The impact of climate change on agriculture in an Alpine region: A Ricardian analysis

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Abstract

The Ricardian approach has been widely applied to many different geographic contexts but most applications concern big countries. Only few studies deal with Europe. This paper applies the Ricardian approach to measure the impact of climate on agriculture in a small Italian region on the southern slope of the Alpine range. Structural and economic data about farmers growing apples and grapes are extracted from the Italian Farm Accountancy Data Network (FADN). Average values of net revenue 2003 and 2006 are used in the estimation so that results reflect more than a single year effect. The importance of controlling for some strategic decisions made by farmers is highlighted. Results show that provided there is enough climatic variation across the sample and control variables are suitable, the Ricardian approach can reveal the influence of climate also on a small territorial scale but the results depend heavily on the adopted functional form.

Keywords: climate change, Ricardian model, FADN, permanent cultivations, Trentino.

1. Introduction

Climate change is a real concern for the sustainable development of agriculture, both globally and within Europe (AEA, 2007). Effects of climate change on agro-systems depend on their exposure and their sensitivity to it, and their adaptive capacity (IPCC, 2007).

Different impacts are expected in different geographic areas. Inside Europe climate change is also expected to magnify regional differences (IPCC, 2007). A better understanding of the interactions

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between agriculture and climate is one of the top listed items in the research agenda in the European Union (EU). More recently, the EU Commission has emphasized the necessity to improve the spatial and time scales of the assessments of expected climatic impacts and vulnerability (EU Commission, 2009).

As reviewed by Bosello and Zhang (2005), there are different approaches available to investigate the effects of climate change on agriculture, each one with strengths and weaknesses (Mendelsohn and Dinar, 2009).

The Ricardian approach, introduced in 1994 (Mendelsohn et al., 1994), is a cross-sectional method that measures the long-term impact of climate on agriculture. It has at least three advantages: "It is relatively easy to estimate, yields geographically precise values, and captures adaptation" (Mendelsohn et al*.,* 2010). Despite some shortcomings discussed in section 2, this approach has been widely applied to many different geographic contexts, both in developed and developing countries (Mendelsohn and Dinar, 2009). Most applications concern big countries and only few studies deal with Europe (Maddison, 2000; Lang, 2007; Lippert et al., 2009; Fezzi et al., 2010).

In this paper we propose an application of the Ricardian approach to measures the impact of climate change on agriculture in a small Italian region. Trentino is located in the south eastern part of the Alps and presents a high environmental and climatic variability. 20% of its 6364 km^2 surface is above 2000 ASL. Agriculture occupies 24% of the surface but meadows and pastures cover 82% of the Utilized Agricultural Area (UAA). Apple orchards and vineyards count for 15.9% of the UAA but contribute to the 65% of the total value produced by the agricultural sector in Trentino (PAT, 2007).

This analysis is based upon structural and economic data from 139 individual farms growing apples and grapes in Trentino belonging to the Farm Accountancy Data Network (FADN). This network monitors representative samples of the farm population around the entire European Union. From the Italian FADN database (RICA) we extracted farms that are present in both the 2003 and 2006 datasets. Following the suggestion of Mendelsohn et al. (2007) about combining more years of data in order to reflect more than a single year effect, average values of 2003 and 2006 are calculated for all the variables and used in the estimations. Climate normals (average temperature and average monthly precipitation for the thirty-year period 1961-1990) were interpolated and associated to each geo-referenced farm.

The contribution of this paper is fourfold. Firstly, it applies the Ricardian approach at a very small scale and it focuses on permanent cultivations. Secondly, it tests three functional forms. Thirdly, it investigates the possibility to exploit the informative potential of data collected and stored in the Farm Accountancy Data Network (FADN) that is easily accessible and available for all the

European regions. Fourthly, it highlights the importance of controlling for some farmers' strategic decision concerning two types of strategies: a) those intimately connected to annual weather conditions such as irrigation and crop protection against pest and pathogens, and b) more general and market related strategies such as specialization or diversification, quality certification or membership of producer organizations.

The paper proceeds as follow. In the next section, method and model specification will be presented. Third section describes data used in this study, the fourth contains results and the fifth reports some conclusions.

2. Method and model specification

The underlying idea of the Ricardian approach is the original observation of Ricardo (1817) that land rent reveals net productivity of farmland. Relying on this, Mendelsohn et al. (1994) regressed the value of land against climate normals (long term climate variables) and other control variables. Through a comparative static analysis, they maintain that it is possible to measure the marginal contribution of climate change, and to forecast future impacts according to different scenarios. To put it simply, projecting in the future the estimated relationship between economic performances and long run average climatic variables allows accounting for climate change impacts. What the model does not measure are the effects of year-to-year change in weather, the change in climate variation or extreme events (Mendelsohn et al., 2010).

The most important advantage of this approach (with respect to the production function) is its ability to overcome the so-called "dumb-farmer" hypothesis, capturing - without analysing it - the farmers' adaptation to local environmental conditions. Nevertheless, this approach does not measure transition costs and cannot account for the effect of variables that do not vary across space, like carbon dioxide concentration (Mendelsohn and Dinar, 2009).

