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How are vineyards management strategies and climate-related conditions affecting economic performance? A case study of Chilean wine grape growers

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Abstract

In wine grape production, growers decide between alternative management strategies of the vineyard that have direct consequences on competitiveness. The aim of this study is to evaluate the impact on economic performance of four management strategies: training system, reserve quality production, irrigation method, and mechanization of labors. The data used in the study comes from face-to-face interviews to 336 wine grape growers of Central Chile, which was complemented with climatic variables retrieved from Geographic Information Systems. A log-log regression model of total value product (TVP) for the main variety grown in the vineyard was estimated, using production factors, vineyards' attributes, management strategies and climate-related conditions as explanatory variables. An interesting contribution of this study is the identification of TVP functions for land, fertilizers, fungicides, other agrochemicals, labor, and age of vines. Our results show that the training system has the most impact on TVP, where tendone-trained vineyards demonstrated 50% higher TVP than those vertically trained. Reserve quality production also has a positive effect on TVP, increasing it by 22% compared to vineyards producing varietal quality grapes. In contrast, the use of pressurized irrigation systems and mechanization in harvesting do not present a significant effect on TVP. The findings of this paper represent an advance in the understanding of the economic performance factors associated with wine grape growing and could serve to guide on-farm decisions and sectoral policies in pursuing the competitive development of wine grape growers.

Keywords: Economic performance, production function, vineyard management, wine grape growing

1. Introduction

One of the main components of competitiveness in wine grape production lies in the capacity to innovate [1] and to improve performance using available resources [2, 3]. The process of innovation at the vineyard level has played a prominent role in emerging countries from South America, South Africa, Asia and Oceania [4, 5, 6]. These countries have expanded their vineyard production, albeit not neglecting wine quality, to the extent that they are not only challenging the old world's leaders but also are increasing their domestic market share [7, 8, 9, 10]. Hence, there is evidence of improvements in competitiveness because of technological modernization processes, which has been especially relevant in developing countries.

An interesting example of this is Chile, a South American country that has experienced rapid development of its export-oriented wine industry in recent decades [11]. Indeed, wine grapes are one of the most important crops in the country [12]. Between 1990 and 2015, vineyard plantations doubled, wine production increased fivefold, and wine export volume grew from 22 to 1,445 million liters [13]. As a result, Chile has become an important player in international markets, being an example of how a traditional industry can become highly competitive in a short period of time by implementing important changes in technologies and production systems.

Despite the overall progress of the Chilean wine grape industry, there are some concerns in the domestic market from producers' associations regarding an oligopsony market structure (i.e., few grape buyers) that would generate competitiveness problems for wine grape growers [14]. For that reason, on-farm competitiveness has turned to be an extremely relevant issue for the viticultural sector and a better understanding is required of the factors affecting vineyards' economic performance, such as the impact of innovations and management strategies. In this regard, management strategies are considered among the most important determinants of vineyard profitability [3, 15, 16, 17]. Within this category we distinguish between production technologies, such as pressurized irrigation or mechanization in harvesting, that are generally more affordable for larger producers because of economies of scale and financial access [3], and cultivation techniques, such as training systems and reserve quality growing, that are generally less demanding in financial capital.

This study seeks to understand the role of vineyards management strategies on the economic outcome exhibited by wine grape growers, controlling for other production factors (e.g., land, labor, and inputs) and climate-related conditions (i.e., potential evapotranspiration, precipitation, and chilling hours). Using Chile as a case study, the aim of this paper is to provide insights about vineyard-level drivers of competitive performance in emerging countries. Prior research analysing vineyards outcomes related to economic performance, efficiency, or productivity, have focused mainly on the effect of economies of scale [5, 10, 18]; to the best of our knowledge, there are no studies analyzing management strategies implemented by wine grape growers in explaining economic performance. The study of Urso et al. [19] is one of the few that evaluates several production unit and contextual factors of vineyards; however, it is focused on production efficiency rather than analyzing the contribution of growers' production decisions on performance. Instead, our paper examines to what extent management strategies implemented by wine grape growers affect the TVP at the vineyard level, considering the heterogeneity of production units' attributes and climate-related conditions under which they operate.

The vineyards management strategies analyzed in this study were: a) training system (tendone vs. vertical structures), b) wine grape destination (reserve vs. varietal wines), c) irrigation method (pressurized vs. gravity irrigation), and d) mechanization in harvesting (mechanized vs. hand-picked). These vineyards' strategies are of different scope and nature, some of them represent structural (fixed) decisions while others are more related to flexible (alternative) decisions. For instance, wine grape destination is a flexible decision that might be defined each season, though it involves an array of practices aiming to regulate vine yield and grape quality, such as canopy management (e.g., pruning/mooring, de-sprouting, canopy defoliation, tipping of shoots) [20, 21], agrochemical use and irrigation regimes, among others. In contrast, the training system is a structural decision that must be made when wine grape growers establish the vineyard and is not (easily) modifiable.

The paper is structured as follows. The next section details the data used to perform the analysis and finishes with the empirical model. The third section presents and discusses results, and the last section summarizes the most relevant conclusions of the study.

