Farm size and productivity in Algerian agriculture: A contingent relationship

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Abstract

The purpose of this paper is to analyze the relationship between farm size and farm performance in Algeria. Unlike most previous studies, this preliminary study uses a large dataset comprising 26 735 farmers in Biskra region. Two farming sectors are considered, namely: date palm sector (typically a traditional farming sector) and greenhouse vegetables sector (relatively a modernizing sector) as dominant activities, to the extent that they represent both 74% of the irrigated farmland in Biskra. The study employs two farm performance measures, farmland productivity (farm output per hectare) and land use intensity. A bivariate non-parametric regression (Nadaraya-Watson approach) and multivariate quantile regression are used to assess the IR in two farming sectors. The main findings show that the IR holds for a traditional agriculture and does not in a modernizing one. Then, when it holds, it follows a systematically monotonic smooth pattern, whereas in a highly input-intense modern sector, the relationship becomes, in the best cases, blurry. The consideration of the nature of the used technology in the underlying sector (i.e., its stage of development) is of crucial importance as a contingency factor in analyzing the IR for any farming system ignored in most studies.

***Keywords**: Inverse relationship, Farm size, Land productivity, Farm performance, Farming system, Algeria.*

1. Introduction

The inverse relationship (IR) between farm size and productivity has long been of an increasing interest and a controversial issue among development and agricultural economists. Particularly in developing countries, the extent to which small farms use resources efficiently is particularly relevant for African countries that seek to modernize their agricultural sector and make the transition from a subsistence-based to a market-driven rural economy (Ali & Deininger, 2015). However, the relationship between farm size and agricultural performance is not clear-cut in developing economies (Verma & Bromley, 1987; Garzón Delvaux *et al.*, 2020a). Boussard (2014) nicely formulated this inference by stating that a large dimension of a farm is not the guarantee of high productivity. Due to its complexity, it seems that the empirical literature has failed to reach a consensus (Fan & Chan-Kang, 2005; Gollin, 2019).

The relationship between farm size and farm performance has been the subject of many empirical tests in large range of countries around the world. In Algeria, Africa's most large country with an agricultural vocation *par excellence*, fragmented farmland plots and small-farm sizes are typical farming units, and should be considered as a key issue by public policy-makers.

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Small-scale farming is considered as one of key leverage for Algeria's public policy to enhance and promote sustainability and higher performance of the agricultural sector since two decades. Diagnosing scale economies and size effects on the performance in Algeria is an urgent requirement for any meaningful policy analysis. Practically, it seems that no study has addressed this issue for Algerian context.

However, an understanding the IR may be important for guiding decision-making among policymakers and investment decisions within the private sector (Omotilewa *et al.*, 2020). Accordingly, as a preliminary analysis for Algerian agriculture, this paper has the advantage of accounting a very large range of farms (26 735 farmers) in one of the agricultural centers in the country, namely Biskra region. This may produce more robust and decisive results different from prior studies that have typically used to employ relatively different sampling methods and household survey data. Hence, one aspect is highlighted to explain the shape of the IR in the region, namely: the stage of development of the studied farm sector.

The date palm sector (typically a traditional farming sector) and the greenhouse vegetables sector (relatively a modernizing sector) are both considered in this study. The date palm farming is considered as a dominant activity in Biskra region, not only for now, but also as ancient economic activity for local farmers. Nowadays, the date palm activity represents 71.6% of the total irrigated farmland in Biskra region (according to statistics of MADR, 2020). It is a typical traditional farming activity, and have a considerable contribution to the national economy and an increasing trend for date exports due to high standards of dates quality (Cheriet & Benziouche, 2012; Benmehaia, 2019).

On the other hand, greenhouse vegetables farming is relatively a new activity, which has been launched and successfully expanded since 2000. As the study of Daoudi & Lejars (2016) asserts, Biskra is one of those regions where Saharan neo-agriculture (as opposed to traditional oasis agriculture) has experienced remarkable development of greenhouse vegetable crops, which have developed in this region by bringing new breath to Saharan agriculture. However, this greenhouse production sector includes today 48 254 greenhouses in Biskra (according to MADR, 2020). The greenhouse farming largely is known for its intensive use of different inputs (fertilizers, pesticides, irrigation technologies, seeds, etc.). This farming activity is considered as a modernizing sector in Biskra region, to the extent that it is in its earliest stages of development within changing nature of greenhouse production technologies.

The difference between the two sectors is flagrant for any observer in terms of the state of arts and the managerial skills. This is why this aspect is essential in the explanation of any structural feature of the agricultural sector of any region.

The study employs two farm performance measures, namely: farmland productivity (physical output yields) and land use intensity. A bivariate Nadaraya-Watson non-parametric regression and multivariate quantile regression models are used to assess the IR in two farming sectors. To the extent that the IR may not be considered universal for any crop or at any time (Garzón Delvaux *et al.*, 2020b), this study hypothesizes and confirms that the IR holds for a traditional agriculture and does not in a modernizing one. When it holds, it follows a systematically monotonic smooth pattern, whereas in a highly input-intense modern sector, the relationship is, in the best cases, blurry.

