Economics of technical efficiency in white honey production: Using stochastic frontier production function

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ABSTRACT
This study estimates and compares technical efficiency levels among beekeeping projects with various production capacities using a sample drawn from Fayoum Governorate in Egypt. The study also compares among beekeeping’s most important economic indicators, estimates the optimum production amount, and investigates why technical efficiency in Egyptian beekeeping is declining. We conclude that the average cost to produce one ton of honey decreases when production capacity increases. Furthermore, the average total, net return, and return on investment of one Egyptian pound increases when production capacity increases. Moreover, the results of a stochastic frontier production function indicate an increased return to scale. Finally, the results of maximum likelihood estimation show that technical inefficiency helps explain the deviation of actual from optimal production amounts.

1. Introduction
Beekeeping projects are a part of an agricultural economy; they produce honey, wax, royal jelly, apitoxin, pollen, and propolis, and include trade in bee swarms and queen bees. Honey has many medical uses, and honeybees are used to inoculate agricultural crops, which can generate a 20-fold increase in crop production and increase seed productivity for some crops (Al-Fil et al., 2007), thus enhancing overall national wealth. In Egypt, beekeeping is attractive to investors. It does not need large capital investments and has a relatively quick business cycle. Beekeeping is lower-risk and its required skills can be acquired more easily than in other agricultural activities. The Egyptian government has expressed interest in encouraging beekeeping through small rural projects. Beekeeping projects play an important role in providing job opportunities for youth and may be a solution to Egypt’s unemployment problem, especially among young people. Around 12,225 beekeeping projects were underway in Egypt in 2016, including about 829,000 beehives. These projects contributed to the production of around 4400 tons of white honey in 2016. Fayoum Governorate represented close to 4.3% of Egypt’s honey production in 2016. It had 524 beekeeping projects in 2016, with a production of about 405 tons, or 9.2% of all the white honey produced in Egypt that year.

Studies on honey production projects have discussed several of its economic aspects, such as its profitability analysis and factors affecting honey production. Among the profitability analyses, Blanc et al. (2018) examined unitary net product and hourly work income for three types of Italian producers defined according to whether the beekeepers were hobbyists or professionals and whether they were located in mountains or hills. The results show that low yields were generated in mountainous areas, while hill beekeepers had the highest production and revenue. Olatubosun et al., 2016 evaluated the operational and maintenance costs and revenue of several hive and extraction technologies adopted by smallholder honey producers in Southwestern Nigeria.

A case study on Dakahlia Governorate (Egypt) conducted by Sayed and Al-Damasi (2015) concluded that Egyptian honey production projects are economically feasible in terms of criteria such as net present value, ratio of revenue to costs, and internal rate of return. Abu Naga and Abdul Ghaffar (2011) found the same results.
after dividing the study sample of apiaries in North Sinai Governorate (Egypt) into three production capacity groups. Their results also indicated that greater capacity leads to greater net present value and return-to-cost ratio. They also found that the average capital recovery period for honey production projects in Northern Sinai was about 4.52 years.

Other studies have conducted technical efficiency analyses in order to investigate how to maximize production output using the available resources (Farrell, 1957). Measuring technical efficiency is popular in the agricultural production economics literature; such analyses have been applied to vegetables in China (Xu et al., 2018), fish cage culture in Malaysia (Islam et al., 2016), pineapples in Colombia (Trujillo and Iglesias, 2013), rice in Vietnam (Khai and Yabe, 2011) and the Philippines (Villano and Fleming, 2006), wheat in Turkey (Alemdar and Oren, 2006), and crop and livestock farms in Poland (Latruffe et al., 2004). Technical efficiency is important for small farmers with small incomes, such as beekeepers.

2. Study problem

Despite the economic and nutritional importance of honeybees and the abovementioned favorable features of the beekeeping sector, the number of beekeepers and their average productivity have declined in Egypt. The number of beekeepers in Egypt decreased from 1,460,000 in 2001 to 829,000 in 2016, and average hive productivity decreased from 5.96 kg in 2001 to about 5.3 kg in 2016; this represents a 43.21% and 10.94% reduction in the number of beekeepers and average hive productivity in Egypt, respectively. The number of modern beekeepers in Fayoum decreased from 108,130 in 2001 to about 78,000 in 2016, and its average hive productivity decreased from about 6.56 kg in 2001 to about 5.19 kg in 2016; this is a 27.87% and 20.79% reduction in beekeepers and average hive productivity, respectively. Thus, Egyptian honey production is facing challenges, which are reducing incomes for producers. In addition, the decrease in beekeepers’ average productivity and the increase in production costs have reduced investment in this sector. Thus, the productivity of existing projects must be increased by addressing the inefficient use of production factors and the failure to use them to optimize production and minimize costs; this may encourage further investments in the beekeeping industry.

