Do Western and Eastern Europe have the same agricultural climate response?

The importance of a large adaptive capacity

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Do Western and Eastern Europe have the same Agricultural Climate Response? The Importance of a Large Adaptive Capacity.

Abstract: Combining a comparative continental-scale Ricardian technique and FADN farm-level data, this study shows that if Eastern Europe were to implement the same adaptation options as Western Europe, it could avoid a significant decrease in land value.

Keywords: Climate change ; Adaptive Capacity ; Ricardian Technique ; Europe
JEL code: Q120, O200

Introduction

It is a striking statistic that in the period 2011-2013, agricultural labor productivity in Eastern Europe was only 19% of agricultural labor productivity in Western Europe (EC, 2013). This is in spite of the investment of about 20 billion of EU and national funds to modernize Eastern European agriculture, during the period 2000-2012 (Erjavec, 2012). Clearly, there continue to be sizeable socio-economic disparities and technology gaps between Western and Eastern Europe, even though Eastern European countries entered the European Union as early as 2004 (Swinnen and Vranken, 2009). In contrast with this slow transition process, UNEP points to the urgent necessity of closing this type of technology gaps in least developed regions because climate change will have a disproportionate impact if their adaptive capacity does not increase fast enough (IPCC, 2014d; UNEP, 2014).

This paper examines this warning for Eastern Europe. It tests whether Western and Eastern Europe have a similar climate response and it determines how these climate change impacts differ over both neighboring regions. To define the climate response, the Ricardian technique is chosen. This is a statistical cross-sectional regression method that measures sensitivity of comparable land values to climate and other factors by using historical data of existing farms that face different climate and soil conditions (Mendelsohn and Dinar, 2003; Mendelsohn et al., 1994). The principal benefit of the technique is that it takes into account adaption in its estimations because farmers have already adapted to the climate in which they live (Mendelsohn et al., 2009). Building further on the work of Mendelsohn and Reinsborough (2007), this paper succeeds for the first time in looking at farmers' actual and adaptive climate response, economically valuating the benefits of unlocking Eastern European potential adaptive capacity.

In sections 1 till 5, the paper discusses successively (1) the Ricardian technique and its assumptions, (2) the data and the model specifications, (3) the empirical findings and projections of different climate scenarios, (4) the discussion and (5) the conclusion.

1. Methodology

The Ricardian model explains variation in land value per hectare of land in different regions (Mendelsohn et al., 1994). It assumes that land value reflects the present value of future net income for each farm (Ricardo, 1817; Seo and Mendelsohn, 2008a). Net income of the farm can be described as (Mendelsohn and Dinar, 2003; Wang et al., 2009):

$$net\ income = \sum P_{qi} Q_i(X_i, L_i, K_i, IR_i, C, W, Z, G) - \sum P_x X_i - \sum P_L L_i - \sum P_K K_i - \sum P_{IR} IR_i$$

where P_{qi} is the market price of crop i, Q_i is the output or production function for crop i, L_i is the vector of labor for crop i, K_i is the vector of capital, IR_i is the vector of irrigation choices for each crop i, W is the available water for irrigation, P_x is the vector for prices of annual inputs, P_L is the vector for prices for labor, P_K is the rental price of capital, P_{IR} is the annual cost of each type of irrigation system, C is the vector of climate variables, Z is the set of soil characteristics, G is a set of economic variables, X_i is the vector of purchased inputs for crop i, and R is the vector of input prices.

The net present value of net income (V) is (Mendelsohn and Dinar, 2003; Wang et al., 2009):

$$V = \int \left[\sum P_{qi} Q_i(X_i, L_i, K_i, IR_i, C, W, Z, G) - \sum P_x X_i - \sum P_L L_i - \sum P_K K_i - \sum P_{IR} IR_i \right] e^{-\varphi t} dt$$

where t is time and φ is the discount rate.

The Ricardian model is derived from the later equation by assuming that each farmer maximizes net income by choosing the optimal amount of all different endogenous variables (Q_i, L_i, K_i, IR_i) and by putting in use land with the most suitable climate for the most profitable activity, subject to the exogenous conditions ($P_q, C, Z, G, R, W, S, P_x, P_L, P_K, P_{IR}$) of each farm (Maharjan and Joshi, 2013; Mendelsohn et al., 1994). By assuming that farmers in one location, behave the same as farmers in a second location, if that location were made to look like the first one, the technique accounts for adaptation under profit-maximization (Lippert et al., 2009; Timmins, 2006). Referring to the example illustrated in the paper of Mendelsohn et al. (1994), this means that if a change in climate lowers the value of producing wheat, a profit maximizing farmer will adapt and switch to corn if these revenues are higher than those of wheat in the new climate. Corresponding to the idea of Hedonic Pricing of environmental attributes, the technique can therefore account for all possible adjustment options of which data of other farmers are available in the dataset (Lippert et al., 2009). The Ricardian model therefore consists only of a set of exogenous variables that affect farm value.

