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ESTIMATING THE EFFECT OF CLIMATE CHANGE ON ARGENTINE VITICULTURE

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Estimating the effect of climate change on Argentine viticulture

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This paper measures the impact of annual changes in temperature and rain on wine prices and revenue per hectare, in order to determine the effect climate change will probably have on viticulture.

Using the Ricardian Methodology and the prices and volumes data from *Mendoza Board of Trade*, *Wine National Institute* and *Argentina's Ministry of Agriculture* I find a non-linear relationship between temperature and revenue per hectare. In Mendoza, income per hectare would reach its maximum for an average temperature of 17.5°C during the grapevine's growing season.

Key words: climate, viticulture, prices, impact.

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I. Introduction

The goal of this paper is to measure the effect of annual changes in temperature and rainfall on wine prices and revenues per hectare in the Province of Mendoza. Mendoza belongs to Cuyo Region, which is an extremely arid one. Most of the vineyards are found in rocky, sandy and relatively infertile areas which are not suitable for other crops. The quality of wines in each zone depends on certain features of the land and environment that ensure the vineyard subsist low winter temperatures.

Thus, prices, performance and the quality of wine strongly depend on the climate. Compared to the Pampa Region, where the land is very fertile and many crops can adapt to it, the lands in Cuyo fit only to certain crops, such as olives, grapes and plums. This means that the possibilities for crop substitution are lower and therefore the changes induced by shifts in temperature, directly reflect the economic impact of global warming.

I use the Ricardian Model originally applied by Mendelsohn, Nordhaus and Shaw (1994) to evaluate the impact of global warming on viticulture. The results show that winemakers' income per hectare in Cuyo has a nonlinear relationship with temperature changes.

A. Viticulture in Mendoza

Argentina is one of the world leading producers of wine; holding an outstanding position in the international market of varietal wines. The country is the fifth in terms of global wine production; lagging behind France, Italy, Spain and the United States (OIV, 2010) with an annual production of 16.5 million hectoliters.

The main changes the wine sector experienced during the last years were the growing importance acquired by the fine wine market -both in the external and domestic market- and the sharp contraction of common and lower quality wine.

Mendoza is the leading province in terms of wine production in Argentina. It concentrates 75% of total wine production and accounts for about 90% of wine exports.

The province is divided in five wine regions: North and East of the City of Mendoza, High Area of Mendoza River, Uco Valley and South Mendocino.

The North and East zones are the most important ones in terms of production volume. These areas are located on the 33° south latitude with more than 60 thousand hectares with vineyards of all kinds. The East is fed by the water of Tunuyan River. The North is marked by gently sloping lands, washed by the water of Mendoza River. The main grapes found in this zone are the white ones, such as Torrontes, Chenin and Pedro Gimenez. The red varieties in this region are easily adapted for the production of light wines.

The vines coming from the High Area of Mendoza River are well-know all around the world. The climate conditions in this zone – an average temperature of 15°C- allow the formation of color and tannins in wine, making them suitable for an extended aging. There are almost 30,000 hectares of vineyards in this area; Malbec and Cabernet are the main wine varieties.

Uco Valley is located in the southwest of Mendoza and it’s the leading zone in terms of wine investments. The average temperature is 14.2°C and the high altitude promotes the large daily temperature ranges. This zone currently holds 8 thousand hectares of vineyards, provided with the waters of Tunuyan River, among others. The highlighted varietals are Malbec, Merlot, Semillon and Chardonnay.

The South Mendocino has an average temperature of 15°C. There are more than 30 thousand hectares with vineyards in this region, fed by the waters of Diamante and Atuel River. The most distinctive varietal is Chenin, and to a lesser extent Chardonnay, Malbec and Cabernet Sauvignon.

B. Viticulture and Climate Change

There is general consensus that emissions of greenhouse gases from human activity will result in higher temperatures and more rainfall in the coming years. According to recent data published by the Intergovernmental Panel on Climate Change, global warming will continue if so do the emissions of greenhouse gases. The World Meteorological Organization's (WMO) climate model projections indicate that it is likely that the global temperature increase between 1.1 to 6.4 ° C during the twenty-first century.

