factors important to farm productivity may vary across space along with climate and these factors should be accounted for (Deschênes and Greenstone, 2007). This study goes to great lengths to control for many explanatory variables such as soils, access to markets (cities and ports), and national policies that may all influence the spatial distribution of land values. Climate must be carefully measured (Fisher et al., 2012). The standard rule by climate is the outcome of 30 years of weather. Variables that do not vary across the sample such as global food prices (Cline, 1996) or carbon dioxide cannot be measured. The absence of price data means that the Ricardian analysis will underestimate the benefit and overestimate the damage from climate change, although the size of the bias is likely to be small (Mendelsohn and Nordhaus, 1996). Rising carbon dioxide levels are expected to increase plant productivity (Kimball, 2007) so including carbon fertilization would likely increase net benefits. The Ricardian model includes farmer adaptation but it does not take into account transition costs. The model is intended for comparative static analysis, not year by year dynamic analysis. It is not clear if these transitory cost are large although. Kelly et al. (2005) argue they could be equal to 1.4% of annual land rents. One final controversial issue concerns irrigation. Schlenker et al. (2005) argue that rainfed and irrigated farmland must be analyzed separately. Although there is no question that the climate sensitivity of rainfed and irrigated farmland is different, the choice of irrigation is endogenous (Kurukulasuriya et al., 2011). Treating irrigated and

rainfed land exogenously does not properly capture the response of the entire agriculture system to climate.

Besides the long series of analyses of US agriculture (e.g., Mendelsohn and Dinar (2003); Schlenker et al. (2005); Massetti and Mendelsohn (2011)), the Ricardian method has also been applied around the world in Africa (Kurukulasuriya et al. (2006); Seo and Mendelsohn (2008b)), in South America (Seo and Mendelsohn, 2008a), and in numerous single countries such as Canada (Reinsborough, 2003) and China (Wang et al., 2009). In fact, several Ricardian studies have been done in selected countries in Europe including Germany (Lang (2007); Lippert et al. (2009)) and Great Britain (Maddison, 2000).

Unfortunately, a comprehensive study of Europe is still missing. This study fills this gap by applying the Ricardian method to a large group of Western European countries (EU-15). We rely on farm-level data from the FADN dataset to study 37 612 farms in 2007.

The rest of the paper is organized as follows. In section 2, we explain the Ricardian analysis. Section 3 presents the data and the model specifications of the Ricardian model using farm level data. In section 4, the empirical findings are presented, while section 5 concludes the paper.

## 2 Methodology

The Ricardian model assumes that farmland value per hectare ( $V$ ) of each farm  $i$  in location  $r$  is equal to the present value of future net revenues from farm activities:

$$V_{i,r} = \int_0^{\infty} (P_r Q_{i,r} - M_r X_{i,r}) e^{-\varphi t} dt \quad (1)$$

where  $P_r$  is the market price of each crop at location  $r$ ,  $Q_{i,r}$  is the output of each crop at farm  $i$  at location  $r$ ,  $X_{i,r}$  is a vector of inputs for each crop at farm  $i$  (other than land),  $M_r$  is a vector of input prices at location  $r$ ,  $Z_r$  is a vector exogenous variables at location  $r$ , and  $\varphi$  is the interest rate.

The farmer chooses the outputs  $Q_{i,r}$  and inputs  $X_{i,r}$  that maximize net revenues. By solving (1) to maximize net revenues and by folding the vectors of prices and inputs  $M_r$  and  $P_r$  into the vector of exogenous variables  $Z_r$ ,  $V_{i,r}$  can be expressed as a function of only exogenous variables:

$$V_{i,r} = f(Z_r) \quad (2)$$

Exogenous variables can be grouped into four subgroups: climate variables (temperature (T) and rainfall (R)), geographic variables (G), soil variables (S) and socio-economic variables (H).

We rely on a log-linear Ricardian model<sup>1</sup> because land values are log-normally distributed (Massetti and Mendelsohn, 2011). We use climatology's – i.e. 30 year time averages – of temperature and rainfall to describe climate. Many Ricardian studies have shown that seasonal differences in temperatures and precipitations have a significant impact on land values. The agronomic literature and many Ricardian studies have shown that the relationship between climate and land values is hill-shaped. We therefore estimate the following model for each farm  $i$  in location  $r$ :

<sup>1</sup> We prefer to use the log-linear functional form. Comparing the ratio of the predicted value (using OLS) to the actual value in each decile, we found that the log-linear model has a more uniform predictive power compared to the linear model.

$$\ln V_{i,r} = \alpha + \beta_{T,k} T_{r,k} + \gamma_{T,k} T_{r,k}^2 + \beta_{R,k} R_{r,k} + \gamma_{R,k} R_{r,k}^2 + \eta S_r + \theta G_r + \vartheta H_r + D_r + u_{i,r} \quad (3)$$

where  $T$  and  $R$  are vectors of seasonal temperatures and precipitations in region  $r$ , with each season indexed by  $k$ ;  $D_r$  is a regional dummy and  $u_{i,r}$  is a random error term which is assumed not to be correlated with climate.

The expected marginal impact of seasonal temperature  $T_k$  on land value per hectare is equal to:

$$E \frac{\partial V_{i,r}}{\partial T_k} = E[V_{i,r}] (\beta_{T,k} + 2\gamma_{T,k} T_k) \quad (4)$$

The marginal impact of seasonal temperature on the percentage of land value is:

$$ME_{T,r} \equiv \frac{\frac{\partial V_{i,r}}{V_{i,r}}}{\frac{\partial T_{r,k}}{T_{r,k}}} \omega_i = \beta_{T,k} + 2\gamma_{T,k} E T_{r,k} \omega_i \quad (5)$$

The marginal effect of precipitation can be calculated in a similar way. The marginal consequently varies across space depending on the underlying land value and climate. To report the mean climate marginals for a country or the entire continent, we weight each location by  $\omega_i$  which is the utilized agricultural land of each farm in location  $r$  multiplied by the number of farms.

The impact of a nonmarginal climate change on the value of land per hectare in farm  $i$  is calculated by comparing the estimated value of land under the new temperature and precipitation  $(T_1, W_1)$  to the estimated value of land under the present climate  $(T_0, W_0)$ :

$$\Delta W_{i,r} = E V_{i,r} (T_1, W_1) - E V_{i,r} (T_0, W_0) \quad (6)$$

The total impact of climate change ( $\Delta W$ ) or welfare loss in location  $r$  is then aggregated:

$$\Delta W_r = \sum_{i=1}^n E V_{i,r} (T_1, W_1) - E V_{i,r} (T_0, W_0) \omega_i \quad (7)$$

with  $n$  the total number of farms and  $\omega_i$  as a weighting factor based on the total utilized agricultural area of farm  $i$  and the number of farms represented by farm  $i$ .

### 3 Data and model specifications

A comprehensive dataset of European agricultural data, present climate, future climate scenarios, socio-economic characteristics and geographic variables for 923 NUTS3 (Nomenclature of Territorial Units for Statistics) regions in the EU-15 has been built.

