Adaptation to weather variations in intermediate areas: crop choice analysis with a structural Ricardian model[1]

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Abstract: This article assesses short-run adaptation to climate change in French intermediate areas, which may be defined as rural territories with no particular agricultural strengths. Intermediate areas are characterized by relatively poor soils, difficult socio-economic situation and are highly specialized in three crops: oilseed rape, wheat and barley. A structural Ricardian approach is used to estimate weather impacts on agricultural revenues by taking into account endogenous farmer's choices among a set of five existing cropping systems. Results show farmers will keep concentrating their production on the three general crops, even though weather variations may imply revenue losses for the corresponding cropping system.

Keywords: short-term adaptation, intermediate areas, agriculture, Structural Ricardian

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1. Introduction

Farm production is affected by several environmental factors. Among them, weather conditions are of critical importance for crop production. However, during the last ten years, weather perturbations occurrences have increased. In France, farms located in intermediate areas are especially affected by these events. These areas may be defined as rural territories with no particular agricultural strengths. They form a large area going from West-central France (Charente) to Northeastern France (Lorraine). Most of their soils are limestone with high rock rates and limited depth. Due to their nature, they also have a low available water capacity, which increases their sensitivity to late frost and drought. In these areas, crop farms are highly specialized and main crop rotation is oilseed rape, wheat, barley (Pierre, 2004). However, weather variations in the short run and climate change in the long run may contribute to reshape rotations by helping some crops to reach higher yields, whereas it may negatively affect others. For example, Brisson and Levrault (2010) shows that wheat and rape yields may increase in the long run. In this paper, we focus on the short-term impacts of weather variations. We propose to assess their impact on crop production in intermediate areas.

Several models were built in order to assess the impact of climate change on agriculture. Mendelsohn and Dinar (2010) proposes a detailed survey of these methods. Among them, the most frequently used in the literature are the Ricardian and the revenue approaches. The first one, initiated by Mendelsohn *et al.* (1994), uses the relationship between land value, as a proxy of the present value of the sum of future revenue streams, and long-term climate averages. An important feature of these models is that they take into account potential adaptations from farmers, which may help mitigating climate change impacts on farm revenue. Indeed, they suppose farmers adapt to climate change by growing the crop with the best profit, therefore switching from one production function to another as climate changes. The second one links annual farm revenues and short-term weather variations. However, these methods were criticized as they do not open the farmer's adaptation black box. Seo and Mendelsohn (2007) propose a new model built on the previous ones, the so-called structural Ricardian model. This model analyses how farmers adapt to climate variability by taking into account endogenous farmer's production choices and consists in two steps. The first one assesses the individual production choice probability of the farmer; the second one estimates the farm revenue associated with each choice and depends on weather conditions. It can show how farmers adapt by comparing their choices under different conditions. The second step is related to the classic Ricardian approach conditional to the choice made on the first step.

Previous studies using a structural Ricardian model have covered several regions and productions. Seo and Mendelsohn (2007) focused on livestock management in Africa. They show that warmer temperatures may lead to a shift from cattle to goat and sheep, whereas a wetter weather would imply a shift to goats and chickens. In Asia, Abidoye *et al.* (2017) study the impact of climate change on net revenue of farmers from several countries (Bangladesh, Indonesia, Sri Lanka, Thailand and Vietnam). They present the results of both a traditional Ricardian model and a structural one. Climate change may have different impacts on the countries of the study depending on the climate scenario retained. The results of the structural Ricardian model show that farmers will switch from one growing season to three growing seasons as climate change should have a negative impact on net revenues related to one growing season and a positive impact for three growing seasons. Ahmed and Schmitz (2015) studied climate change impacts on crop farms in Pakistan. They show that without adaptation, the crop sector may face major losses; however, with correct adaptations, i.e. shifts from some crops to others, farmers may actually benefit from climate changes. They also identify the optimal range of temperatures and precipitations for each crop. Moniruzzaman (2015) also studied climate change impacts in Bangladesh. He concludes that Bengalese farmers may change the rice varieties they grow to adapt to climate change. In Europe, Chatzopoulos and Lippert (2015) model the farm type changes of German farms. They simulate the most profitable farm type under a range of different weather conditions: in higher temperatures, crop farms should become dominant, but precipitations increases are more favorable to forage and mixed farms.