It is expected that the climate change will definitely impact the global economy. Since temperature and rainfall are key inputs for agriculture, then the major effects could be seen in this sector.

Particularly for viticulture, several productivity records show that the optimal areas for growing grapevines vary in relation to weather. The climate defines whether an area is suitable for the production of grapevine and in turn sets the specific style of wine that can be produced. In each productive region, climate variability prints differences in the quality of musts. Climate change, as a phenomenon that influences temperatures and rainfall scheme, then has the potential to produce changes in the production and quality of regional wines.

During the last decade several researches have focused on assessing the influence of climate parameters on agriculture, the majority of them using the production function or the hedonic approach.

Meldensohn, Nordhauss and Shaw (1994) find that for more than 3.000 crops in USA, higher temperatures in all seasons, except fall, reduce the average value of land. Lobell and Field (2007) find that rainfall and high temperature during the growing season of the main crops worldwide -wheat, corn, barley, soybeans, rice and sorghum- explain more than 30% of annual variations in their average yields.

Schlenker, Hanemann and Fisher (2005) outline a model of land value to estimate the possible effects on land values for a range of scenarios of global warming and find that over 75% of the counties experienced a statistically significant effect, ranging from moderate gains to large losses.

In Argentina, Lozanoff and Cap (2010) use the Ricardian Approach and find that both rainfall and temperature has a highly limiting effect for agriculture and livestock production in the country.

Focusing in the viticulture market, Ashefelter and Storchmann (2010) find that a 1°C increase in the average temperature would produce up to a 37% increase in winery revenues in the Mossel Valley in Germany.

Webb, Whetton and Barlow (2008) use the historical statistical relationships between temperature and prices paid for grapes by variety to estimate the effects of climate change in Australia. Allowing for the mix of outputs in different regions and assuming that the mix remained constant, they find that the predicted percent changes in prices are large for most regions and particularly for those with a high proportion of national production such as Riverland and Riverina.

Webb (2006) estimated changes in gross return and find that most of the large producing regions in Australia show significant reductions in gross return, with exceptions for some regions such as McLaren Vale and Langhome Creek.

II. Model

This paper aims to estimate and analyze the effect of changes in temperatures and rainfall on prices and revenue per hectare in the wine sector in the province of Mendoza. The analysis is focused on the five wine regions in Mendoza during 1998 and 2009.

I use the Ricardian Model, originally applied by Mendelsohn, Nordhaus, and Shaw (1994) to evaluate the impact of global warming on viticulture.

The Ricardian Model estimates the importance of climate change and other variables on the revenue per hectare and value land. This model represents the land value as a function of the net revenue. Consequently, the net revenue reflects the present and future value of net productivity.

By measuring prices and revenues per hectare, I estimate the direct impact of climate change on the land value, as well as the indirect inputs substitution, introduction of different activities and any other possible adaptation to different climates.

This is essentially an hedonic model of farm land prices, based on the notion that the land value capitalizes the discounted value of all future profits to be derived from it. The advantage of the hedonic method is that it is based on cross-sectional variation to identify the embedded options of land-owners on the allocation of land among competing uses, rather than directly modeling the decision. In addition, the hedonic function allows to calculate the direct impact on every farmer or sector.

I assume that the wine producers maximize their net income by selecting the vector X, given certain characteristics of the establishment and market prices. The Ricardian model, examines how a set of exogenous variables, F and Z, impact the value of the establishment, where F is a vector of climate variables and Z is a set of edaphic variables such as altitude.

The model reduces to:

$$income\ per\ hectare = \beta_0 + \beta_1 F^2 + \beta_2 F + \beta_3 Z + e \qquad (1)$$

The quadratic term of the equation reflects the non-linear response of income to climate variables.