$$net\ income^* = f(P_q, C, Z, G, R, W, S, P_x, P_L, P_K, P_{IR})$$

$$V = B_0 + B_1 C + B_2 C^2 + B_3 Z + B_4 G$$

These exogenous variables can be grouped in three subgroups: climate variables (C), exogenous control variables (Z) and socio-economic variables (G). For the first subgroup, the climate variables, this study uses temperature and precipitation to describe climate. These climate data are averaged into four seasons because there is a high correlation in climate data from month to month (Wang et al., 2009). For both temperature and precipitation, a linear and a quadratic term are introduced since earlier field studies proved the non-linear nature of the net revenue function (Mendelsohn and Dinar, 2003; Mendelsohn et al., 1994). Due to the quadratic climate term, the marginal impact of a climate variable i on the value of farmland depends upon the level of the climate, C_i, in which the farm is already located (Mendelsohn et al., 2009). Interpreting the climate coefficients is therefore not straightforward and the marginal effect of climate change (determined separately for precipitation and temperature) for season i (ME_i) is therefore calculated as follows:

$$ME_i = \frac{\partial V}{\partial C_i} = \beta_{1,i} + 2\beta_{2,i}C_i$$

The sum of these average seasonal marginal effects, is the annual average marginal effect (ME). The annual marginal impact (MI) of climate (C_i) on land value per hectare for a specific farm n equals

$$MI_n(€) = V_n * \sum_{i=1}^{4}(\beta_{1,i} + 2\beta_{2,i}C_i)$$

The percentage change in land value of a certain region associated with a marginal increase in temperature or precipitation (the ME), is presented in this paper as a weighted average of all individual farm MEs in a specific region. The weight used reflects the total amount of farmland that each farm represents. The same weight is also used to present the weighted average MI per region.

Once the Ricardian model has been estimated, one can calculate what the estimated value of the land under the new climate will be (C_1) and compare this with the current climate (C_0). The difference between the two is the change in welfare (ΔW) after climate has changed from C_0 to C_1 (Mendelsohn et al., 2009). To calculate this non-marginal climate change impact, GCM models can be used (see section 2).

The second and the third subgroup of exogenous variables, control and socio-economic variables, are needed to isolate climate factors from fixed, unmeasured and climate-correlated factors (Chen et al., 2013). When land values are used, it is needed to account for population density, elevation, and distance to ports and cities to control for market access for farm products and the opportunity cost of land utilization (Chen et al., 2013). In addition, one must control for different soil characteristics as these undoubtedly have an influence on productivity. Finally, since the paper is on a continental scale, one must also control for continental influences. A special concern in Europe is whether the EU Common Agricultural Policy (CAP) distorts climate sensitivities. The paper therefore also controls for subsidies at the farm level.

2. Data and modelling

The farm-specific data (agricultural land value, subsidies and land rented) are obtained from farm accountancy data collected by the FADN in 2007 (Farm Accountancy Data Network) (FADN, 2014). FADN provides farm-specific measures of about 80.000 farm holdings in the EU-27, which represent nearly 14 million farms with a total utilized agricultural area of about 216 million hectare. FADN data are collected uniformly and consistently over Europe.

Due to privacy reasons, it is not possible to link these farm holdings to unique locational coordinates, but they can be linked to the different NUTS3 (Nomenclature of Territorial Units for Statistics regions in the EU). These are homogenous geographic units across all European countries that are identified by the EU. We use a sample of 60,694 commercial farms that utilize 5,494,626 hectare of farmland and cover by stratification 54% of all agricultural areas in the EU-27, situated in 1,143 NUTS3 regions. Consequently, the farm sample data are clustered within different countries, and therefore our dataset has a nested structure. This can lead to random effects that influence the variance of the dependent variable because the agricultural land values of observations in the same country are possibly more related to each other than to agricultural land values of observations in other countries (Crawley, 2007). Such a random effect can contain components that allow for heterogeneity, spatial and temporal correlation, random noise and nested data (Zuur et al., 2009). To take into account the added variation caused by the differences between the countries, this study uses the Linear Mixed Effect Model (LMEM). This model consists of fixed effects (that are equivalent to the Ordinary Least Squares estimates) and random country effects that allow to take into account differences between countries by allowing for a random shift around the intercept. This implies that the model assumes that the variation around the intercept is normally distributed for each country and with a certain variance (Zuur et al., 2009). Alternatively, we could use 25 country dummy variables, which would cost 24 degrees of freedom. The Restricted Maximum Likelihood (REML) is used to estimate the LMEM. Furthermore, the paper corrects for non-normality by taking the log transformation of the dependent variable. This is also suggested by Massetti and Mendelsohn (2011b) and Schlenker et al. (2006) since land values are log-normal. In addition, each farm is weighted using total owned agricultural land in that farm to further control for heteroscedasticity. Finally, outlier tests were done. The software used to run the regression model and graph the results, is the open software R (R Core Team, 2014).

All information about fixed effects (climate and control variables) is linked on NUTS3 level. The baseline climate should be representative for the recent average climate in the study region and it should be of a sufficient duration to encompass a range of climatic variations (Carter and La Rovere, 2001). This study uses the 30-year normal period for temperature and precipitation from 1961-1990 from the Climatic Research Unit (CRU) CL 2.0 (New et al., 2002). These long-run climate estimates are stable.

Soil data come from the Harmonized World Soil Database, a partnership of Food and Agriculture Organization (FAO), the European Soil Bureau Network, and the Institute of Soil Science (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009). Additional socioeconomic and geographic variables (population density, distance from urban areas, distance from ports, mean elevation, elevation range) were obtained from EuroGeographics Natural Earth data, the World port index and ESRI respectively (ESRI, 2014; EuroGeographics, 2014; National Geospatial-Intelligence Agency, 2014; Natural Earth, 2014). An overview and detailed description of all model variables and sources can be found in Appendix A.

To test the universality, consistency and the robustness of the climate response over different farmers, a distinction is made between Eastern and Western Europe. Different models are constructed to examine whether there is one climate-response function for all regions in Europe: (i) first the Ricardian technique is applied separately to Eastern and Western Europe. This is done by using a separate dataset for both Eastern and Western Europe. (ii) Then the datasets of both regions are combined and one single overarching relationship is estimated, while assuming that climate coefficients are the same for the two regions. We call this model the ‘single response model’. (iii) Finally, the later model is repeated while allowing climate coefficients to vary between the countries. This is done by multiplying a dummy for Eastern and Western Europe times each climate variable (Mendelsohn and Reinsborough, 2007). We call this model the ‘double response model’.