To the best of our knowledge, there is no study using a structural Ricardian model applied to French farms. Moreover, there are no empirical evidence on weather or climate impacts on agriculture in intermediate areas. The French case was studied as a part of European agriculture by Van Passel *et al.* (2007), Vaitkeviciute *et al.* (2019) and Vanschoenwinkel and Van Passel (2018). Ay *et al.* (2014) linked climate change, land use and bird abundance at the national French scale and Martin and Vaitkeviciute (2016) focused on the Côte d'Or *département*, which contains some intermediate areas. However, these studies use a traditional Ricardian model and do not investigate adaptation patterns. Therefore, this paper contributes to the existing literature by applying the structural Ricardian model to French farms located in intermediate areas for the first time and assessing the impacts of weather variations on crop choice.

2. Methodology

We construct a two-stage model based on pioneer works of Seo and Mendelsohn (2008) on the so-called Structural Ricardian approach. The model is based on the hypothesis that farmers make their decisions under a profit maximizing behavior. Due to our sample characteristics, we assume that farmers make cropping system choices that maximize their profits. More precisely, farmer will choose one cropping system over all cropping system types available, that offers the highest net revenue given the exogenous factors such as weather or soil.

More formally, let's assume that each farmer *i* chooses a cropping system j, with *j=1,…,J* Then we can write the profit of cropping system j (π_j) as follows:

$$\pi_{ij} = Z_{ij}\gamma_{ij} + \epsilon_{ij}, \quad j = 1, \dots, J, \tag{1}$$

with index j indicating the categorical variable for all available cropping systems among J alternatives. The vector Z represents the set of determinants of the net revenues for all the alternatives j, and ε is the error component. When farmer i decides which cropping system to grow, he chooses the one with the highest profit. Thus, $\pi_{i1}^{*}$is observed only if cropping system 1 is chosen:

$$\pi_{i1}^{*} > \pi_{ik}^{*}, \qquad \forall k \neq 1 \tag{3}$$

That is,

$$\epsilon_{ik} - \epsilon_{i1} < Z\gamma_{i1} - Z\gamma_{ik}, \forall k \neq 1 \tag{4}$$

In a first step, the model identifies the probability P_{i1} to choose the first cropping type (1), which is:

$$P_{i1} = \Pr[\epsilon_{ik} - \epsilon_{i1} < Z\gamma_{i1} - Z\gamma_{ik}], \forall k \neq j. \tag{5}$$

Therefore, the probability that farmer *i* chooses the cropping system 1 among the set of available cropping type alternatives *J*, can be expressed as:

$$P_{i1} = \frac{\exp(Z\gamma_{i1})}{\sum_{k=1}^{J} \exp(Z\gamma_{ik})} \tag{6}$$

Given the cropping system 1, farmer will then choose inputs and outputs to maximize the net revenue from this farm type. The optimal profit could be directly estimated with the vector of *Z* variables from equation (1), but would introduce a selection bias. This selection bias should be corrected to obtain consistent estimator. Thus, the second step of the model estimates the conditional net revenues correcting for selection bias:

$$\pi_{i1} = X_{i1}\phi_{i1} + \sigma \sum_{k \neq 1}^{J} r_{ik} \left(\frac{P_{ik}.\ln(P_{ik})}{1 - P_{ik}} + \ln(P_{i1}) \right) + w_{i1} \tag{7}$$

Where Z_{i1} is a set of independent variables including weather and soil variables, ϕ_j is a vector of parameters to be estimated, r_{ik} is the correlation between the profit and choice equations, σ is the standard error of the profit equation and w_{i1} an error component.

