

Article

Efficiency of the Integrated Production Systems: Evidence from the Winegrowing Firms in Italy

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Abstract: In Italy, the environmental sustainability of the agricultural sector is regulated by the National Integrated Production Quality System. It is the foundation of the regional Integrated Production Regulations (IPRs), which identify voluntary agronomic strategies on the use of pesticides, fertilisers, and irrigation water, as well as on soil and plant management. The aim is a reduction in the environmental impacts of the agricultural processes and an increase in the production quality. However, the direct relationship between environmental and economic sustainability of the regional IPRs is not obvious and its absence could weaken the economic efficiency of firms. The study, through the stochastic frontier (SF) method, investigates the possible inefficiencies of the regional winegrowing firms that voluntarily adhere to the Apulian IPRs. The results highlight that some measures in the IPRs aimed at preserving the local agroecosystems (soil management and use of resistant varieties) are efficient, therefore allowing for an increase in the production value and quality. On the contrary, crucial measures concerning the management of irrigation water and pesticides decrease efficiency. Thus, more thoughtful measures are requested by policy makers to improve the economic impacts of the regional IPRs on firms and to make possible a certain convergence between environmental and economic sustainability.

Keywords: technical efficiency; production function; economic sustainability; policy evaluation; Italy



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1. Introduction

Conventional agricultural production systems are the main system responsible for the environmental impacts in the primary sector, often being based on intensive farming that uses large quantities of productive factors and inputs (pesticides, energy, irrigation water, CH₄, NH₃, etc.) per unit area, which can also be much higher compared to extensive farming. The main aim is the maximisation of revenue through high production levels, but this is to the detriment of ecosystems [1]. The impacts are worsened by the depletion of resources and climate change. Thus, there is a strong interest in boosting integrated production systems [2], which are based on sustainable production strategies that improve land use, soil structure and fertility, carbon sequestration, organic matter, and microclimatic conditions [3]. Integrated production systems are common in smallholder firms operating in developing countries (South America and Asia), where integrated crop-livestock-forestry (Brazil) and rice-fish (South Asia) systems are used [4]. Interesting results are also obtained in sub-Saharan Africa, where agroforestry, intercropping, and crop-livestock systems improve productivity, soil fertility, and income [5].

Production and environment are strongly influenced by the integrated production systems, which are characterised by a synergistic relationship among inputs and outputs so that, for example, livestock manure can be used as fertiliser for crops and the latter can be used as feed for livestock. In environmental terms, soil fertility and water availability

are improved by woods, crops, and livestock [5], whose diversity preserves biodiversity. Furthermore, the integrated production systems, by favouring carbon sequestration, reducing greenhouse gas emissions, and requesting low levels of synthetic fertilisers and pesticides, contribute to climate change mitigation [6]. However, in economic terms, these systems are often based on plant varieties and animal races taking more years to generate revenue compared to those used in intensive systems. Furthermore, these systems could compete for resources or could suffer due to crops and livestock diseases, thus know-how and expertise are crucial for their management [5].

Apulia, Southern Italy, is one of the most important agricultural Italian regions. Its favourable climatic and pedological characteristics allow important results on a national scale regarding the production of olive oil, wine, fruit, and cereals in terms of quantities, produce value, and added value [7]. However, these important results often are obtained in intensive areas, which suffer from high environmental impacts. To counteract these dynamics, and in line with the 2030 Agenda and the CAP 2023–2027, Italian Law no. 4 of 3 February 2011 “Provisions regarding labelling and quality of food products” establishes the National Integrated Production Quality System (NIPQS), i.e., a voluntary certification process aimed at improving the quality of the agricultural production and related transformations. These improvements are obtained through the adoption of the technical and agronomic standards that are listed in the regional Integrated Production Regulations (IPRs), which are annually updated by each Italian region. Each regional IPR identifies agronomic techniques on the use of pesticides, fertilisers, and irrigation water, as well as on the management of soil, plants, and livestock, in each process stage, to reduce the environmental impacts of the production processes and to increase the quality of produce [8]. Furthermore, the direct relationship between the environmental and economic sustainability of the regional IPRs is not obvious, and the evaluation of environmental and economic impacts should be provided to avoid the low economic efficiency of firms.

Investigating the environmental and economic trade-off is crucial for an effective implementation of the objectives of the 2030 Agenda [9]. Recent studies have started improving this knowledge by proposing the construction of the sustainable economic competitiveness index (SECI) for agri-food value chains, thus furnishing useful strategies for policy makers [10]. Indeed, an important policy strategy starts from improving the acceptance among farmers of the environmental objectives by compensating them for the positive externalities of environmentally friendly production [11]. On the other hand, investment in new technologies facilitates the reduction in emissions and waste [12,13].

Further specific information for policy makers can come from the investigation of the economic efficiency of farms adopting environmental measures. Thus, the study verifies the economic sustainability of the Apulian IPRs by focusing on winegrowing firms, which ensure high-quality products and the highest added value in the regional agricultural sector [8]. The novelty of this research concerns the measurement of the economic efficiency of voluntary environmental measures on the farm scale in territories characterised by high added value of produce. This approach furnishes useful information for the ongoing and ex-post evaluation of policies by spotlighting the trade-off between farmers’ and community interests.