The rest of the paper is organized as follows. Section 2 presents a brief literature review on the IR, while the research methodology (data and the estimation strategy) is presented in section 3. The study findings are outlined and discussed in section 4 and the paper concludes with section 5 drawing out some policy implications.

2. The inverse relationship: A brief story of "*the small and the beautiful*"

It is not the aim here to review all studies on the IR, even partially, to the extent that it is a difficult task due to the abundant literature. As the section's title suggests, a brief sketch is done in order to give the big picture of the IR, and stressing some current issues.

"Small is beautiful" is an expression that agricultural economists use to refer to a regularity often observed empirically in the context of agriculture (and elsewhere in certain economic activities). It can be summed up as follows: a small farm is generally more productive (or efficient). It was more often attributed high levels of performance (whatever measured). This debate began with the observation of Chayanov (1925, 1927) in the context of Soviet agriculture. Then, the observation becomes a well-established stylized fact through studies such as those of Sen (1962, 1966), Schultz (1964), Srinivasan (1972) and Bardhan (1973) in the context of Indian agriculture. Since then, the literature has become abundant on this subject in an attempt to examine this aspect deeply, whether on a theoretical or empirical level. The literature has advanced some hypotheses in order to explain this fascinating phenomenon, of which the monumental study of Berry & Cline (1979) testifies to the extent of this size-productivity relationship.

The hypothesis that persists until these days, systematically showing its relevance *par excellence*, is the hypothesis of labor market imperfection, or labor-based explanation: the cost of labor to family-based farms is lower than the cost of labor to wage-based farms (Sen, 1964). Along with this explanation, many others have been highlighted such as: soil fertility (Kimhi, 2006; Chen *et al.*, 2011; Barrett *et al.*, 2010), management ability (Assunção & Ghatak, 2003), technique (Gautam & Ahmed, 2019), risks, etc. However, the relationship was assumed to be linear, modeled by a simple linear regression model. Nonetheless, more recent studies have shown that the relationship may exhibit nonlinearities, or it is not even monotonous in some cases.

Presently, the real challenge for agricultural economists is the issue of the statistical estimation of the size-productivity relationship, while the explanation is exhausted by a large array of hypotheses that are appropriately and constantly tested. The shape and pace of this relationship become the cornerstone of this problem. Moreover, some went beyond that and started to question the very existence of this relationship, and contemplate the fact that it is just an artifact. As stated by Carletto *et al.* (2013), a substantial part of the debate, particularly in recent years, has focused on whether the IR may be a statistical artifact, stemming from problems with the available data. One of the current issues on the IR matter seems to be re-questioning the error measurements and accuracy in variables.

Unfortunately, the story, of the relationship between farm size and productivity, has not come to a happy ending, i.e. definitive empirically well-established confirmation. According to recent relatively comprehensive reviews of the literature on the IR, the show goes on and the image becomes ever hazier. In technical words, from a briefing on recent reviews (Garzón Delvaux *et al.*, 2020a; Garzón Delvaux *et al.*, 2020b; Gollin, 2019; Scandizzo & Savastano, 2017), the relationship could be judged as contingent. The major factor of contingency, still neglected and to be highlighted here, is the nature of the used technology at farm- or local-level (which reflects the stage of development of the studied farm sector).

Some scholars maintain that the IR subsists only in traditional agriculture, as a characteristic attribute. Deolalikar (1981) affirmed that the inverse relationship is true only of a traditional agriculture, and that it breaks down with technical progress. While Flinn & Buttel (1980) highlighted the idea that the social consequences of increased scale and mechanization in agricultural production are, of course, exceedingly complex, (a) changes in the socioeconomic characteristics of farm personnel, and (b) changes in the characteristics, especially population size and employment levels, of rural communities. Meanwhile, it seems that researchers on this matter do not consider (or accentuate) this aspect in their conceptual frameworks. Ignoring this contingency factor may lead to a serious prejudice in the conclusions on the shape of the IR whatever the context.

What is certain is that there is no single economically optimal agrarian structure; rather, it appears to evolve with the stage of economic development (Rada & Fuglie, 2019). As the study of Garzón Delvaux *et al.* (2020a) confirms, the IR cannot be taken for granted because of empirical complexities in accurately assessing it and evidence that such a relationship depends on the performance indicator analyzed and may not necessarily be systematic, continuous, stable through time, irreversible or universal.

3. Research methodology

Data sources

The source of data in this study is the "Comprehensive Regional Survey" of Biskra region relating to the year 2018-19, collected on the behalf of the Algerian Ministry of Agriculture and Rural Development (MADR, 2020), by the Division of Agricultural Services and the collaboration of the Regional Chamber of Agriculture in Biskra (Algeria). The dataset comprises 26 735 farmers. The data includes two main farming systems of the region, namely: date palm sector (with 21 502 producers) and greenhouse vegetables sector (with 5 233 producers). The cross-sectional data used covers all the 33 communes (districts) of the region. It is noteworthy to stress that Biskra region have a significant contribution in terms of agricultural production at national level for some crop and livestock products. Moreover, it is a semi-arid pastoral zone with a vocation in agriculture. It is considered as an agricultural pole at the national level, about a third of domestic production in 2018. However, at some extent, the dataset could be representative at national level, while incontestably, it is broadly representative for the two farming systems in the country.