The main hypothesis is that climate modifies the production function; then producers take climate variables as given and adjust their inputs and outputs in an optimal way. The model assumes perfect competition in the wine and supply markets. Moreover, it postulates that the economy has perfectly adapted to climate change, assuming that land prices have already reached its equilibrium value associated to the new climate in the region.

III. Data

Prices and quantities data per varietal and region between 1998 and 2009 are obtained from the *Mendoza Board of Trade* (Bolsa de Comercio de Mendoza) Database, taking the average prices for each zone in each year.

This database is built based on the contracts showed for their registration at the Mendoza Board of Trade. The Provincial Government of Mendoza issued the Order No. 1970 in 2010, by which the registration of wines and musts sales - cash or financed- was forced.

This database also provides information on the vintage of the wine, which allows to estimate the wine age. The age is calculated as the difference between the year of sale and the year of harvest of the grapevines.

In addition, I use the Price Index built by the National Institute of Statistics and Census (INDEC) in order to work with real prices.

Monthly data of rainfall and temperatures for the five wine regions is obtained from the Ministry of Agriculture Database. I use monthly data as to identify the rainfall and average temperature in winter and the grapes' growing season. In Mendoza, the winter season goes from June to August. Then, the growing season of the grapevine begins and extends until February. Given that climate information is not provided for all departments and for all months, I use the Krigging methodology to interpolate missing values. Kriging is a group of geostatistical techniques used to interpolate the value of a random field in an unobserved location from observations of its value at nearby locations[2].

The data of cultivated hectares with vineyards per wine-region are obtained from the National Wine Institute (Instituto Nacional de Vitivinicultura). Income data is calculated as the product of price and production. However, the calculation of income

[2] Special thanks to Laura Beatriz Gastaldi, INTA researcher, for her help in implementing the Krigging Methodology to the interpolation of rainfall and temperatures for certain departments of Mendoza.

per year and region has an additional complexity due to the different prices for each varietal.

The revenue in each zone *(z)* in the year (*t*), is obtained by multiplying the wine price by its quantity, for each varietal:

$$Income_{zt} = \sum_{i=1}^{n} \sum_{q=1}^{n} P_{zt} * Q_{zt} \qquad (2)$$

Tables 1 and 2 show some statistics regarding the wine prices sample. On the one hand, it can be observed that the highest average prices are for Uco Valley wines, whilst the lowest ones are for those wines coming from the South Mendocino. On the other hand, Cabernet and Malbec varietals show the highest average prices followed by Chardonnay and Merlot. At the other extreme, Chenin and Torrontes varietals show the lowest average prices.

In the next sections I will be analyzing the effect of temperatures and rainfall on wine prices. In fact, I find that the wine prices' answer to climate change is highly sensible to the origin of the grapevine.

Table 1. Descriptive Statistics–Average Prices by Wine Region. Period 1998/2007

Wine Region	Average	Minimum	Maximum	Standard Deviation	Observations
North	108.35	10.21	612.14	65.17	2 812
South	90.50	12.85	450.11	45.65	2 772
East	105.06	11.91	655.27	55.17	9 215
High	122.22	13.62	878.23	71.66	9 009
Uco Valley	135.64	19.50	651.51	71.57	2 784
Total	112.91	10.21	878.23	64.47	26 592

Note: The table shows average prices per hectoliter. Prices are expressed in Argentine pesos of 2008.

Table 2. Descriptive Statistics–Average Prices by Varietal. Period 1998/2007

Varietal	Average	Minimum	Maximum	Standard Deviation	Observations
Tinto	95.37	17.02	604.06	43.14	5 590
Malbec	147.39	17.39	878.23	71.59	5 100
Cabernet	148.99	35.74	878.23	69.59	2 887
Blanco	58.97	10.21	346.44	32.86	2 468
Syrah	121.07	40.85	472.71	54.04	1 560
Merlot	130.51	36.01	878.23	59.82	1 422
Chardonay	141.82	13.62	878.23	78.80	1 435
Chenin	77.39	19.28	555.43	39.43	1 154
Bonarda	101.91	21.20	330.89	36.75	1 088
Torrontés	82.00	20.42	472.71	40.25	860
Otros	96.87	13.62	670.06	58.84	3 029

Note: The table shows average prices per hectoliter. Prices are expressed in constant ARG pesos of 2008.