2. Literature Review

The SF analysis furnishes responses to entrepreneurs and policy makers in terms of the efficient use of factors and inputs, but also technologies, infrastructures, etc. In addition, it investigates sources of inefficiency related to the sociodemographic and structural characteristics of producers and farms, respectively. The findings allow the improvement of economic, environmental, and social sustainability and, thus, the formulation of the ex-ante, ongoing, and ex-post evaluations of policies.

The main field in which the SF is carried out concerns the analysis of productivity. Fikadu et al. [14] explore the economic efficiency of Teff production in Ethiopia. The study analyses the neighbourhood effect on the technical efficiency through panel data. The

results indicate a significant contribution of neighbourhood effects for improving technical efficiency. Thus, policy makers could implement knowledge-sharing initiatives to disseminate best practices, innovative technologies, and agronomic knowledge within specific spatial clusters. Akite et al. [15] assess the level of profit efficiency and the sources of inefficiency among smallholder rice farmers in northern Uganda. The results reveal that seed, labour, and transport costs are significantly high, and group marketing exhibits a higher profit efficiency level compared to contract marketing and individual marketing models. The sources of inefficiency are hired labour and access to market information, while inefficiency in rice production has a negative relationship with group marketing, marital status (married), gender of household head (male), and cultivation of upland and lowland rice varieties. The study recommends the need for establishing farmer-affordable local seed businesses, strengthening farmer groups, developing labour-saving technologies, and providing market-tailored training to farmers. Kitole et al. [16] estimate the technical efficiency of cereal producers in Tanzania and investigate its link with the welfare of smallholder farmers. The findings indicate that poor health reduces the productivity efficiency, while efficiency is found to significantly improve household welfare due to better food security, household income, and nutrition status. Thus, health components should be included in rural agriculture development programs for increasing the standard of rural living. Benedetti et al. [17] measure the technical efficiency of irrigated crop and production techniques through a stochastic frontier production method in Southern Italy. The main results show that the most efficient production system concerns the processing of tomatoes, while the lower level of technical efficiency emerges from organic farms compared to conventional farms. González-Flores et al. [18] examine the efficiency of the small-scale potato farms in Ecuador under the program 'Plataformas de Concertación' on productivity growth. The beneficiary farms exhibit higher yields from the increased technology gap, given the same input levels, but a lower technical efficiency in the short run. The SF model is also used for estimating the technical efficiency of beekeeping projects in Egypt [19] by comparing beekeeping's most important economic indicators, estimating the optimum production amount, and investigating why technical efficiency in Egyptian beekeeping is declining. Vasco Silva et al. [20] use data related to crop management, biophysical constraints, and available technologies and study the yield gap from the efficiency, resources, and technology of irrigated rice farms in the Philippines. The results highlight that a technology yield gap generates half of the difference between potential and actual yields, while efficiency and resource yield gaps each explain a quarter of that difference. In the livestock sector, Ying-heng et al. [21] analyse the technical and environmental efficiency of hog production in China. The most environmentally efficient region is Southwest China, while the least efficient regions are the northeast and the northwest territories. Furthermore, the regions with high technical efficiency are the most environmentally efficient ones, and vice versa. The SF model is also used in fisheries. Chiang et al. [22] estimate the potential milkfish farm output and efficiency in Taiwan. Empirical results show that milkfish farming in Taiwan presents diminishing returns to scale, furnishing helpful information on the reallocation of inputs for raising milkfish productivity.

Another important research path concerns the efficiency analysis in using irrigation water. Laureti et al. [23] furnish insights aimed at enhancing farmers' production efficiency for water savings and conservation in Apulia, Southern Italy, as well as for multilevel regulatory and incentive measures. The results, based on the spatial stochastic frontier model focused on crops with a high water demand, highlight that spatial heterogeneity influences farm efficiency. Furthermore, incentives to small family farm activities and on-farm modern water-saving technologies could effectively contribute to water conservation goals. Bopp et al. [24] analyse the efficiency in using irrigation water in Chilean wine grape farms. The authors reduce potential selection bias by using propensity score matching, and the stochastic production frontier model highlights that pressurised irrigation leads to a higher production, regardless of the level of water applied. Furthermore, they assess the shadow values at the observed output for pressurised ($USE\ 0.026\ m^{-3}$) and gravity

(USD 0.033 m⁻³) systems. Bravo-Ureta et al. [25] analyse the impact of a canal irrigation project for rice farms in the Philippines and combine both impact evaluation and efficiency analysis methods. The findings highlight that the project generates a significant impact on output, but not on technical efficiency, suggesting insufficient training and input access.