2.1. Study objectives

This study assesses and compares among the technical efficiency of beekeeping projects of varying production capacities using a sample drawn from Egypt’s Fayoum Governorate. This study compares among the most important economic indicators and estimates the optimal production sizes and technical efficiency levels of the region’s honey production projects; identifies important factors missing from the apiaries due to inefficiency; and makes recommendations for enhancing the technical efficiency of the projects.

3. Research methodology and data sources

3.1. Research methodology

This study performed descriptive and quantitative statistical analysis using the appropriate statistical and econometrics measures. Multiple linear regression via ordinary least squares (OLS) was used to estimate the economic derivatives of the white honey production function, and a stochastic frontier production function (SFPF) was used to assess technical inefficiency levels.

This estimate is based on the theoretical framework of Ramanathan (2001). The production function is defined as follows:

\[ Y_i = f(X_i, b) + e_i \]  

where \( Y_i \) is average honey production of apiary \( i \), \( X_i \) is use of production factor \( j \), \( b \) is function parameters, and \( e_i \) is coefficient of random error.

The stochastic frontier production function (SFPF) contains the coefficient of random error \( e \). This has two main components, \( E_i = V_i - U_i \), where \( U_i \) is variation due to technical inefficiency, and \( V_i \) is variation due to random error. To estimate \( V_i \) and \( U_i \), we assume the distribution of \( V_i \) is normal \([V \sim N(0, \sigma^2_v)]\), while \( U_i \) is a half-normal distribution. These assumptions are required to estimate the coefficient of technical inefficiency \( U_i \) using SFPF. We estimate the parameters of this function using the maximum likelihood estimation (MLE) method, rather than the ordinary least squares (OLS) method (Aigner et al., 1977).

The production function can be expressed as a Cobb–Douglas formula as follows:

\[ Y_i = X_i^b e^{b \cdot g} \]  

The expression of this function in its linear or logarithmic form is formulated as follows:

\[ \ln Y_i = B_0 + \sum_{j=1}^{n} B_j \ln X_{ij} + (V_i - U_i) \]  

where \( \ln \) is natural logarithm, \( Y_i \) is average honey production of an apiary, \( X_{ij} \) is amount used from the production factor \( j \) of apiary \( i \), \( V_i \) is coefficient of random error, and \( U_i \) is technical inefficiency factor of apiary \( i \).

The benefit of using SFPF is seen in the estimation of the contribution of the technical inefficiency factor \( \theta \) in interpreting the difference between optimal farm production and actual production. The value of \( \theta \) is estimated as follows:

\[ \theta = \frac{\hat{\lambda}^2}{1 + \hat{\lambda}^2} = \frac{\sigma^2_u}{\sigma^2_v + \sigma^2_u} \]  

where \( \hat{\lambda}^2 \) represents the square of \( \lambda \) \( (\lambda = \frac{\hat{\sigma}_u}{\hat{\sigma}_v}) \)

Here, \( \sigma^2_v \) represents the variance in technical productivity inefficiency levels, and \( \sigma^2_u \) represents the variance in the random error (Islam et al., 2016). This function can estimate loss of production due to technical production inefficiency at various levels, such as that of individual beekeepers and apiaries or at the level of all apiaries in the study sample. We can also estimate the mean of the production size for each apiary \( Y \). This mean can be used to calculate the ratio of production decline due to technical inefficiency \( (U_i) \), which can be directly estimated using the LIMDEP program (Afriat, 1972; Greene, 1991). This ratio differs from the decline in production due to random factors that are out of the beekeeper’s control. Given these variables \( (U_i, Y) \), the technical efficiency factor \( (TE) \) of production can be estimated using the following equation:

\[ TE = 1 - U_i \]  