Dependent and explanatory variables

This study utilizes two independent variables, namely: Yield (*Y*) and Land Use Intensity (*LUI*). This choice is highly constrained by the available measures in the used dataset. Nevertheless, many other proposed variables would be more relevant for this matter, such as the net output per acre, total factor productivity, technical efficiency, as recommended by Muyanga & Jayne (2019), Rada & Fuglie (2019), Ferreira & Féres (2020) and Helfand & Taylor (2021). Nevertheless, each measure may have its own advantages and inconveniences. The yield measure, computed as the gross value of output per hectare, is a good proxy for the land productivity and is considered as the standard measure in the *IR* study (Muyanga & Jayne, 2019). While the land use intensity, measured as the ratio of cropped land on the total farmland holding, is a well-established proxy for the intensity of land use, meanwhile, it should be noticed that an ideal definition of land use intensity would go beyond the special aspect to include cultivation practices, use of fertilizers, etc. (Sampath, 1992).

In the data subset concerning the dates production sector, this study uses as explanatory variables the available information about structural and socioeconomic characteristics of farms, namely: farm size (operational cropped land in hectares), irrigated land (effectively irrigated plots in hectares), a multinomial variable for different irrigation systems used for each farm, a dummy variable for farmer specialization in dates production, and a locational dummy for the 33 communes. The socioeconomic aspect is reflected by farmers' age and his farming experience (both in years), which are considered as good proxies for farmers' human capital (Bojnec & Fertő, 2021). For the data subset on greenhouse vegetables production sector, due to the available information in the database, the study uses only 4 explanatory variables previously mentioned, namely: farm size, as a mandatory variable for the IR study, in addition of the irrigation system dummy, farmers' age and the locational dummy.

Estimation procedure

The analysis in this study is based on the neoclassical production function approach for the cross-sectional data form. The function relates the farm output to some inputs involved in the production. Its general form is:

$$Q_i = f(X_{ij})$$

where Q_i stands for the output for farm *i* (namely: productivity, income, net value, etc.) and X_{ij} for matrix vector reflecting the used input *j* in farm *i*. For the purpose of this study, the full empirical models to be estimated are specified as:

$$Y_i = \alpha_1 + \beta_1 S_i + \gamma_1 Z_i + \varepsilon_{i1} \quad [1]$$

$$LUI_i = \alpha_2 + \beta_2 S_i + \gamma_2 Z_i + \varepsilon_{i2} \quad [2]$$

where Y_i and LUI_i represent the Yield and Land Use Intensity respectively, S_i is the farm size measure for each farm, Z_i is a vector of explanatory variables set. The variables are used in levels which provides the most straightforward test of the relationship between farm size and productivity (Muyanga & Jayne, 2019). The main purpose of the estimation strategy is to find out the statistical signification and the sign of β_i coefficients for both farming systems.

Before the final estimation procedure, many regressions were run to explore the relevance of the IR in this modeling approach (specifically: ordinary least squares regression, heteroskedasticity-corrected linear model, and some instrumental regression methods) on the whole dataset for each farming system. It was found that the IR holds anyway, with high statistical significance. This would be misleading for many reasons: the systematic divergence between small and large farm scale (Savastano & Scandizzo, 2017; Scandizzo & Savastano, 2017; Feder, 1985; Cornia, 1985), the distribution of conditional mean of the independent variables, normality and non-linearity aspects in regression assumptions. Some of these inconveniencies can be demonstrated by the Kernel density estimation of the two independent variables for both underlying farming systems.

Figures 1 and 2 display the Kernel density of the dependent variables for dates and greenhouse vegetables sectors respectively. Both measures exhibit some anomalies with reference to typical regression assumptions mainly the apparent bimodality and the positive skewness along the whole distribution. Besides, none of the conditional distributions appears to be Gaussian (i.e., convergence by central limit theorem). Moreo-

Figure 1 - Kernel density estimates for dates production.