Once the climate-agriculture interaction model has been built, the estimated parameters of the Ricardian regression are used to simulate impacts from future climate change. This is done based on plausible climate change scenarios. A common method to develop climate scenarios is to use the output of Global Climate Model experiments

(Carter and La Rovere, 2001). To construct GCM-based climate change scenarios, an emission scenario that predicts atmospheric greenhouse gas and aerosol concentrations, should be chosen (Goodess, 2014). This paper uses GCMs that are used in the AR4 and that use the well-known IPCC approved A2 SRES scenario (Nakicenovic et al., 2000): the Hadley CM3 (Gordon et al., 2002), ECHO-G (Legutke and Voss, 1999), and NCAR PCM (Washington et al., 2000) climate models for 2071-2100. These three climate scenarios respectively represent a severe, moderate and mild possible change in climate. The mean temperature and precipitation in Eastern and Western Europe of each scenario can be found in Appendix A.

From these climate models, mean differences between the control climate and the future climate are calculated (Carter and La Rovere, 2001). Then the standard approach in climate science literature is to add these GCM projections of regional climate change of the control period, to the subregional baseline. In this way subregional variation is preserved and regression toward the mean is avoided (Fisher et al., 2012). For temperature variables, differences (future climate minus control climate), and for precipitation variables, ratios (future climate/control climate) are used (Carter and La Rovere, 2001). Finally, the climate generated by GCMs is attributed to each NUTS3 region centroid by interpolating the four closest grid points of the GCM scenario using inverse distance weights.

3. Results

Separate climate responses for Eastern and Western Europe

This section presents the three regressions modelled in this paper and explain under section 2 (see table 1). The first set of regressions study Western and Eastern Europe separately. In both regressions, more than half of the climate coefficients are statistically significant. This implies climate has a significant impact on European agricultural land values. Yet, its impact seems to be more evident in Western Europe where all but three climate coefficients are statistically significant. Also, while it is less clear for Eastern Europe, the Western response to climate change is clearly non-linear: all but one squared coefficients are significant. Looking at the control variables, it can be seen that most of them have the expected signs: a higher pH, a higher population density, and smaller distance from cities and ports, have a positive impact on land values. A higher share of land rented also has a positive impact on land value. This can be explained by the fact that farmers who rent a portion of their utilized agricultural area have more capital left for investments. Furthermore, in Eastern Europe, regions with higher elevations have higher land values. Gravel soils tend to be harmful in Western Europe but beneficial in Eastern Europe and subsidies are significant in both regressions, yet do not increase land value. This might imply subsidies have been spend on unproductive farms (Mendelsohn and Reinsborough, 2007). Finally, with respect to the random effects, there are two sources of random variation: one between countries, and one for observations within a country (Larget, 2007). The variance for the random intercept is (1.15^2) 1.3225 for Western Europe and (0.78^2) 0.6084 for Eastern Europe. It explains how much variability there is between farms over all countries. This means that the average relationship is allowed to be shifted for each country by something that is normally distributed with a variance of 1.3225 for Western Europe and 0.6084 for Eastern Europe. When comparing the variance of Eastern and Western Europe, it can be seen that the differences between farms in Eastern European countries is smaller because their variance is smaller. The residual variance on the other hand is (4.881^2) 23.8242 for Western Europe and (5.07^2) 25.7049 for Eastern Europe. It explains how much variability there is within the different countries. In this case, it can be seen that in Eastern European countries, within differences between farmers are larger than in Western European countries.

Table 2 presents the marginal temperature and precipitation effects on land value. It shows the percentage change in land value when temperature increases by 1°C, or precipitation increases with 1 cm per season. The annual marginal effects are also visualized in figure 1. All countries suffer from increases in summer temperatures. This is because warmer summers stress crops and livestock. Warmer springs on the other hand are beneficial since they lengthen the growing seasons. The effect of higher winter and autumn temperature differs between Eastern and Western Europe. In general, warmer autumns have the same effect as warmer springs, and colder winters are beneficial because they reduce the risks of pests. Nevertheless, this is only the case for Eastern Europe.

On average, Western Europe responds more positively to increasing temperatures than Eastern Europe, even though the marginal effect is also positive for Eastern Europe. When looking at precipitation however, the marginal effect is negative in most Eastern European regions, while positive for Western European regions. Yet, it should be noticed that individual differences between countries need to be taken into account as well (figure 1). Marginal climate effects differ over Europe because of a differing initial climate. Finally, figure 1 clearly shows that Southern countries in warmer climates suffer most from temperature increases, while Northern countries in cooler climates benefit from temperature increases.

Single and Double Climate Response

The second and the third regression (table 1) combine the Eastern and the Western European dataset. They respectively allow climate response in Europe not to differ between Eastern and Western Europe (Single Climate Response), or to differ between Eastern and Western Europe (Double Climate Response). In the latter case, only some variables are common to the entire data set. Of these common variables, all variables have a similar impact on land values when comparing the one and the double climate response. When looking at the climate parameters, squared climate coefficients are also very similar for the one and the double response. However, for the linear climate coefficients, a distinction has to be made between Western and Eastern Europe. For Eastern Europe, some linear climate coefficients differ significantly between the one and the double climate response. These differences cannot be noted when looking at the linear coefficients of Western Europe, which are similar to the linear coefficients of the single climate response. Clearly, Eastern Europe reacts more volatile to climate change in the double climate response regression compared to the single climate-response regression.

The marginal effects of a one unit increase in temperature and precipitation can be found in table 2 for the single and the double climate response. Figure 1 confirms that there are clear differences between both regressions. When the climate response of Eastern and Western Europe is treated as identical (single climate response), the marginal impacts of climate in Eastern and Western Europe are very similar. When the Eastern and Western climate response are assumed to be different (double climate response), three clear differences become visible when compared to the single climate-response function: firstly marginal climate impacts change to the disadvantage of Eastern Europe, while impacts do not change a lot for Western Europe. Secondly, differences between Eastern European countries enlarge. And thirdly, Eastern regions face a more negative impact than Western regions at the same latitude.