3. Data

We focus on a sample of crop and mixed farms located in the French Yonne *département.* A balanced panel of 952 observations was provided by a French accountancy network (CerFrance) for years 2012 to 2016. The 952 surveyed farms manage 177 710 hectares of utilized agricultural area (UAA), accounting for 40 % of total UAA in the Yonne *département* (Agreste, 2013). 90 % of the sample is made of crop farms, with the only 10% remaining being mixed farms. In this area, the average farm size is 187 ha, which is bigger than the French average of 127 ha for crop farms. 38 % of the farms in the sample are located in intermediate areas. These areas may be defined as rural territories with no particular agricultural strengths. They are characterized by clay-limestone soils with high rock rates and limited depth. As a result, these soils also have a low available water capacity, which increases their sensitivity to late frost and drought. Therefore, farms located in these areas have lower yields: they reach an average of 5.9 T/ha of wheat, whereas farms outside these areas produce 6.9 T/ha (Table 6 in Appendix). This may be explained by a poor soil quality limiting crop diversification possibilities. These constraints lead to 78 % of the utilized agricultural area being used for wheat, oilseed rape, or barley (winter and spring), the three main crops in the area. Other crops grown include maize, sunflower, pea or alfalfa. In order to control for these disadvantaged areas, we use a dummy variable taking the value of 1 if the farm belongs to an intermediate area, and 0 otherwise.

The first step of the evaluation assesses probabilities of choosing a particular cropping system among five: (1) mono-crop of one dominant general crop[3], (2) a combination of two general crops, (3) a combination of all three general crops, (4) a combination of two crops with one non-general crop or dominant non-general crop, and (5) other cropping systems. Characteristics of these cropping systems are presented in Table 6. These five cropping systems were defined based on the land share of the farm UAA devoted to each crop. If one crop accounts for more than 40 % of the utilized area and the other less than 30 %, then this one crop is dominant (cropping system 1). Otherwise, if a combination of two cultures accounts for more than 50 % of the utilized area, then those two crops are dominant (cropping system 2). Between these two crops, if one of them is not specified in the database, i.e. is not a general crop, then the farm is classified into a specific class (cropping system 4). This fourth cropping system also includes dominant non-general crops. Farms growing between 20 and 40 % of three general crops are classified as multi-crop (cropping system 3). The last group contains farms were three or more crops are grown, among them a non-dominant crop.

For the second step, the dependent variable is the farm's net crop revenue, defined as the average net revenue per ha for each cropping system. The net revenue is computed as the farm's gross crop revenue without subsidies minus total operational expenses. Gross margins by crop were calculated based on the French accountancy network (CerFrance) data and technical institutes cost reference values.

Daily weather data are provided by Météo France at the municipality scale. We aggregate these data to the district[4] scale as the precise farm location is not available, and calculate seasonal temperature averages and total precipitations (see Table 6 in Appendix). The choice of appropriate variables is of crucial importance in order to obtain proper estimations. Vaitkeviciute *et al.* (2019) study the effect of different climate variables choices. They show that in Europe, the estimates are better for the four-season model compared to the two-season and the growing season ones due to a presence of winter crops in European agriculture. The agriculture of Yonne *département* has similar characteristics and, thus, justifies the choice of four-seasons weather variables. For the estimation of conditional net revenues, we add a quadratic term for both temperature and precipitations following previous literature (Mendelsohn et *al*., 1994 ; Seo, Mendelsohn, 2008 ; Chatzopoulos, Lippert, 2015).

Other factors may affect agricultural productivity and reflect agronomic potential, especially soil characteristics (Martin and Vaitkeviciute, 2016). We use soil data from the European Soil Database[5], derived using soil point data from the LUCAS[6] 2009 soil survey. Dataset contains 500x500m resolution raster from whom we identify the proportion of dominant soil textures (silt, clay and sand), the average water capacity, and coarse and bulk densities for each district.

We also include population density, provided by INSEE[7] at the district scale. Population density can be interpreted in two ways. First, it can be interpreted as a proxy for the urbanization rate of the area and, thus, measure the proximity to urban centers. Farms located in more urbanized areas might be more likely to have higher farm revenues due to their location advantage. Farms

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[3] General crops in this study: oilseed rape, wheat and barley.

[4] The word « district » accounts here for the French "canton", an administrative division composed of a few municipalities.

