Estimation of irrigation efficiency and economic value of environmental trade-offs in grapevine production in Mendoza, Argentina

Sebastian Riera[1], Bernhard Brümmer[1]
(Georg-August-Universität Göttingen)

Abstract

Water is a key resource to agriculture in Mendoza but there are increasing concerns regarding the viability of current practices and availability. Some farms fall short of their production potential, which questions the economic viability of some vineyards, and might trigger structural change and lead to additional pressure on water use. Improvements in irrigation efficiency could help mitigate this problem. Farmers pay for the resource management but do not have to consider the opportunity cost of the resource itself. Estimation of the intrinsic value of irrigation water will provide an additional tool to design specific policies for the sector.

I. Introduction

Water is a key resource to agriculture in Mendoza but there are increasing concerns regarding the viability of current practices and availability. Strong dependency on the unstable economic framework, local markets and inefficient management practices, the grapevine producers are trapped in a declining spiral of water scarcity, production quality and profitability.

The water demand for agricultural is nearly 90 per cent of the total resource availability, exceeding the world average by 20 per cent (Duek & Fasciolo, 2012; Scheierling, Treguer, & Booker, 2016). Agricultural activities represent 6 per cent of the provincial economy but drives the performance of other industries and services strongly linked with employment and economic development.

For more than 130 years, the province of Mendoza has acknowledged the relevance of proper water management with the creation of the water agency (Dirección General de Irrigación, DGI). This autonomous organization is in charge of delivering water throughout the 12,000 kilometer irrigation network. It is responsible for designing and executing the water policies but decentralizes operation and management on user's associations named Inspecciones de Cauce (Hurlbert & Montana, 2015). These associations plan the surface water delivery of their associates, estimate their budget and concentrates producers (Provincia de Mendoza, 1884).

In Argentina, over the last three decades, agriculture has become a key and growing contributor to export earnings and wine has played a relevant and rising role to sustain the regional economies. Vineyard grapes are one of the most relevant crops in western Argentina. With over 160,000 hectares, the province of Mendoza concentrates 70 per cent of the grape production and 65 per cent of the wine elaboration.

The growing reputation of Argentinean wines led to the settlement of international firms, which improved the industry in terms of technology adoption and market orientation. The increasing Argentinean wine production and exports have pushed this sector to make relevant changes in productive strategies, being especially focused on producing high quality grapes highly sensitive to water stress management.

Despite the major evolution of wine production and exports in Mendoza, the production of grapevine is undergoing significant challenges arising from low prices paid to producers, agronomic risks, and climate contingencies. More dependent on economic framework and local markets, the small wine grape producers may be trapped in a *declining spiral* of water scarcity, production quality and profitability. Although, the public sector creates policies oriented to small-scale producers, most of them aim to solve urgent needs instead of other core issues as quality and technical efficiency.

Any input improvement or changes in management practices may increase profitability of grapevine producers, that sell their production at a yearly-stable price per quality paid by wine makers. Therefore, it is relevant to analyze the production efficiency to estimate general scores controlling for location, water quality and technology adoption among others.

Furthermore, this paper will focus in two issues: (i) the role of water in improving farm productivity and (ii) the implications that can be derived from the frontier analysis of technical efficiency. Following a stochastic frontier analysis (SFA), this paper seeks to provide a clear perspective on the use of natural resources, labor and other inputs by the grapevine producers in Mendoza.

II. Literature review

A relevant strand in the economic literature to assess productivity and efficiency using frontier function methodologies. These methods determine a benchmark frontier and provide measure of efficiency in terms of input reduction or potential output expansion with respect to the frontier. This model was first applied by Farrell (1957), who decompose economic efficiency into technical efficiency (TE) and allocative efficiency (AE). The former measures the firm ability to maximize the output given the input set; the latter measures the capability of the firm to relocate inputs according to their prices.

It is widely known that agriculture is the main recipient of water resources. Additionally, there is a wide consensus that the agricultural sector is the less efficient in terms of input oriented efficiency. Bravo et al. (2016) carried a meta-analysis study on production and water use efficiency. In terms of water efficiency, Latin America has the lower average mean on technical efficiency (AMTE) with 55 percent, where US and Western Europe achieved above 80 percent.

In this line, the preliminary task is to define a functional form of the production function that accomplish the axioms of production and achieve the regularity conditions of monotonicity and curvature (Coelli, Prasada Rao, O'Donnell, & Battese, 2005; Greene, 2008). According to the scarce literature on quality grape efficiency, the Cobb-Douglas function is preferred to the transcendental logarithmic for modeling grapevine production (Bravo-Ureta, Moreira, Troncoso, & Wall, n.d.; T. Coelli & Sanders, 2012).

