CENTRE OF PLANNING AND ECONOMIC RESEARCH

No.112

Applying regression quantiles to farm efficiency estimation

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October 2010

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CONTENTS

Εφαρμογή της τεταρτημοριακής παλινδρόμησης (regression quantiles) στην εκτίμηση της αγροτικής αποτελεσματικότητας

Ελένη Α. Καδίτη & Ελισάβετ Ι. Νίτση

ΠΕΡΙΛΗΨΗ

Η εκτίμηση της αποτελεσματικότητας στον αγροτικό τομέα θεωρείται θέμα συνεχούς ενδιαφέροντος τόσο για τους οικονομολόγους όσο και για τους φορείς που ασκούν πολιτική, καθώς επιθυμούν την ορθολογική κατανομή μειούμενων ενισχύσεων σε ετερογενείς αγρότες. Σκοπός της παρούσας εργασίας είναι η εκτίμηση της καμπύλης παραγωγής στο όριο στον αγροτικό τομέα με τη μέθοδο της τεταρτημοριακής παλινδρόμησης (quantile regression). Η προτεινόμενη μεθοδολογία αποδεικνύεται κατάλληλη για την εκτίμηση της αποτελεσματικότητας και εφαρμόζεται σε στατιστικά δεδομένα που αφορούν τον αγροτικό τομέα της Ελλάδας για το 2007.

Δύο προσεγγίσεις έχουν χρησιμοποιηθεί ευρέως έως σήμερα για την εκτίμηση της αποτελεσματικότητας, η μη-παραμετρική Περιβάλλουσα Ανάλυση Δεδομένων (Data Envelopment Analysis - DEA) και η παραμετρική Στοχαστική εν Δυνάμει Συνάρτηση Παραγωγής (Stochastic Frontier Analysis - SFA). Αν και οι δύο αυτές μέθοδοι έχουν χρησιμοποιηθεί εκτενώς, έχουν δεχθεί έντονη κριτική. Η μη-παραμετρική ανάλυση λόγω του σημαντικού επηρεασμού των αποτελεσμάτων από την έλλειψη κάθε υπόθεσης που αφορά στη μορφή τόσο της συνάρτησης παραγωγής όσο και της κατανομής της αναποτελεσματικότητας, και η στοχαστική ανάλυση λόγω των υποθέσεών της αναφορικά με την κατανομή της αναποτελεσματικότητας. Επιπλέον, και οι δύο μέθοδοι δέχονται κριτική για τον επηρεασμό των εκτιμήσεών τους από ακραίες τιμές. Συνεπώς, στην παρούσα ανάλυση γίνεται μία πρώτη προσπάθεια χρήσης της τεταρτημοριακής παλινδρόμησης για την εκτίμηση της αποτελεσματικότητας στον αγροτικό τομέα. Η προτεινόμενη προσέγγιση αποφεύγει τις προηγούμενες κριτικές, καθώς δεν θεωρείται αναγκαία η επιβολή υπόθεσης για την κατανομή της αποτελεσματικότητας, και είναι ιδιαίτερα χρήσιμη σε περιπτώσεις ετεροσκεδαστικότητας.

Ακολουθείται μία διαδικασία δύο σταδίων, όπου στο πρώτο στάδιο γίνεται εκτίμηση της αποτελεσματικότητας στον αγροτικό τομέα της Ελλάδας, ενώ στο δεύτερο στάδιο εκτιμώνται οι επιπτώσεις επιλεγμένων επεξηγηματικών μεταβλητών στο επίπεδο της αποτελεσματικότητας που υπολογίζεται στο προηγούμενο στάδιο. Και στις δύο περιπτώσεις χρησιμοποιείται η προσέγγιση της τεταρτημοριακής παλινδρόμησης. Για λόγους σύγκρισης παρουσιάζονται και τα αποτελέσματα της παραμετρικής Στοχαστικής εν Δυνάμει Συνάρτησης Παραγωγής. Πηγή των στοιχείων είναι το Δίκτυο Γεωργικής Λογιστικής Πληροφόρησης (ΔΙ.ΓΕ.Λ.Π).