Tables 3, 4 and 5 show some statistics regarding the rest of the variables used in the model of climate change impact. Rainfall show large fluctuations year over year in every wine region. Mendoza is an arid region, in fact in certain months rainfall does not exceed 7 mm. In the last decade, the South Mendocino Region showed the highest rate of rainfall received between September and February. The highest average temperature during the grapevines' growing season was observed in the East Zone.

Table 3. Temperature and rainfall in Mendoza. Period 1998/2009

	Average	Minimum	Maximum	Standard Deviation	Observations
Rain during growing season	271.09	73.92	638.41	111.74	168
Rain during winter	32.78	0.80	101.69	23.09	168
Temperature during growing season	18.46	7.37	21.21	2.20	168

Note: The temperature and rainfall are expressed in degree Celsius and millimeters respectively.

Table 4. Average temperature and rainfall by Wine region. Period 1998/2009

Wine Region	Temperature during Growing Season	Rain during Winter	Rain During Growing Season
South Mendocino	17.94	47.16	335.14
East	19.68	21.77	315.28
North	17.58	19.04	257.13
High	18.49	32.46	209.89
Uco Valley	17.32	50.89	204.86

Note: The temperature and rainfall are expressed in degree Celsius and millimeters respectively

Table 5. Evolution of average temperature and rainfall in Mendoza.

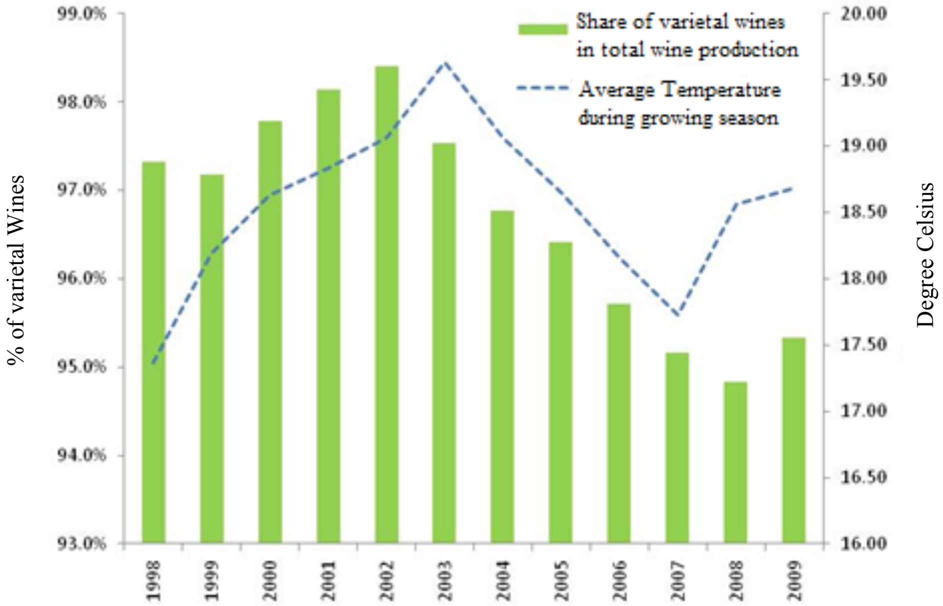
Year	Temperature during Growing Season	Rain during Winter	Rain During Growing Season
1998	17.26	45.84	374.26
1999	18.14	10.31	226.01
2000	18.75	46.13	387.03
2001	18.92	50.87	339.47
2002	19.19	30.43	253.24
2003	19.69	44.15	212.28
2004	18.93	8.38	201.25
2005	18.49	25.25	318.32
2006	17.77	49.79	174.13
2007	17.27	14.26	306.01
2008	18.35	43.20	268.36
2009	18.71	24.70	192.75

Note: The temperature and rainfall are expressed in degree Celsius and millimeters respectively.