2. Materials and Methods

2.1. Sampling procedure and data collection

The study area covers the O'Higgins and Maule regions in Central-South Chile (33° 50' and 36° 33' S, WGS84 datum), located in central Chile in the heart of the fruit and vineyard production (Figure 1). Combined, both regions comprise 73% of the national planted area of vineyards, distributed among three important valleys, from north to south: Rapel, Curicó, and Maule (a brief description of the weather conditions prevailing in these valleys is presented in Appendix 1). The area under study has a temperate Mediterranean climate, characterized by a six month dry season (Sept- Mar) and a rainy winter, with precipitation between 600 and 700 mm annually. The primary data used in this study was generated at the vineyard level, administering a georeferenced survey on-site to 436 wine grape growers between October 2014 and March 2015. This survey was restricted to vineyards from irrigated lands, growing at least one hectare. The sampling procedure consisted of a stratified random sample across 16 municipalities, where the number of surveys administered was determined depending on the relative number of vineyards in each municipality. The municipalities were, in order of number of surveyed producers: San Javier, Sagrada Familia, Curicó, Nancagua, Villa Alegre, Santa Cruz, Talca, Palmilla, San Clemente, Peralillo, Río Claro, Requínoa, Chimbarongo, Maule, San Vicente, and Peumo. After the field data collection process, in September 2020, using the georeferenced point of each survey, the dataset was supplemented with spatialized data of climate-related conditions 2015/2016 from the Chilean Natural Resources Information Center (CIREN) [22]. CIREN is a public institution that provides information on the natural and productive resources of the country through the use of geospatial data and applications. In this paper, the data from CIREN referred uniquely to environmental information for the years 2015-2016. As result of merging the primary and secondary data, the final sample with complete information was reduced to 336 observations because the Geographic Information System (GIS) used in this study did not cover the total distribution of surveyed vineyards.

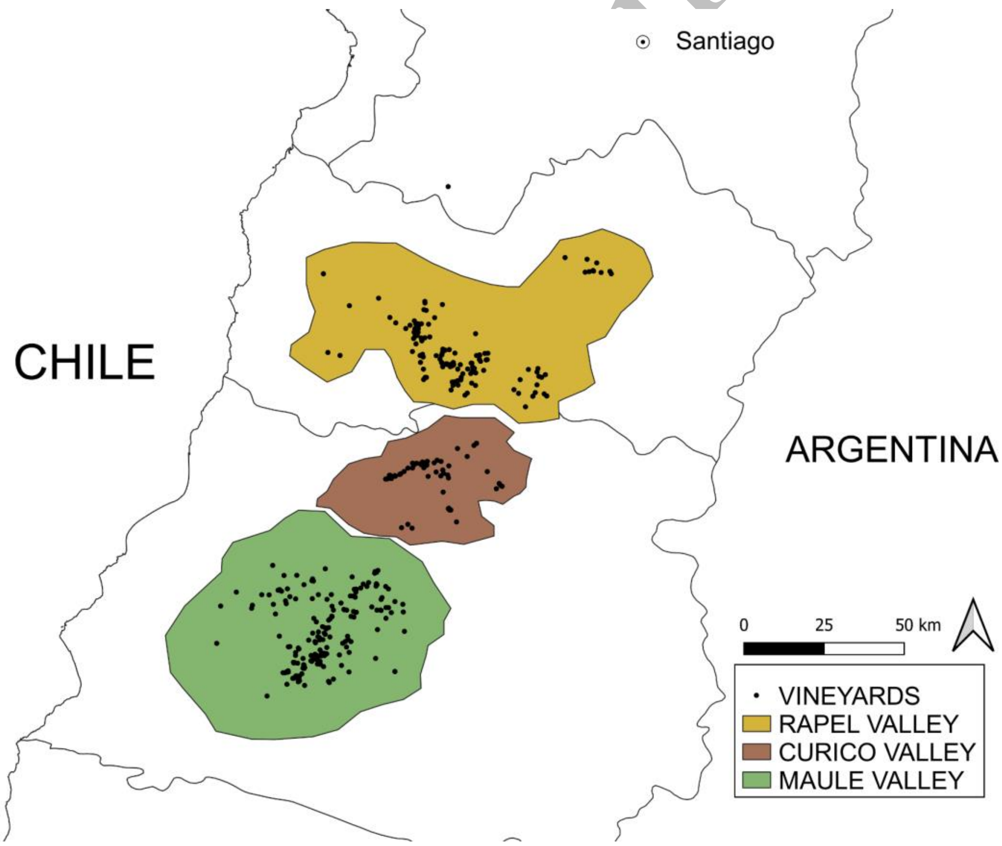


Figure 1. Map of the study area and locations of the vineyards included in the sample (black dots).

2.2. Survey data

The questionnaire administered to wine grape growers collected detailed economic and agronomic information for the main variety grown in the vineyard, such as planted area, yield, grape price, and (per hectare) intensity of use of inputs and labor. Growers were asked about the number of applications, doses, and unitary prices in the case of agrochemicals (i.e., fertilizers, herbicides, insecticides, fungicides, and acaricides) and number of working-days or agricultural machines/equipment in the case of labor (i.e., harvest, pruning/mooring, tipping of shoots, de-sprouting, canopy defoliation, physical weed control, and other labor), which were valued at fixed market prices.

Regarding growers' performance, the yield obtained by each grower (kg ha-1) was multiplied by the average grape price of the variety in the sample ($ kg-1). As in our sample growers identified 19 different varieties, we used the average price for each variety to estimate their incomes. The reason for using fixed grape prices and fixed market prices for inputs and labor was to avoid differences in bargaining power or personal skills among wine grape growers, which are beyond the scope of our analysis as the objective of our paper is to estimate the impact of technical decisions on technical outcomes using an economic model.

Subsequently, to convert the monetary measures per hectare for inputs, labors, and output to the plot level, they were scaled-up (values were multiplied by the planted area of the main variety grown in the vineyard). Hence, the economic output variable analyzed in this paper is the total value product (TVP) generated by the main variety of the vineyard, considering that there are important differences in prices between grape varieties within the sample. For the purposes of this study, expenditures and total value products were converted to US dollars using the average exchange rate of 2015 (654 Chilean pesos per US dollar), the year in which the field survey process finished.