Τα εμπειρικά αποτελέσματα καταδεικνύουν ότι όταν χρησιμοποιείται η τεταρτημοριακή παλινδρόμηση, η κατανομή της αποτελεσματικότητας είναι πλησιέστερα στην κανονική σε σχέση με την εναλλακτική μέθοδο εκτίμησής της. Η παραδοσιακή αυτή μέθοδος οδηγεί σε μία υποεκτίμηση της αποτελεσματικότητας και δεν λαμβάνει υπόψη τις διαφορές στην τεχνολογία παραγωγής που χρησιμοποιείται σε διαφορετικά τμήματα της κατανομής της παραγωγής. Συνεπώς, η προτεινόμενη μεθοδολογία αποδίδει καλύτερες εκτιμήσεις της αποτελεσματικότητας. Επιπλέον, συμπεραίνεται ότι ο τρόπος άσκησης πολιτικής στήριξης, που στόχο έχει τη βιωσιμότητα των αγροτών, θα πρέπει να εφαρμόζεται με τη χρήση

επιδοτήσεων αποσυνδεδεμένων από το επίπεδο της παραγωγής και των τιμών, καθώς και με τις ενισχύσεις αγροτικής ανάπτυξης, οι οποίες επηρεάζουν την παραγωγικότητα του τομέα με τρόπο ομοιόμορφο.

ABSTRACT

This article is concerned with the frontier production function estimation for agriculture and the use of regression quantiles as an alternative approach. Better insights are reached using the proposed methodology that provides robust farm efficiency estimates. Using the 2007 Farm Accountancy Data Network data for Greece, analysis shows that the distribution of efficiency scores is closer to normality when employing regression quantiles. An additional advantage arises from the examination of the impact that a set of covariates might have at different efficiency levels, providing valuable information to policy makers, which could not be retrieved from a Stochastic Frontier Analysis. In the application used, it becomes apparent that various policy instruments affect differently farms that use inputs relatively efficient compared to those that are relatively inefficient.

Keywords: Agriculture, Efficiency, Quantile Regression

JEL codes: C14, D24, Q18

Applying regression quantiles to farm efficiency estimation

Eleni A. Kaditi and Elisavet I. Nitsi

1. INTRODUCTION

Efficiency measurement is a topic of continuing interest to agricultural researchers and policy-makers, who aim to allocate effectively decreasing agricultural funds across heterogeneous farmers and maintain an adequate standard of living in rural communities. This article is concerned with the methodological question of frontier production function estimation for agriculture, and the alternative use of regression quantiles, as a useful semi-parametric approach that provides robust farm efficiency estimates.

In the economics literature, two approaches have been widely used to estimate efficiency, the deterministic data envelopment analysis (DEA) and the stochastic frontier analysis (SFA). DEA has been developed since Charnes *et al.* (1978) and Färe *et al.* (1985) provided measures of efficiency in production, based on the work of Debreu (1951) and Farrell (1957) that makes no assumptions about the functional form of the frontier model as well as the distribution of the error term. In contrast, Aigner *et al.* (1977) and Meeusen and van den Broeck (1977) proposed the SFA approach that uses maximum likelihood to estimate the production frontier and two random terms; inefficiency and the random error. Both methodologies have been criticized. DEA for the hull that it maps out, as it could be affected to a significant degree by the presence of random disturbances in the data, while SFA makes assumptions for the functional form of the inefficiency distribution and is sensitive towards outliers, raising the possibility of misspecification. In fact, strong distributional assumptions on each error component are necessarily imposed when estimating a stochastic production frontier model by maximum likelihood with cross-sectional data. Nevertheless, these approaches have been extensively used to estimate farm efficiency (e.g. Coelli and Prasada Rao, 2005; Wadud and White, 2000).

Recently, there have been some attempts to use quantile regression for the estimation of frontier production functions. Quantile regression was developed by Koenker and Bassett (1978) and provides a description of a response variable as a conditional function of a set of covariates broader than the methods based on conditional means (i.e. ordinary least squares or maximum likelihood). This approach requires an assumption about the functional form of the frontier, while it does not require the imposition of any distributional assumption of the inefficiency term as in SFA[1]. It also avoids the criticism aimed at DEA that does not allow for random error in the observed values of the dependent variable. This criticism remains despite the developed bootstrap techniques employed to analyze the sensitivity of DEA efficiency estimates and obtain confidence intervals (Wilson, 1995; Simar and Wilson, 2000).

