Technical efficiency of dairy production in Tunisia: a data envelopment analysis

LASSAAD LACHAAL*, NAJET CHAHTOUR**, BOUBAKER THABET***

Abstract

The objective of this study is twofold. In first place, a non-parametric frontier analysis of dairy production technical efficiency is carried out for a sample of state-owned farms in Tunisia, using cross section data. Secondly, computed efficiency scores are subsequently regressed on explanatory variables using a Tobit analysis, to help identify inefficiency-related factors. Four farm attributes are identified as being related to efficiency. They are represented by the time devoted per cow present, the feed quality, the average labourer age, and the average herd age. Finally, the importance of these farm attributes to explain technical efficiency scores of dairy production is discussed.

Résumé

Un double objectif a été fixé dans cette recherche. Premièrement, on a estimé, à l'aide de techniques non paramétriques de programmation mathématique, les scores d'efficacité de production laitière d'un échantillon d'exploitations agricoles gérées par l'Office des Terres Domaniales (OTD). Pour identifier les déterminants de cette efficacité, les scores obtenus ont été regressés, dans une seconde étape, sur des variables explicatives, en utilisant un modèle Tobit. Ces variables explicatives sont le temps alloué par vache présente, la qualité de l'alimentation, l'âge moyen du personnel et l'âge moyen du cheptel. En dernier lieu, l'importance de ces variables et leurs rapports avec l'efficacité technique de production laitière sur les exploitations de l'OTD ont été analysés.

1. Introduction

Tunisian agriculture is confronted with declining world commodity prices and stronger competition from both subsidized and non-subsidized overseas products. Agricultural productivity growth needs to be fostered, through either technological progress or an increase in production efficiency, in order to stand the competitive pressure and to remain competitive. On the one hand, the government has carried out a set of appropriate policy reforms, which helped attain major technological progress in different agricultural sectors. On the other, the implementation of protectionist measures to ensure self-sufficiency in strategic products might generate considerable technical inefficiencies.

The dairy sector is a good example of how the Tunisian government has effected several policy reforms to increase the supply of fluid milk products and ensure self-sufficiency. However, given the persistent and substantial variations in dairy farms profitability, it may be assumed that efficiency gains shall be furthered. To this end, measuring dairy efficiency is important insofar as this could be the first logical step in a process that leads to substantial resource savings.

However, despite the great attention given to efficiency measurement and its determinants since the pioneering work by Farrell, published over 40 years ago, the empirical evidence of the Tunisian dairy sector is not substantial yet. Are Tunisian dairy farmers efficient? What would one expect to be the determinants of dairy farm efficiency? Is there a relationship between dairy farm efficiency scores and farmers' age, feed quality, education, average herd age, ...etc.? Is the increase in milk production achieved during the last decade the result of the continuous increase in the number of imported dairy cows and the intensive use of concentrate feeds or rather the result of an improvement in farm efficiency? To the authors' knowledge, only one study has investigated these issues in the Tunisian dairy sector.

The objective of this research is therefore twofold. In first place, we investigated the possibility of improving dairy farm efficiency and provided empirical evidence applying Data Envelopment Analysis (DEA) to a sample of state-owned farms managed by the Office des Terres Domaniales (OTD). Secondly, we resorted to Tobit analysis to assess the effects of several explanatory variables, i.e. the time devoted per cow present, the feed quality, the average labourer age and the average herd age, on technical efficiency of milk production.

Moreover, this paper includes: a review of the dairy policy environment in Tunisia, in section 2, the model development and data description in section 3, the results and analysis illustrated in section 4 and the concluding comments presented in section 5.