The decline in production size can be calculated as a function of technical inefficiency \( (Y_{loss}) \) according to the following equation:

\[ Y_{loss} = Y - U_i \]  

where \( (Y) \) represents the average actual production of honey at the apiary level. The optimal output size \( (Y_{opt}) \) is calculated using the following equation:

\[ Y_{opt} = Y + Y_{loss} \]
Thus, a comprehensive equation for all variables can be formulated as follows (Al-Duwais, 2000):

\[
TE = \frac{\overline{Y}}{Y_{opt}} = \frac{\overline{Y}}{Y + \text{Yloss}} = 1 - U_i
\]

(8)

3.2. Analysis models

The production function expresses the relation between the economic variables used in the production of honey. This study focuses on five variables relevant to honey production projects. The relation between these variables and the final product is defined according to the Cobb–Douglas production function, which is in non-linear form and can be converted to a linear function using the double logarithm function, as follows (Ramanathan, 2001):

\[
\ln Y_i = B_0 + B_i \ln X_i + V_i - U_i
\]

where \(L_n\) is natural logarithm, \(Y_i\) is honey production for each apiary \(i\) (kg), \(X_{ij}\) is quantities of production variable \(j\) on farm \(i\), \(V_i\) is random error of data for farm \(i\), and \(U_i\) is technical inefficiency factor of apiary \(i\).

In this model, the production variables used can be expressed as follows:

\[
L_n Y_i = b_0 + b_1 L_n X_1 + b_2 L_n X_2 + b_3 L_n X_3 + b_4 L_n X_4 + b_5 L_n X_5 + V_i - U_i
\]

where \(Y\) is the production size of honey (kg), \(X_1\) is working hours, \(X_2\) is the quantity of sugar syrup for honeybees (kg), \(X_3\) is the number of beehives, \(X_4\) is years of beekeeping experience, and \(X_5\) is the quantity of antibiotics and vaccines (grams). We use the LIMDEP program to estimate the technical inefficiency factor.

3.3. Data sources

This study depends on published and unpublished secondary data obtained from the Egyptian government’s Central Agency for Public Mobilization and Statistics (CAPMAS) and Ministry of Agriculture as well as the Directorate of Agriculture in Fayoum Governorate. We used sampling to collect the study’s primary data.

3.4. Study sample

The sample comprises 65 modern apiaries in Fayoum. Fayoum has 524 such apiaries in 2016 according to the Information and Decision Support Center in Fayoum Governorate; therefore, the study sample represents 12.4% of Fayoum’s apiaries. The sample apiaries were divided into three production capacity groups based on the number of beehives: the first group comprises apiaries with fewer than 100 beehives (there are 25 apiaries in this group); the second group comprises apiaries with 100–199 beehives (21 apiaries), and the third group comprises apiaries with 200 or more beehives (19 apiaries). The sample size was determined at a significance level of 5% and permissible error limit of 12.16% according to the following equation (Alyahya and Rowe, 2016):

\[
N = \frac{p(1-p)z^2}{d^2} = \frac{(0.25)(1.96)^2}{(0.1216)^2} = 65
\]

where \(N\) is the sample size, \(d\) is the permissible error limit, \(p\) is the ratio of the individual from the study community in which the study characteristic is available, and is often 0.5, and \(z\) is the standard value at a significance level of 5%.

4. Results

4.1. Economic indicators for white honey production

4.1.1. Production costs

Production costs are divided into fixed and variable costs. Fixed costs for honey production projects include capital assets such as wooden beehives, frames, nutrients, bee swarms, queen bees, honey extractor, and storage and sorting rooms. Variable costs include management fees, labor wages, sugar syrup, beeswax, medicine, sera, new swarms, transport costs, packaging, and annual maintenance costs (Abu Naga and Abdul Ghaffar, 2011).

Table 1 indicates the average fixed and variable production costs for one ton of white honey for the study sample’s three production capacities. The average cost is 32,350 and 30,580 Egyptian pounds for the first and second capacity groups, respectively; variable and fixed costs represent 78% and 22% of the total cost, respectively. For the third capacity group, the average cost is 28,820 Egyptian pounds, with variable costs accounting for 83.5% of the total. For the full sample, the average cost is 30,620 Egyptian pounds, with variable costs representing 79.7% of the total. These results show that the averages of the total and fixed costs decrease when capacity increases, while the average variable cost of the first capacity group exceeds that of the second and third groups.