Future welfare changes

Using the Hadley CM3 (severe climate change), ECHO-G (moderate climate change) and NCAR PCM (mild climate change) scenario, this section calculates for each of the regressions the new land value after climate change has taken place according to each of the three scenarios. Table 4 displays the percentage differences between the future land value estimates and the current climate estimates for each type of this paper's regressions. This is also visualized in figure 2.

The NCAR PCM scenario shows that Eastern Europe on average immediately loses, even when climate change is only mild. Precipitation increases by 1.2 mm per year, and temperature increases by 3.1 °C per year. In Western Europe, temperature increases on average by 2.8 °C and precipitation decreases by 0.2 mm per year. As discussed when presenting the marginal precipitation effects, Eastern Europe is very sensitive to increasing precipitation. When the separate or the double climate response are taken, decreases in land value can go over 50%. Only when the single climate response is taken, Eastern Europe would benefit in the NCAR PCM scenario. For Western Europe, decreases in land value are slightly above or under 0% depending on which regression is taken.

If the ECHOG scenario would take place, one can see that Eastern Europe is on average better off than with the NCAR PCM scenario. For Eastern Europe, the increase in rainfall is 0.6 mm less than in the NCAR PCM scenario, while the temperature increases by an additional 1.6 °C. For Western Europe on the other hand, in total, rainfall decreases by 1.3 mm and temperature increases by 4.11 °C compared to the current climate. Land values in Western Europe would decrease by about 30%, independent of which regression is taken. For Eastern Europe, the same conclusions can we drawn as in the NCAR PCM scenario: if the single climate response is assumed to be the correct one, Eastern Europe benefits on average from climate. Otherwise, it faces decreases in land value of up to 54%.

In the very severe HADLEY scenario, temperature in Eastern Europe increases by 5.28 °C and precipitation decreases by 0.56 mm compared to the current scenario. For Western Europe, precipitation even decreases by 2.69 mm and temperature increases by 4.30 °C. For Eastern Europe, decreases in land values would be between 50% for the single climate response and 80% for the other two models. For Western Europe, decreases in land values would be limited to around 55% in all the models.

Furthermore, it should be noticed that Western Europe loses the most in absolute terms because the initial land values are much higher than the Eastern European land values (table 3). Yet, these changes in land values should be looked at by comparing their initial capital. A 100 euro loss per hectare could be relatively more for Eastern Europe, than for Western Europe.

4. Discussion

Since the impacts determined by the single and the double model differ significantly between Western and Eastern Europe, the question is which of the models is correct, and what explains their differences. The single climate response assumes that the coefficients of all the parameters are the same for Eastern and Western Europe, while the double climate response allows the parameters for climate to differ between Eastern and Western Europe. The answer is that neither of the models in this paper is likely to be a good representation of the Eastern European response to climate change. On the contrary, both models should be looked at together on a resilience scale from the current climate response to the most optimal climate response, where the double and the single model respectively represent the extremes on this scale.

Firstly, this is because the Ricardian technique only accounts for adaptation options that are observed in the dataset. For the double climate response, which independently looks at Eastern and Western Europe, this means that there are for each region, two inventories of potential adaptation options: one for Western Europe, and one for Eastern Europe. Since the variation in Eastern European farms is very small, and since agriculture is much less developed than in Western Europe, the inventory of potential Eastern European adaptation options is small in the double climate-response model. Therefore, the negative impact of climate change is overestimated in the double climate response because multiple plausible adaptation options, already existing in Western Europe, are not taken into account.

Looking at the single climate response, the adaptive capacity of Eastern Europe is much larger because plausible adaptation options available in Western Europe are taken into account as well. In the contrary with the double climate response, the single climate response therefore only looks at one combined inventory of potential adaptation options of both Western and Eastern Europe together. However, this is overly optimistic because before Eastern Europe has access to the same level and quantity of adaptation options as Western Europe, complex behavioral, technical, societal and institutional costs and adjustments at all levels of the society are required (Downing et al., 1997; Tol et al., 2004). Nevertheless, the Ricardian model only assumes optimal autonomous adaptation at local, farm-scale level, without looking at the broader contexts (e.g. agricultural and trade policies, policy intervention) or without acknowledging the dynamic processes needed to go from the current equilibrium to the new equilibrium (Kelly et al., 2005; Lippert et al., 2009; Mendelsohn et al., 2009; Polsky and Easterling III, 2001).

Consequently, the double climate response model represents the Eastern European climate response, with its currently low adaptive capacity, when there is no adaptation knowledge transfer from Western Europe. This is the most pessimistic model on the resilience scale. On the other hand, the single climate response model represents the most optimistic model on the other extreme of the resilience scale. This model represents the currently locked, potential adaptive capacity of Eastern Europe, if it is capable of implementing the Western European adaptation technologies. Yet, significant organizational efforts are required before this optimistic scenario can take place.

As a result, where Eastern Europe will end up on the resilience scale highly depends on how devoted policy, society and behavior are to bringing forth an encouraging and favorable adaptation context. Comparison between the double and the single model namely clearly shows that Eastern Europe does have a significant amount of unused potential adaptive capacity. The Common Agricultural Policy and National Governments therefore face the significant challenge to unlock this existing unused adaptive capacity by filling both the technology and organizational gap. With the new 2013 CAP-reform, already more attention is given to this later requirement. For instance, the CAP now contains specific support for advisory services, knowledge transfer, and cooperation between different farmers and organizations. The CAP also continues supporting agricultural research which is of high relevance since a lot of the adaptation solutions come from transferring solutions from the Western European environment. Research to test and implement these solutions in the new Eastern European environment is therefore required. Yet, at the beginning of the reform, it is still too early to judge whether the CAP will succeed in improving the adaptive capacity of the average Eastern European farmer since the budget is relatively low.