In this framework, Bernini *et al*. (2004) estimated a whole spectrum of production functions for the Italian hotel industry and suggested that quantile regression allows to distinguish among technological relations at different efficiency levels. Examining the

[1] In a two stage approach, SFA assumes in the first stage that the inefficiency scores are identically distributed, which is contradicted in the second stage as they are assumed to have a functional form with a set of covariates.

efficiency of German banks, Behr (2010) argued that while in the stochastic frontier approach a composed error term is assumed, the quantile regression approach estimates the production process for benchmark banks located at top conditional quantiles. Both studies have estimated efficiency scores but did not examine different factors that may affect them.

In the present analysis, a first attempt is made to employ regression quantiles as a potential alternative approach to estimate efficiency scores in agriculture. The proposed approach is very robust compared to conditional mean regression against outliers. Quantile regression functions are also especially useful in the case of heteroskedasticity. As farm level data typically display considerable heterogeneity (Kaditi and Nitsi, 2009), quantile regression is especially suited for empirical efficiency analysis in agriculture. Moreover, examining the impact of a set of covariates at different efficiency levels, with the use of quantile regression, new information valuable to policy makers are provided, which could not be retrieved from SFA even if the same covariates are included as explanatory variables for the inefficiency term.

A two stage approach is essentially used, employing quantile regression in both stages. In the first stage, the efficiency scores are estimated, while in the second stage, these scores are regressed over a set of covariates, including policy measures and farm characteristics at different points of the conditional efficiency distribution. For reasons of comparison, stochastic frontier techniques and least squares are applied in the respective stages. Farm level data are retrieved from the Farm Accountancy Data Network (FADN) dataset for Greece for 2007.[2]

2. QUANTILE PRODUCTION FUNCTION

Quantile regression estimators are robust to deviations from distributional assumptions, which is an appealing characteristic in the production frontier function context because of the asymmetric distribution of the stochastic error, as it does not require the imposition of a particular form on the distribution of the inefficiency term. The efficient production frontier is estimated by a quantile regression of high percentile, which describes the production process as the obtained regression parameters display the 'optimal' technique used by the most efficient farms, i.e. farms that produce on the production frontier. Efficiency estimates for all farms are actually derived by using the obtained coefficients and comparing each farm's factual output with its potential output using the 'optimal' technique.

To estimate the production function, cross sectional data for n farms are assumed indexed by i ($i = 1, ..., n$) using k different inputs contained in the input vector x_i' to produce a single output y_i. The conditional τ^{th} quantile of y ($\tau \in [0,1]$), given a covariate matrix x', can be computed employing the conditional quantile function denoted linearly in logarithms by:

$$Q_{\ln y}(\tau | x) = \beta(\tau) \ln x' \qquad (1)$$

whereas the estimator $\hat{\beta}(\tau)$ can be obtained as the solution of the minimization problem:

[2] Source: "EU-FADN – DG AGRI L-3".

$$\min_{\beta \in \Re^p} \sum_{i=1}^{n} \rho_\tau \left(\ln y_i - \beta(\tau) \ln x_i'\right) \qquad (2)$$

Assuming a linear relationship between $\ln x$ and $\ln y$:

$$\ln y' = \beta_0 + \beta(\tau) \ln x' + u_i \qquad (3)$$

the conditional quantile becomes:

$$Q_{\ln y}(\tau | x) = \beta_0 + \beta(\tau) \ln x' + F_u^{-1}(\tau) \qquad (4)$$

where $F_u^{-1}(\tau)$ is the distribution of the error term.

Some arbitrariness remains in terms of the choice of τ for the estimation of the production frontier, as quantiles differentiation depends on the size of the sample and the amount of information it contains about the upper tail of the conditional distribution (Koenker, 2005). One might conjecture that the higher the number of observations, the higher the quantile τ can be chosen. As further explained below, it seems evident that the analysis should focus on the top quantiles, as these percentiles represent the production frontier in the upper tail of the conditional distribution where 'best-practice' farms are operating.

To estimate the production function in agriculture, a multi-input-one-output model is employed. The inputs included are Capital, measured as the value of total assets; Labor, denoted by the number of working hours; Land expressed in hectares' and Intermediates measured as the value of all other expenses per farm. Data for 2007 were retrieved from the FADN dataset for Greece, which includes physical, structural, economic and financial data for 4 014 farms.