The SF model is also used for assessing the impact of climate change on the technical efficiency of farms. Arshada et al. [26] investigate agricultural productivity in territories of South Asia that are characterised by climate change and variability that cause increased heat stress and erratic precipitation patterns. Thus, the economic efficiency of rice and wheat production in Pakistan are analysed by considering the temperature and precipitation anomalies, as well as the number of days with a temperature exceeding the crop specific heat stress threshold. Thus, indicators of climatic variability and heat stress negatively affect the economic efficiency of both rice- and wheat-producing farmers. Ojo and Baiyegunhi [27] measure the technical efficiency of rice farmers in southwest Nigeria in adopting climate adaptation strategies. The results show that labour, herbicides, and the interaction of labour with both farm size and insecticides explains the efficiency. Furthermore, the study identifies the interaction effects between climate change adaptation strategies and the socioeconomic characteristics of farmers. An et al. [28] study the impact of climate change in terms of the fluctuation in temperature and precipitation on agricultural water use efficiency in China and address its volatility and regional disparity over time and across regions. The results reveal average annual temperature, crop growing degree days, and crop harmful degree days have negative impacts on water use efficiency; the decline in precipitation due to climate change lowers water use efficiency. Furthermore, when the information on climate damage is provided to farmers, the negative effect of climate change on water use efficiency can be alleviated. Finally, the regions with shortages of water endowment have the best water use efficiency, while the regions with greater water sources have the poorest performance.

Concerning the dimensional and financial characteristics, Ngango and Hong [29] investigate the relationship between farm size and technical efficiency for the production of maize in Rwanda. The study results show a positive relationship between technical efficiency and farm size, so as to support policies for land consolidation. Furthermore, the effects on technical efficiency by education, cooperative membership, extension services, access to credit, off-farm income, land tenure, and livestock ownership are significant and positive. Another study examines the impact of credit and farm size on the technical efficiency of rice farms in Sindh, Pakistan [30]. The results show that farm characteristics, namely credit, farm size, fertiliser, and labour influence farm productivity. Credit generates a larger and significant scale of elasticity, while farm size has a larger and significant marginal effect. Ali et al. [31] investigate the technical efficiency of hybrid maize farms in Pakistan, focusing on credit-constrained and -unconstrained farmers. The results prove that some characteristics related to the farmer (education of the household head, family size, off-farm income, and farming experience) and firm management (irrigation through water infrastructure, certified seed, and credit size) have positive effects on technical efficiency for both credit-constrained and -unconstrained farmers. Twumasi et al. [32] investigate the effects of credit constraints on the technical efficiency of artisanal fishers in Ghana. The study found fishers' years of fishing experience, education level, credit constraint, and off-farm income as the most important determinants of technical efficiency. While credit constraint and off-fishing income had a detrimental effect on technical efficiency, years of fishing experience and education level help improve efficiency. Appiah-Twumasi et al. [33] examine the impact of innovative agricultural financing on the economic efficiency of maize farms in northern Ghana. Users of innovative financing have higher technical, allocative, and economic efficiency scores than non-users. The access to mechanised services diminishes their technical efficiency; thus, short-term policies for increasing maize output should focus on reducing inefficiency levels by providing technical training to farmers, rather than introducing new technologies. Workneh and Kumar [34] measure the technical efficiency of large-scale agricultural investment in northwest Ethiopia. The

study establishes that a better utilisation of capital, labour, land, and seed inputs increases grain output, while the influence of agrochemical inputs was negative. In efficiency terms, gender and level of education improve technical efficiency, whereas age, occupation, district, and subsidies contributed to technical inefficiency. The study calls for more education for adults, while female producers should be encouraged to manage large-scale grain farming segments.

Other authors use the SF model to measure China's agricultural labour requirement [35] and find a significant apparent labour surplus, which is correlated with factors that affect the incentives of farmers to leave the land. This supports the hypothesis that declines in the agricultural labour force are not adequately measured.

Djuraeva et al. [36] focus on the increase in agricultural productivity and sustainability through Agricultural Extension Services (AES) in the wheat farms of Uzbekistan and, in particular, on the combined effect of extension types and forms. The study finds that technical efficiency is influenced by farmers' characteristics, the frequency of extension visits, and the extension of participatory approaches, highlighting the need of a client-oriented, cost-efficient, and demand-driven AES system.

The SF model is also utilised for investigating the agricultural productivity gaps between men and women in Africa, allowing us to highlight the causes of entrepreneurial inhibition by local conditions that put women at a disadvantage [37]. Authors find that market imperfections in Malawi favour female farmers, who are more efficient and exhibit performance parity. In contrast, Tanzanian and Ugandan labour market imperfections favour male farmers, as do efficiency and performance estimates of total factor productivity.

Concerning the impacts of environmentally friendly farm management, Huang et al. [38] analyse the effect of ecologisation on crop production in Sweden and show that it affects the technical efficiency of crop production. The crop diversity index has a positive effect on efficiency, while organic farming is negatively associated. Rural subsidies increase production performance, but environmental subsidies are not related. Wang et al. [39] analyse the performance of investment in soil and water conservation in China, also considering the change of local environmental managers. The stochastic frontier function model, which also uses soil and water data statistics, found that environmental management under the pressure of promotion will improve the efficiency of water and land resources management. de Azevedo Junior et al. [40] investigate the relationship between the increase in agricultural efficiency and the slowdown of deforestation rates in the past decade and correlate these data with municipalities' agricultural specialisations. The main results highlight that the new institutional path in the 21st century contributes to slow deforestation in agricultural activities through an increase in productivity (yield/ha) in the last decade, mainly for vegetal production. Cattle ranching also increases output and efficiency, but it is the most environmentally impacting activity. However, several municipalities have not developed their agricultural production value in productive areas due to a low-efficient allocation of some technological and productive factors, which results in concentrating deforestation in inefficient systems and limiting the effectiveness of current policies.