A criticized hypothesis assumed by the model is the constancy of input and output prices. As pointed out by Cline (1996), this assumption causes a bias in the estimation leading to an overestimation of damages or of benefits if prices increase or decrease, respectively. However, Mendelsohn and Nordhaus (1996) argue that the bias is small if aggregate supply and global prices do not change a great deal.

After Mendelsohn's pioneering work, the approach has been widely applied to many different geographic contexts, both in the developed and developing countries (Mendelsohn and Dinar, 2009). Recent papers suggest solutions to specific criticisms raised to the original Ricardian model, as the treatment of irrigation (Kurukulasuriya and Mendelsohn, 2007; Fleischer et al., 2008). Others introduce innovations to deal with specific issues, such as estimating climate change impacts on vineyard cultivation and analyzing the econometric relation between solar radiation and grape quality (Ashenfelter and Storchmann, 2010).

Another recent and interesting evolution of the Ricardian model concerns its application to panel data (Deschenes and Greenstone 2007, Lang 2007; Massetti 2010, Fezzi 2010).

At this point we can identify at least four different modalities of application of the Ricardian approach. The first distinction is between the original Ricardian analysis of aggregated data and its application on individual farms. To the former group belong studies concerning the American continent (Mendelsohn and Seo, 2007) and Africa (Maddison et al., 2007; Molua and Lambi, 2007) and numerous countries.[e] To the latter group belongs a smaller group of studies regarding Africa (Maddison, 2000; Molua, 2002; Kurukulariya and Ajward, 2004; Seo et al., 2009; Kurukulasuriya and Mendelsohn, 2007), Israel (Fleischer et al., 2008), Germany (Lang, 2007; Lippert et al., 2009), China (Wang et al., 2009), Mexico (Mendelsohn et al., 2010), and England and Wales (Fezzi et al. 2010).

The second key distinction concerns the dependent variable used in the model. In most studies, the dependent variable is the land value per hectare (LV) as according to the original idea. In some more recent studies (Fleischer et al. 2008; Kumar 2009; Mendelsohn et al. 2010) the annual net revenue per hectare (NR) is used in place of land value. According to Mendelsohn and Dinar (2009), the choice of the dependent variable depends largely on data availability and neither variable is free of defects. While NR is reflecting more annual weather conditions than long-term climate, LV is reflecting long-term uses of land, including development values.

In this study, we applied the NR approach for two reasons. Firstly, annual NR is directly and easily calculable from the FADN dataset. Secondly, the land values in Trentino reflect both the scarcity of land and the competition with other land uses.[f]

The general formulation of the Ricardian model is the following one:

$$y = f\,(F, K) + \varepsilon \qquad (1)$$

Where F is a vector of climate normals for each farm (average temperature and average monthly[g] precipitation in the period 1961-1990), K is a vector of farm variables that explain farms'

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[e] Canada (Weber and Hauer, 2003), China (Liu et al., 2004; Wang et al., 2008), Egypt (Edi et al., 2007), Ethiopia (Deressa, 2007), Kenya (Kabubo-Mariara 2008), South Africa (Deressa et al., 2005), Zambia (Jain, 2007), Zimbabwe (Mano and Nhemachena, 2007), Sri Lanka (Mendelsohn et al., 2004), Brazil (Feres, 2008), and India (Kumar 2009).

f According to the Inea database on land values (http://www.inea.it/prog/bdfond/it/index.php?action=46) the value of an hectare of vineyard in Trentino in 2009 ranges from 278,000 to 490,000 Euros whereas in the more famous Chianti region the value of vineyard ranges from 120,000 to 142,000 Euros.

performance (control variables) and ε is the error term. The dependent variable y is assumed to be equal to annual net revenue (NR).

According to most Ricardian model applications climate variables enter both as linear and as quadratic formulation to reflect the non-linear shape of the net revenue response function. With a positive quadratic term the net revenue function is U-shaped, while with a negative one the function is hill-shaped. From the available literature, we know that in many but not in all cases, farm revenues have a convex relationship with temperature. Following the example of similar studies (Fleischer et al., 2007) we did not simulate a seasonal effect using monthly or seasonal data, because of the small size of the studied area.

On the other hand, since evidence exists that unbiased estimates can be obtained only by including in the model all the environmental and control variables (Deschenes and Greenstone, 2007) particular attention was devoted to the selection of control variables. Latitude and longitude were introduced to account for localization effects (Mendelsohn et al., 1994) while altitude was considered a good proxy for solar radiation effect (Deressa et al., 2005).

Considering soil characteristics, we tested the effect of both the composition (Cambisols, Fluvisols, Luvisols, Phaeozems, Podzols, Leptosols) and the texture (coarse vs medium texture) via dummy variables.

According to the literature on Ricardian models (Schlenker & Roberts, 2006; Seo et al., 2008) we also considered the average slope of the farm soil as explanatory variables by introducing a dummy variable for those farms presenting a predominant flat slope (if flat soil is >60% of farm surface).

Regarding socio-economic information, age and education of the farmer are not included in the FADN dataset but we think that the information about structural and economic characteristics of the farms is more interesting. As most studies (Mendelsohn et al., 2004; Mendelsohn et al., 2010), we considered the size of cultivated area (UAA) both as linear and quadratic terms. Moreover, we introduced some aspects that were disregarded in previous analyses. We focused our attention on the variables which can tell us something about the different strategies adopted by farmers in a mountain region. Two types of strategies were identified: 1) those intimately connected with annual whether conditions such as irrigation and/or crop protection against pest and pathogens and 2) more general and market related strategies such as specialization or diversification, quality certification or membership of producer organizations.