Summary statistics of the used variables are presented in Table 1. On average, Greek farms' output values about €30 000. The average size is about 12 Ha, whereas the operator, family-members and hired-staff work for about 3 200 hours a year. The second column provides the mean obtained from the FADN standard results database. The extrapolated data from the sample to all farms in Greece covered by the survey have been obtained by a special weighting system where each farm in the sample has a weight corresponding to the number of agricultural holdings it represents. As a result, the FADN mean shows high deviations from the sample mean for both the output and all inputs, though the figures are close to the sample median. This characteristic of the sample provides an additional argument in favor of regression quantiles, which is more indicative, as the effect of the covariates on the conditional median is estimated rather than the mean of output.

Table 1. Descriptive statistics of the used variables, 2007

	Mean	Mean[a]	Median	SD	Min	Max
Production, €	29 687	19 176	22 183	29 424	582	469 159
Capital, €	104 463	78 576	81 735	85 213	730	875 508
Labor, hours	3 206	2 693	2 810	2 014	506	22 560
Land, Ha	12.14	7.04	7.20	14.95	0.1	180
Intermediates, €	12 537	7 691	8 068	14 313	226	212 730

[a]: FADN Public Database

In this framework, a simple Cobb-Douglas production function is estimated in logs with the use of quantile regression:

$$\ln y_i = \beta_0 + \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + \beta_3 \ln x_{3i} + \beta_4 \ln x_{4i} + u_i \quad (5)$$

where u is the error term.

Thirty-nine distinct quantile regression estimates, that is a whole spectrum of production functions corresponding to different quantiles of the conditional distributions of output given inputs that may occur due to differences in the technological relations, are presented for a (horizontal) quantile scale ranging from 0.025 to 0.975 as the solid curve with filled dots (Figure 1). The shaded grey area depicts a 90 percent point-wise confidence band for the quantile regression estimates that were obtained by bootstrapping with 2 000 sample replications. The dotted line in each figure shows the least squares estimate of the conditional mean effect, whereas the two dashed lines represent conventional 90 percent confidence intervals for the latter estimate. The coefficients describing the impact of labor and capital on production have an upward trend along the output distribution, with some exceptions. A considerable dispersion is observed for the intermediates at different quantiles of the distribution, as the estimate at the 0.025 quantile is around 0.651, whereas it reaches 0.263 when evaluated at quantile 0.975 indicating a negative relationship. Quantile regression estimates suggest also a positive relationship between land and output, although this relationship becomes statistically significant only for point estimates above the 0.80 quantile. Finally, it is obvious that in all cases results from OLS estimates would lead to simplistic and false conclusions.

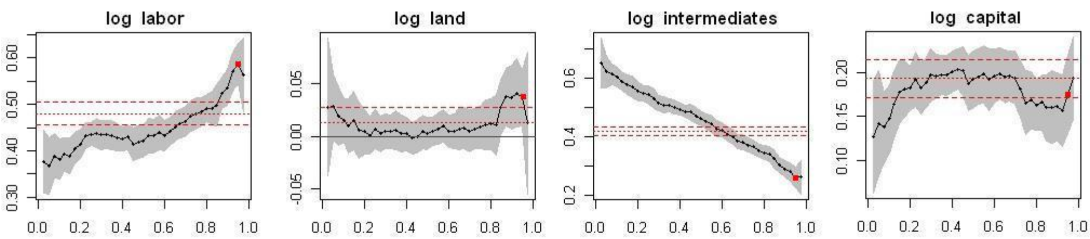

Figure 1. OLS and Quantile regression estimates

The importance of the differences in the quantile parameter estimates was formally examined with the relevant hypotheses testing. The corresponding test statistics for the pure location shift hypothesis and the location-scale shift hypothesis proposed by Khmaladze (1981) and Koenker and Xiao (2002) were performed. Two tests were computed for each hypothesis; a joint test that all covariates effects satisfy the null hypothesis that all the conditional quantile production functions have the same slope parameters; and a coefficient-by-coefficient version of the test. Both tests were decisively rejected (with values 21.97 and 16.26, respectively). The effects of the coefficient-by-coefficient tests are also significant, while the coefficients for intermediates and labor exhibit high significance.