2.3. GIS spatial data

An important feature of this study is the inclusion of climate-related variables as controls in the econometric model. In particular, we included three variables: potential evapotranspiration, precipitation, and chilling hours; a description is presented in Table 1. The selection of these variables, representing referential production conditions for vineyards, is expected to exert an influence on vineyard yields. The climate-related variables were retrieved from high spatial resolution data of the O'Higgins and Maule regions of Chile, using layers and isolines of Agroclimatic Districts (1:250,000 scale) gathered from the Chilean Natural Resources Information Center (CIREN) [22]. An intersection algorithm able to cross climatic layers and the georeferenced sampling site of each vineyard allowed us to add secondary information to our dataset of surveyed wine grape growers. This procedure was performed using the QGIS software (Open-Source Geospatial Foundation Project: http://qgis.osgeo.org).

3. Calculation

According to Chinnici et al. [23], evaluating the operational choices of a vineyard involves knowledge of the potentials and restrictions of both a technical and economic-managerial nature. Indeed, growers face different alternatives in which to invest but they have certain restrictions imposed by their own attributes and other territorial characteristics, ranging from natural resources to the availability of production factors and techniques [1]. Therefore, this paper considers that growers' TVP is a function of production factors (i.e., land, input, labor) attributes of the productive unit, climate-related variables, and management strategies.

To model the TVP generated by wine grape growers, we adopted a Cobb-Douglas functional form estimated using a multiple linear regression, in logarithms for all continuous variables. The empirical model in natural logarithms for the *i*-th wine grape grower can be expressed as follows:

$$ln\, Y_i = \alpha + \sum_{j=1}^{5} \beta_{ji}\, ln\, X_{ji} + \sum_{k=1}^{3} \gamma_{ki}\, A_{ki} + \sum_{m=1}^{4} \varphi_{mi}\, M_{mi} + \sum_{l=1}^{3} \pi_{li}\, E_{li} + v_i \qquad \text{(Eq. 1)}$$

The dependent variable in our study is the total value product of wine grape growers (Y), which comes from the multiplication of yields (kg ha-1) per planted area (ha) and grape price ($ kg-1). The model is expressed as a function of five inputs: Land (X1), Fertilizers (X2), Fungicides (X3), Other agrochemicals (X4), and Labor expenditures (X5). In the case of other agrochemicals, this category represents the sum of expenditures in insecticides, acaricides, and herbicides; fertilizers and fungicides were incorporated in isolation into the model because of their agronomic importance in vineyard production. In the empirical model, there are also three sets of control variables for: a) attributes of the productive unit, b) climate-related variables, and c) management strategies. First, a set of three variables representing productive unit attributes was considered: grape color (A1), age of the vines (A2), and valley where the vineyard is located (A3). Following, a set of four dummy variables for management strategies: pressurized irrigation (M1) and mechanized harvest (M2), training system (M3), and type of wine for which the grapes are intended (M4). And finally, a set of three climate-related variables, namely: Potential evapotranspiration (E1), Precipitation (E2), and Chilling hours (E3). The last term of equation 1, v_i, is the normally distributed error that accounts for statistical noise in the model.

To test the robustness of our empirical model and observe the contribution of the different sets of variables included in the model, several progressive specifications for the above explained sets of explanatory variables were estimated and compared through maximum likelihood ratio tests. A complete explanation of the covariates included in the equations is shown in Table 1. The described model was estimated in STATA 15.1 [24].

4. Results and Discussion

4.1. Vineyards' total value product and explanatory variables

Table 1 presents a description and summary statistics of the variables included in the models. It is worth noting that values are reported for the main grape variety at the plot level.

Table 1. Variable description and summary statistics of variables used in models of vineyard production for three wine grape growing areas of Chile (data at the plot level for the main grape variety of the vineyard; N= 336).

	Variable	Description	Mean	S.D.	Median	Min	Max
DV	TVP	Total value product (1,000 USD)	65.60	104.47	29.36	0.60	1213.76
Production factors	Land	Planted area (hectares)	16.74	20.28	9.90	1.00	140.00
	Fertilizers	Fertilizer expenditure (1,000 USD)	4.34	7.36	1.70	0.00	52.95
	Fungicides	Fungicide expenditure (1,000 USD)	2.89	5.63	0.99	0.00	51.38
	Agrochem.	Expenditure in agrochemicals to control insects, spiders and weeds (1,000 USD)	5.99	17.29	1.52	0.00	201.38
	Labor	Labor expenditure (1,000 USD)	16.49	21.05	8.13	0.28	137.61
Vineyards' attributes	Grape Color	Grape color (red=1; white=0)	0.82	0.38	1	0	1
	Vineyard age	Age of planting (years)	29.84	26.28	19	4	116
	Rapel valley	Rapel valley (yes=1; no= 0).	0.35	0.48	0	0	1

	Curicó valley	Curicó valley (yes=1; no= 0, excluded category in models)	0.20	0.40	0	0	1
	Maule valley	Maule valley (yes=1; no= 0).	0.45	0.50	0	0	1
Management strategies	Irrig. method	Irrigation method (pressurized= 1; gravity= 0)	0.39	0.49	0	0	1
	Mech. harv.	Machinery use for harvest (yes= 1; no= 0)	0.17	0.38	0	0	1
	Training syst.	Training system (tendone=1; vertical=0)	0.18	0.39	0	0	1
	Grape Dest	Grape destination (reserve=1; varietal=0)	0.11	0.32	0	0	1
Climatic conditions	Evapotransp.	Cumulative evapotranspiration from Dec-15 to Feb-16 (mm)	456	21	461	408	512
	Precipitation	Cumulative precipitation from Dec-15 to Feb-16 (mm)	22.81	7.23	24	8	45
	Chilling hours	Cumulative chilling hours in 2016 (hours)	1,287	303	1,380	750	1,830

As shown in Table 1, growers' TVP and input and labor expenditures exhibit considerable differences between the mean and median, which reveals the skewed distribution to the left of these variables. Planted area is also a skewed variable, where the mean surface is 16.7 ha, and the median is 9.9 ha. The use of logarithms, besides its convenience in estimating partial elasticities of productive factors, helps to avoid the skewed distribution of the data.