Temperature hasn't shown large fluctuations over the last decade, approaching an average of 18.5°C. However, average temperature increased 1°C between 2007 and 2009; following the WWO projections this upward trend will be emphasized in the next years. Meanwhile, rainfalls show a downward trend.

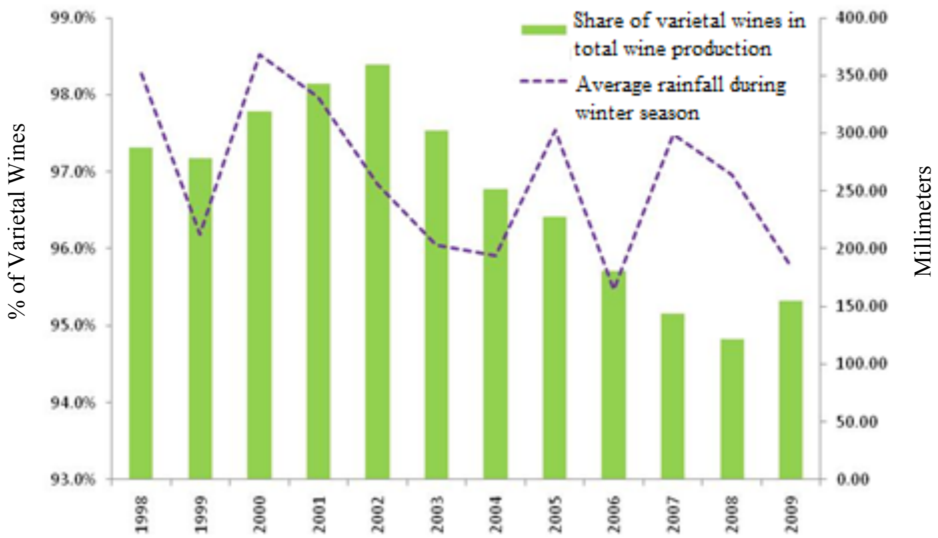
It is interesting to observe the behavior of varietal wines' share of total production during the last years, where temperature and rainfall have varied. Figures 1 and 2 show that varietal or high-quality wines' production perform better during those years with higher average temperature. Nevertheless the relationship between varietal wines' production and rainfall is not that clear.

Figure 1. Varietal wine production and temperature in Mendoza. Period 1998/2009



Note: The left axis shows the share of varietal wines on total production.

Figure 2. Varietal wine production and rainfall in Mendoza. Period 1998/2009



Note: The left axis shows the share of varietal wines on total production.

Regarding the income per capita, Table 6 shows that the High Zone of Mendoza River had the highest income per hectare during 1998 and 2009, followed by East and Uco Valley. Given that producers of high-quality wine stipulate yields per hectare in advance, this data already reflects the adaptation to climate change. Therefore in those years with good weather for viticulture, producers might remove part of the grapevine in order to obtain less yield and higher quality.

Table 6. Average income per hectare by wine region. Period 1998/2009

Wine Region	Average	Minimum	Maximum	Standard Deviation	Observations
South	498.85	46.93	1 112.25	340.85	24
East	1 019.09	34.96	3 741.24	824.73	53
North	798.90	32.65	4 062.94	984.39	24
High	1 844.78	698.19	3 386.27	813.73	24
Uco Valley	995.56	199.76	2 458.80	704.48	36

Note: Income per hectare is expressed in constant ARG pesos of 2008.

IV. Results

Several authors have already shown that the wine quality and price largely depend on climate, measured through temperature and rainfall. Ashenfelter, Ashmore and Lalonde (1995) find that the quality of the harvest for red wines in the Bordeaux area, judged by the prices of mature wines, can be predicted by the climate of the growing season that gave rise to the wines. Likewise, they find that climate information is useful in predicting the prices of mature wines, not young ones.