Having produced a family of production functions, the attention should now be drawn on the particular segment of the conditional distribution that can reflect the production frontier. The choice of the appropriate τ for the estimation of the production frontier focuses on the top quantiles, i.e. $\tau \geq 0.95$. Figure 2 illustrates the estimated efficiency frontier for such quantiles. Using equation (5), it is examined whether farm i belongs to the quantile curve of order τ_i. In particular, the order of the quantile frontier indicates that farm i produces more than (100τ)% of all farms using inputs smaller or equal to x_i and produces less than the 100(1- τ)% remaining farms (Aragon *et al.*, 2005; Daouia and Simar, 2007). If τ_i is close to one, then the farm (x_i, y_i) can be seen to be performing relatively efficiently. As the order of the quantile frontier increases, the number of outliers reduces, whereas farm i denoted by a filled-square becomes relatively inefficient. That is, the number of observations above the quantile estimates $\hat{q}_{\tau,n}$ decreases with τ. However, given the large sample of farms, the number of observations above the quantile frontier $\hat{q}_{\tau=0.95,n}$ remains large, while it is very small at $\hat{q}_{\tau=0.99,n}$. An illustration is given by farm i, which lies above the $\hat{q}_{\tau=0.95,n}$ frontier, but below the $\hat{q}_{\tau=0.99,n}$. This indicates that the empirical quantile frontier $\hat{q}_{\tau=0.975,n}$ defines a reasonable benchmark value, so that $\tau = 0.975$ is chosen for the present analysis.

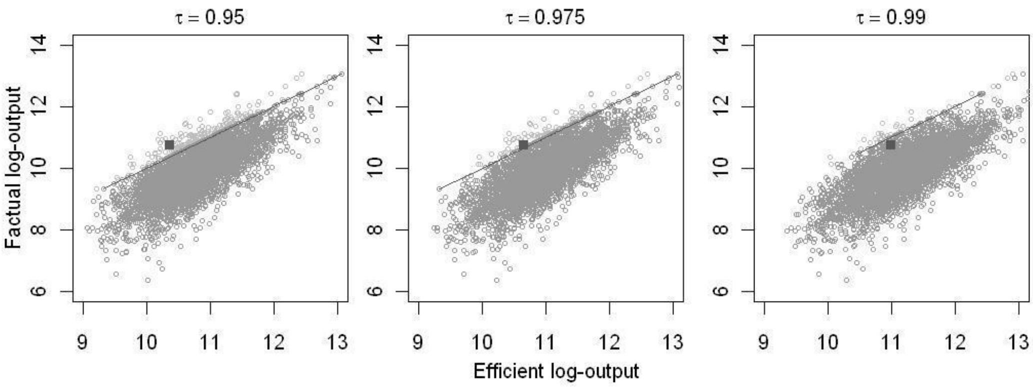

Figure 2. Estimated efficiency frontiers for different τ

3. QUANTILE FRONTIER MODEL AND EFFICIENCY SCORES

As $\tau = 0.975$ has been chosen for defining the benchmark farms, the estimated elasticities for the quantile regression model appear in Table 2. For reasons of comparison, a maximum likelihood estimator (MLE) is also performed using equation (5) for the SFA, presuming that u is composed of a two-sided stochastic term that accounts for statistical noise and a nonnegative term representing the inefficiency component[3].

Using quantile regression, the statistical significance of input coefficients are consistent with the results found using the stochastic frontier approach. The estimations for capital and land are very similar, though only the former appears to be statistically significant. Labor elasticity exceeds the remaining in both cases, whereas the estimated coefficient for intermediates is much lower in the quantile regression. This result can be attributed to a possible difficulty of SFA to capture the different impact that these inputs exhibit on different points of the output distribution, implying possible different technological relations. This is also in accordance with the coefficient-by-coefficient Khmaladge test, which showed significant difference for the labor and intermediates' coefficients among

[3] That is: $u_i = \varepsilon_i + v_i$, where $\varepsilon_i \overset{iid}{\sim} N\left(0, \sigma_\varepsilon^2\right)$ and $v_i \overset{iid}{\sim} N^+\left(0, \sigma_v^2\right)$.

quantiles. Finally, the elasticities add up to 1.03 and 1.1 for the quantile regression and SFA. That is, the returns to scale for agriculture in Greece are just greater than constant.