Other production systems aimed at reducing the environmental impacts of viticulture are organic and biodynamic systems. While the integrated system allows a reasonable use of synthetic fertilisers and pesticides, as well as a quantity of irrigation water that is balanced with the pedoclimatic conditions and the physiological status of plants, the organic system is based on the absence of synthetic fertilisers and pesticides, while biodynamic farming focuses on the preparations to improve soil fertility and plant health [41]. The environmental differences among these systems have mainly been analysed using life cycle assessment, which points out that organic winegrowing has not always had lower impacts than the integrated and biodynamic ones [42–44]. In economic terms, Qiao et al. [45] compare organic and conventional tea farms in China and Sri Lanka. In both instances, organic production performed better. Bolwig et al. [46], in the coffee farms of tropical Africa, found a higher net coffee revenue from adopting organic pesticides, mulching, animal manure, and composting. DeVetter et al. [47] note that blueberry production under

organic management in Washington State expands, when compared to production using a conventional system, due to robust demand. Furthermore, organic yields are comparable to conventional yields, but variable and total costs are greater under organic management, due to the lack of efficacious and cost-effective pesticides to combat invasive pests. Janský et al. [48] compare organic and conventional farming systems in the Czech Republic and highlight that costs are comparable, while revenues are higher for the organic system. Brozova and Vanek [49] analyse the financial statements of organic and conventional farms in Czechia and the results show that the profit is higher among the organic farms.

Náglová and Vlasicova [50] compare the economic performance of conventional, organic, and biodynamic farms between 2007 and 2012 and found that, considering the return on assets, equities, and costs, organic farms perform the best, followed by biodynamic farms. Organic farms show the greatest profitability, while biodynamic farms perform worse financially, even with the largest subsidies per hectare. Conventional farms have the lowest return on assets and equities, as well as the highest asset turnover. In addition, organic farms have lower labour costs compared to conventional farms, probably due to the high share of family labour. Furthermore, organic farms are carried out on owned land, while larger conventional farms typically rent. Finally, biodynamic farms have the lowest total costs, operating revenues, and profits. Forster et al. [51] examine the agronomic and economic impacts of biodynamic, organic, and conventional systems for a cotton–soybean–wheat crop rotation in the period 2007–2010 in India. The results highlight that a yield gap between organic and conventional farming systems for cotton and wheat emerges in the first crop cycle. In the first cycle, conventional farming systems achieve higher gross margins, whereas in the second cycle, gross margins in organic farming systems are significantly higher due to lower variable production costs. Furthermore, organic farming systems are less capital intensive than conventional ones; thus, financial risks related to the changing market prices of synthetic fertilisers and pesticides are minimal.

3. Materials and Methods

3.1. The Economic Data

Between June 2023 and February 2024, a survey form was used to collect economic data from 317 winegrowing firms in Apulia. The cultivated varieties were both landraces—namely historical and local ecotypes (Bombino Bianco, Ottavianello, and Pampanuto) characterised by lower yields and quantities of inputs per unit area (irrigation water, fertilisers, pesticides and energy)—and modern varieties (Montepulciano, Uva di Troia, Sangiovese, Lambrusco, Trebbiano, and Garganega) characterised by high yields, but obtained through the use of higher quantities of inputs.

The survey form, based on the economic balance, gathered data to compare the value of the final production with the related costs. This approach allowed for the assessment of the firm's income and its allocation among the subjects involved in the firm's management [52]. The first section of the survey form gathered information about the production value per unit area (EUR /ha), as well as on the cultivated area, the value of machineries used for the cultivation process, the cost of the hired and family labour, and the costs of inputs, namely fertilisers, pesticides, and irrigation water (Table 1).

The second section of the survey form focused on further variables that could affect the firm's efficiency [53–57]. The age of the entrepreneur negatively affects firm management due to the scarce attitude of older farmers toward modern management solutions and innovation. As a result, it is directly related to inefficiency, while easy access to credit increases a firm's ability to make investments and encourages technical innovations, so as to reduce inefficiency. The number of plots indicates land fragmentation, which is related to travel and surveillance costs and, therefore, to inefficiency, while the terrain slope hinders the mechanised operations and the firm's technological level, so it is directly related to inefficiency [14–51]. Additional variables were related to the adoption of the integrated production system, as reported in the regional IPRs, namely management of organic matter in the soil; use of varieties that are resistant and/or tolerant to the main

plant diseases; management of soil for preserving and improving its structure and fertility, avoiding compaction, erosion, degradation, and the stagnation of rainwater; use of grassing in the inter-row (also by spontaneous vegetation managed by mowing) in areas with a slope between 10% and 30%; assessment of the maximum quantities of fertilisers through a fertilisation plan; estimation of the water volumes through a water balance based on the phenological phases of vines, the characteristics of the soil, and the climatic conditions; use of meteorological instruments and/or climatic data from the Regional Agrometeorological Network (www.agrometeopuglia.it—accessed on 27 May 2024); and implementation of the IPR measures for reducing the use of pesticides. The expected impacts of these IPR variables concern the increase in the economic efficiency of firms.

