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Technical efficiency and socio-environmental sustainability in the wine sector: tradeoff or complementarity? Evidence from Italy

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Abstract. In recent decades, sustainability has risen to prominence across various industries, including agriculture, largely driven by policy initiatives such as the European Union's new Common Agricultural Policy and the Farm to Fork Strategy. Among agricultural activities, viticulture stands as a crucial player in sustainability, intertwining environmental, social, and economic dimensions, as exemplified by the OIV General Principles of Sustainable Viticulture. Italy, one of the main players in the global wine market, has long been making efforts towards the introduction of sustainability-oriented practices and certifications. In this context, our study investigates the relationship between efficiency and socio-environmental sustainability in Italian wineries, using data from the Italian Farm Accountancy Data Network (FADN). Through Stochastic Frontier Analysis, we measure technical efficiency and explore the impact of socio-environmental sustainability factors. The existence of a complementarity or tradeoff between sustainability and efficiency is discussed in the light of exogenous structural characteristics, such as the geographical conditions and the productive orientation of the firm.

1. Introduction

Over the past few decades, sustainability has become a primary concern in multiple sectors, particularly in agriculture. Within the European context, initiatives such as the new Common Agricultural Policy (CAP 2023-2027) and the Farm to Fork Strategy underscore the importance of sustainability in food systems, aiming to establish the EU as a global standard-bearer for sustainability. Key to achieving this goal is the integration of knowledge and information, exemplified by the transition of the Farm Accountancy Data Network (FADN) into the Farm Sustainability Data Network (FSDN) by the EU Commission to collect data for more accurate sustainability indicators.

Among agricultural activities, viticulture stands as a crucial player in sustainability, integrating environmental, social, and economic dimensions, as exemplified by the OIV (International Organisation of Vine and Wine) General Principles of Sustainable Viticulture: "*a global strategy on the scale of the grape production and processing systems, incorporating at the same time the economic sustainability of structures and territories, producing quality products, considering requirements of precision in sustainable viticulture, risks to the environment, products safety and consumer health and valuing of heritage, historical, cultural, ecological, and landscape aspects*" [1].

Italy, a prominent player in the global wine market, has been proactive in implementing national sustainability programs, although the number of companies involved has yet to increase [2]. In Italian viticulture, there is indeed a pressing call for innovation and efficiency, reflected by the growing interest for topics like precision viticulture, waste reduction and energy use [3]. This trend suggests the potential for addressing together both economic challenges, such as rising costs and market competition, and environmental concerns, including climate change.

Recognizing the intertwined nature of these challenges highlights the importance of integrating sustainability and efficiency within viticultural processes, necessitating eco-compatible innovations and the efficient use of energy, natural, material, and informational resources. When referring to the environmental dimension of wine production, it is common to associate efficiency and sustainability. For instance, energy and water efficiency can be used to compare the sustainability of different wines [4], and various sustainability programs include environmental efficiency metrics among their set of indicators [5]. The relationship becomes more complex when considering the social sphere, although Social Life

Cycle Assessment (S-LCA) can be used in wine research to evaluate the social sustainability of wine production processes [6]. The contribution of the present study is to propose a methodological approach to incorporate simultaneously environmental and social factors as exogenous variables explaining variations in efficiency, understood as the capacity to maximize the production output given a set of inputs.

Efficiency and sustainability are two fundamental concepts in the management of natural resources, yet significant discrepancies can arise between them. These discrepancies frequently occur in decision-making processes regarding ecosystems management, where trade-offs between efficiency and sustainability must be considered in an integrated manner [7]. Despite their differences (efficiency focuses on avoiding wasteful behavior, while sustainability aims to maintain critical aspiration levels), these two concepts are not necessarily mutually exclusive in the pursuit of optimal long-term solutions in the intertemporal allocation of resources [8]. The exercise of comparing sustainability and efficiency in agricultural production processes is well-documented in the literature, highlighting various applications and methodological approaches [9, 10]. The urgency to focus on finding win-win solutions that generate both efficient and sustainable outcomes, has been recalled also in the domain of agri-food supply chain management [11].