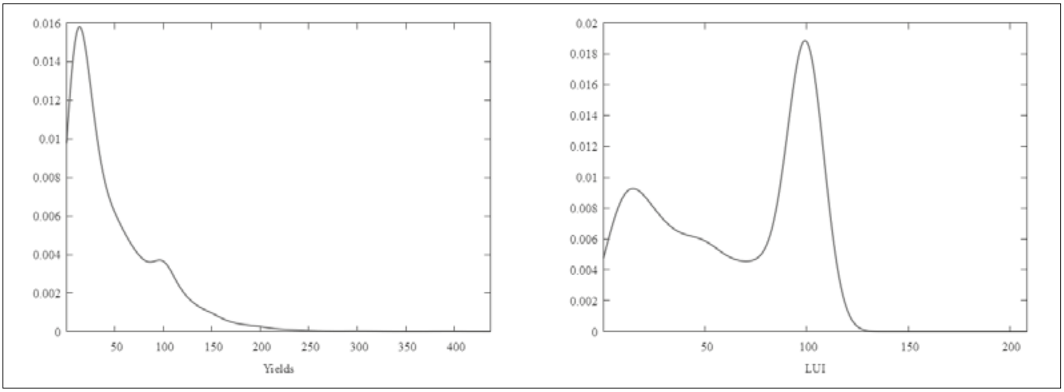
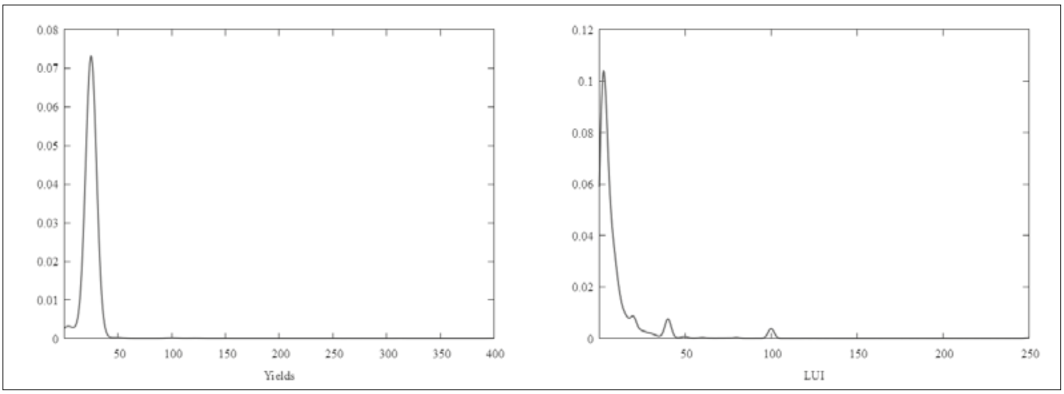


Figure 2 - Kernel density estimates in greenhouse vegetables production.



ver, when a bivariate non-parametric regression is to be run (using Nadaraya-Watson approach)[1] between the used independent variables and the farm size variable, the estimation results should exhibit the systematic (or at least contingent) effects for different ranges of farm size scales.

For these reasons, it seems more appropriate to estimate equations [1] and [2] by the Quantile Regression Model.[2] This econometric approach seems to relevant and robust in the IR studies and recently used by Omotilewa *et al.* (2020), Savastano & Scandizzo (2017), Scandizzo & Savastano (2017), Ramoneda & Pene (2017), Evenson & Mwabu (2001).

4. Results and discussion

Tables 1 and 2 show the main characteristics of farms in both underlying farming systems. The first, Table 1, displays the descriptive statistics of variables used for dates production, and Table 2 for the descriptive statistics in greenhouse vegetables production.

For dates production sector, small farms are less than 2 ha, medium farms scale is between 2 and 10 ha, large scale is to be more than 10 ha. Whereas, in a highly input-intensive farming sector such as in relatively modernizing farming systems, farmland area is not the critical factor for scale. However, in this case specifically, the number of greenhouses (GH) is more relevant and informative. By doing so, the small scale is for farms having 3 or less greenhouses, medium scale is between 4 and 9 greenhouses and large farms scale is to have more than 10 greenhouses. This classification takes into consideration the common regional farming patterns specificities.

The last column for both tables represents the full dataset. Records in this column seems to be less informative and non-relevant for the IR subject due to large range of the sample. Records in the three scale categories are more instructive.

For dates production sector, small, medium and large scales represent 33.7%, 52.6% and 13.6% respectively, which imply that the medium farm size is the dominant scale in this sector, having in average 5.8 ha for the size, 3.2 ha as irrigated area, 64% of them are specialized in dates production. Small farms, by having an average size of 1.3 ha, are more likely irrigated (1 ha), and more strictly committed and specialized (85%), while large farms have in average 22 ha as farm size mean, with largely less irrigated area (about 10 ha) and they are less specialized (53%). Age and experience do not exhibit any significant differences in terms of the underlying scales. For greenhouse vegetables production sector, it seems that the three scale categories are uniformly distributed (28.8%, 34.8% and 36.3% for small, medium and large farms respectively). The farm size and farmers' age do not seem to exhibit any significant differences in terms of the underlying scales.

In terms of the used independent variables, some empirical regularities could be highlighted. For dates production sector, the IR is obviously remarkable. Small scale has higher performances in terms of yields (80 Qx/ha) and land use intensity (about 77%). Medium scale is associated with intermediate performances (32 Qx/ha for yields and 58% for the *LUI*). The large-scale farms present lower performances (17 Qx/ha for yields and 45% for the *LUI*). What makes this blatant regularity unintelligible is their respective variabilities in terms of standard deviations.

For greenhouse vegetables production sector, the picture is ambiguous from the beginning. At the first sight, it seems that the inference exhibits a reverse relationship rather than an IR, i.e., a positive relationship. More specifically, for both independent variables, small-scale farms are associated with low performances, and larger ones with higher performances. Once again, the variability of the underlying records cannot lead to any inference or interpretation ambiguous.

[1] Developed initially by Nadaraya (1964) and Watson (1964), it is one of the nonparametric regression techniques known to estimate a locally weighted average in order to find a nonlinear relationship between a pair of random variables. See Härdle & Linton (1994) for further details of the Nadaraya-Watson nonparametric regression.