Table 1. Variables used in the SF model.

Variables		U.M.	Expected Sign
Output			
Production value	Pv	EUR/ha	
Inputs			
Cultivated area	Ca	ha	+
Machineries value	Mv	EUR/ha	+
Labour costs	Lc	EUR/ha	+
Fertilisers costs	Fc	EUR/ha	+
Pesticides costs	Pc	EUR/ha	+
Irrigation water costs	Wc	EUR/ha	+
Determinants of the technical inefficiency			
Entrepreneur age	Age	Years	+
Dummy = 1: Credit access during the period 2019–2023	Credit	0–1	-
Number of plots	Plots	N.	+
Average land slope	Slope	%	+
Dummy = 1: Management of organic matter in the soil	Organic	0–1	-
Dummy = 1: Use of grape varieties that are resistant and/or tolerant to the main plant diseases	Varieties	0–1	-
Dummy = 1: Management of soil for preserving and improving its structure and fertility, avoiding compaction, erosion, degradation, and the stagnation of rainwater	Soil	0–1	-
Dummy = 1: use of grassing in the inter-row (also by spontaneous vegetation managed by mowing) in areas with a slope between 10% and 30%	Grassing	0–1	-
Dummy = 1: Assessment of the maximum quantities of fertilisers for vines through a fertilisation plan	Fertilisation	0–1	-
Dummy = 1: Estimation of water volumes through a water balance based on the phenological phases of vines, the characteristics of the soil, and the climatic conditions	Irrigation	0–1	-
Dummy = 1: Use of meteorological instruments or climatic data from the Regional Agrometeorological Network (www.agrometeopuglia.it , accessed on 26 April 2024)	Agrometeorological	0–1	-
Dummy = 1: Use of pesticides in compliance with the maximum quantities allowed by the regional IPRs	Pesticides	0–1	-

3.2. The Empirical Model

The SF model estimated the technical efficiency of the Apulian winegrowing firms to measure their ability to achieve the highest possible output, given the prices and levels of fixed factors [58]. Furthermore, this approach converts any errors in the production choice into lower production [59]. In this study, inefficiency was defined as the distance between a firm's production value and the estimated frontier production value that corresponds to the state of its production technology [60].

A stochastic production frontier is based on two models. The first one is a production function [58] and investigates the relationship between production and costs. The likelihood ratio-type test showed that the Cobb–Douglas function was the most appropriate functional

form for the data, compared to the translog function; thus, for the i th firm, it has the following form:

$$\ln \pi_i = \beta_0 + \ln(x_i)\beta + v_i - u_i \quad (1)$$

where the dependent variable π_i is the production value of the i th firm; x_i is the vector of predictors (cultivated area, machineries value, labour costs, fertilisers costs, pesticides costs, and irrigation water costs); and β is a vector of unknown coefficients to be estimated. The error component v_i is assumed to be identically and independently distributed (i.i.d.) as $N(0, \sigma^2_v)$, while u_i is a non-negative, unobservable random variable that captures the technical inefficiency of the observations and is assumed to be distributed independently of the normally distributed error term v_i .

The second model concerns inefficiency and investigates the firm-specific characteristics that cause inefficiency. It is expressed as follows:

$$u_i = \delta_0 + \sum_{m=1}^M \delta_m z_{mi} + \omega_i \quad (2)$$

where z_i 's are the explanatory variables that cause inefficiency; δ_0 and δ_m are the coefficients to be estimated; and ω_i is the unobservable random error assumed to be independently distributed with a positive, half-normal distribution. The inefficiency variables concerned some characteristics of the entrepreneur (age), the firm structure and management (credit access, number of plots, and terrain slope), and the interventions listed in the regional IPRs (management of organic matter, use of tolerant varieties, management of soil, grassing, use of a fertilisation plan, use of an irrigation plan, use of agrometeorological instruments and data, and a reduction in the use of pesticides).

The parameters of the production and inefficiency functions were estimated simultaneously using the maximum likelihood (ML) procedure, following [61]. The models' fitting was carried out through the statistics γ , σ^2 , and γ^* . The first one indicates the level of inefficiency on firms and ranges from zero (no inefficiency) to one (maximum inefficiency) [62]. The second statistics, σ^2 , indicates inefficiency affecting production in firms, while γ^* [63] measures the differences in the efficiency levels between the considered firms and the maximum frontier.

The technical efficiency (TE_i) of the i th firm was estimated using the following predictor [63]:

$$TE_i = E[\exp(-u_i)|\varepsilon_i] = E\left[\exp\left(-\delta_0 - \sum_{m=1}^M \delta_m z_{mi}\right)|\varepsilon_i\right] \text{ where } \varepsilon_i = v_i - u_i \quad (3)$$

where E is the expectation operator. A firm's technical efficiency is between zero and one and is inversely related to the inefficiency effect.

