Evaluation of Climate Change Effects on the Wine Industry: An Interdisciplinary Approach

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Abstract
In this study, the relationship between viticulture and climate change is widely investigated and different approaches are proposed. However, a deficiency of applications emerges, considering the numerous and varied effects of this phenomenon. This paper aims to propose an innovative approach to estimate climate change effects on wine production. It integrates various scientific competencies via the construction of a framework that connects the effects of climate change with a farm's profitability and structure, entrepreneurs' characteristics and agro-meteorological, phenological, eco-physiological and oenological data. A new interdisciplinary model is formulated using the Romanian wine industry as a case study.

1. Introduction

During the past decade, the increased occurrence of climate change events in Romania, including drought and flooding, has generated a negative effect on crop production, which has limited farming profitability and competitiveness.

Dragomir (2007) estimated that approximately 7 million hectares (48%) of farming land are affected by droughts, while approximately 6 million hectares are vulnerable to flooding. These extreme climatic events could diminish crop yield by up to 30–50% (Dragomir, 2007). The Romanian situation appears particularly serious because projections of global scenarios reflect an increase of 2° C in average air temperature in winter, while, during the summer season, global warming is likely to increase temperatures by 4.3° C and 3.5° C in south and north Romania, respectively. Forecasts are also negative for rainfall changes, as deficits will be recorded during summer and winter, especially in the southwest region (Dragomir, 2007).

The Romanian wine industry is particularly involved in the controversial effects generated by climate change. Although the overall effects of climate change on Romanian viticulture are uncertain, it is known that grapevine yields diminish with the occurrence of abiotic stress, such as freezing temperatures, an increase in soil salinity and drought because of the varying effects on grape quality. According to Paltineanu, Mihailescu, Seceleanu, Dragota and Vasenciuc (2007), aridity would likely affect Romanian viticulture, especially during the crop-growing season.

Global warming could lead to modifications of the viticultural regions map, and vines could be grown from the southern to northern regions of Romania. The interim results of a research project in progress at the University of Agricultural Sciences and Veterinary Medicine of Iasi show that the favourable area for grapevine growing has shifted towards the north. Moreover, higher sugar content in ripe grapes and improvement in wine quality were observed. In addition, a long, warm autumn favours good harvests by stimulating differentiation in grapevine buds and shoot maturing (Jitarita, 2006).

Positive effects were more recently demonstrated by Baduca Campeanu, Beleniuc, Simionescu, Panaitescu and Grigorica (2012). They observed the effects of ongoing climate change on vineyards in Oltenia (Romania), highlighting an anticipation of 10 to 15 days of grape absolute maturity and a variation in bud composition affecting wine quality. The grape sugar content at absolute maturity increases, while the total grape acidity decreases. This implies a positive effect on red wine quality and a negative effect on the taste balance for white wines.

These studies only consider some aspects of the problem. It is difficult to give robust previsions of the final effects on winegrowers' income because effects could be negative in terms of production quantity and positive in terms of wine quality. Moreover, it is important to consider the efficiency of strategies adopted by farmers to cope with climate change, their risk perception of climate change and other social and political aspects to design adequate mitigation and adaptation policies.

The aim of this research is to propose an interdisciplinary approach to estimate the effect of climate change on the Romanian wine sector. Effects are assessed in terms of productivity and profitability, considering changes in grape physiology and phenology, berry characteristics and wine quality.

An integrated model is proposed to connect structural, social and economic farming data with agro-meteorological, phenological, eco-physiological and oenological variables. It is a first step towards examining all direct and indirect effects of climate change on viticulture.

From here, the paper is organised into various sections. The second section illustrates the findings of previous studies on climate change and wine production, the third section explains the formulation and data source of the proposed interdisciplinary approach and the fourth section concludes.

2. Literature Review

The effects of climate change on wine production were widely detected in the literature because of the role played by this industry in the world agro-food economy, the spread of viticulture in new areas where it was not previously practised and the various effects of global warming and weather fluctuations on cultivation (Schultz, 2000; Tate, 2001).