Table 2. Estimates of production frontier models

	Quantile regression ($\tau = 0.975$)			SFA		
	Estimate	Std. error	p-value	Estimate	Std. error	p-value
Capital (x_{1i})	0.194	0.033	0.000	0.193	0.013	0.000
Labor (x_{2i})	0.563	0.047	0.000	0.482	0.015	0.000
Land (x_{3i})	0.013	0.042	0.762	0.013	0.009	0.133
Intermediates (x_{4i})	0.263	0.032	0.000	0.413	0.011	0.000
Intercept	1.984	0.461	0.000	0.480	0.171	0.004

Comparing efficiency estimates in Table 3, the average efficiency score in the quantile regression model is 90.4%, higher than the one obtained in the stochastic frontier model that is 71.4%. The correlation of efficiency scores obtained from the different approaches is also examined. The Spearman's Rho nonparametric rank statistic show high correlation coefficient between the efficiency scores obtained, i.e. 0.94 (p = 0.000). Both methods are therefore in accord when scoring (in)efficiency of individual farms in the sample.

Table 3. Efficiency scores

	Mean	Median	SD	Min	Max
SFA	0.789	0.795	0.052	0.462	0.902
Quantile regression	0.904	0.908	0.051	0.623	1.000

The D'Agostino *et al.* (1990) normality test is, finally, used to show statistically (at the 1% level of significance) that the distribution of the efficiency scores obtained by SFA are negatively skewed and kurtic (i.e. -21.721 and 14.828, respectively). These results suggest that the distribution of the dependent variable significantly departs from normality implying considerable heterogeneity and thus justifying the use of quantile regression. This also becomes apparent by the results of the normality test on the efficiency scores obtained by the estimation of the production frontier via quantile regression. Both skewness and kustosis were found much lower (i.e. -15.363 and 7.661, respectively), though there still exists some deviation from normality, allowing the use of quantile regression approach in the second stage of the analysis (Figure 3).

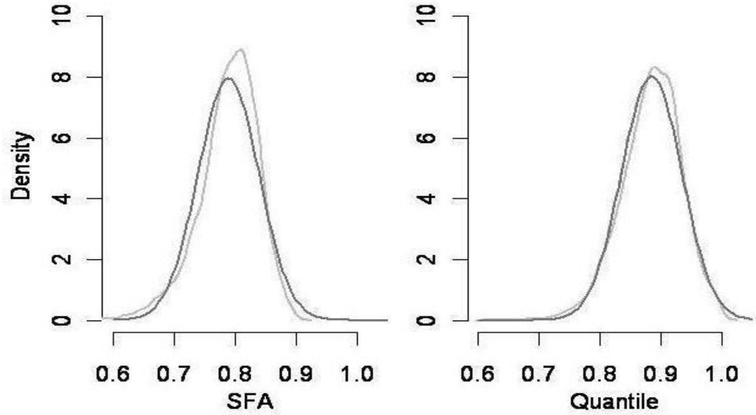

Figure 3. Efficiency scores distributions

4. QUANTILE REGRESSION ESTIMATES

The efficiency scores obtained in the first stage are now regressed using a number of covariates suggested in the literature. Government policies are distinguished between Decoupled payments, Rural development payments and Other payments, and they are expressed as the share of each category in the total farm revenue. The Farm size is measured by a dummy derived from each farmer's European Size Unit (ESU). Nine different economic size classes are essentially used based on the classification provided by FADN. Two variables are included regarding the technology employed. The capital to labor ratio is used as a first proxy of farm Technology, whereas the ratio of Unpaid labor hours to total farm labor hours indicates the workforce composition. Financial information concerning each farm is also included using the share of Owned land in the total land operated. To capture differences in farming practices among farms producing different types of output, a binary variable that equals one is introduced if a farm is producing mainly livestock and zero otherwise (Specialization). The Age of the farm's operator, as well as regional dummies are included.

Given the fact that the distribution of the efficiency scores departs from normality, quantile regression is also employed in the second stage. The empirical results are shown in Table 4, where the 0.10, 0.25, 0.50, 0.75 and 0.90 quantiles are reported. In addition, OLS estimates showing the mean effects of all covariates are presented. To ensure an adequate coverage of the confidence intervals, 2 000 replications were performed for the regression quantiles. The numbers in parentheses are therefore the bootstrapped standard errors computed to measure the precision of the efficiency estimation.

Significant differences are observed among the selected quantiles. In particular, the negative impact of government support on farm efficiency indicates that the motivation for improving farms' performance is lower when they are supported by government policies. The marginal effect of subsidies depends on the agricultural schemes implemented under the first- and second- pillar of CAP, as well as on the different levels of farm efficiency scores.