The results of the variance analysis shown in Table 2 indicate significant differences between the average production costs of white honey within and between the three production capacity levels. However, the results of the least significant difference (LSD) test shown in Table 3 reveal no statistically significant difference between the first and second production capacity levels. The average cost of producing a ton of white honey for the second capacity group is 1770 Egyptian pounds less than that for the first capacity group. In addition, the average cost for the third capacity group is 3430 Egyptian pounds less than that for the first capacity group, while there is no significant difference in average cost between the second and third capacity groups.

4.1.2. Production revenues

Revenue from white honey projects comes from the sale of honey (as the main product) and the sale of secondary products, such as beeswax, royal jelly, pollen, nuclei, and queen bees. Table 1 shows that the average revenue from one ton of produced honey was 42,870 Egyptian pounds for the first capacity group; about 91% of this revenue came from the sale of white honey, and the rest came from the sale of secondary products. Average revenue for the second capacity group is 46,430 Egyptian pounds, of which 85% and 15% come from the sale of white honey and secondary products, respectively. Average revenue for the third capacity group is 48,040 Egyptian pounds, of which 80% came from the sale of white honey. Average revenue for the full sample is 45,780 Egyptian pounds, of which 85% comes from the sale of white honey. The results show that average revenue increases as capacity increases.

The results of the variance analysis shown in Table 2 indicate significant differences between the average revenues for white honey production both within and between the three production capacity groups. The results of the LSD test shown in Table 3 also indicate a statistically significant difference between the first capacity group and the second and third groups. The average revenue from producing a ton of white honey for the first group is 3560 and 5170 Egyptian pounds less than that for the second and third groups, respectively, and the average revenue for the second group is 1610 Egyptian pounds less than that for the third group.
4.1.3. Net return for production

Net return is the difference between the total return and total costs. Table 1 indicates that the average net return from the production of one ton of honey was 10,520, 15,850, 19,120, and 15,160 Egyptian pounds for the first, second, and third capacity groups, respectively. These results show that net return increases as capacity grows.

The results of the variance analysis shown in Table 2 reveal significant differences in average net yield both within and between the three production capacity groups. The results of the LSD test

Table 1
Key economic indicators in producing one ton of white honey in Fayoum Governorate during 2017 season. Source: Calculated from study samples in Fayoum Governorate.

| Economic Indicator                        | First Capacity | Second Capacity | Third Capacity | Average |
|-------------------------------------------|----------------|-----------------|----------------|---------|
| Average production of beehives (kg)       | 5.71           | 6.17            | 6.52           | 6.13    |
| Average fixed cost*                      | 7.12           | 6.73            | 4.77           | 6.21    |
| Average variable cost*                   | 25.23          | 23.85           | 24.15          | 24.41   |
| Average total cost*                      | 32.35          | 30.58           | 28.92          | 30.62   |
| Average value of honey production*       | 39.22          | 39.42           | 38.43          | 39.02   |
| Average value of secondary products*      | 3.65           | 7.01            | 9.61           | 6.76    |
| Average total return*                     | 42.87          | 46.43           | 48.04          | 45.78   |
| Average net return*                      | 10.52          | 15.85           | 19.12          | 15.16   |
| Ratio of total return to total costs      | 1.33           | 1.52            | 1.66           | 1.50    |
| Return on investment of one Egyptian pound| 0.33           | 0.52            | 0.66           | 0.50    |
| Operating ratio                           | 0.75           | 0.66            | 0.60           | 0.67    |
| Quantitative break-even point             | 0.51           | 0.43            | 0.33           | 0.42    |
| Profit margin                             | 24.54          | 34.14           | 39.80          | 33.12   |
| Marginal surplus                          | 17.64          | 22.58           | 23.89          | 21.37   |

* In thousand Egyptian pounds

Table 2
Results of variance analysis of key economic indicators in producing one ton of white honey in Fayoum Governorate during 2017 season. Source: Calculated from study samples in Fayoum Governorate.