[2] Quantile regression model estimates the conditional quantiles of the independent variable. It is one of the alternatives of the linear regression used when the assumptions of the linear regression are violated. See Koenker *et al.* (2017) for further details of the Quantile regression model.

Table 1 - Descriptive statistics of variables used for dates production.

	Small Scale	*Medium Scale*	*Large Scale*	*Full Dataset*
	ha ≤ 2	*2 < ha ≤ 10*	*ha > 10*	
Sample size	7 259	11 317	2 926	21 502
Percentage	33.76%	52.63%	13.61%	100%
Dependent variables				
Y	80.39 (52.24)	32.23 (33.34)	17.44 (21.98)	46.47 (46.47)
LUI	76.75 (29.02)	58.55 (37.67)	45.19 (35.86)	62.88 (36.38)
Independent variables				
Farm size	1.35 (0.53)	5.83 (2.55)	22.88 (23.91)	6.64 (11.27)
Irrigated land	1.03 (0.54)	3.27 (2.65)	9.97 (14.42)	3.42 (6.31)
Specialization	0.85 (0.35)	0.64 (0.48)	0.53 (0.50)	0.70 (0.46)
Age	57.50 (16.12)	56.96 (15.84)	56.18 (15.86)	57.04 (15.94)
Experience	14.66 (4.81)	14.81 (4.29)	14.95 (4.85)	14.78 (4.55)

Note: Values in parentheses represent the standard deviation.

Table 2 - Descriptive statistics for variables used for greenhouse vegetables production.

	Small Scale	*Medium Scale*	*Large Scale*	*Full Dataset*
	GH ≤ 3	*4 < GH ≤ 9*	*GH > 10*	
Sample size	1 509	1 821	1 903	5 233
Percentage	28.83%	34.80%	36.37%	100%
Dependent variables				
Y	21.98 (7.74)	24.82 (3.26)	27.59 (24.46)	25.01 (15.60)
LUI	9.95 (41.48)	6.63 (14.35)	14.70 (22.13)	10.52 (27.52)
Independent variables				
Farm size	0.26 (1.01)	0.27 (0.97)	0.75 (1.32)	0.44 (1.15)
Age	49.77 (16.72)	52.56 (16.75)	50.01 (15.78)	50.83 (16.44)

Note: Values in parentheses represent the standard deviation.

A much clearer picture of the relationship between farm size and farm performances (yield and land use intensity) emerges when examining the relationship by running a Nadaraya-Watson non-parametric regression. The variables are used here in logarithms (not in levels) in order to better fit with data and to alleviate the weights of outliers.

Figure 3 displays the resulted regression fit for performance measures for dates production sector (yields in panel A and *LUI* in panel B). The IR is noticeably observed in which both measures decline with farm size for all ranges. This is the well-established IR results found by most studies on the matter. For this dataset, the

Figure 3 - Nadaraya-Watson non-parametric regression results for performance measures in palm dates production.

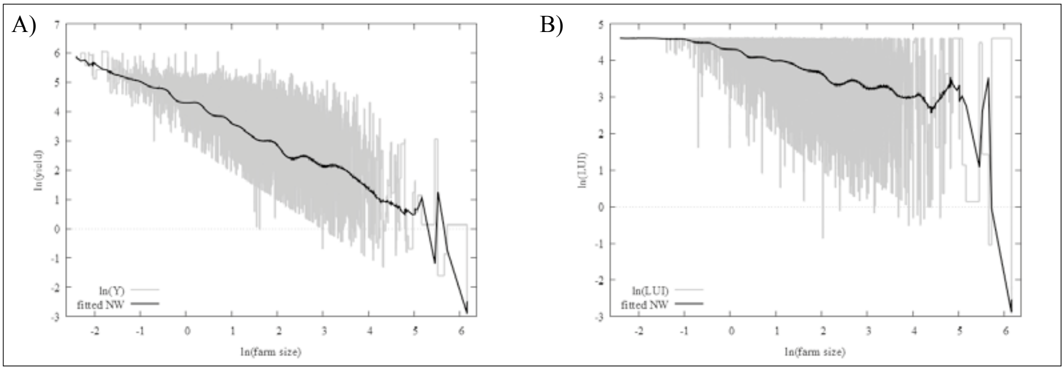
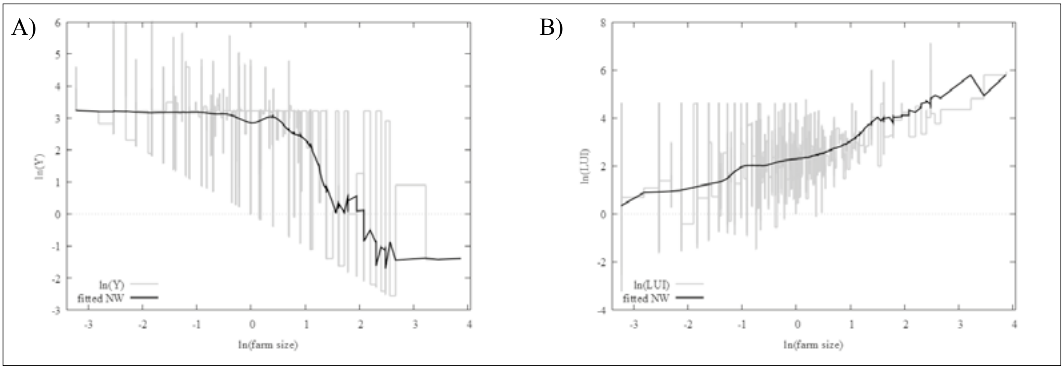