Turning to descriptive statistics, at median values at the plot level wine grape growers spent about US$ 1,700, US$ 990 and US$ 1,520 on fertilizers, fungicides, and other agrochemicals, respectively. The expenditure in labors – including harvest, pruning/mooring, tipping of shoots, de-sprouting, canopy defoliation, physical weed control, and rest of labors – reached a median of US$ 8,130 in the sample. The sum of expenditures on fertilizers, fungicides, other agrochemicals (to control insects, spiders, and weeds), and labor represents an approximation of the operational costs incurred by grape growers in a year, which reach a median value of US$15.005. On the other hand, the median TVP was US$ 29,360. Note that the median planted area was 9.9 ha, which informs about an approximate per hectare outcome of US$ 2,965 (this calculation is close to the actual median of the sample used to estimate the model, which corresponds to USD$ 3,058 per hectare).

Regarding vineyards' attributes, most wine grape growers cultivate red grapes (82%) rather than white grapes (the remaining 18%). The median age of the vineyards was 19 years, within a range of 4 and 116 years old. Regarding wine valleys, the distribution of the vineyards among Rapel, Curicó, and Maule was 35%, 20%, and 45%, respectively.

In terms of management strategies, 39% of the sample had pressurized systems to irrigate the vineyard and 17% used machinery to perform the harvest. The tendone training system was a minority compared to the vertical system (18% vs 82%, respectively), and only 11% of the growers produced reserve quality grapes while the remaining 89% produced varietal quality.

As for climate-related conditions, the average potential evapotranspiration and precipitation of the three warmest months in Chile, during the stage of veraison in grapes (period of accumulation of sugars), were 456 mm and 23 mm, respectively. Concerning annual cumulative chilling hours, the sample mean was 1,287 hours with a wide range (750 to 1,830 hours).

4.2. Contribution of production factors, vineyards' attributes, management strategies and climate-related conditions

As mentioned in Section 3, three sets of explanatory variables were progressively added to the basic production function (Model A) to select the most appropriate specification to explain wine grape growers' TVP. Four specifications, one for each set of regressors, were estimated and compared through maximum likelihood ratio tests. Table 2 reports the TVP model for the main variety of the vineyard under the four alternative models.

Table 2. Cobb-Douglas estimates for total value product of Chilean wine grape growers under four alternative models (N=336).

Variable	**Model A:** *Production factors* **Coeff.[a]**		**Model B:** *A + Vineyards' attributes* **Coeff.[a]**		**Model C:** *B + Management strategies* **Coeff.[a]**		**Model D:** *C + Climatic conditions* **Coeff.[a]**	
Ln Land	0.603	***	0.806	***	0.913	***	0.917	***
Ln Fertilizers	0.033		0.018		0.018		0.020	

Ln Fungicides	0.049	***	0.028	**	0.025	**	0.022	**
Ln Agrochem	0.110	***	0.066	**	0.060	**	0.054	**
Ln Labor	0.274	***	0.156	***	0.056		0.050	
Grape Color			-0.381	***	-0.384	***	-0.371	***
Vineyard age			-0.163	***	-0.112	***	-0.109	***
Rapel valley			0.262	***	0.246	***	0.137	
Maule valley			-0.189	**	-0.168	**	-0.161	**
Irrig method					0.088		0.117	*
Mech harvest					-0.018		-0.019	
Training system					0.492	***	0.513	***
Grape Dest					0.227	**	0.222	**
Ln Evapotransp							0.066	
Ln Precipitation							-0.275	**
Ln Chilling hours							0.123	
Constant	1.394	***	2.011	***	1.674	***	1.246	
Obs (N)	336		336		336		336	
Adjusted R^2	0.831		0.864		0.880		0.876	
BIC	635.687		587.499		567.751		580.637	

[a] Significance: ***=1%; **=5%; *=10%.

First, model A – the basic production function including land, inputs, and labor – presents significant parameters for all the covariates except for fertilizers. The base model was complemented with covariates representing vineyards' attributes (i.e., grape color, vine age, and wine valleys) resulting in model B. To compare models A and B, a likelihood ratio test was performed to verify the hypothesis that the former nested in the latter (i.e., additional covariates do not add to the explanation of growers' TVP). The test rejected the null hypothesis (p-value of 0.000 with 4 degrees of freedom), giving support to the inclusion of vineyards' attributes. Subsequently, we included the set of management strategies (i.e., irrigation method, training system, mechanized harvest, and grape destination) into model B to produce model C. The null hypothesis that model B is nested in model

C is rejected (p-value of 0.000 with 4 degrees of freedom), supporting the consideration of management strategies in modelling growers' TVP. Finally, climate-related variables (i.e., evapotranspiration, precipitation, and chilling hours) were included in model C to produce model D. The likelihood ratio test in this case did not favor model D (p-value of 0.207 with 3 degrees of freedom), which explains that adding climate-related variables did not contribute to explaining growers' TVP.