[5] European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre

[6] The Land Use and Cover Area frame Statistical survey (LUCAS)

[7] French National Institute of Statistics and Economic Studies

situated closer to urban areas (thus, with higher population density) are assumed, following the hypothesis of Von Thünen's concept of homocentric rings, to produce goods that are more expensive and more difficult to transport. Proximity to urban areas is expected to be more attractive to farmers to install their activity and to increase farmers' productivity due to the alternative of easier product distribution and the possibility of growing higher added value products closer. The second way to interpret population density is as the proxy for the less favored areas for agriculture (Chatzopoulos and Lippert, 2015). Higher agriculture abandon rates can be expected when population density is low due to the lack of attractiveness in these areas.

Table 1 : Descriptive statistics by cropping system

	Cropping systems					
	General crops			Other crops		
	1	**2**	**3**	**4**	**5**	**Total**
Number of farms	1103	507	1197	845	1108	4760
Part of farms in intermediate areas	29%	29%	42%	42%	44%	38%
UAA (ha)	175	187	185	192	196	187
Yields						
Wheat (T/ha)	6.57	6.75	6.68	6.10	6.38	6.49
Oilseed rape (T/ha)	2.99	3.04	2.95	2.83	2.87	2.93
Barley (T/ha)	6.56	6.70	6.52	6.00	6.22	6.40
Revenues (€/ha)	530	565	515	337	339	451
Population density (hab./km²)	58	54	46	43	49	50
Soil						
Clay (%)	26	26	26	26	26	26
Sand (%)	25	25	24	26	25	25
Silt (%)	49	50	49	48	49	49
Coarse (%)	15	15	16	15	16	15
Available water capacity	0.10	0.10	0.10	0.10	0.10	0.10
Bulk density (T/m3)	1.25	1.25	1.23	1.21	1.22	1.23
Precipitations						
Spring (mm)	77	77	76	78	77	77
Summer (mm)	61	61	62	62	63	62
Autumn (mm)	75	76	76	77	77	76
Winter (mm)	58	58	60	60	60	59
Temperatures						
Spring (°C)	9.91	9.88	9.98	9.93	9.93	9.93
Summer (°C)	19.03	19.01	18.96	18.94	18.95	18.98
Autumn (°C)	11.61	11.61	11.62	11.63	11.63	11.62
Winter (°C)	4.20	4.21	4.18	4.15	4.18	4.18

Sources: MétéoFrance, CER France, INSEE, European Soil Database

4. Empirical results

Farmers' choices depending on weather variations and soil characteristics for five cropping systems are estimated: (1) mono-crop of one dominant general crop, (2) a combination of two general crops, (3) a combination of all three general crops, (4) a combination of two crops with one non-general crop or dominant non-general crop, and (5) other cropping systems. Table 2 shows the results of the multinomial logit regression estimating the probability for each farmer to choose between different available cropping systems. The model includes precipitation, temperature and soil variables. The base case is the cropping system 1, which is based on the choice of one general crop among wheat, barley and oilseed rape. Few farms opt for barley or rape as the main crop. Therefore, wheat is the main crop of this farm type (93 % of the sample).

First step estimation results offer highly significant coefficients for weather variables. Estimated coefficients for spring temperatures are positive and significant for farming systems 4 and 5, while significantly negative for the probability of simultaneously growing the three general crops (3). Therefore, a higher spring temperature is in favor of choosing cropping systems combining non-general crops. Compared to the reference class, it also reduces the probability to choose cropping system 3. A warmer summer leads farmers to abandon cropping system 1 in favor to all the remaining cropping systems (except system 2, which is non-significant). An increase in autumn temperatures decreases significantly the probability to opt for cropping systems 4 and 5, which include non-general crops, compared to the reference. The estimated coefficient associated with winter temperature is only significant for the cropping system 3, which is based on the combination of all three general crops. Thus, a warmer winter will reduce the probability to choose this cropping system compared to the base case.