Effects were numerous and were classified as direct and indirect in the literature (Marta et al., 2010). Climate change influences the onset and duration of each phenological phase and, consequently, it affects grape production in terms of quantity and quality. However, climate change also affects viticulture, modifying the relationship between plants and pests, that between pathogens and weeds and the short-term responses of farmers. Further, changes can arise because of farmers' long-term responses: they could change varieties or cultivate crops and adopt new technologies in the attempt to contain losses. In situations of economic inefficiency, they could also decide to abandon agriculture.

These phenomena, accompanied by the shifting of suitable areas for grape cultivation caused by climate change, are the main forces that lead to changes in soil usage in a long-term scenario. The literature review found that previous studies on climate change and grapevine growing focused on specific aspects of this change (Holland & Smit, 2010).

Various studies were devoted specifically to analysing the effect on grape quantity (Gouveia, Liberato, DaCamara & Trigo, 2009; Bindi, Fibbi, Gozzini, Orlandini & Miglietta, 1996; Caprio & Quamme, 2002; Santos, Malheiro, Karremann & Pinto, 2011) or on grape quality (Laget, Tondut, Deloire & Kelly, 2008; Webb, Whetton & Barlow, 2008a; 2008b), whereas other studies focused on the effect on wine quality (Nemani et al., 2001; Webb et al., 2008b; Jones, White, Cooper & Storchmann, 2005; Ashenfelter & Storchmann, 2010;

Shanmuganathan, Sallis & Narayanan, 2010; Bock, Sparks, Estrella & Menzel, 2011; Nicholas, Matthews, Lobell, Willits & Field, 2011; Moriondo, Bindi, Fagarazzi, Ferrise & Trombi, 2011; Alonso & Liu, 2013).

Numerous studies addressed grapevine phenology (Webb, Whetton & Barlow, 2007; Duchêne, Huard, Dumas, Schneider & Merdinoglu, 2010; Marta et al., 2010; Baduca Campeanu et al., 2012; Cunha & Richter, 2012; Webb et al., 2012; Santos, Grätsch, Karremann, Jones & Pinto, 2013), also considering the vine's vigour and precocity (Coulon-Leroy, Charnomordic, Rioux, Thiollet-Scholtus & Guillaume, 2012), and others analysed changes to the grapevine harvest date (Falcão et al., 2010; Koufos, Mavromatis, Koundouras, Fyllas & Jones, in press; Moriondo et al., in press).

Some studies modelled the effect of climate change on the interaction between the grapevine and its pests and pathogens (Martín-Vertedor, Ferrero-García & Torres-Vila, 2010; Steffek et al., 2011; Caffarra, Rinaldi, Eccel, Rossi & Pertot, 2012), while others studied changes in soil usage (Hannah et al., 2013) and geographical distribution of grapevine varieties (Sasek & Strain, 1990; Malheiro, Santos, Fraga & Pinto, 2010).

Finally, numerous studies addressed winegrowers' perceptions of climate change and their adoption of strategies to cope with it (Webb et al., 2008a; Battaglini, Barbeau, Bindi & Badeck, 2009; Hadarits, Smit & Diaz, 2010; Diffenbaugh, White, Jones & Ashfaq, 2011; Rauh & Paeth, 2011; Bernetti, Menghini, Marinelli, Sacchelli & Alampi Sottini, 2012; Nicholas & Durham, 2012; Vink, Deloire, Bonnardot & Ewert, 2012; Lereboullet, Beltrando, Bardsley & Rouvellac, in press).

Several considerations arise from the literature analysis. The first concerns the deficiency of applications that imply an integrated approach involving all relevant aspects able to determine positive and negative effects contemporaneously. For example, wine quality could increase; however, grape quantity could decrease simultaneously. What is the final effect on the price of wine? How does winegrower income change? Do winegrowers perceive losses and, consequently, adopt strategies to cope with climate change? Are these strategies efficient?

The study of interactions between climate change and grapevine cultivation also needs to consider the dynamics of physiological, phenological, social and economic aspects. Only a few previous applications estimated the economic effects of climate change on winegrower profitability, also considering changes in price (Webb, Whetton & Barlow, 2005; Ashenfelter & Storchmann, 2010).