Hypotheses relating to some restrictions of the full model were verified as follows:

1. $H_0: \beta_{ij} = 0$ (the translog function can be reduced to a Cobb–Douglas function);
2. $H_0: \gamma = \delta_0 = \delta_1 = \dots = \delta_m$ (there are no determinants of technical inefficiency, so the sampled farms are fully efficient);
3. $H_0: \delta_1; \delta_2; \delta_3; \delta_4; \delta_5; \delta_6; \delta_7; \delta_8; \delta_9; \delta_{10}; \delta_{11}; \delta_{12} = 0$ (no effect on technical inefficiency by each determinant considered).

The Generalised likelihood-ratio test allowed for a comparison between the implemented model and the restricted model based on the aforesaid hypotheses. The related statistic index is defined as follows:

$$-2[\ln L(H_0) - \ln L(H_1)] \quad (4)$$

where $L(H_0)$ and $L(H_1)$ are the likelihood values concerning the implemented model and the restricted models, respectively. The λ statistic can be approximated to a χ^2 distribution, with a number of freedom degrees equal to the parameters affected by the restriction.

4. Results

The descriptive statistics concerning the economic data highlighted a good adherence of the sample with the regional FADN dataset (Table 2). Concerning the variables used to explain the technical inefficiency, on average, the firms were managed by middle-aged entrepreneurs, most of whom have not easily accessed investment credit in the past five years. The firms were discretely fragmented and mostly located in flat areas. As concerns the IPR variables, the most widespread practices related to the integrated production systems concerned the use of resistant and/or tolerant varieties to the main plant diseases, the management of soil for preserving and improving its structure and fertility, avoiding compaction, erosion, degradation, and the stagnation of rainwater, as well as the estimation of the water volumes through a balance based on the phenological phases of the vines, the characteristics of the soil, and the climatic conditions of the territory.

Table 2. Characteristics of the sampled firms (values in EUR 0.000).

Variables	Use of the Variable ^a	U.M.	Sample Farms				Regional Farms (FADN Data)				t-Test
			Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.	
Pv	O	EUR /ha	7.66	17.33	14.21	9.21	8.48	20.46	15.67	8.19	***
Ca	I	ha	0.14	13.19	5.04	11.44	0.12	12.09	5.41	13.22	***
Mv	I	EUR /ha	0.64	2.88	1.93	2.78	0.71	2.76	2.12	3.16	***
Lc	I	EUR /ha	1.33	6.06	3.81	3.15	1.02	7.28	4.79	2.65	**
Fc	I	EUR /ha	1.38	2.29	2.15	3.96	1.45	2.56	2.95	5.88	**
Pc	I	EUR /ha	0.77	1.89	1.21	1.83	0.59	2.19	1.42	2.37	***
Wc	I	EUR /ha	0.38	1.82	0.94	1.75	0.34	2.11	1.67	2.19	**
Age	In	Years	18	67	48.18	26.11	18	68	49.21	24.88	**
Credit	In	0–1	0	1	0.34	0.51	0	1	0.47	0.43	**
Plot	In	n.	1	7	3.07	3.29	1	12	3.60	4.05	***
Slope	In	%	0	7.21	2.95	3.66					
Organic	In	0–1	0	1	0.14	0.13					
Varieties	In	0–1	0	1	0.26	0.28					
Soil	In	0–1	0	1	0.34	0.49					
Grassing	In	0–1	0	1	0.19	0.22					
Fertilisation	In	0–1	0	1	0.18	0.26					
Irrigation	In	0–1	0	1	0.24	0.21					
Agrometeorological	In	0–1	0	1	0.11	0.15					
Pesticides	In	0–1	0	1	0.22	0.35					

** t-test sign—5%; *** t-test sign—1%. ^a O = output variable of the production function; I = input variable of the production function; In = variable of the technical inefficiency.

The hypotheses on the restrictions of the models showed that (i) the translog production function was not the best functional form; (ii) the use of determinants for explaining technical inefficiency provided a sound analysis; and (iii) the determinants concerning the characteristics of farmers and their farms, as well the aspects related to integrated production, were able to explain the technical inefficiency of the sampled farms (Table 3).

Table 3. Hypotheses tests for some restriction of the PSF model.

Restrictions		Area A			
		λ	f.d.	$\chi^2_{0.95}$ *	Decision on H_0
(1)	$H_0: \beta_{ij} = 0$	12.37	21	32.08	Not rejected
(2)	$H_0: \gamma = \delta_0 = \delta_1 = \dots = \delta_m$	36.98	12	20.41	Rejected
(3)	$H_0: \delta_1; \delta_2; \delta_3; \delta_4; \delta_5; \delta_6; \delta_7; \delta_8; \delta_9; \delta_{10}; \delta_{11}; \delta_{12} = 0$	$9.32 < \lambda < 21.75$	1	2.71	Rejected

* Critical values from [64].