Climate variability prints differences in the quality of musts. In general, warmer and dryer areas are expected to obtain higher-quality grapevines. Although this association has already been quantified in different viticulture areas, the link depends on the wine varietal.

Ashenfelter and Storchmann (2010) show that the variability in quality observed in the vineyards located in Mossel Vallley (Germany) is mainly due to the extent the vineyard is capable of capturing solar energy. The results show that those vineyards will considerably increase their value under a global warming scenario. Haeger and Storchmann (2006) find that the price of Pinot Noir in the US is strictly determined by temperature and rainfall; in general, temperature increases are detrimental to Pinot Noir prices. The reputation of oenologists and the reviews by experts are other important variables. Ashenfelter (2008), Jones and Storchmann (2001), Ashenfelter et al (1995) Ashenfelter and Byron (1995) also show that the quality and price of a wine highly depend on climate.

It has also been demonstrated that rainfall during winter season has a positive effect on the quality of the grape and wine, although this relation hasn't been found for every viticulture area were the impact of climate change has been studied.

This paper aims to measure the impact of climate change on the average price of wine and income per hectare of the winemaker.

Thus, I estimate the following equations:

$$\ln(price)_i = \beta_0 + \beta_1 rain - winter_i + \beta_2 rain - growing_i + \beta_3 temperature - growing_i + \beta_4 rain - growing_i^2 + \beta_5 temperature - growing_i^2 + \beta_6 \ln(age)_i + \beta_7 \gamma_i + \beta_8 \delta_i + \beta_9 \mu_i + \varepsilon_i \quad (3)$$

Where γ_i are time dummies, δ_i are regional dummies, μ_i are interactions between growing season temperature and wine region, and ε_i is the error term.

$$\begin{aligned}\ln(revenue\ per\ hectare)_{it} &= \beta_0 + \beta_1 rain - winter_{it} + \beta_2 rain - growing_{it} \\ &+ \beta_3 temperature - growing_{it} + \beta_4 rain - growing_{it}^2 \\ &+ \beta_5 temperature - growing_{it}^2 + \beta_7 trend_t + \beta_8 altitude_i + \beta_8 \delta_i + \varepsilon_{it}\end{aligned} \quad (4)$$

Where δ_i are regional dummies and ε_i is the error term.

Three variables are included in the regression: average temperature during the grapevine's growing season ($temperature - growing$); rainfall during the grapevine's growing season ($rain - growing$); and rainfall during winter season preceding the grapevine's growing season ($rain - winter$). Some viticulture researchers consider there is a non-linear relationship between temperatures, rainfall and wineries income. For this reason, the equation also includes the square of average temperature ($temperature^2$) and rainfall ($rain - growing^2$) both during the grapevine's growing season.

Table 7 shows the regression results for wine prices. It is estimated using Ordinary Least Squares (OLS). It incorporates interaction variables between temperature and wine regions as to measure the specific effect of temperature in each zone. The Uco Valley is used as reference.

The results show that temperature during the grapevine's growing season mainly exerts a positive and statistically significant effect on wine prices. The square of the temperature variable is negative though not significant. This indicates that in spite of the positive effect of temperature on wine prices, this pattern has an inverted U-shape which means that after reaching certain temperature, prices fall as temperatures rises. The interacted temperature variables show that Uco Valley is the most benefited region by increases in temperature.

Rainfall during growing and winter season does not show a significant effect on wine prices. As with temperature, the effect of rainfall on wine prices is nonlinear.

In addition to climate variables, the age was included in the regression. It is expected that higher quality wines are more expensive as they become more aged. Nonetheless, this link does not hold for young wines. The results show that age negatively affects wine prices, which may be reflecting the predominance of low-quality wines in the sample.