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[g] The choice of using monthly instead of cumulated annual precipitations is a matter of convenience and it does not affect final results, except scale.

Irrigation and crop protection strategies are clearly endogenous adaptations strategies to climatic or weather conditions (Kurukulasuriya and Mendelsohn, 2007) but we can consider them only in an exogenous way by using unitary irrigation and protection costs as proxies of the effects of annual weather conditions. Moreover, although the literature suggests to consider irrigated farms separately from the non-irrigated ones, the characteristics of our sample are not supporting this idea. Actually, 55% of farmers irrigated the whole UAA, the 74% irrigated a surface equal or major then 50% of the UAA, and only 10% did not irrigate the crops. To our knowledge, crop protection strategies have not been considered in the literature so far. Since climate change may have not only a direct but also an indirect effect by influencing diseases and pest development (Mendelsohn and Dinar, 2009), it is important to start to think about it.

The final list of the control variables is presented in Table 1.

[Insert Table 1 here]

An important issue to deal with is the functional form. In most Ricardian studies linear and log linear specifications have been employed and tested but it is well known that results are heavily influenced by the ex-ante choice of a specific functional form.

The Box Cox (BC) specification (Box & Cox, 1964) is an interesting starting point towards more flexible functional forms. In a BC specification dependent variable, independent variables, or both, can be transformed using the following non-linear transformation:

(2)

BC specification, in its numerous variants[h], was widely used for the hedonic price estimation. We are aware of only one study that applies a BC specification to forecast the impact of climate change (Lang, 2007). He estimated a quadratic BC function where both independent and dependent variables are transformed using different transforming parameters and all the interaction terms related with climate normals are included among the regressors.

In our models we choose to apply the Box-Cox transformation only to the dependent variable. The principal reason is that many of our independent variables are dummies or include observations

[h] For example, if dependent and independent variables are transformed, it is possible to use the same transforming parameter or not (for a recent review of the use of Box-Cox transformation see Hossain, 2011).

with negative sign and this is incompatible with the primitive Box-Cox transformation which requires that all of the values are positive (see Greene 2007).

According to the original idea of Box and Cox, who introduced their transformation to eliminate interaction terms, we excluded the interaction term. The introduction of untransformed climatic variables as quadratic terms, according to most Ricardian applications, does not defy the Box and Cox primitive assumption.

Our BC transformation of the dependent variable, as presented in equation (3), is flexible because allows the relationship between y and the regressors F and K, to range anywhere from linear (λ equals 1) to logarithmic (λ equals 0) specifications.

(3)

The linear and log linear specifications are nested in this Box-Cox specification and by using a likelihood ratio test the BC becomes “an appropriate instrument for the statistical discrimination among different functional forms” (Lang 2007).

3. Data description

3.1. The Farm Accountancy Data Network

The Farm Accountancy Data Network (FADN) is a data collection tool established in order to evaluate the income of agricultural holdings in the EU. It consists of annual micro-economic surveys carried out by the Member States on a rotating panel of farms. In Italy, the survey is carried out by the National Institute of Agricultural Economics (INEA) and since 2003 the Italian FADN survey has been integrated with the survey organized by the National Institute of Statistics (ISTAT). The farms are sampled as to be representative of the total farm population. The rotating nature of the FADN panel creates an unbalanced panel dataset. Following the example of Mendelsohn et al. (2007) who suggested to combine more years of data in order to reflect more than a single year effect, we had to decide which years to extract from the FADN panel for Trentino, available for the period 2003-2007. Given the fact that in 2007 the panel has been substantially renewed with brand new farms, the choice of year 2003 and 2006 assures a relative time distance and the maximum number of farms.

The 139 farms growing apples and/or grapes both in 2003 and 2006 represent about 70% of the total number of farms sampled in Trentino and about 40% of the sampled UAA. They cultivate

449.78 hectares of apple orchards and/or vineyards that represent about the 2% of the total UAA devoted to these two permanent crops in Trentino.

The dataset provides extensive information about farm structure, production costs and revenues, and assets. Some ratios, aggregated measures of profitability calculated on the balance sheet and other economic indicators are already present in the dataset but we supplemented the dataset with other specifications of farms profitability. The average values of 2003 and 2006 for all the economic variables were calculated.

Unfortunately, the FADN dataset provides information about farms as aggregate units and some very important information such as the location of cultivated plots is missing. Only average farm slope accounts for this information. The total farm surface is split up into 3 slope classes: flat soil, medium slope (if average slope is <15%) and steep slope (if average slope is > 15%). From this information we elaborated a dummy variable to distinguish those farms characterized as predominantly flat (if flat soil is >60% of farm surface).

Farms were geo-referenced by associating latitude and longitude to the farm address according to both the international World Geodetic System WGS84 GD and the UTM ED50 system.