Having analyzed the data from West to East, it is also worthwhile comparing Northern and Southern regions. Confirming observations in previous studies, this study shows that Northern areas suffer less or even benefit from climate change, while impacts on Southern farms are devastating. This is because colder Northern regions that warm, are properly represented by warmer, more Southern regions in the dataset (Vanuytrecht, 2014). However, Southern farmers have less predecessor farmers who had to run a farm under such hot and dry climate conditions, from which they can learn or take an example. For the European case study this means that, when relying on new technologies, or adaptation options from other continents (which are not included in this paper's dataset), the Southern European estimates could be more positive.

Finally, for completeness, it should be noticed that differences between the models might also occur because of missing control variables or because climate is presented too simplistically. Nevertheless, the robustness of the Western European coefficients and marginal impacts over the separate, single and the double climate response should be highlighted. Since the enlargement of the adaptation options inventory does not change Western European estimates significantly, this emphasizes the fact that Eastern European farmers indeed can make significant adaptive improvements to increase their current productivity, only by enlarging their adaptive capacity with currently used Western European practices. Furthermore, since this paper's regressions specify climate as a combination of temperature and precipitation, changes in carbon dioxide concentrations are not taken into account. Higher carbon dioxide concentrations have a double impact on crops: earlier it has been proven that they increase crop yields (Kimball, 2007), but new research of Myers et al. (2014) in Nature shows that increasing levels of carbon dioxide negatively impact the nutritional content of crops.

5. Conclusion

This study traces back the concern whether climate impact estimates are consistent and robust over space, to the question whether policy, institutes, society and behavior are capable of bringing forth equal and optimal adjustment conditions over the entire region studied. Using a comparative continental scale Ricardian analysis and acknowledging its assumption of autonomous farm adaptation behavior, this paper warns against the fact that underlying adaptation requirements are not realistically applicable to certain regions.

With respect to the methodology and further applications, this paper consequently shows the benefits of testing farm systems in developing regions or transition economies with reference to those of more developed regions with comparable climate variations. It does so by modeling both a single climate-response function (implying that two regions have the same adaptive capacity) and a double climate-response function which examines the adaptive capacity of two regions separately (without assuming there is a transfer in adaptation inventory and knowledge). The comparison between the two climate response functions identifies unused adaptive capacity enlargement options and gives insights in the economic value of these potential enlargement options. Further applications of this comparative Ricardian modeling should elicit and visualize which adaptation options are included in the unused adaptive capacity.

With respect to the European case study, this paper mostly improves understanding on the differences between Eastern and Western Europe in impacts and associated costs of climate change. It shows that the region with the lowest adaptive capacity, Eastern Europe, suffers the most from climate change. However, if Eastern Europe were to apply the same adaptation options as Western Europe by 2100, then it would avoid an 11 to 63% decrease in land value depending on the climate scenario. Since it is unrealistic to assume that this will occur by counting on autonomous, profit-maximizing or market-driven farm behavior, this paper justifies the need for planned adaptation in Eastern Europe. The European Union, the CAP, country governments and regional policy must attempt to overcome the barriers to adaptation in Eastern Europe and increase Eastern European adaptive capacity by providing more information on adaptation opportunities, by enlarging the adaptation options inventory, by encouraging knowledge transfer between all European farmers, and by guiding farmers in making efficient adaptation decisions.

Appendix A

	Variable	Description	Units	Mean East	Mean West	Min	Max	Sd	Source
Farm specific	Agricultural land value	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 amount of land owned.	€/ha	1420	15818	50	621900	22938	FADN
	Land owned	Consists of land in owner occupation and land in share-cropping	ha	40.58	37.37	1	4739	94.43	FADN
	UAA	Utilized agricultural area consists of land in owner occupation, rented land, land in share-cropping.	ha	118.47	78.20	1	9808	262.52	FADN
	Farms represented	Sum of weighting coefficients of individual holdings in the sample	number	89.43	56.77	1	10550	243.76	FADN
	Subsidies	Subsidies on current operations linked to production (not investments) per UAA	€/ha	227.80	430.70	0	4981	390.59	FADN
	Share rented land	Total leased land per total utilized agricultural land	ha/ha	0.30	0.33	0	1	0.33	FADN
Soil	Gravel	Volume % gravel (materials in a soil larger than 2mm) in the topsoil	%vol	6.51	9.19	2.44	18.35	2.77	World Soil database
	Sand	Weight % sand content in the topsoil	%wt	27.64	31.53	10.83	45.93	6.45	World Soil database
	Silt	Weight % silt content in the topsoil	%wt	52.39	46.28	18.19	83.02	10.54	World Soil database
	Clay	Weight % clay content in the topsoil	%wt	19.93	21.3	5.80	44.53	5.00	World Soil database
	pH	pH measured in a soil-water solution		5.99	6.28	4.18	7.88	0.65	World Soil database
Geographic and socio-economic	Distance to cities	Distance from cities with population > 500000	km	101.73	115.23	0	843	73.80	Natural Earth data
	Distance to ports	Distance from medium and large ports	km	268.59	162.67	0	636	130.30	World port index
	Elevation mean	Elevation mean	m	199.50	382.54	0	2092	301.30	ESRI
	Elevation range	Elevation range	m	441.63	1145.45	1	4255	869.60	ESRI
	Population density	Population density in 2010	cap/km²	98.50	156.13	2	2883	189.66	ESRI, MBR, and EuroGeographics