In this context, our study aims to provide an understanding of the relationship between efficiency and socio-environmental sustainability of Italian wineries engaged in the production of grapes for quality wine (IGT, DOC, DOCG). By leveraging data from the Italian FADN, our research seeks to provide insights into the economic, environmental, and social dimensions of sustainability within the wine industry. Given the limited number of previous studies on the productive efficiency of Italian wineries [12, 13], our study provides a contribution to this field of research by encompassing elements of social and environmental sustainability, which are rarely included among inefficiency determinants.

2. Methodology

The methodological approach of this study applies Stochastic Frontier Analysis (SFA), specifically employing the model proposed by Battese and Coelli [14], to assess the efficiency of wineries and evaluate the influence of socio-environmental sustainability factors. In particular, a production function of the type is assumed:

$$y_{it} = f(x_{it};\alpha) + v_{it} - u_{it} \qquad (1)$$

where y_{it} is the output generated by the firm, x_{it} are the inputs to production, v_{it} indicates stochastic noise and u_{it} represents technical inefficiency. The random errors are assumed to be independently and identically distributed (i.i.d.) following a normal distribution $N(0,\sigma_v^2)$, while inefficiency is modelled as a function of exogenous variables. The inefficiency determinants function follows the form:

$$u_{it} = \delta_0 + z_{it}\,\delta + w_{it} \qquad (2)$$

where z_{it} is a vector of technical inefficiency explanatory variables, δ is a vector of parameters, and w_{it} is the i.i.d. error term.

The selection of variables to define the production function is informed by a review of the literature [15, 16, 17], as detailed in Santos et al. [18]. Additionally, indicators used to define the sustainability performance of the firms are sourced from the FADN dataset, following the framework established by Sardone et al. [19]. In particular, *i*) relevant production inputs include land usage (ha), labor, energy, pesticides and fertilizers costs in value (€), *ii*) output is measured as grapes production in weight (kg) and *iii*) efficiency determinants reflect both the sustainability performance in the socio-environmental domain (i.e. age, gender, diversification, organic certification, eligibility for agro-climatic-environmental payments and expenditures for toxic pesticides) and other structural factors (i.e. altitude, area, economic size, transformation activity). Specifically, the presence of young or female owner, organic certification, farm diversification, eligibility for agro-climatic environmental payments and low incidence of farm expenditure for toxic and very toxic pesticides on total pesticides expenditure are assumed to generate a positive sustainability performance [19]. The analysis covers a balanced panel dataset (2044 observations) of Italian wineries over the years 2021 and 2022, specialized in the production of grapevines for quality wine.

Prior to initiating parameters estimation within the production function framework, preliminary assessments encompass the determination of the preferred functional form (i.e., Cobb-Douglas versus Translog), confirmation of frontier existence and analysis of inefficiency distribution. Maximum likelihood is then applied to estimate simultaneously the parameters of the stochastic frontier and the model for inefficiency effects.

3. Findings

With regard to the characteristics of the sample, Table 1 shows the descriptive statistics of the variables included in the analysis. On average, it emerges that the five dummy variables related to the socio-environmental sustainability of sampled wineries display values between 0.11 and 0.23, while the usage of toxic products approximates 24% of total expenditure on pesticides. Regarding the production inputs, labor represents the main cost item, with an average value of 19,346 €. In relative terms, expenditures for pesticides constitute 37.6% of variable costs, followed by fertilizers (22.6%) and energy (6.8%). In addition, we see that the sample is mostly composed of wineries producing in inland hilly territories (46%), having an economic size between 100-500k (32%) and situated in the Northeast of Italy (35%). The average area dedicated to production is above the national average agricultural land per winery (2.8 ha) [20], which can be attributed to the exclusion of small farms from FADN's field of observation. Transformation activities within the company take place in 27% of the observations.

Table 1. Descriptive statistics.