More specifically, as shown in Figure 4, where each of the plots gives information about the relevant covariate for government support at any chosen quantile, the question that can be answered is how different is the impact of the corresponding variable on farm efficiency, given a specification of all other conditioning factors. For decoupled payments, the OLS estimate shows that efficiency declines by 17.6 percent. That is, an increase of 1 percent of subsidies contribution related to the first-pillar of the Common Agricultural Policy (CAP) to farmers' income leads to a decrease of 17.6 percent in efficiency. However, the quantile regression estimates show higher losses in efficiency for the lower tail of the distribution, where farms are less productive, while in the upper tail, where farmers are more efficient, the reduction in efficiency is relatively smaller. That is, a reduction in efficiency by 15.7 percent at the 0.90 quantile up to 18.9 percent at the 0.05 quantile. The conventional least squares confidence interval does then a poor job of representing this range of disparity.

The opposite effect is observed when considering other government payments. The mean estimate is negative and close to the coefficient obtained at the 0.50 quantile, remaining statistically significant. The impact of this scheme of government support though varies considerably among the selected quantiles, while its magnitude rises by more than 50 percent when comparing the lower and upper tails of the distribution. In terms of the rural development payments, it appears that government support related to the second-pillar of the CAP affects in a rather similar manner farms' performance independently of their efficiency level. In particular, the negative impact on farm efficiency is about 11 to 14 percentage points at all quantiles, with the exception of the estimations obtained at the higher quantiles.

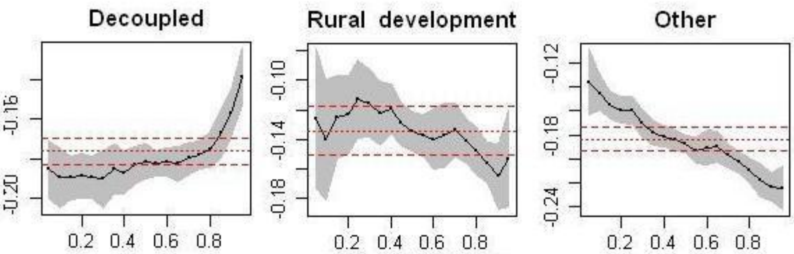

Figure 4. OLS and Quantile regression estimates for government support

Farm size has a positive impact on farm efficiency since it increases efficiency, though different quantiles show a disparity from 1.8 percent at the 0.10 quantile to 1.2 percent at the 0.90 quantile, implying that as a farm becomes larger, it looses efficiency. The OLS estimates show an increase in mean efficiency by 1.4 percent. Moreover, the technology variable appears to affect farm efficiency uniformly, though at a rather small rate, remaining statistically significant for all quantiles. In addition, farms renting land may be more efficient relative to farms that own the operated land, especially for the very efficient farms, as the relevant coefficient is statistically significant and negative. Direct costs of land rentals create then stronger incentives to work the land in a more efficient manner relative to the opportunity costs borne by owned land.

Specialization seems to be significant only for the less efficient part of the efficiency distribution, where it has a positive impact that fades as farmers become more efficient. Interpreting the results, livestock producers are increasing their efficiency relative to crop producers from 1 percent to 0.3 percent up to the median quantile, while specialization does not matter when farmers are more efficient. The estimated coefficients for the regional dummies indicate that efficiency is higher in all three regions in comparison with the reference region, which is Sterea Ellada-Nissoi Egaiou-Kriti, with the exception of the upper tale of the efficiency distribution.