We start with Townsend, Kirsten and Vink (Townsend *et al.* 1998) who analyzed the relationship between farm size, productivity and returns to scale for wine grape producers located in four regions of South Africa for the years 1992 to 1995.

Moreira, Troncoso and Bravo-Ureta (Moreira L. *et al.* 2011) examined the *TE* of wine grape production for a sample of Chilean firms for 2005-06 using a standard cross sectional models. A Cobb-Douglas SPF model using data for 38 farms for which input-output information is available at block level. The results reveal an average farm level *TE* of 77.2 per cent, with block level *TE* ranging from 23.4 to 95.0 per cent. Ma *et al*. (2012) use 1020 farm level observations collected across 24 grape producing provinces in China to estimate a Cobb-Douglas SPF model. Coelli and Sanders (Coelli and Sanders 2013) used an unbalanced panel data set (2006–2007 to 2009–2010) for a sample of 135 farmers specializing in wine grape production located in the Murray and Murrumbidgee river basins in Australia. The authors used the translog functional form to fit SPF models using the Battese and Coelli (Battese and Coelli 1992) approach. The results revealed a mean *TE* equal to 79 per cent, a mean estimate of scale economies of 1.07, and a 2.7 per cent annual average rate of technological change. The findings also suggested that shadow price estimates for irrigation water exceeded average market prices.

Finally, Manevska-Tasevska (2013) uses a three-year (2006-2008) panel data set for a sample of 300 commercial grape producers from Macedonia along with a Cobb-Douglas SPF model and a second stage regression to analyze *TE*.

III. Methodology

Defining a suitable production function, a realistic level of technical efficiency is expected according to the producer's farming and irrigation practices, human capital and policy tools. Regularly, deviations from this expected output are considered deterministically. However, the stochastic frontier approach analyses inefficiency considering two types of errors: random and stochastic.

Starting with the classical stochastic production frontier model that incorporates traditional inputs (land, labor, capital), this analysis is augmented by including quantity of water applied as well as a number of attributes of the vineyard and dummy variables to capture the agro-ecological heterogeneity. Cobb-Douglas and translog are functional forms adopted for estimation and the results are used to quantify output oriented farm level technical efficiency, irrigation water use efficiency and the shadow value of water (i.e., marginal value product).

These results are measures are analyzed considering various characteristics such as plot size, location, and irrigation practices, among others. Results differs depending on type of irrigation systems. Although, some stochastic efficiency analysis has been carried in the region; there is no evidence of technical efficiency (TE) analysis with this focus on agriculture production. In particular, the hierarchical analysis of grapevine plot management that considers different treatment of individual plots

The selected methodology to assess technical efficiency (TE) is the stochastic frontier analysis (SFA), which belongs to the parametric methods in frontier methodology. This approach incorporates statistical noise through a composed error structure with a two-sided symmetric term and a one-sided component. The two-sided error captures random *shocks* outside the control of the firm whereas the one-sided component seeks to explain inefficiency (Bravo-Ureta et al., 2016; Kumbhakar & Knox Lovell, 2003).

As it is explained below, the data characteristics would allow the analysis into hierarchical models. The basic scheme for modelation is:

$$\mathrm{Y}_{ib} = \alpha_i + \sum \beta_i X_{ib} + \sum \gamma_i Z_{ib} + \varepsilon_{ib} \qquad (1)$$

$$\varepsilon_i = v_{ib} - u_{ib} \qquad (2)$$

where:

Y_{ib} = *log of output of the i^{th} farm in the b^{th} plot;*
X_{ib} = *log of inputs;*
Z_{ib} = *variables that capture specific plot level characteristics;*

$\alpha_i, \beta_i, \gamma_i$ = *parameters to be estimated;*

v_{ib} = *random error* (v_i ~ *iid N(0,* σ_v^2);

u_{ib} = $|N(0, \sigma_u^2)|$ is a one sided error representing technical inefficiency of the bth plot in the ith farm.

In this traditional SPF model, the *TE* component is estimated as follows:

$$TE_{ib} = E\,[exp(-u_{ib}) \mid \varepsilon_i] \qquad (3)$$

Further explanation of the potential variability of TE scores in terms of exogenous factors could be achieved with the so-called two-step model where TE is estimated with and without accounting the external factors (Wang & Schmidt, 2002).