Country	Total UAA	Total owned land	Total land represented
Austria	77,906	50,797	2,423,340
Belgium	47,478	13,714	1,163,564
Germany	1,176,215	259,528	13,887,846
Denmark	213,474	150,156	2,291,069
Spain	345,511	250,590	18,026,483
Finland	54,296	34,471	1,977,304
France	273,808	73,850	12,596,828
Greece	37,625	17,070	2,851,355
Ireland	63,316	51,414	4,722,952
Italy	412,512	275,067	10,286,832
Luxembourg	42,346	20,449	129,084
Netherlands	49,136	30,429	1,730,903
Portugal	40,428	33,208	1,615,103
Sweden	82,051	47,104	1,938,570
United Kingdom	377,615	266,165	10,518,956
West	3,293,718	1,574,009	86,160,185

Country	Total UAA	Total owned land	Total land represented
Bulgaria	111,200	14,477	1,322,985
Czech Republic	643,471	58,183	2,936,164
Estonia	118,143	42,211	851,698
Hungary	162,639	75,703	2,563,471
Lithuania	175,466	49,330	1,951,138
Latvia	192,106	82,295	1,300,086
Poland	435,538	284,297	12,404,944
Romania	192,326	130,987	6,210,678
Slovenia	14,617	7,673	465,960
Slovakia	155,401	8,777	599,898
East	2,200,908	753,932	30,607,023

	Winter				Spring				Summer				Autumn				Annual			
	C	1	2	3	C	1	2	3	C	1	2	3	C	1	2	3	C	1	2	3
PWest	6.9	7.2	7.4	7.8	6	6.4	5.6	5.4	5.6	5.2	4.4	3.2	7.2	6.7	6.9	6.6	25.7	25.5	24.4	23
PEast	3.7	4.4	4.4	4.7	4.7	5.8	5.1	5.8	7.4	7.2	6.9	5.2	4.8	4.5	4.9	4.4	20.7	21.9	21.3	20.1
TWest	3.5	6.4	7.1	6.9	9.3	11.7	12.8	12.8	18	20.6	22.7	23.7	11.4	14.5	15.9	16	10.5	13.3	14.6	14.8
TEast	-1.8	2.3	3.6	3.4	8.1	10.6	12.4	12.5	17.5	20.2	21.8	23.5	8.9	12.2	13.8	14.4	8.2	11.3	12.9	13.5

C = current climate ; 1 = NCAR PCM ; 2 = ECHO-G; 3 = Hadley CM3 ; T = Temperature (°C) ; P = Precipitation (10mm)

Table 1 All regressions

Mixed effect model	Single Climate Response						Double Climate Response			
	West		East		West + East		West		East	
	Coef	Se	Coef	Se	Coef	Se	Coef	Se	Coef	Se
Temperature winter	-0.015	0.02	-0.477***	0.05	-0.011	0.02	0.009	0.02	-0.295***	0.04
Temp. winter sq	0.007***	0.00	-0.022**	0.01	0.003**	0.00	0.006***	0.00	-0.024***	0.01
Temperature spring	0.112***	0.04	1.33***	0.14	0.193***	0.03	0.096**	0.04	1.712***	0.13
Temp. spring sq	0.024***	0.00	-0.028***	0.01	0.021***	0.00	0.025***	0.00	-0.053***	0.01
Temperature summer	0.398***	0.07	-0.943***	0.35	0.434***	0.06	0.46***	0.07	-0.953***	0.30
Temp. summer sq	-0.017***	0.00	0.003	0.01	-0.02***	0.00	-0.018***	0.00	0.004	0.01
Temperature autumn	0.339***	0.07	0.607**	0.30	0.198***	0.06	0.287***	0.07	0.127	0.27
Temp. autumn sq	-0.026***	0.00	-0.008	0.01	-0.017***	0.00	-0.024***	0.00	0.000	0.01
Precipitation winter	0.105***	0.02	0.174	0.12	0.085***	0.01	0.076***	0.02	0.017	0.11
Prec. winter sq	0.000	0.00	-0.008	0.01	0.000	0.00	0.001	0.00	-0.003	0.01
Precipitation spring	-0.196***	0.03	-0.249*	0.14	-0.209***	0.03	-0.147***	0.03	-0.025	0.12
Prec. spring sq	0.006***	0.00	0.006	0.01	0.007***	0.00	0.003**	0.00	0.003	0.01
Precipitation summer	0.123***	0.02	-0.357***	0.08	0.129***	0.02	0.134***	0.02	-0.455***	0.07
Prec. summer sq	0.001	0.00	0.019***	0.00	0.000	0.00	0.001	0.00	0.019***	0.00
Precipitation autumn	0.127***	0.01	-0.072	0.10	0.115***	0.01	0.115***	0.01	0.193**	0.08
Prec. autumn sq	-0.011***	0.00	0.008	0.01	-0.01***	0.00	-0.011***	0.00	-0.004	0.01
Population density	0.566***	0.03	0.225*	0.11	0.632***	0.03	0.565***	0.03		
Subsidies	0.000***	0.00	0.000	0.00	0.000***	0.00	0.000***	0.00		
Distance to ports	-0.585***	0.07	-1.099***	0.11	-0.869***	0.05	-0.759***	0.06		
Distance to cities	-0.916***	0.08	-0.842***	0.18	-0.78***	0.07	-0.884***	0.08		
Rented land	-0.078***	0.02	0.482***	0.02	0.13***	0.01	0.13***	0.01		
Elevation mean	0.029	0.05	0.222	0.18	0.146***	0.04	0.124***	0.05		
Elevation range	-0.012	0.01	0.071*	0.04	-0.011	0.01	-0.034***	0.01		
Gravel	-0.037***	0.00	0.06	0.01	-0.003	0.00	-0.02***	0.00		
pH	0.294***	0.01	0.036	0.03	0.261***	0.01	0.249***	0.01		
Silt	-0.022***	0.00	-0.01***	0.00	-0.017***	0.00	-0.018***	0.00		
Sand	-0.022***	0.00	-0.01***	0.00	-0.014***	0.00	-0.018***	0.00		
Constant	2.841***	0.48	10.637***	2.24	1.918***	0.44			12.017***	2.00
Dummy West	NA		NA		NA		2.363***	2.05		
Random effect countries (Std. Dev)		1.15		0.78		1.42				1.03
Random effect residual (Std. Dev)		4.881		5.07		5.02				4.97
N° of observations		42115		18577		60694				60694
AIC		134277		59660		195667				194655
BIC		134537		59895		195938				195079