Table 2 : Multinomial logit choice of cropping system

	Cropping system			
	2	**3**	**4**	**5**
Intercept	1.762	-8.344*	-10.094**	-11.266**
	(6.03)	(4.532)	(4.642)	(4.45)
Temperature				
Spring	-0.142	-0.335*	0.487**	0.460***
	(0.209)	(0.171)	(0.189)	(0.171)
Summer	-0.041	0.471***	0.542***	0.374**
	(0.212)	(0.161)	(0.168)	(0.159)
Autumn	-0.19	-0.011	-1.182***	-0.931***
	(0.396)	(0.31)	(0.334)	(0.312)
Winter	0.063	-0.712***	0.358	0.417
	(0.326)	(0.256)	(0.282)	(0.259)
Precipitations				
Spring	-0.003	-0.015***	0.008	0.010*
	(0.007)	(0.005)	(0.006)	(0.005)
Summer	0.015	-0.020*	0.031**	0.033***
	(0.014)	(0.011)	(0.013)	(0.012)
Autumn	-0.002	-0.025**	0.043***	0.037***
	(0.015)	(0.012)	(0.014)	(0.013)
Winter	-0.017	0.090***	0.071***	0.039**
	(0.017)	(0.019)	(0.02)	(0.018)
Soil				
Clay	0.013	-0.067	-0.231***	-0.163***
	(0.056)	(0.044)	(0.048)	(0.045)
Silt	0.025*	0.019*	-0.094***	-0.025**
	(0.013)	(0.011)	(0.013))	(0.011))
AWC	4.392	55.195***	73.107***	60.454***
	(18.119)	(14.381)	(15.945)	(14.699)
N	845	1197	1103	1108

Pseudo $R^2 = 0.026$
Log Likelihood = -7,280.509

Likelihood Ratio Test (df=48) = 391.908***

Notes: *, ** and *** respectively denote 10%, 5% and 1% significance levels. Standard deviations in parenthesis. Cropping systems: 1 - one dominant general crop (the base case); 2 - combination of two general crops; 3 - combination of all three general crops; 4 - combination of two crops with one non-general crop and dominant non-general crop; and 5 - other cropping systems.

Almost all the estimated coefficients associated with precipitation variables are significantly different from zero for cropping systems 3, 4 and 5. Wetter weather at all seasons is estimated to reduce the probability of choosing the farm type based on the combination of all three general crops (3), compared to the reference. Nevertheless, farmers are more likely to choose crop systems 4 and 5 with increasing precipitations at all seasons.

The soil type variables are also estimated to be significant. Growing one general crop (Type 1) is more likely to be chosen on a clay soil, while a higher silt proportion in the soil goes in favor of cropping systems 2 and 3, and the inverse for the remaining crops. Finally, the available water capacity is positively significant, leading to the conclusion that a higher water capacity increases the probability to select other cropping system than the base case.

In order to interpret the estimates in terms of weather vulnerabilities of the five cropping systems, marginal effects of weather variables were calculated on the choice probability of each cropping system. They are presented in Table 3. Marginal effects measure the variation in percentage of the probability of choosing a particular cropping system when temperature increases by 1°C and precipitation increases by 1 mm. Thus, an increase in temperature decreases the probability to choose the cropping system combining all three general crops (3) by 13.1% and the cropping system based non-general crops (4) by 2.5% in favor of the remaining farm types. A small increase in precipitation increases the probability of choosing cropping systems 1 (1.6%) and 2 (1.4%), and decreases for other alternatives. These results could seem counterintuitive; however, they reflect well the specificities of the region studied. Indeed, due to difficult soil and socioeconomic conditions, farms are highly specialized in crops. Warmer and wetter weather appears to be factors leading farmers to specialize even more in general crops in Yonne's *département*.

Table 3 : Marginal effects on the choice probability of each cropping system (%)

	Cropping systems				
	1	**2**	**3**	**4**	**5**
Spring temperature	6.7	8.8	-10.9	-2.5	-2.2
Summer temperature	4.2	1.8	4.4	-3.5	-6.9
Autumn temperature	-12.6	-11.6	11.1	2.7	10.4
Winter temperature	6.3	10.3	-17.7	0.8	0.3
Total marginal effect of temperature	5.0	9.0	-13.1	-2.5	1.6
Spring precipitations	0.1	0.3	-0.4	-0.02	0.01
Summer precipitations	0.4	0.5	-0.7	0.1	-0.2
Autumn precipitations	0.6	0.7	-0.9	-0.1	-0.2
Winter precipitations	0.5	-0.1	1.2	-0.6	-1.0
Total marginal effect of precipitation	1.6	1.4	-0.8	-0.7	-1.4

Notes: Marginal effects are calculated at the sample mean of each cropping system. All values are in percentage of choice probability.