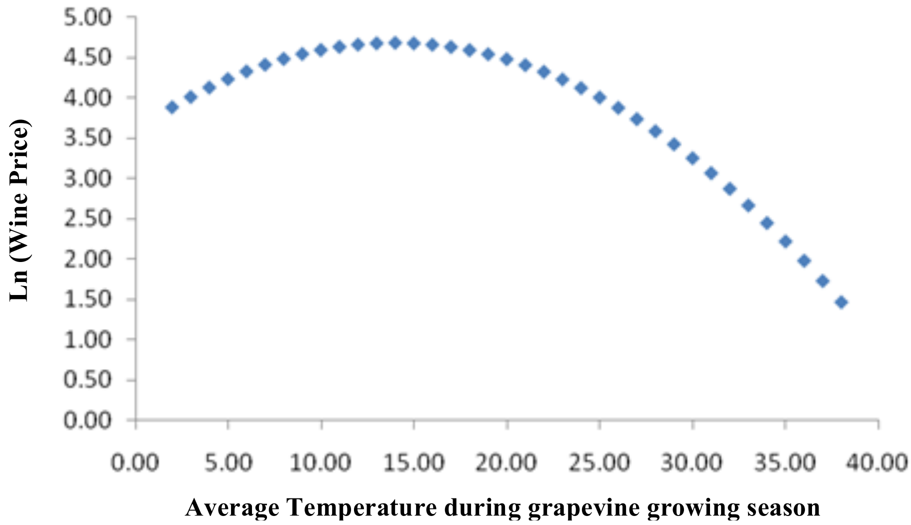
Table 7. Climate and wine prices in Mendoza

VARIABLES	Ln(price)
Rain-winter	0.000300
	(0.000216)
Rain – growing	0.000145
	(0.000255)
Temperature-growing	**0.155****
	(0.0746)
Temperature-growing ^{2}	**-0.00556*****
	(0.00208)
Rain-growing ^{2}	**-1.53e-06*****
	(4.47e-07)
Temperature*North	-0.0118
	(0.0130)
Temperature*South	**-0.0900*****
	(0.0233)
Temperature*East	**-0.100*****
	(0.0195)
Temperature*High	0.00420
	(0.0106)
ln(age)	**-0.0728*****
	(0.00895)
South	-0.0568
	(0.250)
East	**1.153*****
	(0.415)
North	**1.780*****
	(0.377)
High	-0.180
	(0.196)
Constant	**4.129*****
	(0.674)
Observations	23,005
R^2	0.271

Note: The growing season for temperature goes from August to April. For rainfall, the winter season goes from June to August and the summer goes from October to April. Prices are expressed in constant ARG pesos of 2008. Time dummies are not reported. Levels of significance 1% (***), 2% (**), 5% (*); Robust standard error in parenthesis.

Figure 3 illustrates the link between average temperature during growing season and wine prices. The figure clearly shows that non-linear relation between the two variables.

Figure 3. Temperature during growing season and wine prices



Note: This figure is built based on the previous estimations.

Table 8 shows the regression results for income per hectare. In addition to climate variables, it includes two more variables: altitude[3] and trend, to control for possible time effects such as technological change.

The equation is estimated using a Random Effects model for a balanced panel. The Hausman Test was applied to analyze the possible correlation between regressors and the error term. The test verifies the null hypothesis of estimates equality, thus establishing that the Random Effects estimator is the most efficient one[4].

The income per hectare is positively affected by temperature. The results suggest a non-linear relationship between temperature and income per hectare, though the square of temperature is not significant. In this sense, the negative sign of the square of temperature states that even though temperature has a positive and significant effect on income per hectare, this pattern has an inverted U-shape meaning that after reached

[3] See Fleischer A., Lichtman I. and Mendelsohn R. (2007); Seo S., Mendelsohn R. and Munasinghe M. (2005); Gbetibouo, G. and Hassan R. (2004).
[4] Hausman Test Results (Ho: difference in coefficients is not systematic). Chi2(6)=8.34. Prob>chi2=0.2140

certain temperature, income per hectare falls as temperatures during growing season increase. Rainfall variables are not significant in this model.