On the models' fitting (Table 4), the significant variance parameters σ^2 and γ indicated a strong impact of technical inefficiency on output. In particular, the parameter γ was close to one and suggested that the variations of the output were mainly caused by changes in inefficiency; thus, the differences in technical inefficiency among firms explained their output variation well. Furthermore, γ^* measures the effect of inefficiency on the total output variance and highlighted that 51% of the difference between the output of the firms and the output assessed on the frontier was due to inefficiency.

Table 4. Estimate of the PSF and TE parameters.

Variable	Parameter	Coeff.	Std. Err.	Sign.
PSF Model				
Constant	β_0	2.883	0.349	***
ln(Ca)	β_1	0.248	0.041	***
ln(Mv)	β_2	0.381	0.051	***
ln(Lc)	β_3	0.375	0.070	***
ln(Fc)	β_4	0.645	0.076	***
ln(Pc)	β_5	0.513	0.084	***
ln(Wc)	β_6	0.886	0.092	***
Inefficiency model				
Constant	δ_0	1.332	0.207	***
Age	δ_1	0.268	0.046	***
Credit	δ_2	−0.383	0.138	**
Plot	δ_3	0.259	0.050	***
Slope	δ_4	0.286	0.110	**
Organic	δ_5	−0.245	0.107	**
Varieties	δ_6	−0.881	0.141	***
Soil	δ_7	−0.364	0.143	**
Grassing	δ_8	−0.145	0.083	
Fertilisation	δ_9	−0.413	0.165	**
Irrigation	δ_{10}	0.825	0.088	***
Agrometeorological	δ_{11}	0.481	0.196	**
Pesticides	δ_{12}	0.660	0.159	***
Variance parameters				
σ_u^2		0.158		
σ_v^2		0.056		
$\sigma^2 = \sigma_u^2 + \sigma_v^2$		0.214	0.030	***
$\gamma = \sigma_u^2 / \sigma^2$		0.738	0.116	***
$\gamma^* = \gamma / [\gamma + (1 - \gamma)\pi / (\pi - 2)]$		0.506		
Log-likelihood		−283.26		
N. firms		317		
Technical efficiency				
Mean		0.748		
Min.		0.465		
Max.		0.959		
Std. dev.		0.620		

***: sign—1%; **: sign—5%.

The results of the production frontier confirmed that output is positively influenced by the considered predictors. Irrigation water generated the greatest impact on output, so that a 1% increase in the cost of irrigation water generated an increase in the production value of 0.89% (first order of the coefficients interpretable as elasticity of output). These findings are due to the Mediterranean climate, to the characteristics of the regional hydrographic system, and to the types of soil in Apulia, which generate a high demand for irrigation water in summer for obtaining high-quality production. The fertilisers and pesticides costs, whose increase of 1% caused an increase in the production value of 0.64% and 0.51%, were also important. Labour cost and the cultivated area generated the lowest impacts on the production value.

Concerning inefficiency analysis (Table 3), vineyards achieved an efficiency of 75% with their current technology. Based on the output-oriented approach, these firms can achieve a 25% increase in output value by purchasing the current production factors and inputs on the market in a more efficient way. Inefficiency can be reduced by favouring the generational turnover of entrepreneurs, which would boost innovative management strategies, as well as by a more frequent credit access, which would enable investments in innovations. Furthermore, a greater number of plots and a higher terrain slope increase inefficiency for their negative impacts on the organisational time and the mechanised operations. Concerning the cultivation practices listed in the regional IPRs, the use of resistant and/or tolerant varieties generates the strongest reduction in inefficiency, followed by the use fertilisation plans, tillage techniques for preserving and improving the structure and the fertility of soil, and the management of the organic matter in the soil. On the contrary, the recourse to irrigation plans based on water balance cause the highest levels of inefficiency. This result may be due to both to the poor skills of entrepreneurs and to the high irregularity of meteorological variables caused by climate change, which favour the definition of inaccurate irrigation plans. The climate change may also generate inefficiency of the IPR measures concerning a lower use of pesticides. Indeed, the unpredictability and the high variation in temperature, humidity, and precipitation could generate strong changes in the duration of the biological cycles of pests and in the intensity of their infections. Therefore, the doses of pesticides and the timing of pest control as defined in the regional IPRs may be seriously mistaken. In addition, the scarce know-how of entrepreneurs in using the correct agrometeorological instruments and website portals for the interpretation of data to receive intervention advice concerning fertilisation, pest control, and irrigation generates firm inefficiency. Finally, the soil management through grassing does not affect inefficiency, probably due to the location of the firms on flat territories, which makes the process of grassing not strictly necessary.

5. Discussion and Conclusions

The results highlight that the environmental sustainability of the production process does not always ensure a firm's high economic performance and provide useful indications for improving the measures in the regional IPRs by adapting them to the impacts of climate change and to the characteristics of firms and entrepreneurs. The results suggest improvements in line with the objectives of the 2030 Agenda in agriculture and outline important paths to be adopted in the short–medium term on a firm scale for implementing production strategies in compliance with the most important policy documents, such as the CAP 2023–2027 and the European Green Deal. These paths aim for economic and environmental sustainability of produce by increasing the effectiveness in the purchasing of production factors and inputs on the markets.