We derived soil characteristics from the Italian database of soil maps (http://www.soilmaps.it/ita/downloads.html) and we included the soil type via 5 dummy variables identifying 6 soil types (Fluvisols, Cambisols, Luvisols, Phaeozems, Leptosols, Phaeozems). Data on dominant soil texture are extracted from the European Soil Database (ESDB) maintained by the European soil data centre (http://eusoils.jrc.ec.europa.eu/). A dummy variable was introduced to distinguish between the 2 dominant soil textures: coarse texture (clay<18% and sand>65%) and medium texture (18%<clay<35% and sand > 15%, or clay<18% and 15%<sand < 65%).

3.2 Climate data

Starting from the air temperature and daily precipitation data registered in Trentino in the last fifty years by the observation network of Autonomous Province of Trento (PAT), the Climatology Research Group of Edmund Mach Foundation (FEM) carried out a homogenisation trial of all climatic series with the help of the R procedure “RHtestV2” (Wang and Feng, 2007). In brief, the protocol consisted in a series of actions: a preliminary auto-homogenisation of the series, the reconstruction of missing data with the help of neighbouring stations (weighted mean with elevation corrections), the building of “reference series” (from the five closest stations) and their homogenisation, the check of consistency of time trends (annual and seasonal), and mean daily thermal range (only for temperatures). After this homogenisation procedure, they constructed monthly climate normals (monthly temperature and precipitation in 1961-1990) for about 40 different meteorological stations spread around Trentino, including all series with at least 25 years of data. Average temperature and average monthly precipitations during 1961-1990 are highlighted in Figure 1 and Figure 2, where average values calculated over other time periods are also reported. This allows also to perceive the exceptionality of the five year-period 2003-2007.

[Insert Figure 1 here]

[Insert Figure 2 here]

The Research Group on Predictive Models for Biomedicine & Environment of the Bruno Kessler Foundation (FBK) interpolated average temperature and precipitation for 1961-1990 on the entire surface of Trentino according to the methodology provided by Uboldi et al. (2008). This methodology was specifically designed to account for the presence of a complex topography with strong gradients and, more in general, the mountain character of the region. This spatial interpolation algorithm, previously validated on Lombardy - a neighbouring region on the southern slope of the Alpine range - allowed us to extract average temperature and precipitation corresponding to the spatial coordinates of each farm.

Descriptive statistics for all the variables are reported on Table 2.

[Insert Table 2 here]

3.3 Climate projections

Climatic projections for the current century are available from many sources. Among these, EU project Ensembles (www.ensembles-eu.org) provides probabilistic projections of climate for Europe, addressing the problem of the important scattering of results that are intrinsic in the multi-model approaches to climate modelling.

The standard for Ensembles is the representation of climate in 30-year “time slices”: 1961-1990 (the reference period), 2021-2050, and 2071-2099. The Ensemble approach infers statistic features from the sample of model output, each of them calculated from model runs according to the atmospheric scenario A1B (IPCC, 2000). Both large-scale models and regional models enter the pool of model tools employed by Ensembles, even if results are dealt with separately.

In our application, simulation results from Ensembles have been used as an approximate assessment of the expected climatic shift for the period 2021-2050, compared to the standard reference period 1961-1990. Annual values representative for Trentino have been estimated averaging the data presented in Goodess et al. (2009) with a seasonal resolution, coming from the output of 18 climatic models. The average increase in temperature is roughly estimated as +1.4 (±0.6) °C, with top values in summer. The change in precipitation is more questionable, being uncertainty of the same order of the total shift. A decrease is expected in summer and autumn, while winter and spring projections yield values not too different from those of the reference period. In figures, an average decrease of about 6% (±5%) in total annual rainfall amount is projected. This average value has little climatic importance, if compared with the natural annual variability of rainfall (around 20% as standard deviation).

5. Results

In the earlier version of this study (De Salvo et al. 2010) we first tested different NR specifications built on FADN data and the best specification for NR turned out to be gross revenue minus cultivation and breeding costs.[i] Moreover, we followed a step-by-step procedure suggested by Mendelsohn et al. (1994) and Deressa (2007) by estimating first the effect of climatic variables, and then by including different groups of control variables into the model. Soil characteristics and slope were not available at that time of the research.

In the present paper we started estimations by assuming two different functional forms: linear and log-linear. Since the results of Breusch–Pagan tests revealed heteroskedasticity, the White heteroskedasticity robust covariance matrix was used to obtain heteroskedasticity-consistent standard errors. Table 3 reports results.

[Insert Table 3 here]

To test the importance of the different groups of control variables for the individuation of a simplified model structure some tests on estimated parameters are carried out (Table 4). Tests show that control variables concerning with soil characteristics can be omitted from the models.

[Insert Table 4 here]

To model a more flexible functional form we estimate a Box Cox specification, transforming only the dependent variable. Box-Cox specifications can be estimated using OLS only if a particular

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i This specification does not take into account the annual cost of farm capital and labour costs. The latter are mainly implicit costs for the sampled farms; that means they have to be calculated since they are not associated to monetary transactions. In fact, in most of the sampled farms household members provide labour, while hired help is often used only at harvest time.

fixed value for the transforming parameter is supposed. Otherwise model parameters can be jointly estimated using numerical methods or using nonlinear least squares, that is, minimizing the sum of squared residuals. In this study we used the procedure implemented by STATA, which finds the Maximum Likelihood joint estimate of parameters. Results are showed in Table 5.