| Economic Indicator                        | Sum of Squares | DF  | Mean Square | F     | Significance |
|-------------------------------------------|----------------|-----|-------------|-------|--------------|
| Average honey production of beehive       |                |     |             |       |              |
| Between Groups                            | 7.57           | 2   | 3.79        | 91.29 | 0.00         |
| Within Groups                             | 2.57           | 62  | 0.04        |       |              |
| Total                                      | 10.14          | 64  |             |       |              |
| Average total return                      |                |     |             |       |              |
| Between Groups                            | 313.59         | 2   | 156.80      | 47.11 | 0.00         |
| Within Groups                             | 206.34         | 62  | 3.33        |       |              |
| Total                                      | 519.94         | 64  |             |       |              |
| Average total cost                        |                |     |             |       |              |
| Between Groups                            | 127.96         | 2   | 63.98       | 6.39  | 0.00         |
| Within Groups                             | 620.59         | 62  | 10.01       |       |              |
| Total                                      | 748.56         | 64  |             |       |              |
| Average net return                        |                |     |             |       |              |
| Between Groups                            | 835.12         | 2   | 417.56      | 38.13 | 0.00         |
| Within Groups                             | 678.95         | 62  | 10.95       |       |              |
| Total                                      | 1,514.07       | 64  |             |       |              |

Table 3
Results of LSD for key economic indicators in producing one ton of white honey in Fayoum Governorate during 2017 season. Source: Calculated from study samples in Fayoum Governorate.

| Dependent Variable                        | (I) Production Capacity | (J) Production Capacity | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval |
|-------------------------------------------|--------------------------|--------------------------|-----------------------|------------|------|-------------------------|
|                                            | First Capacity           | Second Capacity          | -0.47                 | 0.06       | 0.00 | -0.59 - 0.35            |
|                                            |                          |                          | -0.83                 | 0.06       | 0.00 | -0.95 - 0.70            |
|                                            | Second Capacity          | First Capacity           | 0.47                  | 0.06       | 0.00 | 0.35 - 0.59             |
|                                            |                          | Third Capacity           | -0.36                 | 0.06       | 0.00 | -0.48 - 0.23            |
|                                            | Third Capacity           | First Capacity           | 0.83                  | 0.06       | 0.00 | 0.70 - 0.95             |
|                                            |                          | Second Capacity          | 0.36                  | 0.06       | 0.00 | 0.23 - 0.48             |
|                                            | First Capacity           | Second Capacity          | -3.56                 | 0.54       | 0.00 | -4.64 - 2.48            |
|                                            |                          | Third Capacity           | -5.17                 | 0.56       | 0.00 | -6.28 - 4.06            |
|                                            | Second Capacity          | First Capacity           | 3.56                  | 0.54       | 0.00 | 2.48 - 4.64             |
|                                            |                          | Third Capacity           | -1.61                 | 0.58       | 0.01 | -2.77 - 0.46            |
|                                            | Third Capacity           | First Capacity           | 5.17                  | 0.56       | 0.00 | 4.06 - 6.28             |
|                                            |                          | Second Capacity          | 1.61                  | 0.58       | 0.01 | 0.46 - 2.77             |
|                                            | First Capacity           | Second Capacity          | 1.77                  | 0.94       | 0.06 | -0.10 - 3.64            |
|                                            |                          | Third Capacity           | 3.43                  | 0.96       | 0.00 | 1.50 - 5.35             |
|                                            | Second Capacity          | First Capacity           | -1.77                 | 0.94       | 0.06 | -3.64 - 0.10            |
|                                            |                          | Third Capacity           | 1.65                  | 1.00       | 0.10 | -0.35 - 3.66            |
|                                            | Third Capacity           | First Capacity           | -3.43                 | 0.96       | 0.00 | -5.35 - 1.50            |
|                                            |                          | Second Capacity          | -1.65                 | 1.00       | 0.10 | -3.66 - 0.35            |
|                                            | First Capacity           | Second Capacity          | -5.33                 | 0.98       | 0.00 | -7.29 - 3.37            |
|                                            |                          | Third Capacity           | -8.60                 | 1.01       | 0.00 | -10.61 - 6.58           |
|                                            | Second Capacity          | First Capacity           | 5.33                  | 0.98       | 0.00 | 3.37 - 7.29             |
|                                            |                          | Third Capacity           | -3.27                 | 1.05       | 0.00 | -5.36 - 1.17            |
|                                            | Third Capacity           | First Capacity           | 8.60                  | 1.01       | 0.00 | 6.58 - 10.61            |
|                                            |                          | Second Capacity          | 3.27                  | 1.05       | 0.00 | 1.17 - 5.36             |
shown in Table 3 indicate a statistically significant difference between the first production capacity group and the second and third groups. The average net return for the first group is 5330 and 8600 Egyptian pounds less than that for the second and third groups, respectively, and the average net return for the second capacity group is 3270 Egyptian pounds less than that for the third group.