2. The dairy policy environment in Tunisia

In Tunisia, the dairy sector contributes by about 9% to the total agricultural production and by roughly 22,5% to the total animal production. During the last decade, the

* Head of the Department of Agricultural Economics, Institut National de la Recherche Agronomique de Tunis

** Chief Engineer, Office des Terres Domaniales

*** Professor of Agricultural Economics at INAT, Deputy Director and Chief of the promotion division, Int. Olive Oil Council

milk production strategy and country efforts were aimed at increasing the level of milk production reaching self-sufficiency in both milk and dairy products. This was the primary objective to attain by the year 2000. To this end, several measures were taken mainly to develop a dairy industry based on national production. These measures (i.e., a price support program, subsidized investment loans to dairy enterprises, grants to purchase pure-bred dairy heifers,...etc.,) have resulted in a substantial rise in the total cow population from 355,000 heads, in 1987, to 482,000 heads in 2000. However, while the total cow population increased at an average rate of 2.7%, the number of pure-bred herd increased at an average rate of 10.0%, shifting from 88,000 to 203,000 heads in the same period. As a result, the milk production obtained was more than double, rising from 356,000 tons, in 1987, to 817,00 tons in 2000.

In 2000, the milk production increase covered for the first time the total population demand for dairy products (Gilait, 2000) even though the management conditions of dairy herds did not seem to benefit much from the high genetic potential of imported dairy breeds. Indeed, compared to their country of origin, the imported dairy breeds displayed a low milk production and below-average reproductive performances. The national average milk production per cow (considering all breeds) is about 3,330 kg and that of cows under the national dairy herd record system (only 13% of the total population) is around 5,800 kg. The average calving interval is often more than 400 days for large and small herds and the number of services per conception is about 2.2.

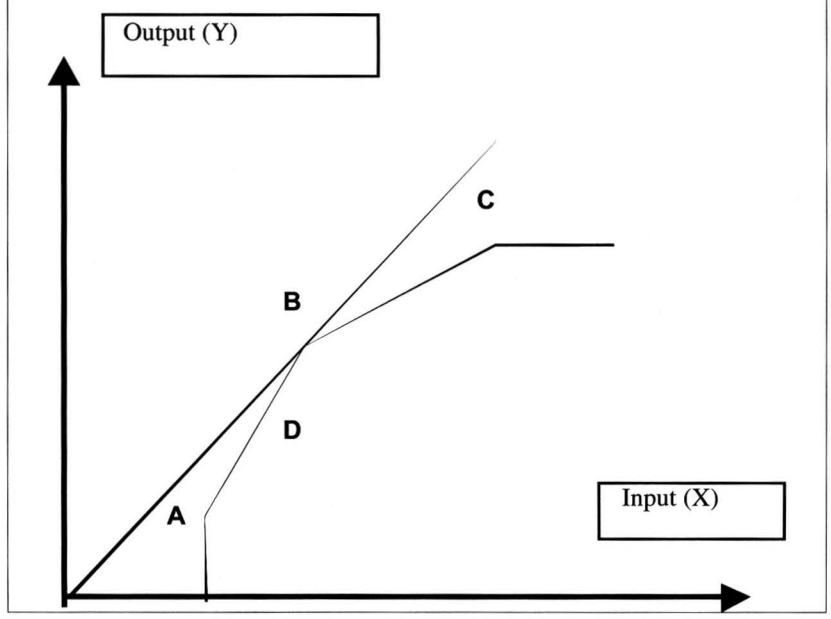
In a recent review of the Tunisian dairy sector, Lahmar and Bouraoui (1998) reported that productivity of dairy cows is significantly affected by several structural and technical factors. These include farm management practices, labour skills, feed quality, reproductive management and animal health. However, while the authors provide useful information and a descriptive analysis of the sector's constraints, a conceptual framework assessing the importance of these constraints as a source of inefficiency in the Tunisian dairy sector is still lacking. As a matter of fact, most of the research conducted in this area deals with the descriptive analysis of production systems and the determination of milk production costs.

In this study, efficiency is analyzed within the framework of a formal economic model concerning a sample of state farms managed by the Office des Terres Domaniales (OTD). OTD was created in 1961 to manage several farms covering about 153,000 ha and scattered across the whole country. Since then, OTD has played a key economic and social role and has contributed to the production, processing and marketing of basic commodities such as, cereals, olive oil, milk and red and white meat. Although dairy production represents an important activity within OTD, the dairy technical efficiency of these Tunisian state-owned farms has never been investigated. Consequently, the assessment of these measures could be of great interest for at least two purposes. Firstly, these measures are reliable indicators of relative farm performance and they can be used by OTD managers as an important tool for decision-making. Secondly, efficiency measures for state-owned farms can be used for a comparative evaluation of privately owned farms to investigate the impact of ownership on efficiency levels (Sterner, 1990). However, due to the differences in terms of incentives, managerial performance, access to credits and enterprise objectives, such a comparison should be made with great care.