We have farm specific measures of the dependent variable ( $V_{i,r}$ ), the agricultural land value per hectare and some farm specific socio-economic variables (e.g., rented land). Most of the exogenous variables are unique to each NUTS3 region including climate (seasonal temperature and precipitation), soil (e.g., percent gravel and pH), socioeconomic (population density), and geographic variables (e.g., distance from urban areas, distance from ports, latitude, mean elevation).

variable		mean	min	max	sd
Farm specific socio-economic variables					
Agricultural land value	Euro/ha	15970.40	4.74	2060296.00	29615.89
Land owned	ha	33.91	1.00	2695.53	67.19
Utilized agricultural area	ha	59.91	1.00	7845.25	109.35
Farms represented	number	59.25	1.00	10550.00	212.25
Share rented land	ha/ha	0.31	0.00	0.99	0.33
Regional socio-economic variables					
Pdnsty	Cap/km <sup>2</sup>	155.94	2.00	3048.00	211.38
Regional specific climatic variables					
Temp. winter	°C	3.68	-14.94	12.01	4.04
Temp. spring	°C	9.67	-2.77	15.96	2.96
Temp. summer	°C	18.64	6.83	26.15	3.32
Temp. autumn	°C	11.97	-1.81	19.67	3.49
Prec. winter	10mm	7.18	1.89	25.54	2.83
Prec. spring	10mm	6.30	2.08	17.06	2.29
Prec. summer	10mm	5.66	0.15	20.98	3.46
Prec. autumn	10mm	7.49	3.56	28.71	2.49
Regional specific soil characteristics					
t_gravel	(%vol)	9.35	2.44	18.35	2.71
t_silt	(%wt)	31.66	10.83	45.99	5.78
t_sand	(%wt)	45.93	28.25	83.02	9.34
t_clay	(%wt)	21.49	5.79	40.22	4.69
pH		6.31	4.18	7.88	0.70
Regional specific geographic variables					
Cities500k	km	116.67	0.97	842.84	81.64
PortsML	km	160.96	0.91	536.51	108.00
Elevation mean	m	393.79	0.01	2091.87	330.79
Elevation range	m	1201.17	1.00	4255.00	904.21
Latitude	°	45.81	35.14	67.71	6.05
Longitude	°	7.48	-9.19	29.97	9.04

A detailed description of all model variables can be found in appendix A

### Table 1: Descriptive statistics

Finally, controlling for country fixed effects is very important. Although there is a common agricultural policy in all European member states, individual land sales market regulations, such as price restrictions, tax regulations and purchase and use of agricultural land regulations, can differ between European member states (Swinnen et al., 2009). These differences are captured by the country variables which are highly significant (omitted variable is the United Kingdom).

Table 1 shows the descriptive statistics of our model variables. The average farm level land value is nearly 16 000 Euro per hectare but there are large differences between farms with very low land values (e.g., marginal land) and high land values (e.g., farms producing high value products).

Farm accountancy data (FADN) of 2007 is used for the farm specific variables. FADN is a survey carried out by all Member States of the European Union. We use accountancy data of 37 612 farms in the EU-15, excluding all farms with land under glass (greenhouses). FADN contains micro-economic data that is harmonized (using the same bookkeeping principles) and is representative for

commercial agricultural holdings<sup>2</sup>. It is a stratified sample, based on type of farming, economic farm size and regions, ensuring to reflect adequately farming heterogeneity. There are 5 662 480 farms in the EU-15 (census 2007 data), with a total utilized agricultural area of about 120 million hectares. Our data sample of commercial farms covers 2 253 423 hectare utilized agricultural area and a total agricultural area of 73.2 million hectares. The sample covers 60% of all agricultural area.

Present climate data are derived from the Climatic Research Unit (CRU) CR 2.0 dataset (New et al., 2002). The climatologies for temperature and precipitation rely on measurements from 1961-1990. Soil data are originating from the harmonized world soil database, a partnership between the Food and Agriculture Organization (FAO) and the European Soil Bureau Network. An overview and detailed description of all model variables and sources can be found in appendix A.

Farm level data is linked with the regional data on district level using NUTS3. In order to generate estimates of coefficients that are less sensitive to outliers we use a median regression. Furthermore, we weight each observation by the square root of land owned by the farmer  $i$  to correct for heteroskedasticity.

To calculate the welfare change (equations 6 and 7), associated with predicted future climate, we rely on climate model projections from the IPCC data distribution center. Long term emission predictions (2100) are taken from the SRES (Special Report on Emissions Scenarios) A2 scenario (Nakićenović et al., 2000). The A2 scenario predicts global CO<sub>2</sub> concentrations of 830-850 ppm by 2100 and represents a Business as Usual Scenario (no mitigation). In order to examine a reasonable range of climate outcomes, we analyze three different climate models (i) Hadley CM3 (Gordon et al., 2000), (ii) ECHO-G (Legutke and Voss, 1999), and (iii) NCAR PCM (Washington et al., 2000).

## 4 Results

Section 4.1 discusses the results of the regressions across the EU-15 farms. A regression is done of the entire sample in order to understand the impact climate has on the entire sector. A set of subsamples are also analyzed to understand different components of European agriculture. Section 4.2 utilizes the regression of all farms and the climate projections to calculate the expected impacts of future climate scenarios. Section 4.3 analyzes the robustness of the Ricardian regressions.

### 4.1 Ricardian regression

The first two columns in Table 2 show the coefficients and standard errors of the log-linear regression of the entire sample of farms.

Twelve of the sixteen seasonal climate coefficients are statistically significant in this first regression revealing that climate has a significant impact on the value of European farmland. Only one of the squared temperature coefficients are significant implying seasonal temperature generally has a linear effect on land value. Land values fall with warmer winter and summer temperatures but they

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<sup>2</sup> A commercial farms is defined as a farm which is large enough to provide a main activity for the farmer and a level of income sufficient to support his or her family. The land use and value of non-commercial farming in the EU-15 is negligible.

increase with warmer spring and autumn temperatures. This is consistent with other evidence suggesting that a cold winter kills pests and so is valuable and that warmer spring and autumns are valuable because they lengthen the growing season. The squared term for summer temperature is negative implying summer temperature has a hill-shaped relationship with land value. Dividing the linear coefficient by twice the squared coefficient reveals that the peak summer temperature is 9.5°C which is cooler than most European farms. Warmer summer temperatures are generally harmful in Europe.

EU-15					
	coef	se		coef	se
Temp. winter	-0.267***	0.025	PortsML	-1.199***	0.080
Temp. winter sq	0.001	0.002	Elevation	-0.522***	0.058
Temp. spring	0.370***	0.047	Elevation	0.055***	0.013
Temp. spring sq	0.001	0.002	Latitude	-0.040***	0.007
Temp. summer	0.228***	0.079	Longitude	-0.029***	0.003
Temp. summer sq	-0.012***	0.002	AT	-2.199***	0.065
Temp. autumn	0.184**	0.084	BE	0.031	0.047
Temp. autumn sq	-0.004	0.003	DK	0.938***	0.063
Prec. winter	0.149***	0.015	ES	-0.712***	0.063
Prec. winter sq	-0.002***	0.001	FI	0.049	0.099
Prec. spring	-0.333***	0.029	FR	-1.276***	0.049
Prec. spring sq	0.019***	0.002	GR	0.566***	0.102
Prec. summer	0.150***	0.020	IE	1.104***	0.032
Prec. summer sq	-0.005***	0.001	IT	0.924***	0.071
Prec. autumn	0.025	0.017	LU	-0.312***	0.054
Prec. autumn sq	-0.007***	0.001	NL	1.056***	0.045
t_gravel	-0.047***	0.004	PT	-2.229***	0.079
t_sand	-0.004	0.003	SE	0.221***	0.076
t_silt	-0.003*	0.002	WDE	0.410***	0.047
pH	0.286***	0.017	EDE	-0.965***	0.066
Rented land	-0.009	0.018	UK	(ommitted)	
Pdnsty	0.320***	0.028	cons	5.929***	0.683
Cities500k	-0.658***	0.098	number obs.	37612	

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 2: EU-15 Ricardian regression**

Precipitation is also very important. All the squared terms for seasonal precipitation are significant. The seasonal squared terms are generally negative except for spring which is positive. For most of the seasons, precipitation has a hill-shaped relationship. More rainfall is good up to a point but then becomes harmful. The peak monthly precipitation is 37, 15, and 2 cm for winter, summer, and autumn respectively. For all of Europe, more winter rain is good (allowing farmers to start their season with moist soils) and more autumn rain is harmful because autumn rain damages many crops. For most of Europe, more summer rain is also beneficial. Spring precipitation has a U-shaped effect on land value, making it quite different from the other seasons. Spring rainfall is harmful at first and becomes beneficial only once it exceeds 8.8 cm/month.