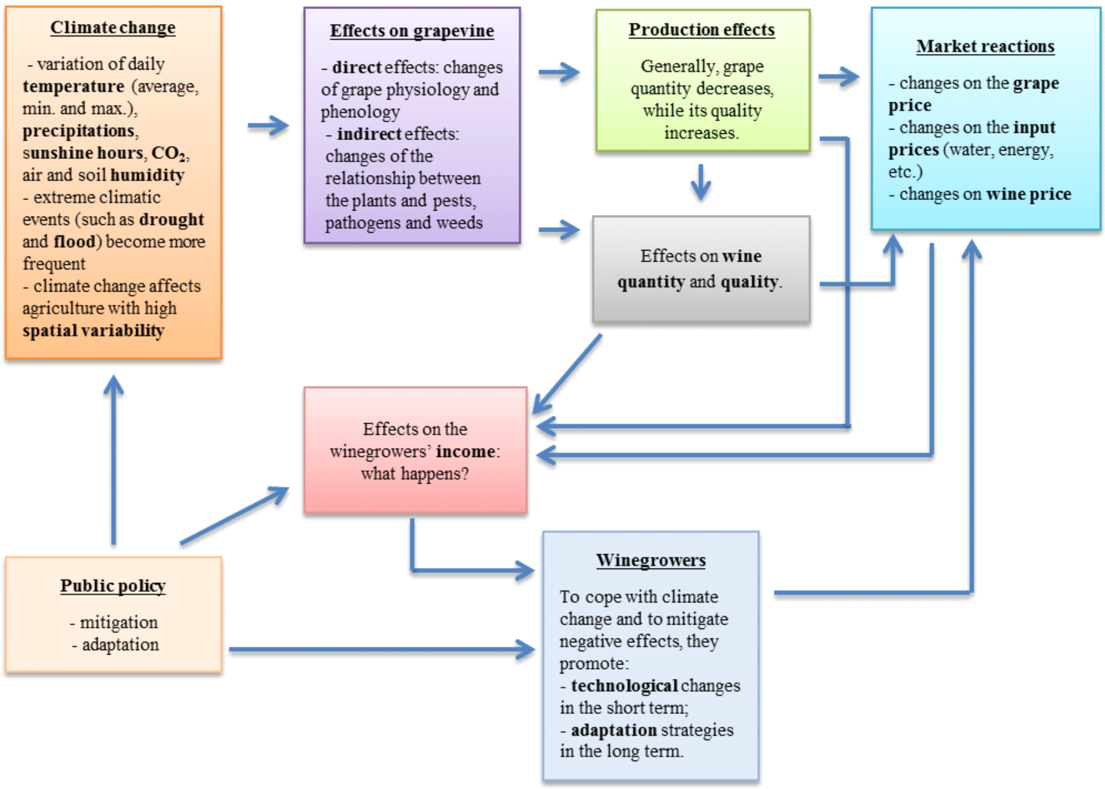
Moreover, the literature review highlights that estimated effects are extremely uncertain and change according to the applied method, the location of the studied area and the grapevine variety. These aspects mean that the research topic is extremely diverse and stimulate new models that are able to undertake the diverse effects of this phenomenon.

3. Proposal of a New Interdisciplinary Approach

Figure 1 summarises the effects of climate change on the wine industry. The figure was created by integrating findings observed by various scholars in the literature review into a framework. The final effect on winegrowers' income is uncertain because of the opposite effects of climate change on wine quality and quantity. Winegrowers adopt technological changes and adaptation strategies to decrease losses. Moreover, economic losses depend on the effects of climate change on the wine market where they cause grape prices to increase because of decreased supply and quality improvement.

In light of this scenario, the study proposes an interdisciplinary approach to assess the effects of climate change on the Romanian wine industry. The aim is to build an econometric model specifically designed to account for the diverse factors that are involved in wine production and the specificities of the case study area. These factors concern interdisciplinary research topics: agro-meteorology, grapevine phenology and eco-physiology, grapevine growing and oenology techniques and performance, business strategies and economic results. A case study area was chosen in the Moldavia region, the largest Romanian wine region, comprising of a third of all national vineyards.