4.1.4. Beehive productivity

Table 1 shows that the average yields of a single beehive for the sample are 5.71, 6.71, 6.52, and 6.13 kg for the first, second, and third capacity groups and the full sample, respectively.

The results of the analysis of variance shown in Table 2 reveal significant differences in average beehive productivity both within and between the three production capacity groups. The results of the LSD test shown in Table 3 confirm these differences and clarify them, revealing that the average white honey yield for the first capacity group is 0.47 and 0.83 kg less than that of the second and third groups, respectively. Moreover, the average honey yield for the second capacity group is about 0.36 kg less than that for the third group.

4.1.5. Ratio of total return to total costs

The ratio of total return to total costs, one of the most important criteria for measuring economic efficiency, is calculated by dividing total return by total costs. This amounts to about 1.33%, 1.52%, 1.66%, and 1.50% for projects in the first, second, and third capacity groups and the full sample, respectively.

The operating ratio is calculated by dividing total costs by total revenue. Table 1 shows that the operating ratios are 0.75, 0.66, 0.60, and 0.67 for the first, second, and third capacity groups and the full sample, respectively. Their values are less than one, which indicates the feasibility and profitability of the projects.

4.1.6. Return on investment

A return on investment of one Egyptian pound is used to measure the capital efficiency of production. It is calculated by dividing net return by total costs. The values of this ratio are 0.33, 0.52, 0.66, and 0.50 for the first, second, and third capacity groups and the full sample, respectively.

4.1.7. Operating ratio

The operating ratio is calculated by dividing total costs by total revenue. Table 1 shows that the operating ratios are 0.75, 0.66, 0.60, and 0.67 for the first, second, and third capacity groups and the full sample, respectively. Their values are less than one, which reflects the profitability of the projects.

4.1.8. Quantitative Break-even point

The quantitative break-even point is the production amount generated when total revenue is equal to total costs. It is calculated by dividing fixed costs by the selling price of one unit minus the variable costs for one unit. The lower the break-even point, the better. Table 1 shows that the quantitative break-even points were about 0.51, 0.43, and 0.33 for the first, second, and third capacity groups, respectively, and 0.42 for the full sample. Therefore, increased production capacity is beneficial for the honey production project owners in our sample.

4.1.9. Profit margin

The profit margin averages for one ton of white honey in the sample are 24.54%, 34.14%, and 39.80% for the first, second, and third capacity groups, respectively, and 33.21% for the full sample.

4.1.10. Marginal surplus

Table 1 shows that the marginal surplus in the production of white honey was 17,640, 22,850, 23,980, and 21,370 Egyptian pounds/ton for the first, second, third capacity groups and the full sample, respectively. These results show that promoting white honey production projects and increasing their production capacity are economically feasible; doing so may help improve project owners’ standard of living.

4.2. Estimation of physical production function

4.2.1. Determination of production elasticities and technical efficiency

Table 4 shows the estimates of the production elasticities of the factors in the production of white honey at a modern apiary in Fayoum Governorate using the OLS model for the double logarithmic production function. In addition, SFPF was used to estimate the technical efficiency of the sample’s apiaries.

The results of the OLS model for the full sample indicate the significance of the estimated model; the study variables were able to explain about 99% of the change in the dependent variable (the production quantity of honey). The elasticities of the production variables indicate a statistically significant positive relation between the quantity of honey production (Y) and two production factors—the quantity of sugar syrup (X2) and the number of beehives (X3). A 10% increase in these will lead to a 5.46% and 2.54% increase in honey production, respectively. A significant relation is observed between honey production (Y) on one hand and years of experience (X1) and quantity of antibiotics and vaccines (X5) on the other. A 10% increase in X4 and X5 will lead to a 0.90% and 0.72% increase in honey production, respectively. The OLS regression also revealed that the effect of working hours (X1) is insignificant.