Several of the control variables in the regression are also significant. Gravel soils tend to be harmful. A higher pH (more alkaline soil) increases land value. Higher population density increases land values which makes sense because higher density implies land is scarcer. Distance to markets reduces land value whether it is to large cities or ports. The coefficient is twice as large for ports as cities



	EU-15 (only rainfed)		EU-15 (only irrigation)		EU-15 (only crop farms)		EU-15 (only grazing)	
	coef	se	coef	se	coef	se	coef	se
Temp. winter	-0.137***	0.026	-0.486***	0.003	-0.334***	0.029	-0.342***	0.032
Temp. winter sq	0.004**	0.002	0.015***	0.000	-0.021***	0.002	-0.006***	0.002
Temp. spring	0.357***	0.047	-1.168***	0.007	-0.582***	0.064	-0.079	0.059
Temp. spring sq	-0.003	0.003	0.045***	0.000	0.046***	0.003	0.043***	0.004
Temp. summer	0.301***	0.080	1.097***	0.009	1.042***	0.113	1.061***	0.106
Temp. summer sq	-0.011***	0.002	-0.031***	0.000	-0.038***	0.003	-0.047***	0.003
Temp. autumn	0.019	0.082	1.323***	0.012	0.002	0.105	0.513***	0.105
Temp. autumn sq	-0.005	0.003	-0.022***	0.000	0.021***	0.005	-0.010**	0.004
Prec. winter	0.059***	0.016	-0.120***	0.001	0.225***	0.026	-0.019	0.021
Prec. winter sq	0.001	0.001	0.016***	0.000	-0.005***	0.001	0.004***	0.001
Prec. spring	-0.296***	0.032	0.606***	0.003	-0.054	0.041	-0.131***	0.035
Prec. spring sq	0.016***	0.002	-0.044***	0.000	-0.012***	0.002	0.007***	0.002
Prec. summer	0.130***	0.021	0.134***	0.002	0.129***	0.029	0.007	0.023
Prec. summer sq	-0.004***	0.001	0.003***	0.000	0.000	0.001	0.005***	0.001
Prec. autumn	0.076***	0.017	-0.287***	0.002	-0.283***	0.032	0.054***	0.019
Prec. autumn sq	-0.009***	0.001	0.010***	0.000	0.013***	0.002	-0.009***	0.001
t_gravel	-0.046***	0.004	0.006***	0.000	-0.074***	0.005	-0.028***	0.005
t_sand	0.001	0.003	-0.033***	0.000	-0.011***	0.004	-0.021***	0.004
t_silt	-0.003	0.002	-0.022***	0.000	-0.007***	0.002	-0.010***	0.002
pH	0.238***	0.017	0.064***	0.001	0.271***	0.022	0.107***	0.023
Rented land	0.027	0.018	-0.057***	0.001	-0.046**	0.019	0.210***	0.023
Pdnsty	0.255***	0.027	0.195***	0.003	0.256***	0.033	0.167***	0.033
Cities500k	-0.746***	0.100	-0.940***	0.008	-1.022***	0.112	-0.427***	0.131
PortsML	-1.299***	0.082	-0.743***	0.008	-0.691***	0.101	-1.175***	0.110
Elevation mean	-0.784***	0.063	-0.377***	0.004	-0.444***	0.074	-0.871***	0.076
Elevation range	0.038***	0.014	0.024***	0.001	0.220***	0.014	0.218***	0.023
Latitude	-0.063***	0.007	0.024***	0.001	-0.038***	0.009	-0.059***	0.010
Longitude	-0.031***	0.003	-0.058***	0.000	-0.076***	0.004	-0.035***	0.004
AT	-1.941***	0.065	-0.766***	0.012	-1.483***	0.079	-2.839***	0.079
BE	0.123***	0.045	1.329***	0.013	0.386***	0.070	-0.174***	0.053
DK	1.116***	0.062	0.771***	0.008	0.727***	0.075	0.932***	0.081
ES	-0.886***	0.063	-0.160***	0.014	-1.111***	0.078	-1.278***	0.074
FI	0.232**	0.096			-0.075	0.123	0.679***	0.118
FR	-1.242***	0.048	-0.666***	0.013	-1.165***	0.058	-1.594***	0.057
GR	0.500***	0.106	1.469***	0.014	1.053***	0.116	0.534***	0.136
IE	1.002***	0.030			1.636***	0.058	1.052***	0.033
IT	0.806***	0.074	1.641***	0.012	1.145***	0.091	1.010***	0.081
LU	-0.110**	0.053			0.307***	0.100	-0.279***	0.061
NL	1.149***	0.044			1.176***	0.053	1.011***	0.052
PT	-2.215***	0.080	-2.437***	0.014	-2.634***	0.109	-2.949***	0.098
SE	0.339***	0.072	1.891***	0.013	0.528***	0.092	0.302***	0.091
WDE	0.578***	0.046	0.553***	0.013	0.639***	0.060	0.154***	0.058
EDE	-0.820***	0.063			-0.838***	0.072	-1.187***	0.083
UK	(ommitted)				(ommitted)		(ommitted)	
cons	7.689***	0.698	-5.019***	0.109	4.566***	0.977	3.033***	0.904
number obs.	28792		8820		8812		12575	

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1; crops farms are classified as specialized field crops (including cereals, root crops, field vegetables and various field crops); grazing farms are classified as specialized grazing livestock (including dairying, sheep, goats, cattle rearing and fattening) (<http://ec.europa.eu/agriculture/rica/> )

**Table 3: EU-15 Ricardian regressions with only rainfed farms, only irrigated farms, only specialized field crops and only specialized grazing livestock**

suggesting ports lead to more valuable markets for farmers. Higher elevation is more harmful. Generally, higher elevation farms must cope with more diurnal temperature variance which tends to be harmful. Increased longitude is harmful implying that there is an advantage to being close to the Atlantic coast. Increased latitude is also harmful because it implies a reduction in sunlight. Country dummies are generally significant implying higher average land values in Denmark, Ireland, Italy, and the Netherlands, but lower values in Austria, France, East Germany, and especially Portugal.

Columns 1 and 2 in Table 3 describe a Ricardian regression estimated on only rainfed farms. Columns 3 and 4 describe the Ricardian regression for irrigated farms. The rainfed regression coefficients resemble the coefficients found for the entire sample, partially because rainfed farms make up three fourths of the total sample. The significant climate coefficients have the same sign except for the squared term on winter precipitation. So the general effect of climate on land value discussed above applies to rainfed farms. Even with respect to winter precipitation, it can still be argued that it is beneficial. However, only a few of the temperature effects are slightly different. Autumn temperature has no significant effect on land value and the summer peak temperature is 13.7°C in rainfed farms. The effect of the control variables is also quite similar for the rainfed farms.

Some of the regression results for the irrigated farms are different from the rainfed farms. The climate coefficients are all significant and the seasonal coefficients are generally larger. The squared terms for winter and spring temperature are positive (implying U shapes) while the squared terms for summer and autumn temperature are negative (implying hill-shapes). However, when one analyzes the shapes of these functions, warmer winters are harmful and warmer autumns remain beneficial for Europe. The summer peak for irrigated farms is higher than for rainfed farms, close to the current mean temperature for European farms. Spring is also different with warmer temperatures generally being harmful for much of Europe. The seasonal precipitation squared terms have the opposite sign for irrigated farms. The minimum values of the U-shaped functions for winter, summer, and autumn are 4, -22, and 14 cm/month for winter, summer, and autumn respectively. This implies that precipitation in all three seasons is beneficial (except for a few very wet farms in autumn). The peak value for spring precipitation is 7 cm/month which is close to the mean for Europe which means it is beneficial for dry farms and harmful for wet farms.