3. Model development and data description

Since the pioneering work of Farrell (1957), two competing paradigms on frontier estimation have been developed in the literature. The first one relies upon econometric techniques to estimate a frontier function and estimate primal and dual efficiency scores of the estimated frontier. The second one, applies non-parametric mathematical programming techniques to construct a transformation frontier and compute primal and dual efficiency of the frontier.

Fig. 1. *Technical efficiency*



Non-parametric frontier analysis, known as data envelopment analysis (DEA), overcomes some of the critical points of the statistical frontier approach. In particular, there is need for restrictive assumptions about the functional form of the frontier or the distribution form of inefficiency. In-

stead of fitting a regression surface into the data center, DEA lays a piecewise linear surface on the top of the observations.

In this paper, we used data envelopment analysis to investigate technical efficiency in a sample of state-owned dairy farms in Tunisia. Technical efficiency refers to the ability of a farm to produce maximum output, given the technology available and the set of inputs used. Failure to operate on the production frontier may be caused by insufficient technical skills, inadequate information or even lack of motivation. Graphically, technical inefficiency can be represented by the distance [BD] separating observed and potential output as illustrated in Fig. 1. Observations A, B, and C are technically efficient since they lie on the production frontier. Observation D lies within the frontier and thus, it is technically inefficient. Indeed, the same level of input could theoretically be used to reach a higher level of output and would allow this farm to be on the frontier at point B.

DEA attempts to construct a non-parametric envelopment frontier on observations so that all the observed points might lie on or below the production frontier. Within this framework, a convex piecewise linear convex hull is constructed based on observed input- output combinations through programming techniques. This approach was first developed in a programming problem by Charnes, Cooper and Rhodes (1978). Since then, many works in the literature have been devoted to the non-parametric programming approach to frontier analysis.

The input requirement set L(y) for a sample of k firms can then be represented as:

$$L(y) = \{x : Yz \geq y,\ Xz \leq x,\ z \geq 0\} \quad (1)$$

where Y = [y^1, ...y^k] is a k vector of outputs, X = [x^1, ... x^k] is a nxk matrix of inputs, z is a k-vector of constants, and y^k, x^k are the output and input levels of the k^{th} firm, respectively. Within this framework, technical efficiency

$$Eff^k = \min\{\lambda : \lambda x^k \geq L(y^k)\} \quad (2)$$

This measure is interpreted as the equiproportional (radial) reduction of input usage by the k^{th} firm to such a level that it would still provide the same output level y^k.

The efficiency score 8 for the k^{th} firm can then be computed by solving the following linear program problem:

$$\begin{aligned} \min\ & \lambda \\ s.t.\ & Yz \geq y^k \\ & \lambda x^k - Xz \geq 0 \\ & z \geq 0,\ \lambda = free \end{aligned} \quad (3)$$

A value of one for 8 indicates a point on the efficiency frontier and thus a technically efficient firm. We note here that the linear program in (3) assumes constant returns to scale. To account for variable returns to scale situations, however, one can easily modify (3) by adding the convexity constraint: N'z = 1, where N is nx1 vector of ones (Seiford and Thrall, 1990).

To implement the computation of technical efficiency scores in (3), data for a sample of 17 state-owned farms were collected from various farm records in 1998. In particular, data on milk production as well as inputs used were required. Four broad categories of milk production inputs were considered. These were: average herd population measured in heads (P), feed input (F), labour input (L) and material input (M). The feed input included concentrates, hay and silage, and other feeds. The labor input included permanent and hired labor. The material input included fuel, electricity, dairy supplies, and other miscellaneous material inputs. For each of these categories of inputs, a geometric quantity index was computed and 1996 was used as a basic year.