IV. Data

The total area of the research project has 740 km^2 and holds nearly 15,000 ha of grapevine area, farmed by 510 producers. Bulk production is estimated at 11,000 tons in approximately 2,500 plots. As located on the Andes mountain range, the terrain and water resources vary substantially within this area. From northwest to southeast, elevation decreases from 980 to 770 meters above sea level and the depth of groundwater raises from -120 to -20 meters below the surface (Hernández et al., 2012).

Considering the heterogeneity of the region, the sampling procedure required careful stratification and randomization in order to ensure representativeness of the sample. The coordination with the DGI and the Statistics Bureau of the province (DEIE) allowed a detailed planning. Initial field visits were performed as a guest of DGI to measure the static groundwater levels[1] in the region, and compared with historical values. Upon signature of agreements, preliminary data bases were provided by different government organizations[2], which could only be merged with the support of DEIE, that provided the database key coding and executed the spatial merge of the data. Furthermore, DEIE advised on the way how socio-economic characteristics of producers should be obtained, and supported the logistic planning to collect the data and corresponding retribution to enumerators according to their standards.

The collected sample of 1,500 grapevine plots of 220 producers is representative of the study area and contains relevant input and output information with current prices, as well as management practices, water source, and technology adoption per plot. To correctly address the irrigation efficiency, soil typology will be considered and this information is available at the webpage of the National Institute of Agriculture Technology (INTA) at a reasonable scale for the analysis.

Survey questions gather straightforward information on management practices, external assistance, quality of water, and market orientation at plot level. On average, grapevine producers have at least 2.3 plots. Nearly 30 per cent have 15 plots per farm. The sample should gathered information on 1200 grapevine plots. In terms of data quality, the gathered information seeks to capture the unobserved heterogeneity in production functions for grapevine producers.

The collected data was instantly available in digital form, and was processed with the CSPro software, which allowed continuous monitoring and overnight corrections.

[1] During the winter season, most of the perennial crops are rarely irrigated. Therefore, fewer groundwater is pumped to the surface and groundwater levels are stabilized. This level is known as groundwater table.

[2] Collaboration agreements were signed with DGI, Direction of Agriculture and Climate Contingencies (DACC), Provincial Body for Energy Regulation (EPRE), Provincial Direction of Electricity Services, and Statistics Bureau of the Province (DEIE). All the collaboration agreements are specific for this research and available upon request.

Eventually, if the producer did not have enough time to end the survey in one visit, information was collected manually and later digitalized. Additionally, 140 groundwater samples were taken from producers to analyze salinity and acidity of the resource. Unfortunately, some producers did not have groundwater wells or did not agreed to receive a water quality test. This groundwater quality analysis will contribute to improve the description of management practices considering the environmental quality of natural resources.

At the same time, many producers manage more than one vineyard and may share moveable capital between them; which could imply lower management costs. The selected methodology considers hierarchical models. That is, clustering plots and vineyards per producer into a multi-level efficiency analysis. Initially, three (3) hierarchical levels have been identified.

There is considerable heterogeneity in terms of grape type (red or white), quality (premium or varietal), and irrigation practices. Nearly halve of the sample use modern irrigation and the rest have irrigation by gravity; however, alternative mechanisms and scheduling strategies are observed for both systems that can drive water efficiency practices.

V. Discussion and conclusions

After interpretation of collected data and interviews with experts, it is expected lower efficiency scores at some locations. At the southern end of the research area, within the districts of Ugarteche, El Carrizal and Anchoris, producers can only irrigate with deeper groundwater from the second aquifer due to salinization of the resource. DGI applied a zooning restriction for new drillings and later increased the annual fee for existing wells. By all means this translate into higher production costs and lower profitability which, limited investments, technology adoption and new practices. These characteristics were reviewed during data collection and might determine lower efficiency scores.

Overall, a metafrontier reflects the TE levels at different groups of producers clustered according to their similarities. The TE value of the industry is relatively high with interesting heterogeneity within inner frontiers.

As a major outcome, this research project aims to provide reliable water efficiency estimations for designing policy instruments that address economic and environmental challenges focusing on the responsible use of natural resources. Furthermore, the directional distance functions approach is applicable as policy valuation tool for decision makers and as a cost internalization strategy for stakeholders. At the same time that facilitate the decision-making process for public policy on environmental adaptation and mitigation in affected area.