Figure 4 - Nadaraya-Watson non-parametric regression results for performance measures in greenhouse vegetables production.



relationship between farm size and yields (or land use intensity) is relatively steep and downwarding. Figure 4 presents the same procedure results for greenhouse vegetables production sector (yields in panel C and *LUI* in panel D). It is remarkable that the relationship is slightly positive for *LUI* measure (panel D), whereas for yield measure, it is quite neural (no clear effect) for small scale (less than 2 GH), and it becomes more ambiguous for other ranges (without a smooth fit). However, for both farming systems, it is possible that other structural or socioeconomic effects may have an influence on these bivariate relationships; hence, multivariate analysis is required.

Tables 3 and 4 summarize the results of the quantile regressions for the two underlying farming systems. Table 3 represents results of cross section quantile regression of the IR in dates production, and Table 4 for greenhouse vegetables production.

The different types of regressions, whether in the pre-processing of the data or those that are actually reported, always present a high level of robustness and overall significance (by adjusted R^2 and F-tests). The coefficients of the explanatory variables (other than farm size) are generally significant throughout the deciles examined. Their detailed interpretation is of no interest here since their inclusion is only to eliminate their effects in the regression.

The variable of interest here is the farm size for both performance measures (*Y* and *LUI*). The most striking result is that the coefficients of this variable are highly significant with negative magnitudes, and this is for all deciles in the dates sector (Table 3), without any exceptions. This provides an evidence that the IR holds for this sector. While in the greenhouse vegetables sector, this variable shows negative and statistically significant values up to the third decile ($Q_{0.3}$). Beyond that, the magnitudes become

Table 3 - Results of cross section quantile regression of the IR in dates production in Algeria (N = 21 502).

Variables	*Low performance*				*Median*	*High performance*			
	$Q_{0.1}$	$Q_{0.2}$	$Q_{0.3}$	$Q_{0.4}$	$Q_{0.5}$	$Q_{0.6}$	$Q_{0.7}$	$Q_{0.8}$	$Q_{0.9}$
Physical Yield (Y)									
Farm size	-0.87***	-1.04***	-1.12***	-1.25***	-1.43***	-1.47***	-1.56***	-1.52***	-1.12***
Irrigated land	-0.01*	0.01*	0.05***	0.29***	0.54***	0.77***	0.84***	0.75***	0.29***
Irrigation system	-0.06***	-0.04	-0.03	-0.07	0.05	0.16	-0.06	0.10	-0.15
Specialization	3.88***	7.11***	11.87***	17.39***	26.23***	33.82***	43.61***	54.81***	60.31***
Farmers' age	-0.01***	-0.009***	-0.009**	-0.02**	-0.02***	-0.04***	-0.04**	-0.01**	-0.01
Farmers' experience	0.13***	0.13***	0.14***	0.16***	0.19***	-0.0005	-0.18**	-0.53***	-1.95***
Communes	0.003	-0.009	-0.01*	-0.03**	-0.05***	-0.08***	-0.06***	-0.08***	-0.21***
Const.	11.82***	14.44***	16.18***	19.47***	23.04***	31.38***	41.07***	56.42***	95.88***
Land Use Intensity (LUI)									
Farm size	-2.83***	-4.13***	-4.63***	-5.50***	-5.58***	-5.03***	-4.30***	-3.03***	-1.81***
Irrigated land	4.94***	7.22***	8.24***	8.84***	8.19***	6.32***	4.63***	3.03***	1.82***
Irrigation system	0.05	-0.01	-0.14	-0.18*	-0.002	0.02	0.02	0.00004*	0.0003
Specialization	6.51***	9.85***	6.44***	7.09***	10.80***	11.96***	4.11***	0.0007***	0.02***
Farmers' age	-0.04***	-0.07***	-0.05***	-0.02**	-0.01	0.003	0.004***	0.0001***	0.002
Farmers' experience	0.51***	0.86***	0.77***	0.75***	0.97***	1.05***	0.30***	0.0004***	0.0009***
Communes	0.02*	0.03*	0.01	-0.01	-0.06**	-0.01	-0.006*	-0.0002***	-0.004
Const.	17.63***	25.24***	36.59***	46.94***	51.29***	62.61***	89.24***	99.99***	99.97***

*Note: Asterisks indicate the significance levels: *** for 1%; ** for 5% and * for 10%.*

Table 4 - Results of cross section quantile regression of the IR in greenhouse vegetables production in Algeria (N = 5 233).