Figure 1: Climate change and its implications on the wine industry



Source: authors' elaboration on findings

The formulation of the econometric model begins with the identification of the unit of observation, which is the vineyard (Y) specified through:

- the wine region (zn)
- the grape variety (cv)
- the farm's characteristics (frm)
- the harvest year (yr).

The function can be formulated in the following way:

$$Y_{zn,\, cv,\, frm,\, yr} = f(x)$$

The dependent variable identifies the vineyard. Focusing the analysis on the vineyard, rather than the farm, gives different advantages. Estimations can take into account the various aspects that generate variability inside the farm as spatial variation linked to vineyard location, differentiation in varieties' sensitivity to climate change, farm characteristics to include the farmers' aversion/propensity towards risk and the farmers' adoption of mitigation/adaptation strategies among the explicative variables and the use of panel data to reduce the year effect.

The dependent variable is quantified using a farm productivity index expressed through the output value (Y). This allows the analysis to consider simultaneous changes in grape supply and price, which is important because price is extremely reactive to quality and quantity variations and some of these variations are directly connected to climate change. In fact, it is possible that the price increases in years characterised by production loss because of climate change. Consequently, in these situations, production losses are compensated by the increase in grape prices, and a decrease of farms profitability is not observed. Moreover, the grape price is directly connected with the quality of the grape. Consequently, the dependent variable also considers, implicitly, wine quality variations that are due to climate change.

The independent variables include the main factors that are subject to influence from climate change and farmers' responses to cope with this. It is hypothesised that these variables affect the farmers' production value. Variables include climate conditions, vineyard characteristics, grape physiology and phenology, variations in wine quality parameters, farmers' technological choices and short-term adjustments and farmers' perception of climate change and the propensity to modify the production function to face or adapt to climate change. Table 1 summarises these variables. For each, the time variant/invariant characteristic in relation to the reference period (harvest years 2009–2010, 2010–2011 and 2011–2012) is specified, as well as factors in terms of which variables are constant (farm, grape variety or wine region).

Data represented in Table 1 by variables included in Groups 1–6 were obtained via a survey of winegrowers carried out from 2010 to 2012. For this purpose, a questionnaire was designed to collect farms' structural characteristics, farmers' perceptions of climate change and adaptation strategies and business performance. The survey was conducted through face-to-face interviews with winegrowers. A sample of 65 winegrowers with 280 vineyards located in the Moldavia wine region was analysed. Figure 2 shows the winegrowers geographical distribution. The sample was selected by considering all winegrowers enrolled in the Romanian Association of Wine Producers and Exporters.

The grape production and market price data necessary to calculate the dependent variable were obtained through the survey, which also allowed for the collection of information needed to define dependent variables concerning the following farm factors:

- vineyard specifics, such as characteristics of cultivated surface, variety, planting year and density
- farm specifics, such as geographical location, use of labour factor and role of the family irrigation practices
- winegrower specifics, such as age and education, business strategies, investment choices, processing activities, role of public support, expectations of profitability and perception of climate change effects.

Regarding weather conditions, data collection aimed to catch various microclimates. Data came from three main meteorological stations located in the study area (see Figure 2). Weather variables at the vineyard level were spatialised by considering spatial coordinates and calculating the great-circle or orthodromic distance with respect to the three meteorological stations for each vineyard. For each climatic variable, the average value with respect to the three observed values (at the station point) was calculated, weighting the distance between the farm and each meteorological station.