Solution to (3) provides information about the production efficiency of each individual farm of the sample and does not imply irrational behavior of non-efficient farmers. Byerlee (1987) noted that failure of farmers to produce potential output could be the result of factors such as property rights, legislative conflicts, non-monetary objectives ...etc., rather than of some irrational decisions. However, from a policy point of view, it is interesting to investigate the sources of inefficiency and to identify farm attributes potentially related to it.

In some works, production efficiency has been linked with a number of socioeconomic variables. The relationship between technical and allocative efficiency and education has been extensively investigated in agriculture (Bravo-Ureta and Rieger, 1991; Kumbhakar et al., 1989; Lockheed et al., 1981). However, the nature of this relationship is not homogeneously defined (Phillips, 1987).

The production efficiency may also be related to the farm size. Large farms are often considered more efficient than small farms due to economic advantages concerning the organization and technical knowledge. Empirical evidence, provided by several studies on the relationship between efficiency and the farm size, has also been taken into account (Aly et al., 1987; Garcia et al., 1982; Byrnes et al., 1987). Another variable which seems to be related to efficiency is the farmer's age. Old farmers are often assumed to have had more time to learn and become more experienced in managing their farms and thus, they are thought to be more efficient.

The main conclusion that can be drawn is the lack of substantial evidence of the relationship between efficiency and these attributes and hence, more empirical research is still needed. Indeed, in this analysis, several variables are identified as potential determinants of techni-

[1] Here, Tobit analysis is used because the dependent variable, technical efficiency, is a censored variable, having an upper limit of one (Maddala, 1992).

[2] Here, Milk permitted by basal diet, MPBD, is used as a proxy to feed quality and measured as the ratio of basal diet milk forage unit (UFL) over 0.43 (INRA, 1988).

cal efficiency. These variable reflect the time devoted per dairy cow present, the feed quality, the labourer average age and the average herd age. To this end, the efficiency scores obtained are regressed on these farm attributes using the linear Tobit model[1] in (4).

$$Eff = \alpha_0 + \alpha_1 TC + \alpha_2 FQ + \alpha_3 DP + \alpha_4 DH + \varepsilon \quad (4)$$

where :
Eff is the efficiency of dairy farmers.
TC is the time devoted per dairy cow present.
FQ is the feed quality dummy variable measured by the Milk Permitted by Basal Diet variable[2] (MPBD) = 0 if less than or equal to 5, = 1 otherwise.
DP is the average labourer age dummy variable = 0 if less than 50 years old, = 1 otherwise.
DH is the average herd age dummy variable = 0 if between 2 and 5, = 1 if above five.
Σ is the error term.

4. Analysis and Results

Using the linear programming methodology outlined above, non-parametric analysis of relative technical efficiency is performed for dairy production in the state-owned farms of the sample. Program (3) was solved 17 times to provide the efficiency score for each individual farm. Frequency distribution of technical efficiency scores for the farms in the sample as well as the number of farms are reported below. Given the large variability in the computed measures, farms are clustered into three groups (Table 1).

Frequency distribution results showed that average technical efficiency of the first group is 31%, ranging from a minimum of 24% to a maximum of 38 %. This means that the farms of this group can increase their milk production by as much as 69% using the same production inputs more efficiently. An analysis of current feeding practices within this group revealed the quality of the basic diet composed of 13% of hay, 8% of green and 79% of poor quality silage. One year after the completion of this study, farms of this group have ceased producing milk.

The second and third group display more decent mean efficiency scores; 71% and 93%, respectively. This means that farms of these groups can increase their milk production by as much as 29% and 7%, respectively, using the same production inputs more efficiently. The sample overall average technical efficiency measure is 68%. This score is lower than the one reported by Lachaal et al. (2000). Indeed, the authors, investigating the determinants of technical efficiency in a sample of 61 privately owned dairy farms in northern Tunisia, reported an average technical efficiency score of 75%. A comparison of these measures should be made with great care. Due to the differences in sample size and the estimation approach of the production frontier, more empirical evidence is needed to conclude that private dairy farms are more efficient than public dairy farms.