Some evidence shows that agricultural extension services were not effective as planned (Cerdán-Infantes 2008), maybe due to inaccurate planning and baseline information. Currently, agricultural policies are very much in focus for their environmental effects. Therefore, a solely standing analysis of technical efficiency will enhance understanding of farmer's limitations at the individual level. Moreover, an environmental analysis will assess the management of resources from a greater perspective that includes the environmental trade-offs into the equation.

Incorporating the irrigation efficiency practices into the production function represent a step forward to conducting technical efficiency analysis for grapevine production. Irrigation practices can be aggregated controlling for soil and agronomic characteristics of the vineyard. With the one-step approach of using a multi-output, multi-input stochastic input-oriented distance function based on the field survey data, we will estimate the TE of grapevine production on the northern basin of Mendoza, Argentina. The inclusion of TE analysis could improve policy making to tackle specific aspects on water management practices considering environmental effects of their decisions.

VI. Literature

Bravo-Ureta, B. E., Jara-Rojas, R., Lachaud, M. A., Moreira, V. H., Scheierling, S. M., & Treguer, D. O. (2016). *Agricultural productivity and water: evidence from the frontier*.

Bravo-Ureta, B. E., Moreira, V. H., Troncoso, J. L., & Wall, A. (n.d.). *Alternative Measures of Technical Efficiency and Unobserved Heterogeneity: Evidence from a Cross Section of Chilean Wine Grape Producers*.

Coelli, T. J., Prasada Rao, D. S., O'Donnell, C. J., & Battese, G. E. (2005). *An introduction to efficiency and productivity analysis* (2nd ed.). New York: Springer.

Coelli, T., & Sanders, O. (2012). The technical efficiency of wine grape growers in the Murray-Darling Basin in Australia. In *Enometrics XIX*. Coimbra & Viseu. Retrieved from www.vdqs.net/2012Coimbra

Dagnino, M., & Ward, F. A. (2012). Economics of agricultural water conservation: Empirical analysis and policy implications. *International Journal of Water Resources Development*, *28*(4), 577–600. http://doi.org/10.1080/07900627.2012.665801

Duek, A. E., & Fasciolo, G. E. (2012). Uso de agua en las bodegas de Mendoza. *Revista de La Facultad de Ciencias Agrarias UNCuyo*, *44*(2), 263–268.

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*, *120*(3), 253–290.

Greene, W. H. (2008). The econometric approach to efficiency analysis. *The Measurement of Productive Efficiency and Productivity Growth*, 92–250. http://doi.org/10.1093/acprof

Hernández, J., Martinis, N., & Fornero, L. (2012). *Modelación hidrológica de la cuenca norte de Mendoza* (No. 146–CRA). *Informe técnico*. Mendoza, Argentina.

Huang, W., Brümmer, B., & Huntsinger, L. (2016). Incorporating measures of grassland productivity into efficiency estimates for livestock grazing on the Qinghai-Tibetan Plateau in China. *Ecological Economics*, *122*, 1–11. http://doi.org/10.1016/j.ecolecon.2015.11.025

Hurlbert, M. A., & Montana, E. (2015). Dimensions of adaptive water governance and drought in Argentina and Canada. *Journal of Sustainable Development*, *8*(1), 120–137. http://doi.org/10.5539/jsd.v8n1p120

Kumbhakar, S. C., & Knox Lovell, C. A. (2003). *Stochastic Frontier Analysis* (First). Cambridge: Cambridge University Press.

Meinzen-Dick, R. (2007). Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences*, *104*(39), 15200–15205. http://doi.org/10.1073/pnas.0702296104

OECD. (2011). *Water governance in OECD countries: A multi-level approach*. OECD Publishing. http://doi.org/10.1787/9789264246744-en

OECD. (2012). *Meeting the Water Reform Challenge*. *OECD Studies on Water*. OECD Publishing. http://doi.org/10.1787/9789264170001-en

Parmeter, C. F. (2014). Efficiency analysis: a primer on recent advances. *Foundations and Trends® in Econometrics*, *7*(3–4), 191–385. http://doi.org/10.1561/0800000023

Scheierling, S., Treguer, D. O., & Booker, J. F. (2016). Water productivity in agriculture: looking for water in the agricultural productivity and efficiency literature. *Water Economics and Policy*, *2*(3), 1650007. http://doi.org/10.1142/S2382624X16500077

Wang, H. J., & Schmidt, P. (2002). One-step and two-step estimation of the effects of exogenous variables on technical efficiency levels. *Journal of Productivity Analysis*, *18*(2), 129–144. http://doi.org/10.1023/A:1016565719882