Table 1
Description of the variables included in the econometric model

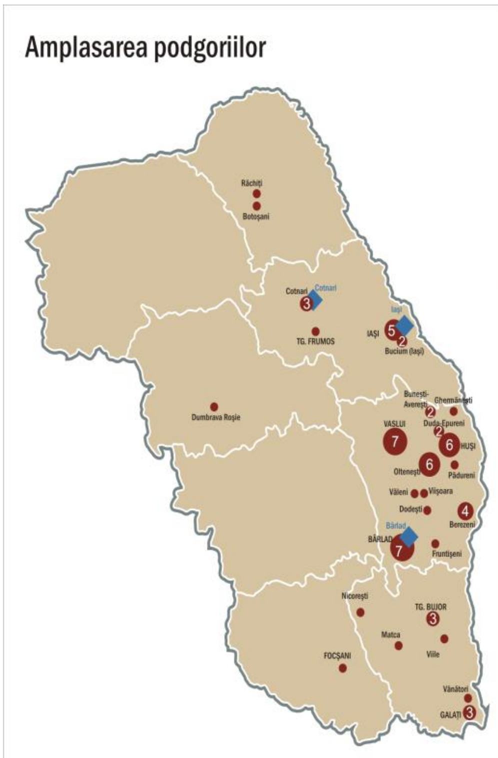
Variable	Type of variable	Unit of measurement	TV v. TINV*	Related to:
1) Climate change effects in terms of:				
Quantity of grape	Continuous	q/ha	TV	Vineyard
Price	Continuous	€/q	TV	Vineyard
Value of grape	Continuous	€/ha	TV	Vineyard
2) Farm's structure:				
Cultivated surface	Continuous	ha	TV	Vineyard
Altitude	Continuous	m	TINV	Vineyard
Age of plants	Continuous	years	TINV	Vineyard
Number of plants	Continuous	plants/ha	TINV	Vineyard
Soil type	Dummies	5 types of soils	TINV	Vineyard
3) Farmer's profile:				
Education	Continuous	Years	TINV	Farm
Age	Continuous	Years	TINV	Farm
4) Farmer's climate change perception:				
Climate change is problematic	Dummy	yes/no	TINV	Farm
Climate change increases costs of production	Dummy	yes/no	TINV	Farm
5) Farmer's strategies:				
Grape's processed at the farm	Dummy	yes/no	TINV	Farm
Bottling at the farm	Dummy	yes/no	TINV	Farm
Variety reconversion	Dummy	yes/no	TINV	Farm
Received subsides	Dummy	yes/no	TINV	Farm
Investments in the vineyard	Dummy	yes/no	TINV	Farm
Other types of investment	Dummy	yes/no	TINV	Farm
Value of investments	Continuous	€	TINV	Farm
6) Farmer's strategies able to cope with climate change:				
Use of the labour factor	Continuous	hours/ha	TV	Farm
Irrigation	Dummy	yes/no	TINV	Farm
7) Climate conditions:				
Total precipitations for each phenological phase	Continuous	Mm	TV	Wine region
Average temperature for each phenological	Continuous	°C	TV	Wine region

Variable	Type of variable	Unit of measurement	TV v. TINV*	Related to:
phase				
Total hours of sunshine for each phenological phase	Continuous	Hours	TV	Wine region
Global thermic balance	Continuous	t°g	TV	Wine region
Active thermic balance	Continuous	t°a	TV	Wine region
Useful thermic balance	Continuous	t°u	TV	Wine region
Average annual wind speed	Continuous	km/h	TV	Wine region
Average annual air relative humidity	Continuous	%	TV	Wine region
Nebulousness per year	Continuous	Index	TV	Wine region
No. of days with maximum temperature > 30° C per year	Continuous	Days	TV	Wine region
Length of bioactive period per year	Continuous	Days	TV	Wine region
Real heliothermic index per year	Continuous	Index	TV	Wine region
Hydrothermic coefficient per year	Continuous	Index	TV	Wine region
Bioclimatic index per year	Continuous	Index	TV	Wine region
Oenoclimatic index per year	Continuous	Index	TV	Wine region
Annual index of aridity	Continuous	Index	TV	Wine region
8) Physiological indexes:				
Chlorophyll (at the end of flowering, grape maturation and bachelor growth phases)	Continuous	Chlorophyll Content Index	TV	Wine region and variety
Photosynthetic pigments (at the end of flowering, grape maturation and bachelor growth phases)	Continuous	Index	TV	Wine region and variety
Amount of starch (during the deep sleep phase)	Continuous	%		Wine region and variety
Amount of carbohydrates (during the deep sleep phase)	Continuous	%	TV	Wine region and variety
Amount of protein (during the deep sleep phase)	Continuous	%	TV	Wine region and variety

Variable	Type of variable	Unit of measurement	TV v. TINV*	Related to:
Amount of dry matter (during the deep sleep phase)	Continuous	%	TV	Wine region and variety
9) Oenological index:				
Wine quality	Continuous	index	TV	Wine region and variety

* TV: Time Variant; TINV: Time Invariant.