Variables	*Low performance*				*Median*	*High performance*			
	$Q_{0.1}$	$Q_{0.2}$	$Q_{0.3}$	$Q_{0.4}$	$Q_{0.5}$	$Q_{0.6}$	$Q_{0.7}$	$Q_{0.8}$	$Q_{0.9}$
Physical Yield (Y)									
Farm size	-5.39***	-2.07***	-0.06***	-0.00002	-0.00002	-0.00002	-0.00002	-0.00003	-0.00004
Irrigation system	-0.042***	-0.016***	-0.0008***	-0.00009	-0.00006	-0.00001	-0.00001	-0.00002	-0.00008
Farmers' age	-0.002***	-0.0005***	0.000007*	0.000008	0.000003	0.000006	0.000008	0.00001	0.00008
Communes	-0.001***	-0.003***	-0.0001***	-0.00002	-0.00005	-0.00009	-0.00001	-0.00002	0.00003
Const.	25.58***	25.30***	25.01***	25.00*	25.00*	25.00*	25.00*	25.00**	25.00***
Land Use Intensity (LUI)									
Farm size	0.37***	0.53***	0.72***	0.80***	0.88***	0.95***	0.94***	0.90***	0.72***
Irrigation system	0.10***	0.09***	0.11***	0.12***	0.15***	0.15***	0.17***	0.17***	0.18***
Farmers' age	-0.008***	-0.008***	-0.008***	-0.009***	-0.009***	-0.008***	-0.010***	-0.011***	-0.012***
Communes	0.004**	0.01***	0.01***	0.01***	0.01***	0.02***	0.02***	0.02***	0.04***
Const.	0.23***	0.59***	0.79***	0.99***	1.13***	1.20***	1.53***	1.85***	2.32***

*Note: Asterisks indicate the significance levels: *** for 1%; ** for 5% and * for 10%.*

Figure 5 - Coefficient estimates of farm size in each quantile for dates production.

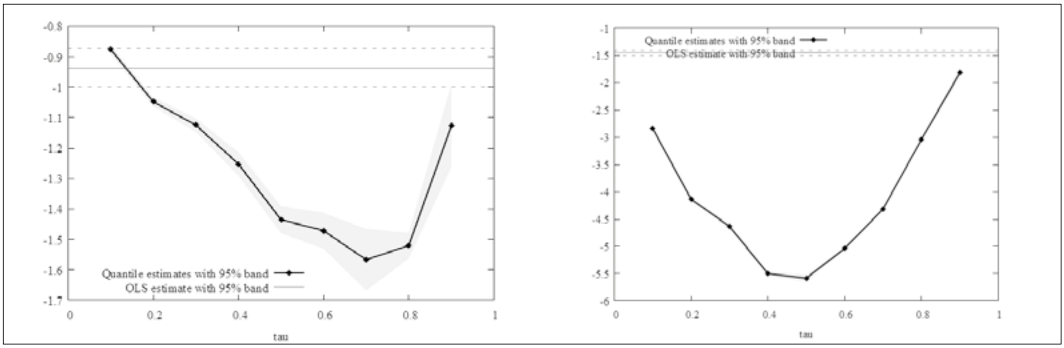
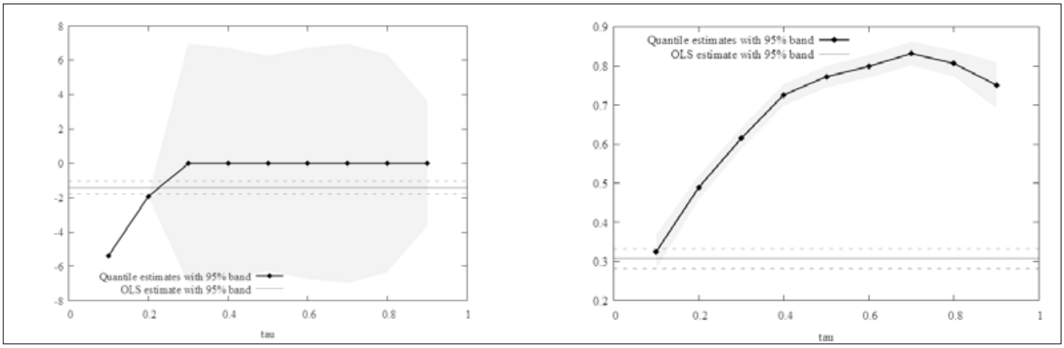


Figure 6 - Coefficient estimates of farm size in each quantile for greenhouse vegetables production.



almost zero along with their respective signification levels from the fourth decile (for the *Y* measure). Nevertheless, for the *LUI* measure, the coefficients keep a high level of significance but surprisingly with positive magnitudes.

A more in-depth examination of the farm size coefficients in both cases should lead to conclusive results on the shape of the relation. To do this, a post-estimation plot is made for the farm size coefficients estimated by the four quantiles regression models. Figures 5 and 6 show the results of such a procedure. Figure 5 displays the coefficient estimates of farm size in each quantile for dates production and Figure 6 for greenhouse vegetables production.

Concerning the dates sector, the effect of the farm size variable on yield (*Y*) has negative magnitudes for all deciles which evolve along the 10 deciles as follows: values are in descending order up to seventh decile ($Q_{0.7}$), i.e., at a maximum slope of –1.56, beyond this level the curve becomes less steep. For the effect of the farm size variable on the land use intensity (*LUI*), the curvature takes almost the same shape, except that here a kind of inflection point appears in the middle, i.e., at the median ($Q_{0.5}$), where the curve becomes less steep from the median with a maximum value of the coefficient at –5.58. However, the two pictures of the evolution of the farm size coefficients taken together provide a visible evidence that the IR takes a curvature of a decreasing hyperbola with the abscissa axis as an asymptote.