Integrated production systems have a strong impact on the economic and environmental sustainability of the regional winegrowing firms. The efficiency analysis allows for a comparison between the measures in the regional IPRs and the ordinary agricultural practices, in reference to soil management and the use of fertilisers, pesticides, and irrigation water. In relation to these aspects, generational turnover, credit access for technological investments, use of tolerant or resistant varieties, and an improvement in the entrepreneurs' know-how contribute to a reduction in the costs of inputs, to modernise the fertilisation, pest control, and irrigation practices; to preserve the environment; and to counteract the impact of climate change [65].

Thus, the results allow to increase know-how in the following ambits:

- impact of the costs of production factors and inputs on revenues;
- relationship between quality systems and economic sustainability of firms;
- relationship between environmental and economic sustainability.

The methodological approach allows the evaluation of costs and benefits related to the voluntary adhesion to the IPRs and the assessment of possible compensatory measures for

entrepreneurs. These are important aspects, for which it is important to deepen knowledge. Indeed, it is not obvious that the environmental sustainability and the quality of production systems have positive effects on the firm's production function. If these approaches limit the economic performance, interventions are desirable through strategies aimed at rebalancing public costs and benefits with the private counterparts. Lacking corrective approaches, firms risk exiting the market in the short–medium term [66]. Advantages also concern consumers, since producers are able to identify and overcome possible economic hot spots caused by integrated production systems, with positive impacts on the selling prices.

In general, the methodological approach can be used in ex-ante, ongoing, and ex-post policy evaluation for the investigation of drivers and barriers regarding the NIPQS certification for firms [67]. This process is crucial since it allows for the formulation of feedback for validating the effectiveness and efficiency of the regional IPRs through shared, transparent, independent, flexible, and comparable evaluations. These should not remain isolated and self-referential, but should allow for integration with the evaluation of other EU policies. On this aspect, the following efforts are needed:

- to train administrations to increase their technical knowledge;
- to improve governance in terms of the better distribution of roles, resources, and responsibilities between the public and private actors involved;
- to manage information in terms of transmission, homogenisation, and certification, for providing solid foundations in the evaluation process;
- to ensure a third-party opinion by using an Evaluation Authority;
- to improve research aimed at providing positive and normative tools for the different needs of evaluators.

The results also contribute to the strengthening of the regional agri-food system in terms of employment. The measures of the regional IPRs request improvements in work competencies, giving resilience to the agricultural workforce, which largely operates in small- and medium-sized family firms. Its strengthening is fundamental for the preservation of the economic and social systems in the regional rural areas, since these firms are a buffer against unemployment [7]. Furthermore, the measures in the regional IPRs request a preventive introduction of innovation into the firms and this could favour the generational change needed by the primary sector. Thus, the integrated production systems can boost the technological modernisation of the Apulian agricultural firms by attracting young entrepreneurs, also ensuring social sustainability.

The study highlights a certain trade-off between economic and environmental sustainability. To make the convergence of these two aspects in the regional winegrowing sector possible, specific strategies should be implemented by focusing on markets, environment, producers, consumers, legality, and policy making. Indeed, the producers' revenue should be supported through the promotion of grape and wine products in quality and niche supply chains, and also by strengthening the certification system [67]. This last point, in addition to the EU schemes of geographical indications, namely the protected designation of origin (PDO) and the protected geographical indication (PGI), as well as the certifications related to organic and integrated production systems, could be integrated by the certification of origin based on DNA techniques certified by blockchain [68]. As concerns environmental sustainability, it is possible to improve the knowledge and skills of producers regarding the most innovative technologies, aimed at making the use of technical inputs more efficient [69]. On the other hand, consumers need a deeper level of training and information about concepts like sustainability, competitiveness, and the origin of products, so as to make their demand more aware [70]. Finally, policy makers need to strengthen and improve the income compensation system based on agri-environmental subsidies in favour of the most virtuous firms. Furthermore, deeper and more thorough checks by the competent authorities on markets and firms are necessary for improving the transparency and legality of production processes and selling [71]. By adopting or strengthening these

strategies, policy makers could continue to guarantee the same, or a higher, level of income, with a significant reduction in environmental impacts.

In conclusion, the analysis approach assesses the firm's capacity of building in and using more efficient technologies through innovation transfer and training for environmental, economic, and social sustainability. The insights also favour the creation of networks among firms, institutions, scientific authorities, and entrepreneurs' organisations to enhance knowledge on the improvement of the production quality and the environmental performance of processes. This should also increase the involvement of new young experts with a high technical and scientific know-how. The environmental, economic, and social impacts of these changes could be huge, especially if coordinated, promoted, and valorised at a regional level and supported at each level (production, consumption, institutions, and community).

This study has some limitations. Firstly, it focuses on a single crop. For the integrated production system to contribute to the reduction in environmental impacts in a sensitive and sustainable way, the efficiency analysis must involve all the crops of the regional territory. Furthermore, the study only considers the integrated system, while efficient policy making should be based on a comparison among all the production systems carried out in the regional territory. Therefore, future research may concern an extension of the set of crops and production systems analysed, even over larger territories.

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