In addition, we tested the inclusion of climate-related conditions in models A and B to corroborate whether these variables have an effect in alternative models (results not shown but available upon request). Only in model A was the inclusion of climate-related conditions supported by the likelihood ratio test (p-value of 0.000 with 3 degrees of freedom), while in model B it was not (p-value of 0.704 with 3 degrees of freedom). Thus, the inclusion of climate-related variables into the TVP models was not supported by statistical tests, except for the base model. Although somewhat unexpected, we believe that there is a competing effect between climate-related conditions and the variables controlling for vineyard location (i.e., the categorical variables for wine valleys). Indeed, analyses of variance demonstrate statistically significant differences for the climate-related variables across valleys (see Appendix 3). Each valley has distinct characteristics that are captured by the climate-related variables (for a further description of valley characteristics see Appendix 1). An additional possible explanation for the non-significant effect of climate-related variables in model D is the date of the primary and GIS data, which differed in one productive season. Specifically, the survey was administered to grape growers in 2014-2015, and the environmental information from GIS referred to 2015-2016. Although the timing of these two sources of information is not exact, due to GIS data availability, climate-related variables in this study contribute to characterizing the microclimate of the wine valleys included in the sample.

From the above, we can conclude that model C is preferred over the four confronted specifications, being selected as the most appropriate to explain growers' TVP. It should also be noted that goodness of fit statistics reported at the bottom of Table 2 confirm that model C is the best alternative (maximum Adjusted R-squared and lower Bayesian Information Criterion). Hence, model C is further discussed in the following section.

4.3. Results and discussion of the Selected Model C

Table 2 shows that nine out of 13 covariates were significant ($p<0.05$) and explained 88% of the variance of growers' TVP. The estimated parameters must be interpreted as partial elasticities of production (or percentage impact after exponentiating coefficients in the case of dummy covariates) because of the logarithmic metric used in the model. The parameters of conventional inputs, here referred to land, inputs, and labor, are all positive and less than one, and thus consistent with economic theory [25]. The sum of these coefficients was 1.073, which was tested for constant return to scale. The null hypothesis was rejected (p-value of 0.014 with 1 degree of freedom), hence we concluded that the production function exhibits increasing returns-to-scale. This result is consistent with the findings of Galindro et al. [18], who analyzed vineyard size in the Demarcated Douro Region of Portugal, and with the findings of Sheng et al. [26] who found increasing returns to scale using a sample of different agricultural establishments in Australia.

The parameter of the variable Land had a significant contribution in the explanation of growers' TVP, with an average elasticity of 0.91, meaning that a 10% increase in planted area translates into a 9.1% higher TVP, when holding all other variables constant. Concerning other inputs, pesticides (i.e., fungicides and other agrochemicals) were all significant, while fertilizers were not. These results may be explained by the inherent characteristics of the crop (i.e., the *Vitis* genus), as wine grapes are highly attractive to pests and diseases due to their elevated content of water and sugar, and vines have a natural tendency to grow vigorously. Fertilization management, as in the case of irrigation, must be carefully administered to the vineyard in order to have a correct balance between vegetative growth and fruit production [27]. The latter seems to be supported by the data used in our study since fertilizers, compared to pesticides, represent a smaller fraction in the total expenditure (sample average sum of fungicides, insecticides, acaricides, herbicides, and fertilizers; see Table 1). The use of fungicides increases the TVP with an average elasticity of 0.025 (i.e., a 10% increase in fungicide expenditure translates into a 0.25% higher TVP). As for other agrochemicals – that includes insecticides, acaricides, and herbicides – the growers' TVP increases by 0.6% when the expenditure in this item rises 10%. These results are expected since grapes are very sensitive to fungus, such as powdery mildew, botrytis, and grapevine trunk diseases [28, 29, 30] and pests, such as *Lobesia botrana*, *Brevipalpus chilensis*, *Pseudococcidae* spp. [31, 32, 33].

Concerning labor expenditure, corresponding to the sum of expenses of performing the different management activities evaluated in this study, the estimated parameter was not significant. This result was unexpected since models A and B showed a significant contribution of labor expenditure in explaining growers' TVP. The only difference between these models and model C is that the latter includes management strategy variables; therefore, it is likely that its inclusion has diluted the effect of labor. Indeed, alternative training systems and grape destinations have implications in terms of the use of labor (i.e., harvest, pruning/mooring, tipping of shoots, de-sprouting, canopy defoliation, physical weed control, and other labors). For instance, the tendone training system imposes several limitations for mechanizability [34], which translates into a greater dependence on manual labor. Then, management strategies may act as confounding variables with labor expenditure. To illustrate the differences in labor expenditure by training system and grape destination, Tables A.2 in Appendix 2 present a complete characterization of the vineyards, respectively.