Table 4. Empirical results

	OLS estimates	Quantile regression estimates 0.10	0.25	0.50	0.75	0.90
Decoupled payments	-0.176 (0.004)***	-0.189 (0.009)***	-0.189 (0.005)***	-0.181 (0.004)***	-0.178 (0.004)***	-0.157 (0.006)***
Rural development payments	-0.134 (0.010)***	-0.140 (0.018)***	-0.113 (0.012)***	-0.135 (0.010)***	-0.141 (0.0125)***	-0.165 (0.015)***
Other payments	-0.184 (0.006)***	-0.145 (0.013)***	-0.159 (0.008)***	-0.188 (0.006)***	-0.203 (0.006)***	-0.224 (0.008)***
Farm size	0.014 (0.001)***	0.018 (0.001)***	0.014 (0.001)***	0.012 (0.001)***	0.013 (0.001)***	0.012 (0.001)***
Technology	0.0002 (0.000)***	0.0002 (0.000)***	0.0003 (0.000)***	0.0003 (0.000)***	0.0003 (0.000)***	0.0002 (0.000)***
Owned land	-0.031 (0.002)***	-0.030 (0.004)***	-0.032 (0.002)***	-0.031 (0.002)***	-0.035 (0.0023)***	-0.038 (0.003)***
Specialization	0.0039 (0.002)***	0.010 (0.003)***	0.007 (0.002)***	0.003 (0.002)*	-0.000 (0.002)	-0.004 (0.002)
Region 1	0.008 (0.002)***	0.018 (0.003)***	0.011 (0.002)***	0.009 (0.002)***	0.003 (0.002)**	-0.006 (0.0023)***
Region 2	0.007 (0.002)***	0.008 (0.003)**	0.007 (0.002)***	0.007 (0.002)***	0.010 (0.002)***	0.010 (0.002)***
Region 3	0.008 (0.002)***	0.015 (0.004)***	0.009 (0.003)**	0.008 (0.002)***	0.004 (0.002)*	-0.005 (0.003)
Intercept	0.914 (0.006)***	0.837 (0.011)***	0.893 (0.007)***	0.921 (0.006)***	0.941 (0.0067)***	0.970 (0.0081)***

The estimates of farmers' age and unpaid labor are not reported as they do not appear to affect significantly efficiency.

Region 1 refers to *Macedonia–Thrace*; Region 2 is *Ipiros–Peloponnisos–Nissoi Ioniou*; Region 3 represents *Thessalia*, and Region 4 denotes *Sterea Ellada–Nissoi Egaiou–Kriti*.

Values in the parentheses are Standard Errors. Significance levels: 0.01***, 0.05**, 0.1*.

The pure location shift and the location-scale shift hypothesis were, finally, performed in the second stage as well to test the null hypothesis that all the conditional quantile functions have the same slope parameters. Both tests were rejected (with values 221.54 and 343.39, respectively). The effects of the coefficient-by-coefficient tests were also tested and showed significance for the explanatory variables of interest.

5. CONCLUSIONS

This article is a first attempt to employ regression quantiles as a potential alternative approach to estimate efficiency scores in agriculture. The proposed approach overcomes the potential problem that arises when estimating a stochastic production frontier model using maximum likelihood, as strong distributional assumptions must be imposed on each error component, especially with cross-sectional data. Regression quantile does not require the imposition of any distributional assumption of the inefficiency term. As a result, robust farm efficiency estimates are provided. An additional advantage arises from the examination of the impact that a set of covariates might have at different efficiency levels, providing new valuable information to policy makers, which could not be retrieved from SFA.

The application was conducted by examining efficiency in Greek agriculture using farm level data for 2007. In the first stage, production frontiers are estimated by the methods of quantile regression and SFA, while in the second stage, these scores are regressed over a set of covariates at different points of the conditional efficiency distribution. Empirical results suggest that the sector is characterized by almost constant returns to scale, while the average efficiency obtained using SFA is about 79 percent. The efficiency scores obtained from the quantile regression frontier estimation are though higher (90 percent). The SFA leads then to an overestimation of inefficiency, since the employed MLE-estimation is based on the conditional mean estimations, which does not take into account differences in production technology used in different segments of the output distribution. Furthermore, it appears that the distribution of efficiency scores is closer to normality when employing regression quantiles.

Factors that affect efficiency are also examined using quantile regressions to capture the remaining deviance from normality. The results suggest that government support aimed at enhancing farms viability should be directed towards payments decoupled from output or prices, as well as rural development payments that affect efficiency in a uniform way. It further appears that small farms are relatively more efficient than their counterparts, probably due to their flexibility to adjust easier in a continuously changing environment. Farms location, specialization and land ownership are also statistically significant determinants of efficiency. Less successful is the variable measuring farmers' age and workforce decomposition.

Overall, a semi-parametric estimator of the efficient frontier is employed, based on conditional quantiles of an appropriate distribution associated with the production process. This line of research generates further discussion on the issue of the appropriate methodology for the estimation of efficiency, as well as on the effect of various covariates that should be estimated at different points of the conditional efficiency distribution rather than just only the mean. The proposed methodology essentially provides better estimates of the production frontier function, leading to robust farm efficiency scores that can be used as more accurate regressors in the second stage to examine the relevant (policy) questions.

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