[Insert Table 5 here]

Beside the usual statistics on goodness of fit (R-squared, Akaike Information Criteria (AIC), Bayesian information criteria (BIC)), Table 5 reports the Box Cox test[j] to compare linear versus log linear specification. Since the estimated value for the statistic of the test exceeds critical value, it is possible to reject the null hypothesis that the two models are the same. According to AIC and BIC statistics, the log linear specification fits the data better than the linear one.

In order to compare the linear and log-linear specification with the Box Cox one, we carried out likelihood ratio tests on the theta value (Table 6).

[Insert Table 6 here]

If the theta value is proved to be equal to zero or one, the Box Cox specification reduces to the loglinear or linear one, respectively. In our case, both tests show that it is possible reject the null hypothesis, so theta is statistically different from zero and one. Box Cox specification fits the data better, and therefore should be preferred for prediction.

Going back to the results presented in Table 5 and looking at the significance of control variables, altitude as a proxy of the radiation effect is not significant in all the model specifications, while latitude is significant at 1% in all the models, and shows a positive effect on NR. As concern quality policies, quality certification for grape and membership of apple producer organization (Melinda) increase the farm profitability. Moreover, farm revenues are negatively affected by diversification, as showed by the significance of the area cultivated with crops other than apples and grapes and breeding, a dummy variable used to account for farms with breeding activities. According to the positive sign of the UAA quadratic term, the relationship between NR and UAA is U-shaped. Moreover, apple orchards irrigation costs per hectare are significant in all specifications.

Coefficients of climate variables expressed as long term averages (climate normals) are all significant in each model specification both as linear and quadratic terms. Quadratic term

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j The basic idea of the Box Cox test is to transform data so as to make the Residual Sum of Squares (RSS) comparable. To do this each observation of the dependent variable is divided by its geometric mean. Then, the transformed variable, and its logarithmic, are regressed on X. The model with the lowest RSS is the one with the better fit.

coefficients signs reveal a flat U-shaped relationship between farm net revenues and temperature, and a hill-shaped relation between the dependent variable and precipitation. We represent this relationships in Figure 3 and 4, where predicted RN per hectare are the mean values of the predicted RN calculated for each single farm.

The expected economic impact of climate change, in term of NR variation, is reported in Table 7. The period 1961-1990 represents the reference scenario (C1), while the alternative scenario (C2) is 2021-2050. According to Ensemble projections based on 1961-1990 period, a 1.4°C increase in temperature and a 6% decrease in precipitation are expected for 2021-2050. NR per hectare is forecasted for each farm separately according to the different model specifications. Then average predicted RN per hectare calculated on the reference scenario (C1) is compared to the average NR per hectare forecasted for the alternative scenario (C2). Linear model predicts an increase of annual NR per hectare equal to €/ha 1.386,97. With the log-linear specification the increase turns out to reach €/ha 3.446,11. Finally if a Box Cox specification is adopted, the impact of climate change according with the Ensemble projections amount to €/ha 2.253,89.

[Insert Table 6 here]

6. Conclusions

An exhaustive literature exists which demonstrates negative impacts of climate change on the agricultural sector, and on country's economy in underdeveloped countries, as Latin America, Cameron, Ethiopia, and Egypt, to mention few. In particular, climate change records its most dramatic impacts on regions that are already stressed by high temperatures and low precipitations. Changes that intensify these conditions will only worsen the outcomes. If climate becomes more hostile, a notable reduction of low rural incomes is predictable (Mendelsohn et al., 2004).

However, as highlighted by Fleischer et al. (2008, p. 514), "the impact depends on the location, level of development, technological advancement, and the institutional setting in the countries".

Conversely, there is uncertainty about the economic impacts of climate change in Europe. Lang (2007) demonstrates that global warming brings benefits to German agriculture, especially in the short run. Lippert et al. (2009) confirm this result. However, they do not exclude losses in the long run, where different scenarios of temperature and precipitation variation might appear. Overall beneficial effects on agriculture are expected also in England and Wales, but the impacts are highly heterogeneous with areas in the flat South-East and in the upland West being the net losers (Fezzi et al., 2010).

This study is a first exercise in applying the Ricardian approach to a very small Alpine region. It presents some novelties. It is an application at a very small geographic scale that concerns permanent cultivations. It investigates the possibility to exploit the informative potential of data collected and stored in the Farm Accountancy Data Network (FADN) that is easily accessible and available for all the European regions (http://ec.europa.eu/agriculture/rica/). It emphasizes the critical role of control variables and in particular, the role of variables that reflect important strategic decisions made by farmers (irrigation, crop protection, specialisation vs. diversification, quality certification, and membership of producer organizations). Even if the FADN dataset does not provide all the control variables generally used in the literature, the goodness of fit of our estimated models are comparable to previous studies (Molua and Lambi, 2007; Fleischer at al., 2008).

Moreover, the study addresses the critical issue of model specification and try to introduce some flexibility by means of a Box-Cox specification, without reaching the sophistication of the flexible smooth functions proposed by Fezzi et al. (2010).