Domain	Variable	Mean	St. Dev.	Min	Max
Output	Grapes produced (*kg*)	851.32	1641.50	9.00	51160.00
Input	Fertilizers (*€*)	2424.67	5408.00	1.00	83966.00
	Pesticides (*€*)	3845.51	6960.88	19.00	97560.00
	Crop area (*ha*)	9.06	13.52	1.36	277.17
	Labor (*€*)	19345.76	33805.46	80.00	672000.00
	Energy (*€*)	1114.22	4470.69	1.00	58072.00
Sustainability	Bio (*1=yes*)	0.19	0.39	0	1
	Gender (*1=female*)	0.23	0.42	0	1
	Diversified (*1=yes*)	0.15	0.36	0	1
	Young (*1=yes*)	0.11	0.32	0	1
	Aec payments (*1=yes*)	0.21	0.41	0	1
	Toxic over total pesticides expenditure (*%*)	0.24	0.39	0	1
Structural factor	Transformation activity (*1=yes*)	0.27	0.44	0	1
	Altitude inland hills (*1=yes*)	0.46	0.50	0	1
	Altitude coastal hills (*1=yes*)	0.12	0.33	0	1
	Altitude mountains (*1=yes*)	0.13	0.34	0	1
	Altitude plains (*1=yes*)	0.29	0.45	0	1
	Economic size 8-25k (*1=yes*)	0.14	0.34	0	1
	Economic size 25-50k (*1=yes*)	0.24	0.43	0	1
	Economic size 50-100k (*1=yes*)	0.27	0.45	0	1
	Economic size 100-500k (*1=yes*)	0.32	0.47	0	1
	Economic size >500k (*1=yes*)	0.03	0.18	0	1
	Geography centre (*1=yes*)	0.15	0.36	0	1
	Geography islands (*1=yes*)	0.10	0.30	0	1
	Geography south (*1=yes*)	0.20	0.40	0	1
	Geography north west (*1=yes*)	0.20	0.40	0	1
	Geography north east (*1=yes*)	0.35	0.48	0	1

After verifying *i*) the appropriateness of the Translog form (LR chi2(15) = 130.52) and *ii*) the presence of significant influence of inefficiency effects (LR chi2(19) = 384.57) by means of likelihood ratio tests, the estimated parameters are presented in Table 2. The lambda value being significantly different from zero indicates the greater importance of inefficiency than random shocks in production shortfalls from the frontier.

As expected, external factors reflecting geographical conditions, such as the region and altitude where the winery operates, significantly influence efficiency levels [18]. Additionally, there is a positive relationship between company size and efficiency, aligning with previous research on wine production efficiency in Italy [13]. This result could be attributed to enhanced organizational capabilities or higher levels of capitalization, even if this cannot be inferred from the data used. In terms of Utilised Agricultural Area (UAA) classes, efficiency scores fluctuate from 0.67 (<5 ha) to 0.68 (5-15 ha), 0.65 (15-40 ha) and 0.63 (>40 ha), which suggests that importance of considering also the capital value (e.g., technological status) of the farm. Performing an auxiliary regression with UAA classes instead of Economic size does not report statically significant effects of the former on inefficiency. Furthermore, operating in the Southern and Northeastern regions of Italy has a positive effect on efficiency, although we recognize- using monetary units of measurement for production variables- the potential influence of heterogenous input costs in explaining regional differences among Italian areas.

Table 2. Estimated parameters for the frontier and efficiency models.

Variable	Coefficient	Std. err.	P>z
Frontier			
ln*Fertilizers*	-0.013	0.041	0.750
ln*Pesticides*	0.341	0.099	0.001
ln*Area*	1.092	0.172	0.000
ln*Labor*	0.004	0.090	0.964
ln*Energy*	0.096	0.030	0.001
ln*Fertilizers_Pesticides*	0.005	0.008	0.565
ln*Fertilizers_Area*	-0.014	0.014	0.326
ln*Fertilizers_Labor*	-0.009	0.010	0.351
ln*Fertilizers_Energy*	-0.004	0.003	0.109
ln*Pesticides_Area*	-0.011	0.039	0.771
ln*Pesticides_Labor*	-0.041	0.020	0.038
ln*Pesticides_Energy*	-0.021	0.006	0.001
ln*Area_Labor*	0.066	0.037	0.073