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

Table 2 Percentage Land Value Marginal Effects at Median Temperature and Precipitation (%/ha per °C or cm/mo)

		Marginal effect of temperature					Marginal effect of precipitation				
		Annual	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn
Climate response separately	East	0.097***	-0.396***	0.881***	-0.852***	0.464***	-0.149***	0.114***	-0.190***	-0.081***	0.008***
	West	0.122***	0.034***	0.552***	-0.200***	-0.264***	0.078***	0.102***	-0.124***	0.137***	-0.036***
Single climate response	East	0.139***	-0.021***	0.529***	-0.260***	-0.110***	0.089***	0.082***	-0.142***	0.132***	0.017***
	West	0.115***	0.009***	0.579***	-0.277***	-0.196***	0.057***	0.008***	-0.124***	0.132***	-0.030***
Double climate response	East	-0.035***	-0.206***	0.857***	-0.806***	0.121***	-0.013***	-0.008***	0.007***	-0.166***	0.154***
	West	0.141***	0.051***	0.558***	-0.197***	-0.272***	0.083***	0.085***	-0.109***	0.148***	-0.041***

Weighted T-test to test whether values significantly different from 0 (i.e. no impact): ***p<0.01,**p<0.05,*p<0.1

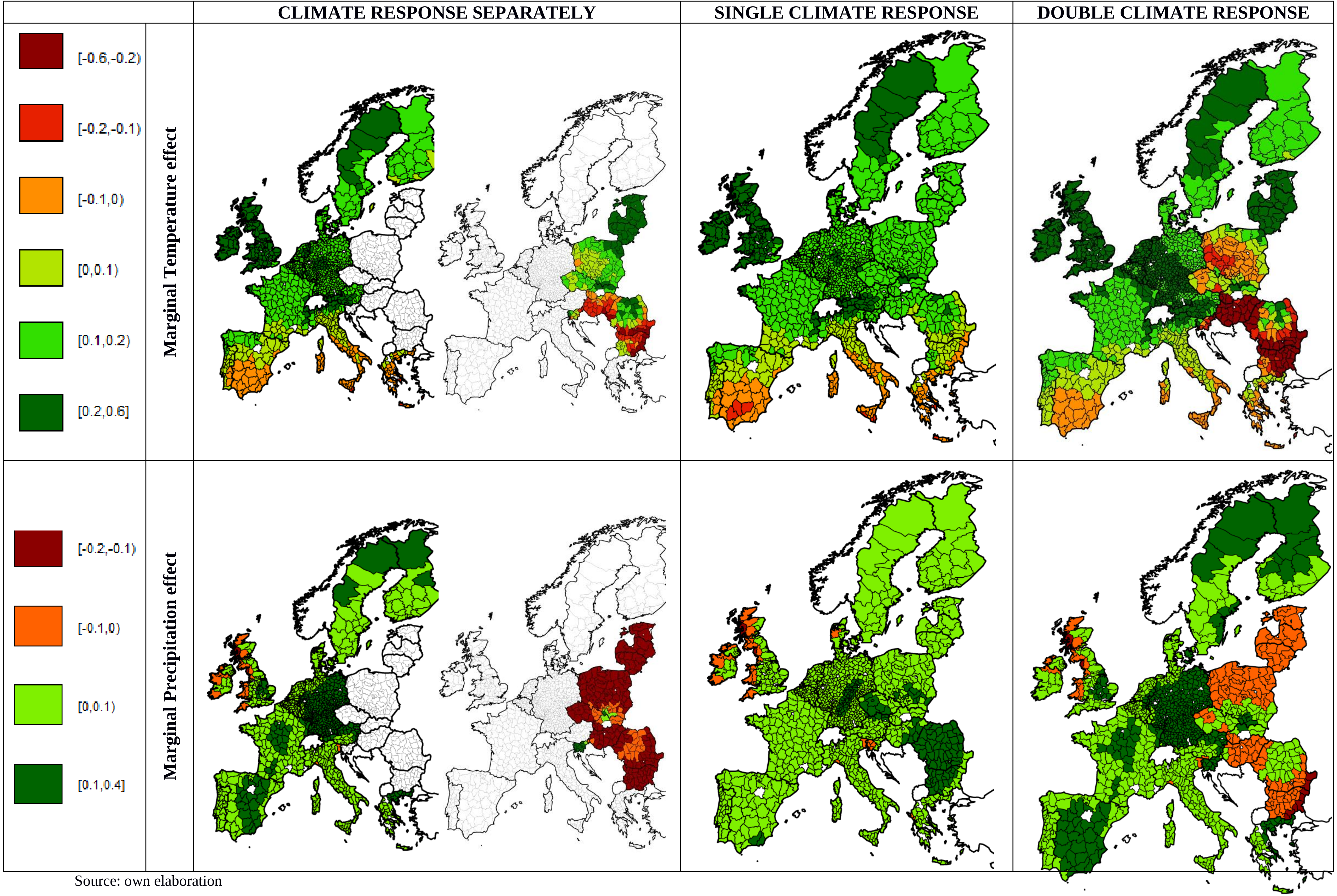
Table 3 Absolute Marginal Effects at Median Temperature and Precipitation (Euro/ha)