Table 8. Climate and Income per hectare in Mendoza

	ln(revenue per hectare)
Temperature-growing	**0.368***
	(0.201)
Rain – winter	-0.001
	(0.0125)
Rain – growing	-0.0008
	(0.0014)
Rain - growing ^{2}	0.00004
	(0.0001)
Temperature-growing ^{2}	-0.0104
	(0.0071)
Trend	**-0.113*****
	(0.0283)
Altitude	**0.003****
	(0.0012)
Constant	1.575
	(-1.536)
Observations	148
R2	0.3832
Number of departments	14

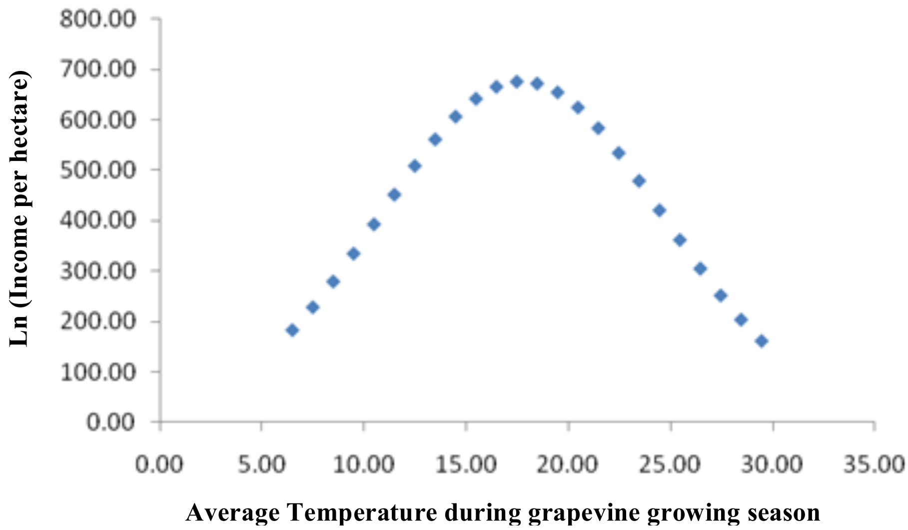
Note: The growing season for temperature goes from August to April. For rainfall, the winter season goes from June to August and the summer goes from October to April. Prices are expressed in constant ARG pesos of 2008. Regional dummies are not reported. Levels of significance 1% (***), 2% (**), 5% (*); Robust standard error in parenthesis. Model estimated using Random Effects. The Hausman Test was used to select between RE and FE Models.

Based on the results, it is possible to estimate the optimum temperature during growing season, from which it would be obtained the highest income per hectare. This can be calculated using the following formula:

$$\frac{\partial \log(rev)}{\partial Temp} = \beta_3 + 2\beta_5 Temperature - growing = 0$$

Figure 4 shows that income per hectare would reach its maximum for an average temperature of 17.5°C.

Figure 4. Temperature during growing season and income per hectare



Note: This figure is built based on the previous estimations.

Under the assumption that costs and climate change are not correlated, these changes in income would be directly transferred to profit and land prices.

Since the average temperature in the province of Mendoza is 18.5°C, increases in average temperature would imply a fall in revenue per hectare.

V. Conclusions

This paper aims to estimate and analyze the effect of changes in temperatures and rainfall on prices and revenue per hectare in the wine sector in the province of Mendoza.

I find a non-linear relation between temperature and income per hectare. Rainfall variables are not significant in the model. Revenue per hectare would reach its maximum for an average temperature of 17.5°C. Under the assumption that costs and climate change are not correlated, these changes in income would be directly transferred to profit and land prices.

Since the average temperature in the province of Mendoza is 18.5°C, increases in average temperature would imply a fall in revenue per hectare.

However, there are some limitations to these results. On the one hand, this analysis does not take into account general equilibrium effects which might result in a restructuration of land prices. Mendoza is perfectly suit for grape growing. As a result, a slight change in the relative prices of vineyards of different qualities due to climate change might have an additional effect on the estimated results.

On the other hand, the results show only a small part of an overall assessment of the role of climate change on viticulture. Certainly there are other places where the temperature increase involves a direct fall on the quality of grapes.

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