Econometric modeling of production resources usage in dairy cattle breeding

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Abstract. To solve the problem of maximizing the efficiency of multifactorial production of dairy products, a production function of the Cobb-Douglas type is proposed, in the identification of which indicators characterizing the use of land, labor and capital are selected as cost categories. Based on the study of the performance of 126 agricultural organizations of the Krasnodar Territory (Russia) for 2016–2018, panel data were formed in order to build panel regression models, which made it possible to take into account the effect of time, explaining the dynamics of the states of a set of economic entities. The regression model with deterministic individual effects in the form of a production function of the Cobb-Douglas type, which characterizes the influence of labor, land and financial resources on the cost of products of the studied sub-industry, was recognized as statistically significant. Based on the results of the calculations, the main determinants of the development of dairy cattle breeding were identified and the reasons that hinder it were identified.

1. Introduction
The main tasks of Russia in the context of sanctions and the implementation of the import substitution program include the stable provision of the population with domestically produced food. A special place in the food market of the country is given to dairy products, which traditionally have one of the primary values in the diet of the population. An increase in the volume of its production is possible only on the basis of an increase in the efficiency of the functioning of dairy cattle breeding, which, for a number of objective reasons, is currently experiencing a protracted crisis.

Econometric modeling can be used to identify and describe the most significant links of economic processes in dairy farming and to assess the parameters of production of products in this sub-industry. The resulting regression models in the form of production functions will be useful in determining the efficiency of the use of resources and the feasibility of their further involvement in production. The indisputable advantage of such models is the comparative simplicity of the functional dependencies described by them, with a fairly high level of practical universality.

The purpose of this study is to obtain econometric models that allow assessing the existing level of raw milk production and identifying areas for further increasing its efficiency in the Krasnodar Territory.
2. Production functions in agro-economic research

2.1. Formation of a methodology for constructing production functions

As the experience of developed countries shows, the task of maximizing production efficiency must be solved taking into account the available resources and restrictions from the external environment. The most famous approaches to the analysis of efficiency are DEA (data development analysis) and SFA (stochastic frontier analysis). Since real socio-economic processes are, as a rule, stochastic in nature, the second of them is more often used, in which the final conclusions regarding the effectiveness of individual economic entities or industries (sub-sectors) are made on the basis of a predetermined specific model. As the latter, many modern researchers use various modifications of the production function.

The first successful experience of constructing a production function as a regression equation based on statistical data was obtained by American scientists - mathematician D. Cobb and economist P. Douglas in 1928.

The function originally proposed by them was as follows:

\[ Y = AK^\alpha L^\beta, \]  
where \( Y \) — volume of products; \( K \) — production assets (capital); \( L \) — labor costs; parameter \( A > 0 \) — coefficient that reflects the level of technological productivity and does not change in the short term; indicators \( \alpha \) and \( \beta \) - coefficients of elasticity of output (\( Y \)) by the factor of production: by capital and labor, respectively. When the price of capital is equal to its marginal product, and the price of labor is equal to the marginal product of labor, \( \alpha \) and \( \beta \) determine the proportion in which labor and capital receive their remuneration for the product created.

Then the share of capital in income is \( \alpha Y \), and the share of labor in income is \( \beta Y \). Equality \( \alpha + \beta = 1 \) reflects consistent returns to scale.

Later, P. Douglas and his followers changed the constraint according to which the elasticity in the production function must add up to one, and the resulting power function, linear when taking the logarithm, became known as the Cobb-Douglas function [1].

The disadvantage of the original version of the Cobb-Douglas function was that it did not take into account the element of time and the “turnover” of capital. To take into account technical progress, a factor (of technical progress) is introduced into the Cobb-Douglas function

\[ Y = Ae^{\mu t} K^\alpha L^\beta, \]

where \( \mu \) — constant number characterizing the rate of development. As a result, the function takes a “dynamic” form:

\[ Y = Ae^{\mu t} K^\alpha L^\beta, \]  

For multivariate manufacturing, the Cobb-Douglas function looks like this:

\[ Y = A \sum_{i=1}^{n} X_i^{\alpha_i}, \]

Where: \( Y \) — volume of products, \( X_i \) \((i = 1, 2, \ldots, n)\) — costs of the resource of the \( i \)-th type.