Results obtained from different specifications are obviously quite different. Considering Ensembles' climate projections for 2021-2050 forecasting a moderate increase in temperature (+1.4°C) and decrease in precipitation (-6%), linear model predicts an annual NR per hectare increase equal to €/ha 1.386,97, while this value increases to €/ha 3.446,11 applying the log-linear specification. The Box Cox specification produces an in-between estimation, that is €/ha 2.253,89. In line with the results of the studies on Germany (Lang, 2007; Lippert et al., 2009) and on England and Wales (Fezzi et al., 2010), climate change seems to imply some benefits for our study area. We cannot figure out whether these results are inflated or not by our NR specification that does not take into account annual capital costs and labour costs. It depends on the complex relationship between climate change and labour costs, whose investigation goes beyond the scope of this paper.

Following Mendelsohn et al. (2007), we can conclude that if there is enough climatic variation across the sample and suitable control variables are introduced in the model, cross-sectional analysis can reveal the influence of climate also on a small territorial scale. Unfortunately, all the control variables are treated in the models as exogenous, even if some of them (crops protection and irrigation) are adaptation strategies directly related, to a different extent, with climate conditions.

As further research, we plan to make full use of the panel nature of our FADN dataset and to investigate the spatial effects, which are attracting increasing interest in the most recent Ricardian applications (Lippert et al., 2009; Kumar, 2009; Fezzi et al., 2010).

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Tables and Figures

Table 1 – Control variables

Variable	Type of var.	As proxy for
Latitude (decimal degrees)	Continuous	Localization
Longitude (decimal degrees)	Continuous	Localization
Altitude (meters)	Continuous	Effect of solar radiation
Soil typology (Cambisols, Fluvisols, Luvisols, Phaeozems, Podzols, Leptosols)	Dummies	Soil characteristics
Soil texture	Dummies	Soil characteristics
Predominantly flat	Dummy	Soil characteristics
Cultivated area (Total UAA) in hectare	Continuous	Physical dimension
UAA for other crops in hectare	Continuous	Lower degree of specialization
Breeding activity in the farm	Dummy	Presence of diversification
Unitary crop protection costs for apple and grapes (€)	Continuous	Adaptation strategies for crop protection
Unitary crop irrigation costs for apple and grapes (€)	Continuous	Adaptation strategies for irrigation
High quality grape certification	Dummy	Quality
Membership of Melinda producer organizations	Dummy	Quality

Table 2 – Descriptive statistics

Variable	Min	Max	Average	Standard deviation
Net renevue	128.13	24845.72	7747.50	4846.06
Average temperature (°C) 1961-1990	5.00	12.90	10.62	1.33
Average monthly precipitation (mm) 1961-1990	65.50	99.50	80.82	7.03
Latitude	45.70	46.44	46.16	0.19
Longitude	10.81	11.53	11.04	0.11
Altitude	10.00	1200.00	459.42	262.54
High quality grape	0.00	1.00	0.49	0.50
Melinda	0.00	1.00	0.27	0.45
UAA others crops	0.00	117.90	2.88	11.83
Breeding	0.00	1.00	0.13	0.34
UAA	0.54	119.03	6.31	12.19
Apple irrigation cost per hectare	0.00	99.70	24.25	30.73
Grape irrigation cost per hectare	0.00	188.00	8.56	24.67
Apple protection cost per hectare	0.00	1355.83	491.14	486.37
Grape protection cost per hectare	0.00	1071.67	156.71	286.49
Predominantly flat	0.00	1.00	0.61	0.49
Soil texture	0.00	1.00	0.36	0.48
Cambisols	0.00	1.00	0.27	0.45
Fluvisols	0.00	1.00	0.36	0.48
Luvisols	0.00	1.00	0.19	0.40
Phaeozems	0.00	1.00	0.13	0.34
Podzols	0.00	1.00	0.01	0.08
Leptosols	0.00	1.00	0.04	0.19

Table 3 – Full models including all the available control variables

	Variable	Linear specification		Log linear specification	
β_1	Temperature	-4737.1842	*	-1.2595752	***
β_2	Precipitation	207.45252		0.10919827	***
β_3	Temperature squared	300.81874	**	0.07655599	***
β_4	Precipitation squared	-1.845793		-0.00077545	***
β_5	Altitude	1.438878		0.00070805	
β_6	Latitude	11238.346	***	1.8185675	***
β_7	High quality grape	707.07067		0.39896971	*
β_8	Melinda	2246.244		0.43500101	**
β_9	UAA others crops	-632.2477	***	-0.11431021	***
β_{10}	Breeding	-2745.3671	**	-0.91596847	***
β_{11}	UAA	253.14444		0.04987875	**
β_{12}	UAA squared	3.0804488	***	0.00035368	**
β_{13}	Apple irrigation cost per hectare	4.6465885	**	0.00047986	*
β_{14}	Grape irrigation cost per hectare	-0.06295228		0.00012312	
β_{15}	Apple protection cost per hectare	-11.334678		-0.00302633	
β_{16}	Grape protection cost per hectare	-17.233644		-0.00250802	
β_{17}	Predominantly flat	64.48618		-0.11538627	
β_{18}	Cambisols	745.67226		0.04601727	
β_{19}	Fluvisols	1784.9165		0.37895889	
β_{20}	Luvisols	981.85579		0.22529033	
β_{21}	Phaeozems	-483.70894		0.00450615	
β_{22}	Podzols	2743.5754		0.17563599	
β_0	Constant	-502684.46	***	-75.139485	***
R-squared		0.5487		0.7202	
AIC		2687.9711		235.25865	
BIC		2755.464		302.75155	
Rank		23		23	

Note: *, **, and *** denote, respectively, significant at 1%, 5% and 10%.