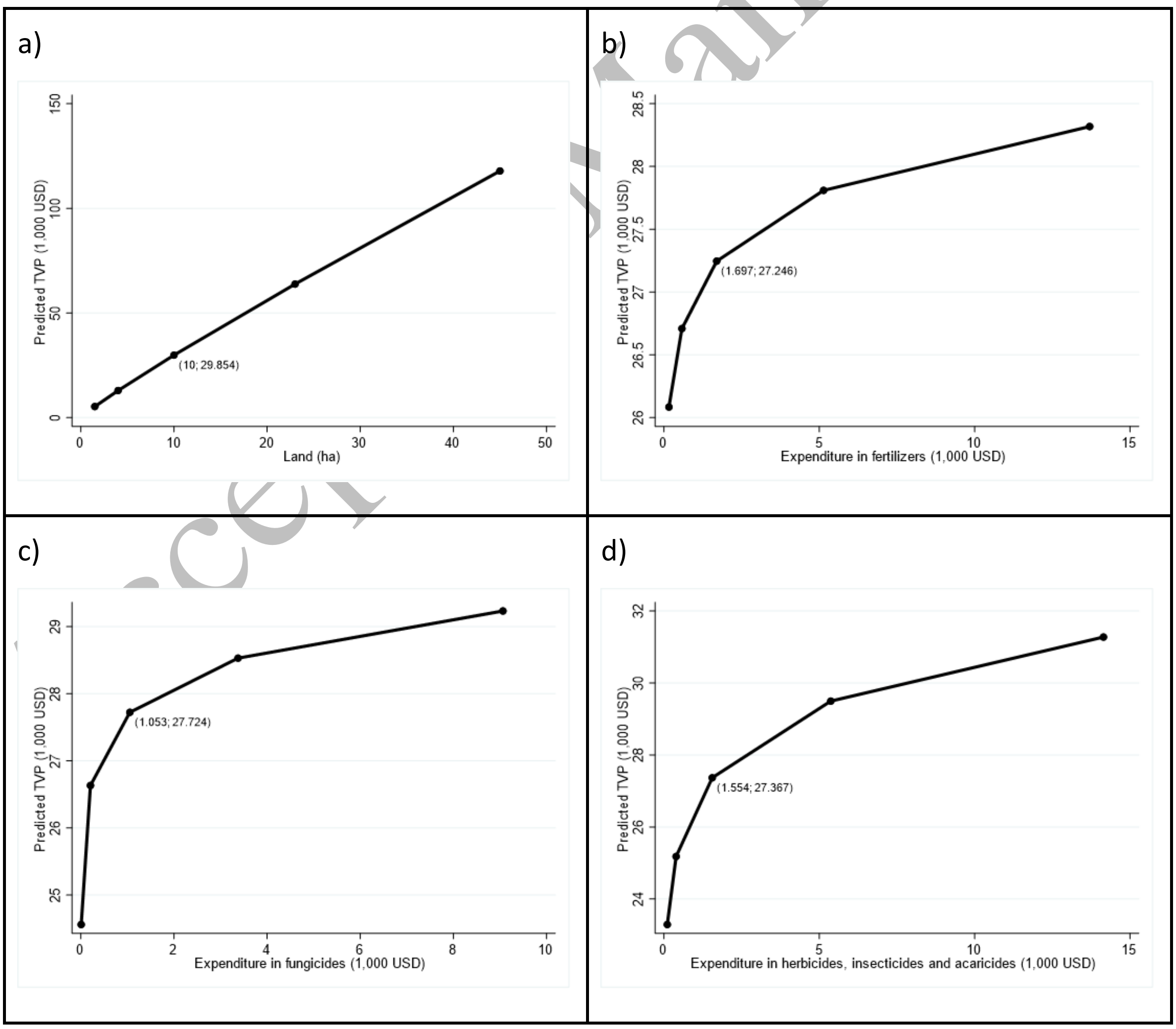
As mentioned above, the training system and grape destination played a relevant role in our TVP model, while pressurized systems and mechanized harvesting were not statistically significant. According to our results, the training system is a determinant variable in the explanation of growers' TVP, increasing it by 63% when vineyards are trained as tendone compared to vertical training systems (the marginal effect of binary variables correspond to their exponentiated parameter estimate in model C). Grape destination was also significant in the model, showing that vineyards producing reserve grapes (i.e., of superior quality) demonstrated a 25% increase in TVP compared to varietal oriented vineyards. Appendix 2 show that tendone training systems exhibit considerably higher yields and harvest expenditure and lower prevalence of mechanized harvesting and agrochemical expenditure. The reserve quality grape destination, for its part, presents lower yields that are compensated by higher prices to demonstrate a higher TVP (compared to varietal). As expected, it also presents a higher aggregate labor expenditure (see item other labors).

As for vineyards' attributes, all the variables included within this category were significant in explaining growers' TVP. It was found that vineyards growing red grape varieties generate 32% less TVP than vineyards growing white grapes, holding all other variables constant. This is because white grape varieties receive higher prices and present higher yields than red grape varieties in our sample: the average price per kilo is USD$ 0.292 vs USD$ 0.246, respectively, and the average yield per hectare is 16.7 tons and 14.5 tons, respectively. The age of the vineyard also plays a relevant role in the model, indicating that TVP is reduced by 1.1% when the age is increased by 10%. In the empirical literature there is mixed evidence on this topic, particularly on yield effects rather than on grape quality effects. Some studies have found that vine age may reduce yields [35], while others have found a positive [36] or no significant effect on yields [37].

In terms of production valleys, using Curicó as a reference, wine grape growers from Rapel exhibit 28% higher TVP while those from Maule are 16% lower. That is to say, the growers' TVP increases as moving north in the study area. This result corresponds with average data displayed in Table A.3 (see Appendix 3), showing that growers from the northernmost valley (i.e., Rapel) present higher average grape prices and yields. The same table shows that growers from Rapel face a lower incidence of precipitation and higher evapotranspiration between December and February, which may affect positively quality and yields, respectively.