The regression coefficients \( \alpha_i \) obtained by logarithm serve as the coefficients of the elasticity of production. The individual coefficients can be summed up in order to determine the coefficient of change in the scale of production \( \varepsilon \), which shows how many percent the output increases when the costs of all factors increase by 1%. An increase in the costs of all factors by 1% will cause an increase in output by 1% if \( \sum_{i=1}^{n} \alpha_i = 1 \) (constant efficiency). If \( \sum_{i=1}^{n} \alpha_i < 1 \), then there is a “falling” efficiency, while at \( \sum_{i=1}^{n} \alpha_i > 1 \) — “Increasing” efficiency [1].
2.2. Application of the methodology for constructing production functions in agriculture

The basis of the methodology for calculating production functions in agriculture, in particular in animal husbandry, was the early work of P. Douglas and his colleagues in the field of industry.

The earliest empirical calculations of production functions for farms were performed by E. Heddy on the basis of a random sample survey of 738 farms in Iowa in 1939. He obtained functions for both individual types of farms and for different areas of the state. At the same time, land, labor, energy and equipment, livestock and feed, operating costs were considered as cost categories. All indicators, as well as product output, were expressed in dollars. For calculations, the Cobb-Douglas function was used without restrictions imposed on constant elasticity indicators. In all cases, the sum of the elasticity coefficients turned out to be less than one, which indicates a decrease in the efficiency indicator. At the same time, management costs were not included in the model as a separate factor due to the lack of an objective unit of their measurement. If it were present, the results obtained would probably differ significantly among themselves.

In 1942, G. Tintner for 609 farms in Iowa received the Cobb-Douglas function, in which the product was measured in value terms, and the categories of costs were land, labor, farm improvement costs, easily realizable assets, working capital and current cash costs. All costs were measured in dollars, excluding land and labor, expressed in acres and months, respectively.

It should be emphasized that in the studies discussed above, the products of agriculture and animal husbandry were combined into one article. In addition, since the costs in the calculations were aggregated over time, and the sample was heterogeneous, there may have been a distortion of functions. Inaccurate measurement of costs also led to biases in calculations. At the same time, it was simultaneously recognized that these same limitations are inherent in other types of research in the field of farm management [1].

Specifically, for livestock production, the first work on the production function was published by E. Jensen and his co-authors in 1942. It examined the input-output balance of milk production. The results of this work were used to illustrate how deviations from standard feed rations should be in order to maximize profit per cow based on fluctuations in feed and milk prices. The authors calculated the marginal feed efficiency for farms with different levels of animal milk productivity. This work played an important role in changing views on the nature of the production function in dairy farming [1, 2].

Since mathematical modeling based on the construction of production functions can reveal the most significant connections between economic objects and phenomena and evaluate production parameters, it is on it that the analysis of the use of production resources in dairy cattle breeding in the Krasnodar Territory is based, the results of which are described below.

3. Econometric modeling in the dairy industry

3.1. Characteristic data

The source of the initial information for the analysis of panel data was the empirical base based on the statistical reporting of 126 agricultural organizations of the Krasnodar Territory for 2016–2018. The resultant indicator \(Y\) was the cost of milk produced in current prices per cow (thousand rubles). This choice of the dependent variable is dictated by the possibility to take into account not only the quantity, but also the quality of the milk produced.

11 indicators were selected that characterize the efficiency of using the main production resources in dairy farming, which can be conditionally divided into three groups: labor, land, costs and capital.

The list of indicators characterizing the efficiency of the use of labor resources:

- \(X_1\) - direct labor costs per cow, man-h;
- \(X_2\) - number of cows per one milking machine operator, head;
- \(X_3\) is the average monthly salary of one milking machine operator, rubles.

The list of indicators characterizing the efficiency of the use of land resources:
The list of indicators characterizing the efficiency of capital and cost use:

- **X4** - yield of forage per 100 hectares of agricultural - x. land, c feed. units;
- **X5** - livestock concentration per 100 hectares of agricultural land, head;
- **X6** - production costs per 100 hectares of agricultural land, thousand rubles.

In addition, the following variables were used in the calculations:

- **subsidies** is a dummy variable that takes the value 1 if there are subsidies for the development of dairy farming, and the value 0 otherwise.
- **d2016** is a dummy variable that takes a value of 1 in 2016 and a value of 0 in other years;
- **d2017** is a dummy variable that takes a value of 1 in 2017 and a value of 0 in other years;
- **d2018** is a dummy variable that takes a value of 1 in 2018 and a value of 0 in other years.

In order to level the asymmetry of the distribution of econometric values, a transition was made to their logarithms, which made it possible to consider the distribution of the regression residuals to be close to normal. For the econometric analysis, the STATA 14 package was used [3-11]. The results obtained for constructing the main types of regressions for the dependent variable Y are shown below.