Having chosen a cropping system, a farmer maximizes the net revenue from that system by choosing inputs and outputs optimally. In Table 4 we estimated the conditional net revenue for each of the farm systems (*preliminary results*), including squared weather variables and controls for soil quality, population density and the fact of belonging to intermediate areas. The probabilities of choosing different cropping systems estimated by multinomial logit model in the first step leads to only four of five cropping system options as cropping system 2 is not the dominant probability for any farm. Thus, the conditional net revenue regressions concern farm types 1, 3, 4 and 5.

The estimated models have a good quality as adjusted R^2 goes from 0.50 to 0.74, and F-statistics show that estimated coefficients are globally significant. However, coefficients associated to weather variables are significantly different from zero only for cropping systems 1 and 3.

The results show that agriculture responds differently to weather variations depending on the cropping system. For the first cropping system, based on the choice to concentrate the production on one general crop, mostly wheat, summer temperature and winter precipitation appear to play a major role as they are estimated significantly. The model estimates a decrease at an increasing rate impact of warmer summer, and a concave relationship between winter precipitation and conditional revenue. A warmer summer is estimated to be harmful after the optimal temperature level situated at 19.1°C. Knowing that the average summer temperature observed for the farms with the dominant probability to choose cropping system 1 is around 19.3°C, a major part of farms is probably already experiencing negative summer temperature effects on agricultural revenues.

On the contrary, cropping system 3, based on the choice to concentrate the production on the combination of the three general crops, is more sensitive to spring and winter temperature variations. Warmer temperatures in spring and winter will be harmful for agriculture in crop system 3. The optimal spring temperature level is around 10.5°C, thus a spring average temperature below 10.5°C will result in a positive marginal temperature impact, and temperatures over this threshold will have a negative impact. Similar effects are estimated for winter temperature with the threshold of 5 °C for optimal winter temperature level. Currently, the average winter temperature is below the optimal threshold. Therefore, some farmers still have a decreasing positive marginal impact on their revenues.

Table 4: Conditional net revenue regression (€/ha)

	Cropping systems			
	1	3	4	5
Constant	34,105.400***	6,126.772	-118,881.100	-139,520.600
	(11,529.060)	(31,382.170)	(238,519.300)	(2,373,778.000)
Temperature				
Spring	23.824	-5,904.979**	-5,890.226	-40,802.650
	(549.617)	(2,438.797)	(7,146.836)	(148,374.700)
Summer	-2,936.440**	2,718.523	8,040.685	47,881.290
	(1,166.312)	(2,600.943)	(18,710.960)	(266,146.700)
Autumn	-1,413.027	1,765.475	11,978.670	-27,287.060
	(1,078.047)	(2,592.276)	(15,152.230)	(78,435.430)
Winter	165.260	-4,089.413***	-472.787	16,972.720
	(252.215)	(1,412.205)	(4,757.344)	(25,429.690)
Spring^2	3.775	282.116**	266.025	2,364.885
	(28.582)	(122.386)	(276.964)	(8,140.350)
Summer^2	76.882**	-67.519	-200.835	-1,315.903
	(30.057)	(69.515)	(449.054)	(6,866.285)
Autumn^2	69.266	-74.563	-511.405	1,169.122
	(45.788)	(127.433)	(628.725)	(3,397.426)
Winter^2	-73.568**	409.655***	13.287	-1,786.728
	(29.385)	(137.238)	(372.726)	(4,184.650)
Precipitations				
Spring	-24.581**	-31.621	-12.992	75.107
	(10.143)	(26.659)	(30.919)	(543.387)
Summer	1.158	88.259*	-18.471	446.410
	(12.329)	(52.475)	(182.761)	(2,572.591)
Autumn	9.695	97.401	151.395	-488.291
	(9.710)	(69.071)	(394.387)	(817.977)
Winter	80.604***	-365.065***	-9.810	-112.431
	(29.993)	(79.432)	(150.885)	(376.057)
Spring^2	0.084	0.115	-0.043	-0.102
	(0.060)	(0.146)	(0.241)	(2.778)
Summer^2	-0.006	-0.551	0.347	-3.609
	(0.102)	(0.425)	(1.671)	(21.037)
Autumn^2	-0.079	-0.859*	-1.083	3.820
	(0.058)	(0.518)	(3.020)	(5.911)
Winter^2	-0.792***	2.622***	0.053	
	(0.269)	(0.601)	(0.694)	
Observations	1,675	2,024	269	765
R2	0.745	0.535	0.539	0.691
Adjusted R2	0.741	0.529	0.503	0.685
Residual Std. Error	174.901 (df = 1651)	191.512 (df = 2000)	186.547 (df = 249)	161.314 (df = 749)
F Statistic	209.322*** (df = 23; 1651)	99.937*** (df = 23; 2000)	15.295*** (df = 19; 249)	111.520*** (df = 15; 749)