		Marginal impact temperature					Marginal impact precipitation				
		Annual	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn
Climate response separately	East	111.65	-554.29	-1164.81	633.20	1197.55	-155.04	147.28	-249.45	-74.88	22.01
	West	1531.43	351.66	5857.72	-1985.28	-2692.67	796.36	1090.98	-1306.33	1484.53	-472.81
Single climate response	East	205.95	-26.99	-343.84	-150.20	120.01	111.86	-182.30	726.97	181.28	9.16
	West	1445.56	92.75	-2786.83	-2016.42	567.61	853.44	-1298.82	6156.06	1411.78	-398.79
Double climate response	East	-74.77	-296.64	1160.59	-1103.66	164.94	15.67	-14.89	15.19	-189.58	204.95
	West	1733.58	542.90	5925.91	-1944.26	-2790.97	844.62	916.00	-1150.48	1601.26	-522.16

Table 4 Percentage and absolute change in land value (%/ha and Euro/ha)

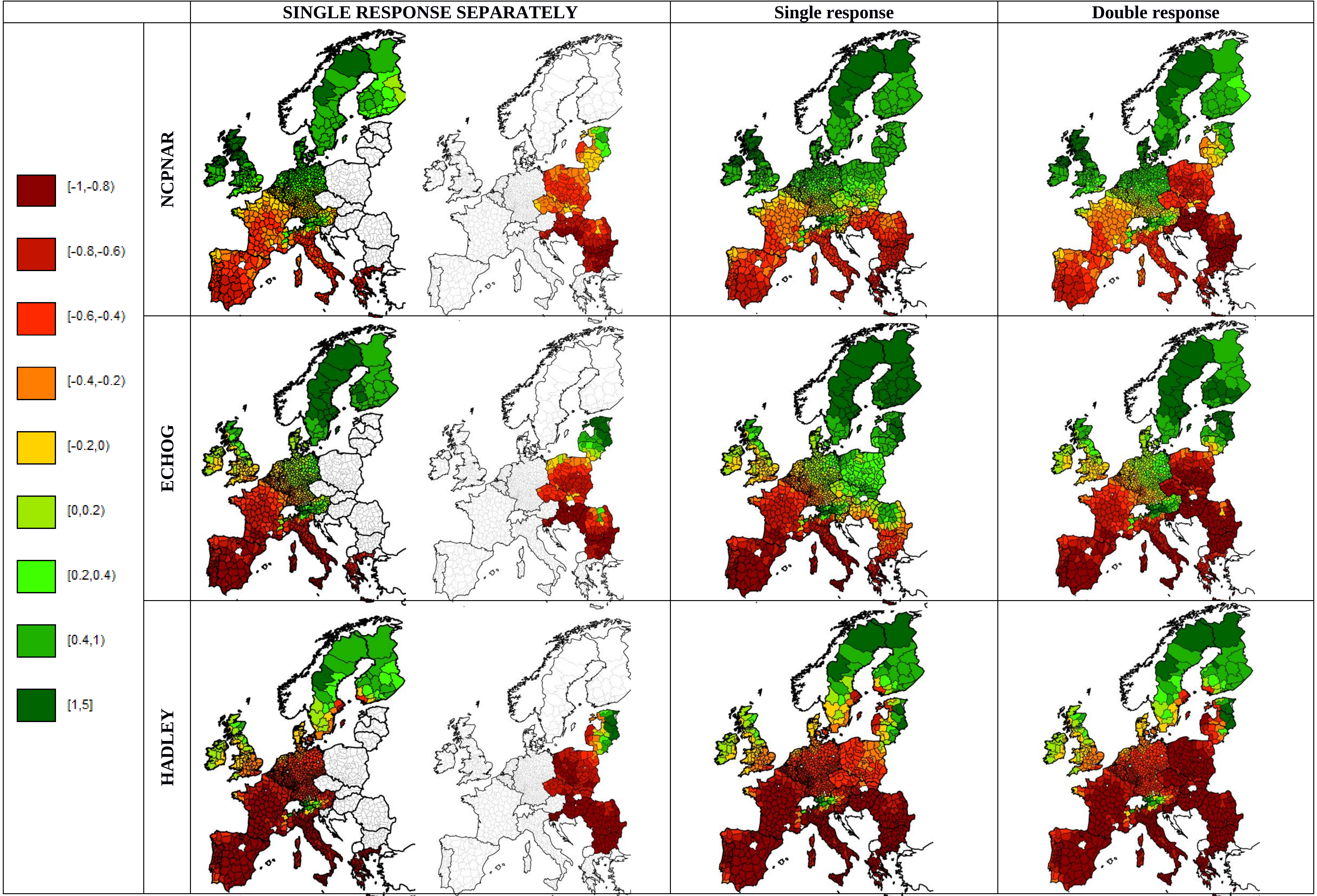
		% change in land value after climate change			Absolute change in land value after climate change		
		NCAR PCM	ECHOG	HADLEY	NCAR PCM	ECHOG	HADLEY
Climate response separately	East	-0.551	-0.542	-0.784	-544.27	-612.53	-853.50
	West	0.031	-0.306	-0.554	1151.86	-3272.76	-5743.54
Single climate response	East	0.063	0.224	-0.510	108.82	208.02	-677.10
	West	-0.001	-0.341	-0.581	1341.71	-3373.48	-5725.56
Double climate response	East	-0.461	-0.403	-0.660	-740.60	-878.49	-1057.87
	West	-0.019	-0.329	-0.563	1684.58	-2924.16	-5432.23

Figure 1 Marginal effect of temperature and precipitation



Source: own elaboration

Figure 2 Percentage change under different climate scenarios



Source: own elaboration

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