The control variables also have different coefficients for irrigated versus rainfed farms. For irrigated farms compared to rainfed farms, gravel soils become beneficial and alkaline soils are less beneficial, distance to cities matters more and distance to ports less, elevation has a smaller impact, and latitude becomes beneficial. It is more important for irrigated farms not to lose the moisture that is applied to the fields which explains the aversion to more sandy soils. The interaction with distance implies irrigated farms are more likely to send farm output to nearby cities than ports compared to rainfed farms. Elevation sometimes makes it easier to obtain surface water since delivery systems can rely more heavily on gravity. It is not clear why higher latitude favors irrigated farms.

Table 3 also presents the regressions for specialized crop farms and specialized livestock farms. Several of the climate coefficients are quite different in these two subsamples. For example, the autumn temperature squared term is positive for crops but negative for livestock. For crops the squared precipitation terms are negative for winter and spring (hill shaped) but positive for fall (U-shaped). For livestock, they are positive for winter, spring and fall (U shaped), but negative for autumn (hill-shaped). But despite these differences, climate has very similar effects on both crops

and livestock. Warmer summers and winters are harmful but warmer springs and autumns are beneficial. More rain is beneficial in winter and summer but more rain is harmful in spring (at least for most livestock farms). The big climate difference between crops and livestock is autumn rain which is harmful to most crop farms but beneficial to livestock farms.

Some of the control variables are also different between specialized crop and specialized livestock farms. Gravel soils are more harmful to crops, sandy soils are more harmful to livestock, alkaline soils are more beneficial to crops, population density is more beneficial to crops, distance to cities is more important to crops and distance to ports is more important to livestock, higher elevation and latitude are more harmful to livestock, and longitude (being further from the Atlantic) is more harmful to crops. But other variables are similar. For example, the countries with relatively low valued cropland (Austria, Spain, France, Portugal and East Germany) also have low-valued grazing land (although Austria's grazing land is worth a lot less than its cropland). The countries with high valued cropland (Greece, Ireland, Italy, Netherlands, and Denmark) also have high valued grazing land. Some of these control variables, such as elevation and longitude, may reflect omitted climate variables such as diurnal temperature variation (which increases with elevation) or interannual temperature variance (which increases with distance from oceans).

Table 4 presents the marginal results of the regression in Table 2 using the entire sample of farms. Marginal values refer to the percentage change in land value associated with a marginal increase in temperature and precipitation by season and for the whole year. Values are calculated for each country as well as for the EU-15 as a whole. Values vary across countries because of their underlying average climate.

For the EU-15, seasonal temperature and precipitation has a significant effect on farmland value. Warmer winter and summer temperatures are harmful and warmer spring and fall temperatures are beneficial. More precipitation in winter and summer is beneficial but more precipitation in spring and fall is harmful. The seasonal temperature effects cancel each other out so that annual temperature does not have any marginal effect on EU-15 average farmland values. The seasonal precipitation effects are offsetting but a marginal increase in annual precipitation increases farmland value.

The marginal effects differ a great deal across countries within the EU-15. Annual temperature has a beneficial marginal effect on Austria, Belgium, Germany, Denmark, Finland, Ireland, Luxembourg, Netherlands, Sweden, and Great Britain. All of these countries are northern members. Annual temperature has a negative marginal effect on Spain, Greece, Italy, and Portugal which are southern members. The magnitude of the marginal effects varies by countries. The marginal benefit is the highest in Sweden and Finland which gain about 9% of land value per °C. Spain, Greece, Italy, and Portugal all lose about 10% of land value per °C.

A marginal increase in annual precipitation is beneficial to Austria, Belgium, France, Germany, Greece, Italy, Luxembourg, Portugal, and Spain. Additional precipitation is harmful to Denmark, Finland, and Sweden and has no significant effect on Ireland, Netherlands, and Great Britain. The northern countries in Europe near the Atlantic appear to be the only countries that do not benefit from more rain. The countries that gain the most from more rain are Portugal, France and Spain which all gain about 6% of land value per cm/month. Finland loses about 5% of land value per cm/month.

The marginal effect of seasonal temperature is stable across all the countries of the EU-15. They all benefit from warmer spring temperature and they all are harmed by warmer winter and summer temperatures. The positive marginal effects of autumn temperatures are not always significant in every country. The marginal seasonal precipitation effects are completely stable across countries increasing land values in winter and summer and decreasing land values in spring and fall.

	Temp. annual	Perc. annual	Temp. winter	Temp. spring	Temp. summer	Temp. autumn	Prec. winter	Prec. spring	Prec. summer	Prec. autumn
Austria	0.076 ***	0.049 ***	-0.273 ***	0.380 ***	-0.156 ***	0.125 ***	0.126 ***	-0.024 **	0.039 ***	-0.092 ***
Belgium	0.042 ***	0.037 ***	-0.261 ***	0.383 ***	-0.186 ***	0.105 **	0.123 ***	-0.079 ***	0.082 ***	-0.089 ***
Germany	0.048 ***	0.028 ***	-0.266 ***	0.382 ***	-0.181 ***	0.114 ***	0.130 ***	-0.121 ***	0.080 ***	-0.060 ***
Denmark	0.073 ***	-0.034 ***	-0.266 ***	0.380 ***	-0.156 ***	0.115 ***	0.129 ***	-0.165 ***	0.092 ***	-0.090 ***
Spain	-0.099 ***	0.056 ***	-0.251 ***	0.388 ***	-0.310 ***	0.074	0.127 ***	-0.143 ***	0.128 ***	-0.056 ***
Finland	0.096 ***	-0.049 ***	-0.288 ***	0.374 ***	-0.142 ***	0.152 **	0.137 ***	-0.219 ***	0.092 ***	-0.059 ***
France	0.012	0.059 ***	-0.257 ***	0.385 ***	-0.212 ***	0.096 **	0.123 ***	-0.073 ***	0.095 ***	-0.085 ***
Greece	-0.131 ***	0.035 ***	-0.251 ***	0.389 ***	-0.336 ***	0.067	0.119 ***	-0.154 ***	0.130 ***	-0.061 ***
Ireland	0.118 ***	0.012 *	-0.255 ***	0.382 ***	-0.120 ***	0.110 ***	0.109 ***	-0.043 ***	0.084 ***	-0.138 ***
Italy	-0.081 ***	0.035 ***	-0.252 ***	0.387 ***	-0.291 ***	0.075	0.122 ***	-0.093 ***	0.106 ***	-0.100 ***
Luxembourg	0.046 ***	0.043 ***	-0.264 ***	0.383 ***	-0.185 ***	0.112 ***	0.119 ***	-0.068 ***	0.082 ***	-0.091 ***
Netherlands	0.056 ***	0.005	-0.260 ***	0.383 ***	-0.173 ***	0.106 ***	0.126 ***	-0.128 ***	0.087 ***	-0.080 ***
Portugal	-0.102 ***	0.058 ***	-0.243 ***	0.391 ***	-0.309 ***	0.060	0.112 ***	-0.108 ***	0.135 ***	-0.080 ***
Sweden	0.092 ***	-0.034 ***	-0.276 ***	0.377 ***	-0.144 ***	0.134 ***	0.133 ***	-0.189 ***	0.092 ***	-0.070 ***
UK	0.110 ***	0.009	-0.258 ***	0.381 ***	-0.126 ***	0.112 ***	0.113 ***	-0.062 ***	0.083 ***	-0.125 ***
EU-15	-0.003	0.033 ***	-0.257 ***	0.385 ***	-0.225 ***	0.095 **	0.123 ***	-0.106 ***	0.100 ***	-0.084 ***

Impact (in %) of an increase of 1°C or 10mm, reported values are weighted averages, based on total farm utilized agricultural land and the number of farms represented by each farm. Significant different from 0 (no impact): \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