The results of the OLS for the first capacity group indicate the significance of the estimated model, and the study variables can explain about 81% of the change in the dependent variable (annual production of honey). The production elasticities of the production variables indicate a statistically significant positive relation between the quantity of honey production (Y) and two production variables—the quantity of sugar syrup (X2) and the number of beehives (X3). A 10% increase in these variables will lead to a 6.75% and 4.37% increase in honey production, respectively.

For the second capacity group, the results of the OLS analysis indicate the significance of the estimated model, and the study variables can explain about 95% of the change in apiaries’ amount of white honey production. The production elasticities of the production factors in the estimated model indicate a statistically significant positive relation between the annual honey production amount (Y) and three production factors—sugar syrup quantity (X2), number of beehives (X3), and antibiotics and vaccines quantity (X5). An increase of 10% in each of these factors will lead to a 3.12%, 4.88%, and 1.74% increase in honey production, respectively.

The OLS analysis for the third capacity group shows that the independent variables explain 98% of the change in the production amount of honey. The result indicates a statistically significant positive relation between annual honey production (Y) and three inputs—sugar syrup quantity (X2), number of beehives (X3), and years of experience (X4). A 10% increase in each of these variables will lead to a 2.45%, 5.85%, and 0.84% increase in annual honey production.

The OLS regression results also show that the total production elasticities are 1.32 for the first capacity group, 1.13 for the second, and 1.16 for the full sample, which indicates an increasing return to scale. In other words, the increase in honey production exceeds the increase in input factors. This also means that an increase of 10% in the input factors of the estimated function will lead to a 13.2%, 11.3%, and 11.6% increase in honey production for the first and second capacity groups and the full sample, respectively. The total production elasticity for the third capacity group is 0.899. Therefore, the proportional change in output is less than the change in input, which indicates decreasing returns to scale for sample apiaries with 200 beehives or more.
The results of the SFPF (using MLE) shown in Table 4 for the full study reveal the high relative importance of the number of bee- hives ($X_2$) for honey production, followed by the quantity of sugar syrup ($X_3$), years of experience ($X_4$), quantity of antibiotics and vaccines ($X_5$), and working hours ($X_6$). For the first capacity group, the results show the relative importance of the production factors. The quantity of sugar syrup ($X_3$) is most important, followed by the number of beehives ($X_2$) and the quantity of antibiotics and vaccines ($X_5$). For the second capacity, the number of beehives ($X_2$) is most important, followed by the quantity of sugar syrup ($X_3$), the quantity of antibiotics and vaccines ($X_5$), and working hours ($X_6$). For the third group, the number of beehives ($X_2$) and years of experience ($X_4$) are most important, followed by the quantity of sugar syrup ($X_3$), the quantity of antibiotics and vaccines ($X_5$), and working hours ($X_6$). The results of the MLE and the OLS models showed the same signs for the coefficients of the production variables, and the variables had the same statistical significance levels in each production group.

The lambda value ($\lambda$) represents the standard deviation of the technical inefficiency factor $\sigma(u)$ to the random error factor $\sigma(v)$. The values of $\lambda$ are 1.15, 1.24, 1.78, and 1.06 for the first, second, and third capacity groups and the full sample, respectively. This means that the effect of the technical inefficiencies factor exceeds the effect of the random error factor in the deviation from the optimal annual production. These values suggest that beekeepers are failing to follow best practices and to fully exploit the available production factors, as the actual annual honey production does not match the optimal one. This situation is known as the “inefficiency of technical production” and is not due to random causes that cannot be controlled by beekeepers.

The estimated values of $\theta$ are 0.57 for the first capacity group, 0.60 for the second, 0.76 for the third, and 0.53 for the full sample. This means that, for those groups, 57%, 60%, 76%, and 53% of the difference between actual annual production and optimal annual production is due to technical inefficiencies, while the rest of the difference is due to random factors beyond the control of the beekeepers. This result shows the importance of increasing beekeepers’ expertise in order to improve the operational efficiency of their apiaries. The study can estimate the TE of the apiaries using the estimated percentage of the technical production inefficiency factor $u$, which is 22% for the first capacity group, 18.6% for the second, 14% for third, and 17.22% for the full sample. The technical efficiency levels are thus between 86% and 78%. Therefore, the same level of production can be achieved by reducing the production variables by 22% to 18.6%, depending on the production capacity level.