Figure 2: Location of interviewees and meteorological stations



Weather variables mainly affect duration and temporality of phenological phases, grape production and wine quality. These variables were determined for the main phenological phases that characterise the most relevant grape varieties in Romania, such as the deep sleep period (from October to February), recovery and vegetative development (March to April), flowering and bunch formation (May to June) and bunch maturation (July to September). The model assumes the hypothesis of a quadratic relationship between production value and weather variables, and the significance of the interactions between temperature and precipitations is tested.

Physiological and oenological variables came from analyses carried out by experts in these fields on some investigated varieties grown in experimental vineyards located in Iasi, Cotnari and Târgu Bujor (see Table 2). This information relates to the Chlorophyll Content Index and the dynamics of chlorophyll content, which was measured with the spectrophotometer at 320–325 nm, 431–432 nm and 662–663 nm at the end of the flowering, grape maturation and bachelor growth phases. Information on the percentage of starch, carbohydrates, proteins and dry matter, measured during the grapevine deep sleep phase, is also available. Through these parameters, it was possible to evaluate the effects of climate change on the physiological phases schedule in relation to the activation and length of each phase, as well as the output quantity and quality. Wine quality variations were evaluated by oenologists. These evaluations were based on the analysis of wines processed using the grapes harvested from the experimental fields in the periods 2009 to 2010 and 2011 to 2012. They estimated the wine quality index (ranges between one and five) by considering chemical and physical parameters, such as alcohol concentration, total acidity, volatile acidity, relative density, sugar and free SO_2.

Table 2

Varieties analysed by each experimental field

Grapevine variety	**Iasi**	**Cotnari**	**Târgu Bujor**
Fetească albă	X	X	X
Fetească regală	X		X
Frăncuşă	X	X	
Grasă de Cotnari	X	X	
Tămâioasă românească	X	X	
Riesling italian	X		X
Băbească gri	X		X

4. Conclusion

This paper proposes a new approach to estimating the effect of climate change on the wine industry, using the Moldavia wine region as a case study. The main novelty concerns the interdisciplinary approach adopted for the analysis that allows the model to integrate several aspects of climate change. These include agro-meteorology, grape phenology and eco-physiology, grapevine growing, oenology techniques, wine quality, business strategies and performance.

The literature review highlights a lack of studies that were able to incorporate the numerous and diversified climate change effects into an integrated model, distinguishing between positive and negative effects. Further, only a few previous studies estimated the effects on winegrowers' profitability by considering changes in price. The winegrowers' perception of risk and their mitigation/adaptation strategies were not treated in-depth by the literature.

In this study, the methodological approach proposed aimed to overcome this gap using a model specification that is able to explain the variability of the dependent variable (the vineyard's output value) in relation to the vineyard's location, the cultivated variety, the farm's characteristics and the harvest year. Using this formulation, the econometric model should capture a higher proportion of the variability generated within the farm because it considers sensitivity to climate change, which is territorial and crop specific (as highlighted in the literature), as well as effects on the farm's economic performance.

The data for the specification of dependent and independent variables were collected through a primary source to reach the desired level of detail. The winegrowers' survey had the advantage of obtaining detailed information concerning the qualitative aspects of farmers' responses to climate change. The other variables were obtained by integrating different capabilities to represent the most significant elements concerning climate conditions, grape physiology and phenology and wine quality parameters.

This approach allows the study to consider the following aspects not previously analysed in an integrated model: the effect of grape physiological modifications on farm productivity, the relationship between grape and wine quality changes and market prices, the effect of wine quality and grape physiological parameters on marginal product value, the relationships between output values and weather conditions, the explanatory power of farmers' characteristics (such as production choices, entrepreneurs' culture, perception of risk and business strategies), the suitability of technological innovations to climate change and the effect generated by these factors in the presence of alternative climate change and market scenarios.

In addition, by carrying out the analysis by grape variety and wine region, the model was able to provide evidence of the effect of geographical variability and to contribute to addressing businesses strategies and public policies that enable farmers to cope with climate change to mitigate its negative effect on the Romanian wine industry.

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