**Table 4: Temperature and Precipitation Marginal effects**

			Hadley CM3		ECHO-G		NCAR PCM	
	Land value (Euro/ha)	Total Land value (million Euro)	Impact (Euro/ha)	Total impact (million Euro)	Impact (Euro/ha)	Total impact (million Euro)	Impact (Euro/ha)	Total impact (million Euro)
Austria	1216	2510	-487	-1010	-270	-559	-168	-347
Belgium	16813	15100	-7409	-6640	-3724	-3340	-673	-604
Germany	16667	135000	-7493	-60700	-2234	-18100	-382	-3090
Denmark	18591	29800	-5273	-8450	2851	4570	1236	1980
Spain	3745	63800	-2928	-49900	-2563	-43700	-1619	-27600
Finland	3960	7000	-1406	-2480	-993	-1750	-1916	-3390
France	3486	36400	-2307	-24100	-1713	-17900	-722	-7550
Greece	10826	28400	-9148	-24000	-7051	-18500	-7333	-19200
Ireland	28124	123000	1598	7010	2520	11100	12615	55300
Italy	21794	218000	-16219	-162000	-14234	-143000	-8695	-87100
Luxembourg	10550	904	-5815	-498	-3667	-314	-531	-46
Netherlands	42063	60100	-13077	-18700	-3139	-4490	2235	3190
Portugal	1312	2070	-791	-1250	-927	-1460	-552	-869
Sweden	5790	10500	-2177	-3930	1524	2750	-1118	-2020
UK	10075	94600	-745	-7000	254	2390	3005	28200
EU-15	11303	828000	-4971	-364000	-3166	-232000	-861	-63100

**Table 5: Welfare change per ha and total welfare change**

## 4.2 Projections with climate scenarios

In this section, we examine nonmarginal changes in climate predicted by climate models for 2100. As mentioned in section 3, we compare the current climate with the 2070-2100 climate predicted by each climate model: (i) Hadley CM3, (ii) ECHO-G and, (iii) NCAR PCM. These predictions are commonly used to assess the effects of climate change (e.g., Olesen et al. (2007); Iglesias et al. (2012a)). The NCAR PCM scenario is relatively mild, predicting a 2.8°C increase and a decrease of 42 mm in annual precipitation. The ECHO-G and Hadley CM3 predict warming of 4.3°C and 4.4°C and a reduction of 168 mm and 273 mm in annual precipitation respectively. These models also make different regional predictions within the EU-15.

We use the coefficients from the estimated median regression of all farms (Table 2) to measure the consequence of these future climate scenarios. We begin by calculating what the regression model predicts the current farmland value is in the EU-15. We then calculate what the model predicts the future farmland value will be given the new climate scenario. The calculation takes into account the predicted change in both temperature and precipitation at each location. The effects are then aggregated across space to measure country impacts and EU-15 impacts. The first two columns in Table 5 show the current farmland value per hectare as well as the aggregate farmland value for each country and the EU-15 as a whole. The remaining columns show the change in land value per hectare and the change in aggregate land value associated with each climate scenario. For the EU-15 as a whole, land value per hectare falls in all three climate scenarios. The change in land value per hectare is -€900/ha, -€3200/ha, and -€5000/ha for the NCAR PCM, ECHO-G, and Hadley CM3 scenarios. The aggregate lost farmland value in the EU-15 is € 63 billion, € 232 billion, and € 364 billion, respectively. This is a capital loss and not an annual loss of net revenue. The damage reflects an aggregate loss of 8%, 28%, and 44% respectively.

Reported land values are predicted values; reported impact values are weighted averages, based on total farm utilized agricultural land and the number of farms represented by each farm. The effect is not at all uniform across the EU-15. Denmark, Ireland, Netherlands, and Great Britain benefit in the NCAR PCM climate scenario, Denmark, Ireland, Sweden, and Great Britain benefit in the ECHO-G scenario, and Ireland benefits in the Hadley CM3 scenario. Some countries are hurt more than others by each climate scenario. Italy has the largest aggregate losses with € 162 billion in the Hadley CM3 scenario, € 143 billion in the ECHO-G scenario, and € 87 billion in the NCAR PCM climate scenario. Partly this is because the Italian farmland is worth so much (€ 218 billion) and partially because they lose a high fraction of this value to climate change (almost 75% in the Hadley CM3 scenario).

Perhaps the most obvious way to visualize the results across countries, however, is to look at Figures 1, 2 and 3 which depict the percentage change in farmland value in each NUTS3 region for each climate scenario. All three climate scenarios show a negative impact of climate change on European agriculture. The impact is clearly worse moving from the NCAR PCM to the ECHO-G to the Hadley CM3 climate scenarios. With the NCAR PCM scenario, some countries in the north gain (UK, Ireland, Denmark, the Netherlands, Germany and Austria) whereas others in the south lose. For example, Portugal, Spain, Southern France, Italy and Greece all lose in the NCAR PCM scenario. With the ECHO-G scenario, the damages get worse and the benefits shrink. With the Hadley CM3 scenario, the southern regions lose more than 60% of their land value and almost no region benefits in Europe.

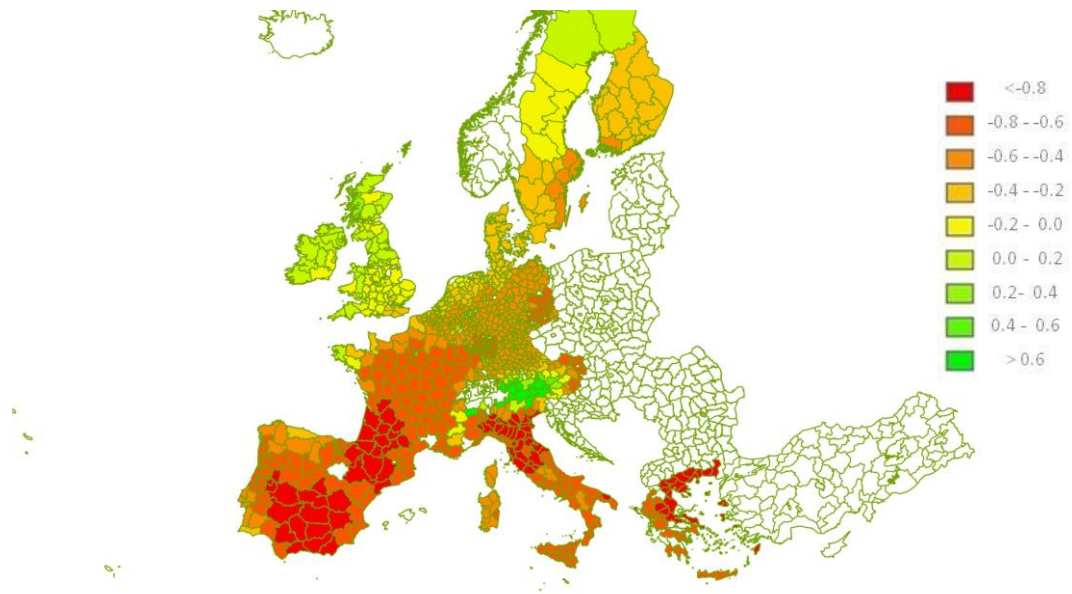


Figure 1: Impact of Hadley CM3 A2-climate scenario (2100) on EU-15 farmland values (in %)