4.2.2. Amount of loss in annual production and net return due to technical inefficiency

We can compare losses in annual production due to technical production inefficiency, as well as the difference between optimal and actual annual honey production totals at the bee hive, apiary, and production capacity levels in Fayoum Governorate. Table 5 shows that the annual production shortfall due to inefficiency in technical beehive production is 1.04 kg, 1.26 kg, 1.23 kg, and 0.91 kg for the full sample and the first, second, and third production capacity groups, respectively. Moreover, the annual production shortage at the apiary level is 141.9, 72.7, 146.9, and 201.7 kg for the full sample and the first, second, and third production capacity groups, respectively. Furthermore, the total annual production shortfall due to inefficient technical production is about 8.7 tons, 1.8 tons, 3.1 tons, and 3.8 tons for the full sample and the first, second, and third groups respectively. Therefore, the optimal annual production amount for the full sample was about 59 tons, 17% more than the actual amount. In addition, the optimal annual production amounts for the first, second, and third production capacity groups were 10.1 tons, 18.5 tons, and 31.2 tons, which exceeds the actual production by 22%, 20%, and 14%, respectively. The loss in annual net revenue due to technical inefficiency is estimated at 397,000, 77,000, 143,000, and 184,000 Egyptian pounds for the full sample and the first, second, and third production capacity groups, respectively. It is thus important to
increase the technical production efficiency of honey production projects through worker training, thereby increasing production capacity in Fayoum Governorate as a whole.

Based on its results, this study makes the following recommendations to enable honey projects to generate the optimal production amounts and net revenue. First, it is important to increase the technical production efficiency of honey production projects and ensure optimal production. The Ministry of Agriculture could train agriculture extension agents in how to guide and educate beekeepers and apiary workers. Second, we recommend increasing the production capacity of honey production projects in order to enhance efficiency and improve productivity. Third, beekeepers should follow best practices and exploit all available production elements, which should improve technical production efficiency and increase honey production. Fourth, the size of honey production projects in Fayoum Governorate should be increased to move to the economical production stage. Fifth, apiaries should employ workers with long experience in honey production projects to increase production efficiency. Sixth, seminars and training courses should be delivered to young graduates in order to explain the economic importance of honey production projects. Finally, medicines should be provided to prevent diseases and pests that can impede honey production.

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Table 5

| Production Level | Study Sample | First Capacity | Second Capacity | Third Capacity |
|------------------|--------------|----------------|----------------|---------------|
| **1- Apiary level** |              |                |                |               |
| Average of actual production (kg) | 6.13 | 5.71 | 6.17 | 6.52 |
| Decrease in production amount due to technical inefficacy | 1.04 | 1.26 | 1.23 | 0.91 |
| **2- Apiary level** |              |                |                |               |
| Number of apiaries | 65 | 25 | 21 | 19 |
| Average of actual production (kg) | 835 | 330.4 | 734.4 | 1440.6 |
| Decrease in production amount due to technical inefficacy | 141.95 | 72.69 | 146.88 | 201.68 |
| Average of optimal production (kg) | 976.95 | 403.09 | 881.28 | 1642.28 |
| **3- Full sample level (all apiaries)** |              |                |                |               |
| Average of actual production (tons) | 51.1 | 8.3 | 15.4 | 27.4 |
| Decrease in production amount due to technical inefficacy | 8.7 | 1.8 | 3.1 | 3.8 |
| Average of optimal production (tons) | 59.7 | 10.1 | 18.5 | 31.2 |
| Average total cost for actual production * | 1,563.1 | 267.2 | 471.6 | 791.6 |
| Average total return for actual production * | 2,337.2 | 354.3 | 716.1 | 1,314.9 |
| Total return for optimal production * | 2,734.6 | 432.0 | 859.3 | 1,499.0 |
| Average net return for actual production * | 774.1 | 86.9 | 244.5 | 523.3 |
| Net return for optimal production * | 1,171.5 | 164.8 | 387.7 | 707.4 |
| Difference between actual and optimal return * | 397.33 | 77.90 | 142.22 | 184.09 |

* Thousand Egyptian pounds.