Table 1. *Frequency distribution of technical efficiency for a sample of 17 state-owned dairy farms in Tunisia.*

Technical efficiency level (%)	Group I TE ≤ 50	Group II 50 < TE ≤ 80	Group III TE > 80
Number of Farms	2	6	9
Mean efficiency	31,3	71,3	93,3
Min. efficiency	24,2	56,1	80,7
Max. efficiency	38,4	78,3	100

Table 2. *Tobit analysis testing inefficiency and factors associated to it for a sample of 17 state-owned dairy farms in Tunisia*

Variables	Technical efficiency
Intercept	6,098*
	(3,832)
Time devoted per cow	-3,454*
	(-2,675)
Feed quality	1,828*
	(4,220)
Average labourer age	-1,522*
	(-2,187)
Average herd age	-2,487*
	(-3,249)

Table notes: one asterisk indicates significance at 5% level

To identify factors associated with technical inefficiencies, the Tobit regression defined in equation (4) is estimated and results are presented in table 2. As for the time devoted per dairy cow present, our results are in contrast with conventional wisdom in that this variable has a statistically significant negative effect on efficiency. However, we must take into account that beyond its economic role, OTD has played an important role of government employer in that, in 1998, it provided more than 3 million workdays to the rural population to help prevent migration to urban cities. As a result, this labor-intensive environment may have caused some distortions in input utilization and consequently, any more hiring in the dairy sector would negatively affect efficiency levels.

Feed quality shows a significant positive relationship with technical efficiency suggesting that effi-

ciency would improve with good feed quality. The average labourer age has a significant relationship with efficiency. The estimated coefficient is negative, suggesting as we have assumed, that labourers close to retirement lack motivation and are therefore less efficient than middle-aged workers.

The estimated coefficient of the dummy variable representing the average herd age is negative and statistically significant at 5% level. This result corroborates the already reported contention that milk production declines after the fifth lactation.

5. Conclusions

In this paper, a non-parametric analysis of technical efficiency for a sample of Tunisian state-owned farms is carried out using a two-step procedure framework. The first step, based on Charnes et al., makes it possible to overcome the critical points of statistical frontier models. The second step allows to investigate the sources of technical efficiency within the sample and to identify potential farm attributes related to it.

Empirical results show that significant inefficiencies in dairy production are found within the sample of state-owned farms at hand. In particular, 47% of the farms are found to produce below 80 % of their potential due to technical inefficiency. Indeed, overall efficiency measure suggests that state-owned farms in Tunisia could increase milk production by as much as 32% through a more efficient use of their production inputs. This result seems to confirm that the increase in milk production over the last decade in Tunisia is the result of an increase in the number of imported dairy cows rather than of an improvement in dairy production efficiency.

The relationship between efficiency and four farm attributes (e.g., time devoted per cow present, feed quality, average labourer age, and average herd age) is assessed by resorting to Tobit analysis. Empirical results suggest that:

Time devoted per cow present, in contrast with our expectations, is found to be negatively correlated with dairy production efficiency. Though this result is interpreted as a probable effect of the excess use of labour on these farms, in our view this aspect should be investigated more thoroughly .

Feed quality displays a significant positive relationship with technical efficiency, which means that the latter increases with better feed quality. This is consistent with what would be expected. Therefore, a sounder management of the forage harvesting stage, the crude protein and fiber content as well as the storage conditions would enhance feed quality and lead to higher technical efficiency levels in dairy production on these farms.

The average labourer age is found to be associated with lower technical efficiency. Older workers, who have reached the top of the administrative ladder, might become less motivated and consequently, might reduce their efforts and become less efficient. Therefore, an incentive scheme, linking production results to some kind of compensation to workers, could contribute to reach higher scores of efficiency on these farms.

Finally, as underlined before, the average herd age has proved to be related to technical efficiency level. As a result, from the management viewpoint, it is advisable to decrease the average herd age on these farms through a more accurate control of the culling rate.

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