Table 4 – Likelihood ratio tests on simplified models structures

Hypothesis		**Linear specification**		**Log linear specification**	
	Degree of freedom (g)	**F (g, 116)**	***P-value***	**F (g, 116)**	***P-value***
Climate variables $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$	4	35.9100	*0.0000*	16.4000	*0.0000*
Localization variables $H_0: \beta_5 = \beta_6 = 0$	2	7.9600	*0.0006*	8.5800	*0.0003*
Strategic decisions variables $H_0: \beta_{13} = \beta_{14} = \beta_{15} = \beta_{16} = 0$	4	2.9300	*0.0237*	2.3900	*0.0545*
General strategic variables $H_0: \beta_7 = \beta_8 = \beta_9 = \beta_{10} = \beta_{11} = \beta_{12} = 0$	6	15.2700	*0.0000*	33.2500	*0.0000*
Soil characteristics variables $H_0: \beta_{17} = \beta_{18} = \beta_{19} = \beta_{20} = \beta_{21} = \beta_{22} = 0$	6	**1.0500**	***0.3975***	**1.2700**	***0.2762***

Table 5 – Linear, log linear and Box Cox models estimations

	Variable	Linear		Log linear		Box-Cox	
β_1	Temperature	-5578.6304	***	-1.293473	***	-12.53134	***
β_2	Precipitation	286.99397	*	0.11024026	***	0.99193212	*
β_3	Temperature squared	342.4513	***	0.07820103	***	0.75641875	***
β_4	Precipitation squared	-2.3073746	**	-0.00078501	***	-0.00714813	*
β_5	Altitude	0.29898706		0.00057441		0.003827	
β_6	Latitude	10841.235	***	1.6431684	***	18.170646	***
β_7	High quality grape	648.57923		0.43841903	*	3.5224385	**
β_8	Melinda	1943.2528		0.38080599	**	3.8068692	**
β_9	UAA others crops	-647.80779	***	-0.11809711	***	-1.2310697	***
β_{10}	Breeding	-2970.2228	**	-0.91367213	***	-7.9066567	***
β_{11}	UAA	268.88577		0.05204107	**	0.49354446	**
β_{12}	UAA squared	3.0430568	***	0.00036373	*	0.0050449	***
β_{13}	Apple irrigation cost per hectare	4.8840601	**	0.00048733	*	0.00601815	*
β_{14}	Grape irrigation cost per hectare	0.20044818		0.00016595		0.00152285	
β_{15}	Apple protection cost per hectare	-19.871174		-0.00427653		-0.03863727	
β_{16}	Grape protection cost per hectare	-18.193134		-0.00233822		-0.03067701	
β_0	Constant	-482003.68	***	-66.733816	**	-792.43462	
θ						0.27848047	*
σ						5.2388518	
R-squared		0.5333		0.7009			
F[16. 122] (prob)		110.16		53.4			
AIC		2680.6229		232.56025		2595.9067	
BIC		2730.5089		282.4463		2598.8412	
Rank		17		17		1	
Box Cox test on functional form:							
RSS(*)		44.5712		**33.9568**			
N/2*log(RSSlargest/RSSsmallest)~$\chi^2(1)$			8.2099				

Note: * p<0.05; ** p<0.01; *** p<0.001

(*) This statistic is calculated on the model where y is transformed dividing each observation by its geometric mean.

Table 6 – Likelihood ratio tests on theta value

Test H0:	Restricted log likelihood	LR statistic $\chi2$	P-Value Prob > $\chi2$
Theta = 0 (Box Cox vs. log linear)	-1304.4071	14.91	0,00
Theta = 1 (Box Cox vs. linear)	-1323.3114	52.72	0,00

Table 7 – Forecasts of average Net Revenues (€/ha) according with different specifications

	Average temperature	Average monthly precipitation	Linear	Log linear	Box Cox
C(1): 1961-1990	10.55°C	80.21 mm	3377.14	3016.92	3116.13
C(2): 2020-2050	11.94 °C	75.40 mm	4764.11	6463.03	5370.02
D(C)=C(2)-C(1)	1.4 °C	4.81 (-6%)	1386.97	3446.11	2253.89