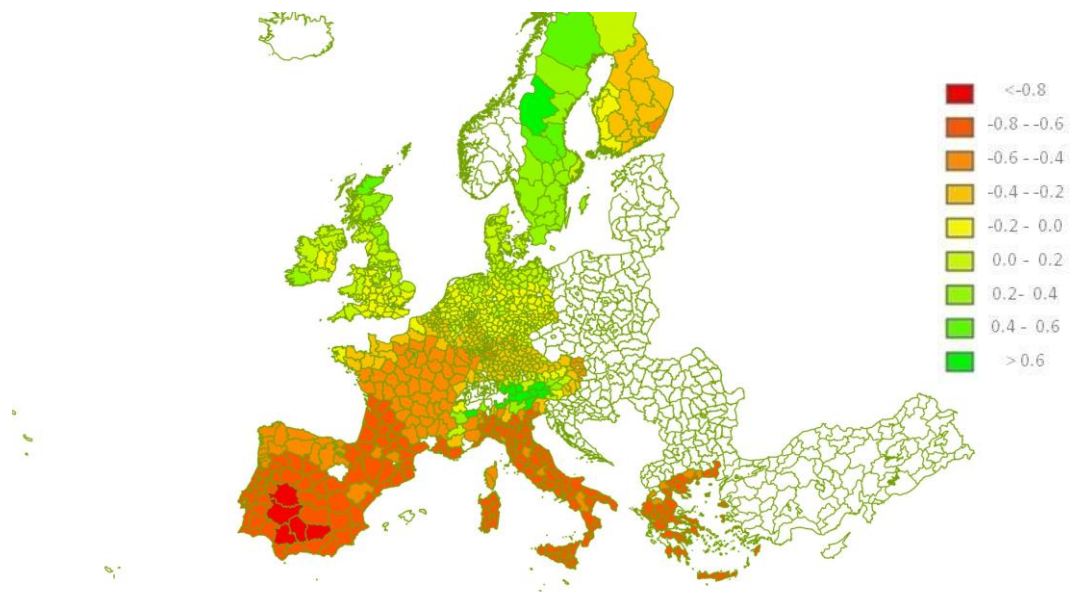


Figure 2: Impact of ECHO-G A2-climate scenario (2100) on EU-15 farmland values (in %)

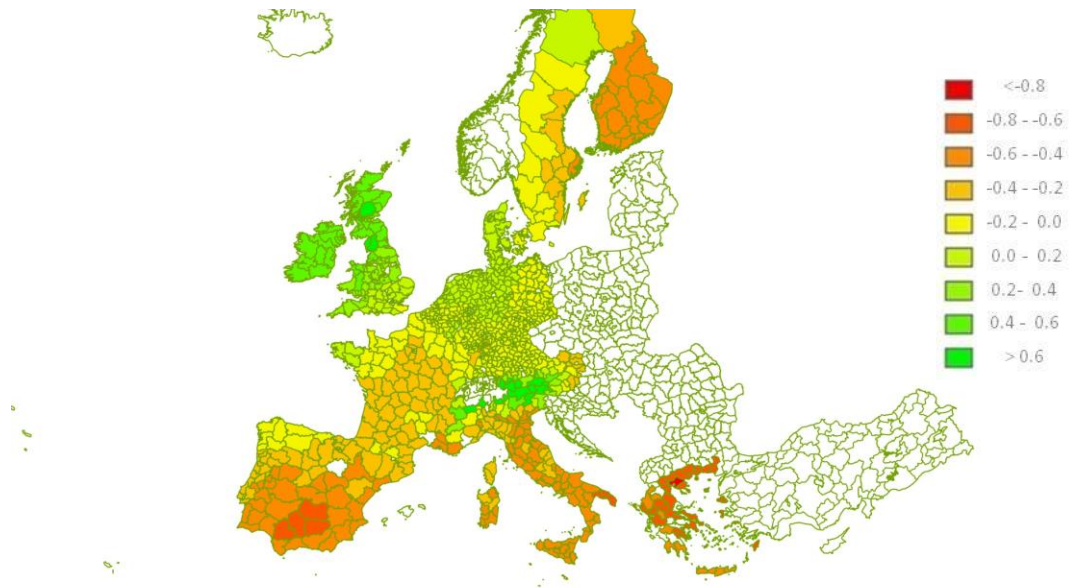
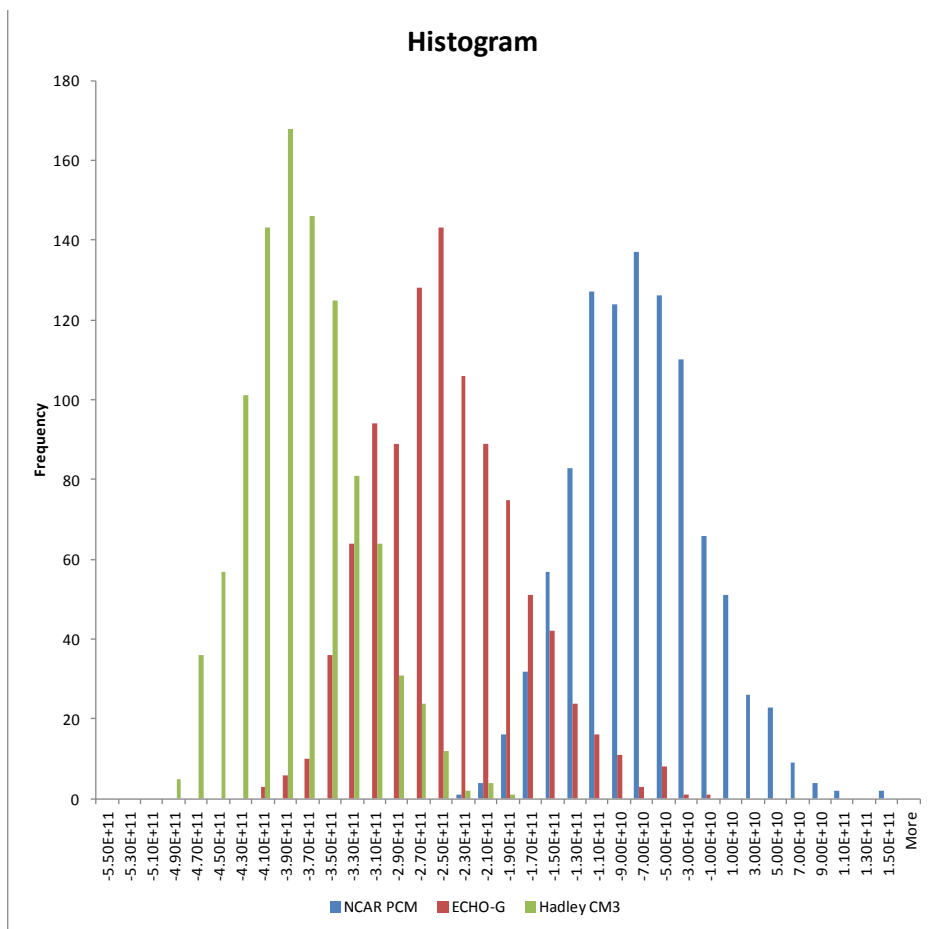


Figure 3: Impact of NCAR PCM A2-climate scenario (2100) on EU-15 farmland values (in %)



Based on bootstrap estimation with 1000 repetitions.

Figure 4: Total economic impact of Climate change

In order to quantify the uncertainty surrounding the welfare estimates in Table 5, we conduct a bootstrap analysis. These measures calculate the uncertainty of the welfare estimates conditional on each climate scenario. That is, they reflect the uncertainty in the Ricardian regression coefficients. Figure 4 shows the results of bootstrap estimations with 1000 repetitions using the median regression and a bootstrap sample estimated with replacement. The results illustrate the robustness of the negative impact of the climate change scenarios on European agriculture. Warming will be harmful to European agriculture by 2100. The results also indicate that the Hadley CM3 scenario is significantly more harmful than the NCAR PCM scenario. There are significantly different results across at least some climate scenarios. It is consequently very important for welfare studies of climate change to include a range of plausible climate scenarios and not just rely on a single climate model such as the Hadley CM3 or NCAR PCM climate model.

### 4.3 Robustness checks

The regressions in Tables 2 and 3 were estimated with median regressions. Appendix B compares estimates of the median regression with an otherwise similar OLS regression using the whole sample. We do not observe large differences in the coefficients between the two regressions or changes in sign. We do observe that the median regression leads to a flatter overall climate response function. The results imply that the fringe predictions of the OLS regression are sensitive to extreme data points.