4.4. Total value product functions derived from model C

Figure 2 displays several TVP functions for the production factors considered in this study (i.e., land, fertilizers, fungicides, other agrochemicals, and labor) and the age of the vines. They represent the relationship between each of these variables and vineyards' outcomes, by showing the average prediction of TVP in the sample (fitted value) at increasing values of the variable, holding all other covariates in the model constant at observed values. In each TVP function, the pair of coordinates that correspond with the median value of the variable (X-axis) and their expected TVP (Y-axis) is presented. For example, in the case of land, the median value is 10 hectares, which is associated with an expected TVP of US$ 29.854, holding all other covariates in the model constant at observed values (see Figure 2.a). It can also be seen that there is a positive and almost linear (barely concave) response of TVP as the quantity of hectares of vineyard increase. Notwithstanding, in the case of fertilizers, fungicides, other agrochemicals, and labor, the concavity of the TVP function is very clear, which indicates that the marginal effect of these variables is positive but decreasing. As for the age of vines, the relationship is negative and convex, showing a decreasing marginal effect on TVP as the number of years increase (see Figure 2.f).



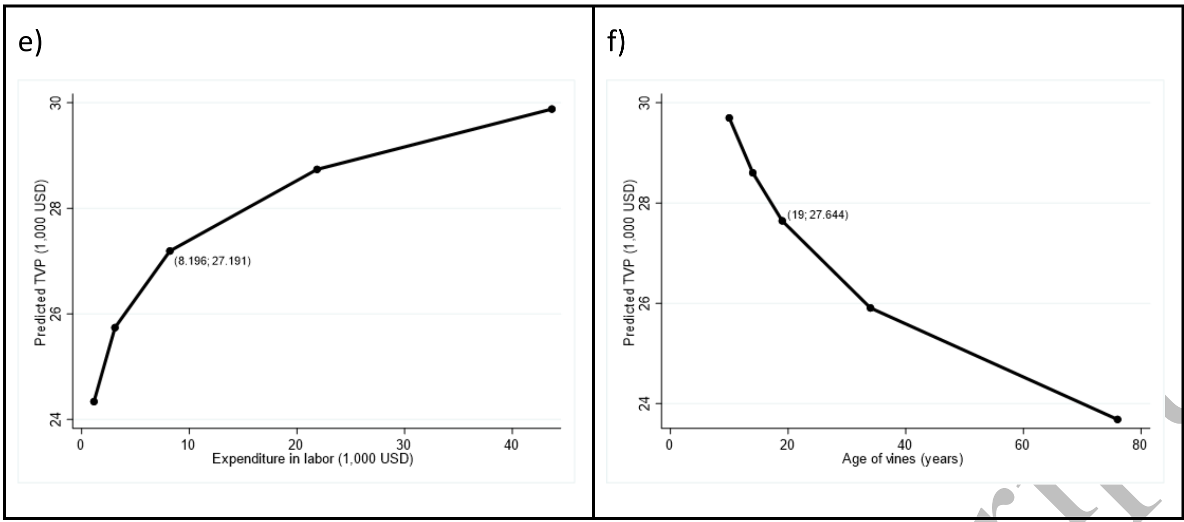


Figure 2. Total value product functions from a sample of 336 Chilean wine grape growers for: a) land, b) expenditure in fertilizers, c) expenditure in fungicides, d) expenditure in other agrochemicals, e) expenditure in labor, and f) age of vines. In each graph there are plotted five data points that, from left to right, correspond to the 10th, 25th, 50th, 75th and 90th percentiles. Therefore, coordinates (X, Y) represent median values in X and the associated values in Y.

5. Conclusions and production implications

The economic analysis carried out in this study showed the impact of alternative management strategies and cultural practices, controlling for vineyards' structural variables and production conditions, using a sample of 336 vineyards. Among significant variables, the results reveal that the vineyard training system, grape color, grape destination, and vineyard age play an important role in explaining growers' total value product (TVP). In particular, a better economic performance is expressed by vineyards using tendone training systems, growing white varieties, producing reserve quality grapes, and having younger aged vines. These results have direct implications for both wine grape growers and sectorial policy makers aiming to improve the competitiveness of viticultural production by providing management strategies that result in better outcomes. In addition, we improve on the existing literature as our results are based on a diverse, comprehensive, and relatively large dataset, while previous studies tend to focus on specific or narrow factors of economic performance (e.g., testing the effect of a particular management practice) and generally use purposive samples that do not guarantee diversity or representativeness. In this regard, we disentangle the role of a diversity of factors affecting viticultural production and estimate their impact on growers' TVP, which at the end is the ultimate goal of a vineyard.

We also included in the econometric model a set of climate-related variables from a GIS, which do not appear to be significant in explaining growers' TVP. This result was unexpected since agricultural systems are naturally determined by climatic conditions, especially in recent years as they are increasingly challenged by climate change. We believe that the joint inclusion of climate-related variables in the econometric models with other crucial variables for wine grape growing (particularly, the valley of production) competed in explaining the variance. In this regard, the study area of this paper is centered in three important and traditional wine valleys of central Chile, the core of the country's vineyard production, which at some point capture climate-related conditions. The results indicate that vineyards located in northern wine valleys – characterized by a lower on-season precipitation, lower annual chilling hours, and higher evapotranspiration – demonstrate a higher growers' TVP. Another potential reason for the non-significant effect of climate-related variables, apart from the competing effect by the variance with the valley of location in the statistical models, is that vineyards are not as sensitive as other crops to the climate-related variables analyzed in this paper. We suggest more research on this topic; deeper analyses are needed to explore this eventual trait of vines as our data and analyses are limited in this regard. Future research might explore the adaptive capacity of vines compared to other crops in light of the climate change phenomena affecting our planet.