However, the analysis and the post-estimation results of the cross-sectional quantile regression for the greenhouse vegetables sector suggest a different picture. The relationship between the farm size and productivity for low performance farms (low productivity) is negative and relatively steep until the third decile ($Q_{0.3}$). Nevertheless, from the fourth decile ($Q_{0.4}$), the relation becomes neutral, where the magnitude will be zero because of the large variability in terms of the standard error of coefficient estimates throughout the remained deciles (having a very large confidence interval). Therefore, the relationship does not take any clear curvature. It becomes superfluous on a wide spectrum of scales. While the relationship between farm size and land use intensity (*LUI*) is clearly positive with values in ascending order up to the seventh decile ($Q_{0.7}$) becoming less steep at the end, whatever also positive. The two cases here provide visible evidence that IR does not hold, on the contrary, the reversed relationship is likely true.

Our major findings suggest that farm size and farmland productivity (or intensity) are systematically related in a typical traditional farming system, whereas in a highly input-intense modern sector, the relationship becomes positive (or at least ambiguous).

The overall picture emerging from this study is that the IR holds between farm size and the two measures of farm performance in a traditional farming system, while not for a modernizing farming system, at least for Algerian agriculture. Regardless of whether performance is defined in terms of yield or land use intensity, the IR is indeed found to hold for any range of dates farm scales. In a highly input-intense farming system, such as the greenhouse vegetables production, the relationship between farm size and farm productivity is ambiguously positive.

Another consideration should be highlighted reflecting the fact that more attention is needed in the use of farm performance measures to the extent that land productivity measure is problematic and potentially misleading when used in modernizing agricultural contexts (Helfand & Taylor, 2021). In explaining the IR patterns, however approached, the stage of development in the underlying farming sector is crucial, as confirms few previous studies such as Ghose (1979), Dyer (1991) and Rada & Fuglie (2019). They provide a relevant potential explanation for the fact that the IR may hold in a static relatively backward agriculture, and vanish along with advanced technological innovations. The argument is that, in the dynamic context of technical innovation, the greater access to the new inputs by the large-scale labor-hiring farms and their inherent scale advantages lead to the disappearance of the inverse relation in technically advanced farming systems.

These findings, which seem confirmed along a vast set of cases around the world, suggest that the ubiquitous IR relationship reported by previous literature may have been an artifact of the presumption that the relationships observed were linear and omnipresent without a consideration of the stage of development in the underlying farming sector. It appears that the relationship is pronouncedly monotonous in static traditional farming systems, and it is drastically different across farms in a modernizing farming sector, depending on their position on development stages of the modernization process. The policy implications of these findings are also significant. For farms in the highest performances in a modernizing farming sector, this result in fact implies that some land expansion may be beneficial, but lack of management ability will create diseconomies of scale so that better management and technology are needed more than land increases. Furthermore, the argument that a redistribution of land from the large to the small farms will increase yields and hence agricultural output cannot be extended to a farming system experiencing technical changes and moving towards a more input-intensive use.

5. Conclusion

This study examines the relationship between farm size and farm performance over a very large range of Algerian farms than has typically been examined in Africa or the Mediterranean. To our knowledge, this is the first study to examine the farm size-productivity relationship in Algeria. Most prior farm size-productivity studies in different countries rely on household surveys data for which there are relatively few observations. This study is therefore motivated by the need to understand whether the well-established inverse farm size-performance relationship holds when a broader range of farms sample is considered.

The study uses a dataset comprising 26 735 farmers in Biskra region where two farming sectors are considered, namely: date palm sector (as typically a traditional farming sector) and greenhouse vegetables sector (as a relatively modernizing sector). The study employed two farm performance measures, farm productivity (measured by farm output per hectare) and land use intensity. A bivariate non-parametric regression (Nadaraya-Watson approach) and multivariate quantile regression are used to assess the IR in two farming sectors.

The major finding suggests that farm size and farmland productivity (or intensity) are systematically related in a date palm farming system, whereas in the greenhouse vegetables sector, the relationship becomes positive (or at least ambiguous). This provides evidence that the IR holds for a static traditional agriculture and does not in a modernizing one. Furthermore, when it holds, it follows a monotonic smooth pattern, whereas in a highly input-intense modern sector, the relationship becomes, in the best cases, blurry. Accordingly, the consideration of the nature of the used technology in the underlying sector (i.e., the stage of development in the studied farming sector) is of crucial importance as a contingency factor in analyzing the IR for any farming system.

A natural extension to this study is the deeper analysis of the underlying causes of the farm size heterogeneity regarding farm performance and efficiency in each farming sector. Identifying the factors that accounts for the relationship between farm performance and farm size in Algerian agriculture is of paramount importance to enhance the efficiency of public intervention through the long-standing failures of agrarian reform policies since 1970s.

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