We conduct a different robustness check in Appendix C by using different methods to control for unobserved variables. The regressions in Table 2 and 3 use a Ricardian regression with country dummies (for each country, and a dummy for West-Germany and East-Germany). In Appendix C, we compare these results with a regression with no country dummies and a regression with 63 NUTS1 regional dummies. The fact that many of the country dummies in Tables 2 and 3 are significant implies that there remain some country-specific variables that are not included in the regression. These include country level policy variables. But they may also reflect other unmeasured variables such as unique varieties and breeds or even unique geographic or technological features peculiar to each country. Including the NUTS1 regional dummies removes even more spatial variation. This invariably removes even more unmeasured variables. However, it also removes a great deal of the desired variation in climate. It is no surprise then that the more heavily controlled regional regression pushes the climate coefficients towards zero. This same phenomenon can be seen in the panel regression results of Deschênes and Greenstone (2007) where the climate coefficients move towards zero as more and more controls remove the remaining variation of climate in the sample.

One final robustness check explores the degree of spatial correlation in the data. In this analysis, we explore whether the error terms across farms within a NUTS3 region are correlated. Of the 923 NUTS3 regions, the farm level errors are correlated in 416 regions. This correlation suggests that there remain some missing variables that explain why farm values are higher in one NUTS3 region versus another.

We then explore an aggregate regression model, using each of the 923 NUTS3 regions as observations. The mean farmland value per hectare of each region is the dependent variable and the characteristics of each NUTS3 region are the independent variables. Appendix B shows the results of the aggregate Ricardian regression, including the standard error corrected for spatial



autocorrelation<sup>3</sup>. Logically, the results are very similar, although we see that several climate variables do not have a significant impact on farmland. With the corrected standard errors, winter, spring and autumn temperature and spring and autumn precipitation all have a significant impact on agricultural land value.

## 5 Discussion and Conclusions

Climate currently matters to European farmers. Our empirical results show that the seasonal climatic variables have a strong influence on current farmland values across Europe. In all cases, increasing spring temperature is beneficial while increasing summer temperature is detrimental for agricultural land value. Also important to mention is the beneficial impact of more precipitation in summer. The results are consistent with the results found in other studies using different approaches.

The climate coefficients also suggest that climate change is going to have a strong influence on future farmland values in Europe. The results suggest that climate change will be harmful to European agriculture by 2100. European agriculture is harmed in every tested climate scenario. The impacts are very different, however, for each climate scenario. With the milder climate scenario (NCAR PCM), European farms lose an average 8% of their value. With the more intermediate climate scenario (ECHO-G), European farms lose 28% of their value by 2100. Finally, with the more severe Hadley CM3 climate scenario, farms lose 44% of their value by 2100.

The impact of climate change is not uniform across Europe. With all three climate scenarios, the impact is more severe in southern Europe which is harmed in all cases. In contrast, with the two milder climate scenarios, several northern European countries benefit from climate change. Only Ireland, however, appears to benefit in all three climate scenarios.

Our results show that the climate sensitivity of irrigated farms is not the same as the climate sensitivity of rainfed farms. Rainfed farms cannot be used to predict the climate outcome of irrigated farms (and vice-versa). However, that does not imply, as suggested by Schlenker et al. (2005), that one cannot estimate a Ricardian model for the combination of all farms. The choice of whether or not a farmer selects irrigation is climate sensitive (endogenous) (Kurukulasuriya et al., 2011). If one is trying to model the outcome of the entire agricultural sector, one should include both rainfed and irrigated farms in the analysis. Estimating them separately as exogenous samples, as suggested by Schlenker et al. (2005), leads to biased outcomes.

The analysis also suggests that the climate sensitivity of cropland and grazing land is different. One cannot use a cropland Ricardian regression to estimate a grazing Ricardian regression (and vice versa). In order to measure the climate sensitivity of the entire agriculture sector, it is important to estimate a Ricardian model with both samples included. Analyzing the impact of climatic variables on just crops or just livestock does not allow substitution between crops and livestock. The Ricardian model captures adaptations that farmers can make with current crops, livestock, and technology. The analysis does not take into account adaptations that can be made through new breeds, varieties, and technologies. One important role of government is to conduct research and technology that

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<sup>3</sup>STATA code by Professor Timothy G. Conley : [http://economics.uwo.ca/faculty/conley/code\\_gmm.html](http://economics.uwo.ca/faculty/conley/code_gmm.html), accessed July 4, 2012

might provide farmers with new opportunities to adapt to new climates. Another important role of government is to manage surface and ground water supplies to increase their overall efficiency. Finally, governments have an important role to play in reforming agricultural policy to facilitate farm adaptation. They must be careful to avoid creating incentives that inadvertently discourage farmers from making efficient responses to climate change.

Note that we use the estimated Ricardian functional form to predict how future climate change might affect future agricultural land value, assuming that all other conditions are kept constant. In other words, we simply isolate the effect of climate change and we do not make a forecast of how farmland values actually change. It is a comparative analysis and hence we do not take into account other likely changes such as in technology, prices, and investment. A major advantage of the Ricardian approach is that structural changes and farm responses are implicitly taken into account. Our study also takes into account all current major farming activities in Europe such as crop and livestock farms. There remain several interesting topics for future research. It is important to explicitly capture adaptation within the Ricardian framework and estimate structural Ricardian models (e.g., Seo and Mendelsohn (2008b)). It is important to expand the analysis to include the new European member states of Eastern Europe and it is important to include changes in water supply especially in the regions of Europe that will depend on irrigation.

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## Appendix A: overview of the model variables

Variable	Description	Source
Farm specific socio-economic variables		
Agricultural land value (Euro/ha)	The agricultural land is valued on the basis of prices (net of acquisition costs) applying in the region for non-rented land of similar situation and quality sold for agricultural purposes. The replacement value is divided by the utilized agricultural area in owner occupation.	FADN
Rented land (ha/ha)	Total leased land per total utilized agricultural land	FADN
Regional socio-economic variables		
Pdnsty (1000 cap/km <sup>2</sup> )	Population density in 2010	ESRI, MBR and EuroGeographics
Regional specific climatic variables		
Temp. winter(°C)	Average air temperature 1961-1990 during winter	CRU
Temp. spring(°C)	Average air temperature 1961-1990 during spring	CRU
Temp summer(°C)	Average air temperature 1961-1990 during winter	CRU
Temp. autumn(°C)	Average air temperature 1961-1990 during spring	CRU
Prec. winter(cm/mo)	Precipitation 1961-1990 during winter	CRU
Prec. spring(cm/mo)	Precipitation 1961-1990 during spring	CRU
Prec. summer(cm/mo)	Precipitation 1961-1990 during summer	CRU
Prec. autumn (cm/mo)	Precipitation 1961-1990 during autumn	CRU
Regional specific soil characteristics		
t_gravel (%vol)	Volume percentage gravel (materials in a soil larger than 2mm) in the topsoil	World Soil database
t_sand (%wt)	Weight percentage sand content in the topsoil	World Soil database
t_silt (%wt)	Weight percentage silt content in the topsoil	World Soil database
t_clay(%wt)	Weight percentage clay content in the topsoil	World Soil database
pH	pH measured in a soil-water solution	World Soil database
Regional specific geographic variables		
Cities500k (1000 km)	Distance from cities with population > 500 000	Natural Earth data
PortsML (1000 km)	Distance from medium and large ports	World port index
Elevation mean (km)	Mean level of elevation	ESRI
Elevation range (km)	Range of elevation	ESRI
Latitude (°)	Latitude	ESRI
Longitude (°)	Longitude	ESRI
Country dummies	AT (Austria), BE (Belgium), WDE (West-Germany), EDE (East-Germany) <sup>4</sup> , DK (Denmark), ES (Spain), FI (Finland), FR (France), GR (Greece), IE (Ireland), IT (Italy), LU (Luxembourg), NL (Netherlands), PT (Portugal), SE (Sweden), UK (United Kingdom)	FADN

<sup>4</sup> We opt to divide Germany in two regions: West and (former) East Germany. Mapping residuals revealed high correlation between the NUTS3 regions of former Eastern Germany, if we only use one German country dummy. The average farm land value in West-Germany is 21475 Euro, while the average farm land value in East-Germany is only 6174 Euro.