Notes: *, ** and *** respectively denote 10%, 5% and 1% significance levels. Cropping systems: 1 - one dominant general crop; 3 - combination of all three general crops; 4 - combination of two crops with one non-general crop and dominant non-general crop; and 5 - other cropping systems.

Table 5 shows the marginal effects of weather variables in €/ha of crop and for the whole farm. The marginal values correspond to the significant coefficients of the conditional net revenue regressions. As no coefficient is significant for cropping systems 4 and 5, they are not presented here.

Table 5 : Marginal values for each predicted cropping system

	Cropping system		**Cropping system**	
	1	**3**	**1**	**3**
	€/ha		**Total in €**	
Spring temperature	NA	-170.80	NA	-32,211
Summer temperature	6.42	NA	1,145	NA
Autumn temperature	NA	NA	NA	NA
Winter temperature	NA	-631.27	NA	-119,048
Total marginal effect of temperature	6.42	-802.08	1,145	-151,259
Spring precipitations	-11.87	NA	-2,119	NA
Summer precipitations	NA	15.46	NA	2,916
Autumn precipitations	NA	NA	NA	NA
Winter precipitations	-4.87	-38.60	-868	-7,278
Total marginal effect of precipitation	-16.74	-23.13	-2,987	-4,362
Total marginal effect of weather variables	-10.32	-825.21	-1,842	-155,621

Notes: Marginal effects are calculated at the sample mean of each cropping system. Total marginal effects are calculated by multiplying marginal values per hectare by the agricultural area.

First, coefficients for autumn variables are never significant. This may be explained by the fact that cropping systems 1 and 3 are based on crops usually sown in middle-autumn (except for rapeseed). Autumn conditions have therefore a low impact on conditional revenues for these systems. A 1°C increase of temperatures has a small positive effect on cropping system 1, but a high negative effect on cropping system 3, which appears to be highly vulnerable to higher spring and winter temperatures. However, for both systems, a 1 mm precipitations increase has a negative impact, generating a loss of 16.7 €/ha for cropping system 1 and 23.1 €/ha for cropping system 3, mostly because of the negative effect of an increase in winter precipitations. Finally, the total marginal effect of both temperature and precipitation is negative for both systems. However, the effects appear to be much higher for cropping system 3, where a temperature increase may lead to negative revenues, with a decrease of 825 €/ha, that is 155,621 € at farm scale.

5. Conclusion and discussion

This paper is the first application of a structural Ricardian model to French farms, and especially in intermediate areas. It evaluates farmer's behavior regarding his cropping choices depending on weather conditions and measures how weather variations impact farmer's short-term revenues. First, a multinomial logit model is used to assess a probability of choosing one cropping system among a set of five. Then, based on these predicted probabilities, conditional net farms revenues are estimated. This method allows us to consider how agricultural landscape will evolve in the near future due to changes in weather.

The first step of the model confirms that weather evolution will contribute to reshape cropping systems in our sample. The use of seasonal temperatures helps us to refine the effects of temperature and precipitation variations. Indeed, an increase in spring temperatures leads to a higher probability of adopting farming systems with non-general crop, whereas an increase in autumn temperatures increases chances to stay with the general crops. This estimation also takes into account soil types, and the significance of the coefficients associated with soil variables confirms the importance of soil quality.