Figure 1 – Average temperature (C°) in Trentino in different time periods

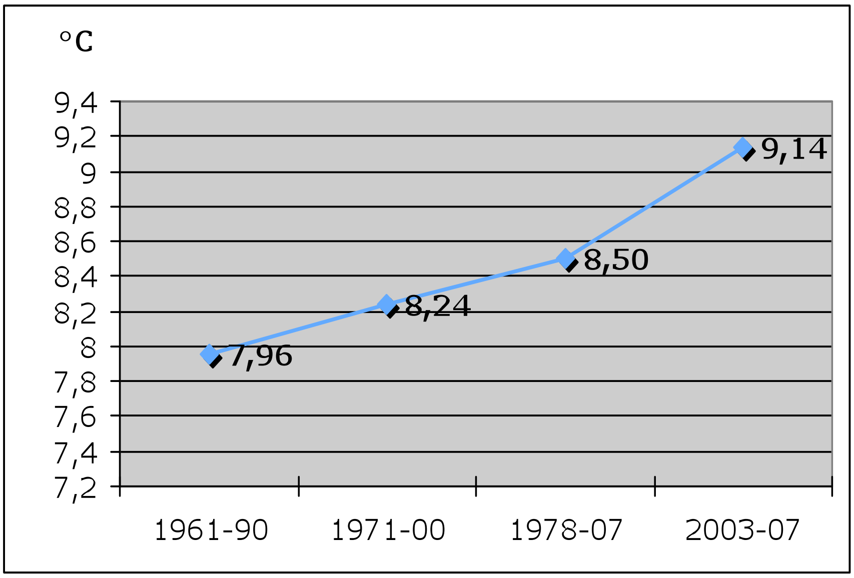

Figure 2 – Average monthly precipitation (mm) in Trentino in different time periods

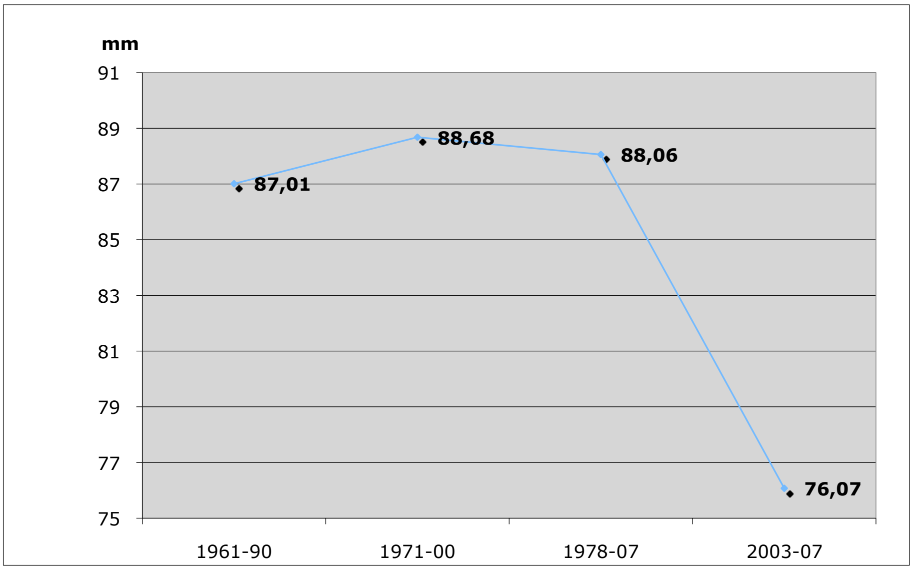

Figure 3 – Predicted RN (€/ha) as a function of temperature (°C) according with different specifications

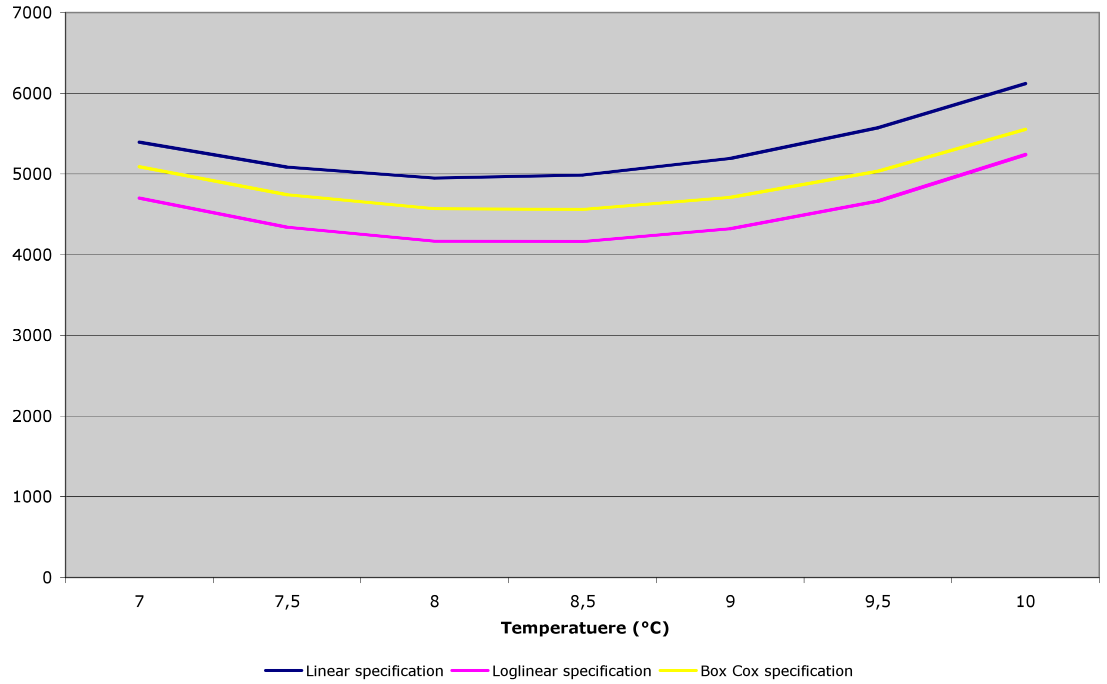

Figure 4 – Predicted RN (€/ha) as a function of precipitation (mm) according with different specifications