ln*Area_Energy*	0.048	0.011	0.000
ln*Labor_Energy*	-0.012	0.006	0.062
ln*Fertilizers_2*	0.022	0.004	0.000
ln*Pesticides_2*	0.003	0.014	0.835
ln*Area_2*	-0.203	0.043	0.000
ln*Labor_2*	0.014	0.010	0.179
ln*Energy_2*	0.001	0.003	0.682
_cons	2.498	0.537	0.000
Inefficiency			
Bio_yes	0.194	0.076	0.011
Gender_f	0.016	0.066	0.803
Diversified_yes	0.224	0.075	0.003
Young_yes	-0.056	0.085	0.509
AecPayments_yes	-0.166	0.079	0.036
Pesticides_toxic	0.068	0.071	0.340
Transform_yes	0.717	0.091	0.000
Altitude (*Ref*:Plains)			
Inland hills	0.220	0.085	0.010
Coastal hills	-0.293	0.126	0.020
Mountains	0.070	0.115	0.543
Economic size (*Ref*:8-25k)			
25-50k	-0.271	0.099	0.006
50-100k	-0.372	0.113	0.001
100-500k	-0.465	0.128	0.000
>500k	-0.581	0.222	0.009
Geography (*Ref*:Centre)			
Islands	-0.146	0.117	0.211
South	-0.877	0.148	0.000
North West	-0.035	0.085	0.683
North East	-0.724	0.118	0.000
Year (*Ref*:2021)			
2022	-0.029	0.055	0.597
cons	0.228	0.173	0.188
λ	3.140	0.041	0.000
Log-likelihood	-923.641		

Moving to sustainability attributes, a comparison of Tables 2 and 3 reveals notable differences in production orientation between wineries engaged in transformation activities and those that are not. Despite demonstrating a greater interest in organic certification and diversification activities, the former exhibit lower efficiency levels compared to the latter. Demographic variables such as age and gender do not appear to exert any significant influence on efficiency, neither does the incidence of toxic products over total pesticides expenditure. However, the positive impact of eligibility for agro-climatic-environmental payments, though requiring further analysis of the measures considered (and being significant only at the 10% level), appears promising. This finding suggests that participation in eco-schemes under the CAP may not negatively impact productive efficiency.

In summary, the results indicate a difference in efficiency between wineries involved in transformation processes and those that focus solely on production. The former appear to be generally more sustainable, showing a statistically significant higher frequency of organic certifications and diversification activities, which in turn are negatively correlated with efficiency, thus explaining the higher efficiency scores of latter wineries.

Table 3. Means, standard deviation and Mann-Whitney statistics for sustainability variables.

	Transf_No (N=1499)		**Transf_Yes** (N=545)		**Mann Whitney z**	**p-value**
	Mean	St.Dev.	Mean	St.Dev.		
Bio_yes	0.15	0.36	0.30	0.46	-7.34	0.00
Gender_f	0.22	0.41	0.25	0.44	-1.57	0.12
Diversified_yes	0.09	0.29	0.31	0.46	-11.87	0.00
Young_yes	0.11	0.31	0.13	0.33	-1.20	0.23
AecPayment_yes	0.20	0.40	0.23	0.42	-1.72	0.09
Pesticides_toxic	0.23	0.39	0.26	0.42	-0.89	0.38
Efficiency	0.72	0.17	0.53	0.20	18.02	0.00

4. Conclusions

In conclusion, our study aims to contribute to the understanding of the relationship between economic performance and socio-environmental sustainability within the Italian wine sector. By employing SFA and integrating socio-environmental sustainability attributes, we shed light on previously unexplored dimensions of efficiency in Italian wineries. Ultimately, our research underscores the dual challenge facing the Italian wine sector, which requires optimizing productive performance while advancing socio-environmental sustainability goals, thus paving the way for a more resilient and responsible industry in future years. However, meeting sustainability targets could be difficult without a substantial investment in innovation. Considering the renewed attention to innovation efficiency in wine production systems to explain market performance [21], further analysis would benefit from the inclusion of additional variables explaining the sustainability-oriented innovation within the wineries belonging to the FADN dataset. In addition, despite the large number of observations, we recognize that the present study provides a static, short-term analysis of the sector, and does not consider the economic impact due to evolving drivers like climate change on Italian viticulture, which still remains largely unexplored in the literature [22].

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