The second step of the model estimates how farm revenue is impacted by weather, controlling for soil type and other control variables. The effects depend on the farm type; for example, it shows that for farms having one dominant crop (cropping system 1), net revenue should decrease with warmer summers and wetter springs.

These results emphasize the short-term impacts of weather on Yonne's agricultural sector and offers some tools to discuss the needs of short-term adaptation measures. Indeed, farmers are estimated to favor the specialization to one dominant crop when weather becomes warmer and wetter, despite the loss of agricultural revenues under these weather conditions associated to this cropping system. The choice of this highly specialized cropping system may be due to the particular Yonne's agricultural structure, however it actually leads to maladaptation. Thus, the support of public policy is needed to avoid the maladaptation and to encourage farmers to diversify.

It must be reminded that this study is based on weather variations and not long-term climate ones, and therefore assesses short-term adaptations. What is more, data availability led us to make choices that may limit the results' accuracy. The low diversity of crops and cropping systems in the area studied makes it difficult to identify differences between cropping systems. The cropping systems classification retained aggregates several crops grown on small areas under one category in be able to estimate consistent choice probabilities. Therefore, there is a loss of information on marginal crops, which may become more important in the future. What is more, the model does not take into account the possibility for farmers to grow new crops. For example, sorghum might be an interesting alternative in the face of drought increase, as it needs less water than the current crops produced in the area. Finally, the model robustness may be enhanced by taking into account time effects.

Future work could include a long-term assessment of farmers located in intermediate areas adaptation to climate change. We focus on a rather small area, but it could also be useful to apply this method to other intermediate areas in France in order to develop specific policies, which is not currently the case, even though the specific needs of intermediate areas are recognized.

6. Appendix

Table 6 : Descriptive statistics and data sources

Source	**Variable**	**Intermediate areas**	**Plain**	**Total**
CER France	Average UAA (ha)	203	177	187
		(107)	(86)	(95)
CER France	**Yields**			
	Wheat (T/ha)	5.86	6.88	6.49
		(1.56)	(2.00)	(1.91)
	Oilseed rape (T/ha)	2.42	3.22	2.92
		(1.01)	(0.97)	(1.07)
	Barley (T/ha)	5.46	6.79	6.28
		(2.09)	(2.37)	(2.34)
CER France	**Revenues**			
	Wheat (€/ha)	430	599	535
		(345)	(406)	(392)
	Oilseed rape (€/ha)	341	658	540
		(323)	(319)	(355)
	Barley (€/ha)	278	493	411
		(239)	(318)	(309)
	Other (€/ha)	341	523	454
		(269)	(330)	(320)
INSEE	Population density (hab./km²)	27	64	50
		(62)	(87)	(81)
European Soil database	**Soil**			
	Clay (%)	28	25	26
		(1.3)	(2.0)	(2)
	Sand (%)	22	27	25
		(3.1)	(4.5)	(5)
	Silt (%)	50	49	49
		(1.9)	(4.8)	(4)
	Coarse (%)	17	14	15
		(0.6)	(0.9)	(2)
	Available water capacity	0.11	0.10	0.10
		(0.003)	(0.006)	(0.01)
	Bulk density (T/m^3)	1.15	1.28	1.23
		(0.04)	(0.08)	(0.09)
Météo France	**Precipitation**			
	Spring (mm)	83.29	72.82	76.79
		(28.28)	(25.29)	(26.95)
	Summer (mm)	62.34	61.64	61.91
		(13.34)	(16.86)	(15.62)
	Autumn (mm)	81.31	73.01	76.16
		(16.38)	(18.76)	(18.34)
	Winter (mm)	61.67	57.48	59.07
		(10.09)	(9.62)	(10.01)
Météo France	**Temperature**			
	Spring (°C)	9.91	9.95	9.93
		(0.95)	(0.88)	(0.91)
	Summer (°C)	19.04	18.93	18.98
		(0.76)	(0.74)	(0.75)
	Autumn (°C)	11.58	11.64	11.62
		(0.73)	(0.72)	(0.72)
	Winter (°C)	4.02	4.28	4.18
		(1.06)	(1.03)	(1.05)

Notes: Mean values, standard deviations in parenthesis.

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