Despite the contributions of this paper, there were some inherent limitations that can be considered by future investigations. First, in this study we use the main grape variety plot of the vineyard as the unit of analysis, but it is likely that growers produce several grape varieties within a vineyard. Future studies might consider this complexity when analysing economic performance by modelling simultaneously the different outcomes of vineyards. Second, we believe that subsequent studies may improve the findings presented here by including soil heterogeneity variables that may have an important effect on vineyards' economic performance. Although our model barely captured this effect through the variable valley of location, we suggest the consideration of specific measures of the terroir aiming to isolate this source of variability. Third, today's digital technologies, such as GPS, PDA, remote sensing or GIS, are becoming relevant in agricultural systems as they generate valuable information to make better decisions and thus turn production processes more efficient. In our study, we did not consider the adoption of these technologies as a management strategy that allows for making precision agriculture at the sub-plot level. We acknowledge it as a shortcoming that could be addressed in future research on this topic.

The main contribution of this paper is to advance in the understanding of economic performance factors in wine grape growing, by simultaneously considering management strategies, production conditions, and vineyards' attributes. Capturing the effects of on-farm decisions made by the vineyards, using a relatively large sample distributed in three different wine valleys, represents valuable information to develop a strategy for the primary sector in Chile, which faces significant competitiveness challenges compared to other agents of the marketing chain. Hence, our findings are hopefully valid for other emergent countries in the global wine industry, and especially for those that enjoy a Mediterranean climate. The practical implication of identifying what factors allow vineyards to be more profitable serves to guide on-farm decisions of the private sector, both growers and investors. Notwithstanding, the above is especially relevant for policy makers, to the extent that improved economic performance at the vineyard level can have an aggregate impact on the commercial success of the whole industry.

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Conflict of Interest

The authors declare no conflict of interest.

Appendices

Appendix 1

Valley	Surveyed producers	Characteristics
Rapel	164	Composed by the sub-valleys Cachapoal and Colchagua, both are located in the O'Higgins region of Chile and are characterized by their sub-humid, Mediterranean temperate climate, ideal for the production of red varieties. The hours of light, high thermal oscillation, and the existence of various microclimates allow for growing different wine varieties. This region has a pronounced seasonality, where winter concentrates the most of annual rainfall. It has an average temperature of 22 °C and precipitation around 600 mm. The soils are alluvial in origin. These valleys are located north of the Curicó and Maule valleys.
Curicó	91	Located in the Maule region of Chile, Curicó valley is considered the center of the Chilean wine growing because of its high concentration of vineyards. It has a temperate Mediterranean climate with a dry period five months a year, precipitation around 700 mm, and an average temperature of 20 °C. White varieties are best grown in the coolest areas of the valley. It has numerous water sources and the soil is alluvial and volcanic in origin.
Maule	181	Located in the Maule region of Chile south of Curicó valley and considered the "Cradle of Chilean wine" because of its origin during the time of Spanish colonization. It has a temperate Mediterranean climate with rainy winters. The soils are acidic and clayed, which partially reduces productivity to benefit the quality of the grapes. It has many rivers that also exert influence on the quality of their wines.
Total	436	

482 **Appendix 2**

483

484 Table A.2. Vineyards' characterization by training system and grape destination.

485

	Training system				Grape destination			
	Vertical		Tendone		Varietal		Reserve	
Variable	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
Grape price (USD kg-1)	275	0.260	61	0.229	298	0.235	38	0.409
Yield (ton ha-1)	275	12.609	61	26.000	298	15.554	38	11.011
Planted area (ha)	275	17.297	61	14.249	298	16.644	38	17.527
Fertilizer expenditure (1,000 USD)	275	4.228	61	4.818	298	4.468	38	3.291
Fungicide expenditure (1,000 USD)	275	3.111	61	1.904	298	2.807	38	3.560
Expenditure in agrochemicals to control insects, spiders and weeds (1,000 USD)	275	6.453	61	3.883	298	5.674	38	8.435
Labor expenditure (1,000 USD)	275	15.680	61	20.116	298	16.226	38	18.521
Expenditure in pruning/mooring (1,000 USD)	270	4.616	61	7.181	295	5.174	36	4.392

Expenditure in harvesting (1,000 USD)	265	5.789	60	10.373	287	6.567	38	7.154
Expenditure in desprouting (1,000 USD)	232	1.722	47	1.355	247	1.645	32	1.777
Expenditure in thinning of shoots (1,000 USD)	217	0.895	26	0.489	214	0.858	29	0.808
Expenditure in physical weed control (1,000 USD)	200	0.985	52	0.953	229	0.971	23	1.048
Expenditure in other labors (1,000 USD)	167	4.436	27	1.508	167	3.665	27	6.276
Grape color (red=1; white=0)	275	0.829	61	0.803	298	0.829	38	0.789
Age of planting (years)	275	32.335	61	18.574	298	29.658	38	31.237
Irrigation method (pressurized= 1; gravity= 0)	275	0.378	61	0.459	298	0.396	38	0.368
Machinery use for harvest (yes= 1; no= 0)	275	0.200	61	0.033	298	0.178	38	0.105
Training system (tendone=1; vertical=0)	275	-	61	-	298	0.201	38	0.026
Grape destination (reserve=1; varietal=0)	275	0.135	61	0.016	298	-	38	-

Appendix 3

Table A.3. Mean comparison of grape price, yield and climate-related variables across valleys.

Variable	**Rapel**		**Curicó**		**Maule**	
Grape Price (USD kg^{-1})	0.30	a	0.25	b	0.22	b
Vineyard yield (ton ha^{-1})	17.42	a	15.22	a	12.63	b
Precipitation (mm)	15.24	a	27.16	b	26.65	b
Evapotranspiration (mm)	464.28	a	453.27	b	450.06	b
Chilling hours (hours)	1009.13	a	1542.43	b	1395.87	c

* Different letters within the same row means statistically significant differences ($p< 0.05$)

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