## Appendix B: EU-15 Ricardian regressions: median and OLS

	EU-15 (median regression)		EU-15 (OLS regression)		EU-15 (aggregated OLS regression)		
	coef	se	coef	se	coef	se	se corr
Temp. winter	-0.267***	0.025	-0.271***	0.022	-0.291***	0.077	0.113
Temp. winter sq	0.001	0.002	0.008***	0.001	0.005	0.005	0.009
Temp. spring	0.370***	0.047	0.307***	0.043	0.113	0.154	0.220
Temp. spring sq	0.001	0.002	0.011***	0.002	0.022***	0.008	0.013
Temp. summer	0.228***	0.079	0.092	0.075	-0.058	0.265	0.445
Temp. summer sq	-0.012***	0.002	-0.011***	0.002	-0.010	0.007	0.012
Temp. autumn	0.184**	0.084	0.520***	0.068	0.660***	0.240	0.351
Temp. autumn sq	-0.004	0.003	-0.022***	0.003	-0.022**	0.010	0.016
Prec. winter	0.149***	0.015	0.093***	0.015	-0.010	0.055	0.094
Prec. winter sq	-0.002***	0.001	0.001**	0.001	0.003	0.002	0.004
Prec. spring	-0.333***	0.029	-0.382***	0.029	-0.396***	0.102	0.149
Prec. spring sq	0.019***	0.002	0.017***	0.002	0.019***	0.005	0.008
Prec. summer	0.150***	0.020	0.121***	0.020	0.134*	0.072	0.095
Prec. summer sq	-0.005***	0.001	-0.002	0.001	-0.003	0.003	0.004
Prec. autumn	0.025	0.017	0.067***	0.015	0.113**	0.054	0.086
Prec. autumn sq	-0.007***	0.001	-0.009***	0.001	-0.010***	0.002	0.003
t_gravel	-0.047***	0.004	-0.055***	0.003	-0.032***	0.012	0.019
t_sand	-0.004	0.003	-0.012***	0.002	0.006	0.007	0.009
t_silt	-0.003*	0.002	-0.010***	0.001	0.001	0.005	0.006
pH	0.286***	0.017	0.300***	0.015	0.289***	0.049	0.062
Rented land	-0.009	0.018	0.058***	0.018	-0.599***	0.144	0.211
Pdnsty	0.320***	0.028	0.304***	0.025	0.390***	0.085	0.084
Cities500k	-0.658***	0.098	-0.631***	0.084	-0.742**	0.307	0.427
PortsML	-1.199***	0.080	-1.184***	0.074	-0.474*	0.261	0.419
Elevation mean	-0.522***	0.058	-0.602***	0.063	-0.561***	0.215	0.287
Elevation range	0.055***	0.013	0.101***	0.012	0.185***	0.042	0.075
Latitude	-0.040***	0.007	-0.066***	0.007	-0.054**	0.024	0.038
Longitude	-0.029***	0.003	-0.022***	0.003	-0.038***	0.011	0.018
AT	-2.199***	0.065	-2.419***	0.062	-2.221***	0.216	0.274
BE	0.031	0.047	0.159***	0.055	0.509***	0.171	0.176
DK	0.938***	0.063	1.088***	0.050	1.115***	0.174	0.232
ES	-0.712***	0.063	-0.658***	0.056	-0.666***	0.188	0.268
FI	0.049	0.099	0.134	0.100	0.565*	0.336	0.385
FR	-1.276***	0.049	-1.127***	0.041	-0.914***	0.142	0.198
GR	0.566***	0.102	0.546***	0.095	0.941***	0.333	0.518
IE	1.104***	0.032	1.017***	0.030	0.829***	0.121	0.182
IT	0.924***	0.071	0.983***	0.059	1.116***	0.205	0.330
LU	-0.312***	0.054	-0.197***	0.054	0.189	0.182	0.179
NL	1.056***	0.045	1.097***	0.041	1.194***	0.148	0.132
PT	-2.229***	0.079	-2.298***	0.064	-1.780***	0.229	0.428
SE	0.221***	0.076	0.418***	0.067	0.563**	0.232	0.309
WDE	0.410***	0.047	0.387***	0.040	0.774***	0.141	0.167
EDE	-0.965***	0.066	-1.118***	0.053	-0.316*	0.182	0.232
UK	(omitted)		(omitted)		(omitted)		
cons	5.929***	0.683	8.237***	0.669	8.383***	2.369	3.773
number obs.	37612		37612		923		

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

## Appendix C: EU-15 Ricardian regressions with and without country dummies and with regional dummies

	EU-15 (country dummies)		EU-15 (no country dummies)		EU-15 (regional dummies)	
	coef	se	coef	se	coef	se
Temp. winter	-0.267***	0.025	0.064**	0.031	0.101***	0.004
Temp. winter sq	0.001	0.002	-0.001	0.002	-0.005***	0.000
Temp. spring	0.370***	0.047	0.853***	0.064	0.570***	0.008
Temp. spring sq	0.001	0.002	-0.034***	0.003	-0.019***	0.000
Temp. summer	0.228***	0.079	-0.358***	0.095	0.664***	0.012
Temp. summer sq	-0.012***	0.002	0.009***	0.002	-0.018***	0.000
Temp. autumn	0.184**	0.084	-0.491***	0.112	-0.812***	0.012
Temp. autumn sq	-0.004	0.003	0.012***	0.004	0.023***	0.000
Prec. winter	0.149***	0.015	0.356***	0.020	0.281***	0.002
Prec. winter sq	-0.002***	0.001	-0.012***	0.001	-0.004***	0.000
Prec. spring	-0.333***	0.029	-1.213***	0.044	-0.255***	0.004
Prec. spring sq	0.019***	0.002	0.068***	0.002	0.001***	0.000
Prec. summer	0.150***	0.020	0.702***	0.029	0.066***	0.003
Prec. summer sq	-0.005***	0.001	-0.037***	0.001	0.004***	0.000
Prec. autumn	0.025	0.017	0.216***	0.023	-0.043***	0.003
Prec. autumn sq	-0.007***	0.001	-0.011***	0.001	-0.004***	0.000
t_gravel	-0.047***	0.004	-0.047***	0.005	-0.064***	0.001
t_sand	-0.004	0.003	-0.028***	0.004	-0.000	0.000
t_silt	-0.003*	0.002	-0.003	0.003	-0.006***	0.000
pH	0.286***	0.017	0.672***	0.023	0.292***	0.002
Rented land	-0.009	0.018	-0.154***	0.027	0.013***	0.002
Pdnsty	0.320***	0.028	0.543***	0.040	0.256***	0.004
Cities500k	-0.658***	0.098	1.219***	0.128	-1.387***	0.013
PortsML	-1.199***	0.080	-1.247***	0.104	-0.323***	0.013
Elevation mean	-0.522***	0.058	-1.044***	0.090	-0.016**	0.008
Elevation range	0.055***	0.013	0.082***	0.018	-0.010***	0.002
Latitude	-0.040***	0.007	-0.055***	0.009	0.071***	0.001
Longitude	-0.029***	0.003	0.027***	0.002	-0.008***	0.001
AT	-2.199***	0.065				
BE	0.031	0.047				
DK	0.938***	0.063				
ES	-0.712***	0.063				
FI	0.049	0.099				
FR	-1.276***	0.049				
GR	0.566***	0.102				
IE	1.104***	0.032				
IT	0.924***	0.071				
LU	-0.312***	0.054				
NL	1.056***	0.045				
PT	-2.229***	0.079				
SE	0.221***	0.076				
WDE	0.410***	0.047				
EDE	-0.965***	0.066				
UK	(ommitted)					
regional dummies (63)					(not reported)	
cons	5.929***	0.683	10.675***	0.928	1.853***	0.108
number obs.	37612		37612		37612	***

p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1