### 3.2. Results and discussion

#### 3.2.1. End-to-end regression

End-to-end regression does not take into account panel data structures. It was considered for all years, and the estimate of its parameters in the STATA 14 package after discarding insignificant coefficients using the least squares method is given in Table 1.

| Variable | Coefficient elasticity | Standard error |
|----------|------------------------|----------------|
| lnX3     | 0.075\(^a\)            | 0.0340         |
| lnX5     | 0.1173\(^a\)           | 0.0293         |
| lnX6     | -0.1082\(^a\)          | 0.0319         |
| lnX8     | 0.130\(^a\)            | 0.0582         |
| lnX9     | 0.871\(^a\)            | 0.0386         |
| subsidies| 0.098\(^a\)            | 0.0293         |
| d2018    | 0.394\(^a\)            | 0.0657         |
| const    | -0.2841                | 0.3732         |

Adjusted coefficient of determination 0.7105

\(^a, b, c\) — significance levels 1%, 5% and 10%, respectively.

In the course of the analysis, it was found that the production costs per cow have the greatest influence on the effective trait. This circumstance confirms the need and importance of further consistent intensification of the dairy cattle breeding sub-sector in large and medium-sized agricultural organizations of the Krasnodar Territory. The high value of the adjusted coefficient of determination indicates the correctness of the choice of factor signs and the adequacy of the analysis.
3.2.2. Regression “between”. The regression “between” is also estimated using the usual least squares method and is considered in terms of the values of the studied factors of dairy production, averaged over time.

The regression between $=0.6870$ characterizes the quality of the fit of the regression model and shows that in this case, the change in the time-average indicators had a more significant effect on each variable than the temporal fluctuations of the studied milk production factors relative to the average, although most of the regression coefficients turned out to be statistically insignificant. The estimation of the parameters of this model is given in table 2.

| Variable | Coefficient elasticity | Standard error |
|----------|------------------------|----------------|
| $ln X3$  | 0.034                  | 0.0597         |
| $ln X5$  | 0.126$^c$              | 0.0727         |
| $ln X6$  | $-0.114$               | 0.0865         |
| $ln X8$  | 0.130                  | 0.1127         |
| $ln X9$  | 0.860$^a$              | 0.0815         |
| subsidies| 0.201$^a$              | 0.0656         |
| $d2018$  | –                      | –              |
| $const$  | $-0.289$               | 0.6796         |

$R$-$sq \text{ between}=0.6870$

$^a, b, c$ — significance levels 1%, 5% and 10%, respectively.

3.2.3. Regression within. The within regression allows estimating the coefficients of a regression model with deterministic individual effects (FE) (table 3).

The quality of the regression fit is good because the regression within value is quite high (0.7582). Consequently, interindividual differences were more pronounced than dynamic ones, which indicates the need to take into account individual effects and allows us to put forward a hypothesis against the end-to-end assessment model. The resulting contradiction between the models will be resolved below using the ideology of testing statistical hypotheses.

| Variable | Coefficient elasticity | Standard error |
|----------|------------------------|----------------|
| $ln X3$  | 0.121$^a$              | 0.0431         |
| $ln X5$  | 0.092$^b$              | 0.0384         |
| $ln X6$  | $-0.112^a$             | 0.0343         |
| $ln X8$  | 0.131$^c$              | 0.0689         |
| $ln X9$  | 0.886$^a$              | 0.0457         |
| subsidies| 0.039                  | 0.0276         |
| $d2018$  | 0.395$^a$              | 0.0613         |
| $const$  | $-0.623$               | 0.4593         |

$R$-$sq \text{ within}=0.7582$

$^a, b, c$ — significance levels 1%, 5% and 10%, respectively.

Studies have shown that during the period under review, on average for the studied population of agricultural organizations, the cost of milk produced per cow increased by 39.5%. At the same time, the most significant determinant influencing the performance indicator was the factor $X9$ (production costs per cow). With its increase by 1%, the cost of milk per head grew by an average of 0.886%. A 1% increase in the average monthly wage for milkers contributed to an increase in the value of milk received from one cow by 0.121%. This circumstance confirms the need to improve the system of material incentives for personnel in order to increase the level of their labor productivity in the sub-industry. An increase in the concentration of livestock in the main herd by 1% led to an increase in the cost of milk...
from one cow by 0.092%. Consequently, in the existing realities, a higher milk productivity of animals and the quality of raw milk obtained are characteristic of large farms in the region with developed dairy cattle breeding and a high level of intensification of production.

An increase in the rate of calf yield per 100 cows and first-calf heifers by 1% led to an increase in the cost of milk per cow by an average of 0.131%. It should be noted here that the organization of year-round calving allows you to get more milk per head. At the same time, the fertility of animals can decrease due to an increase in the duration of the service period and an imbalance in the diets of pregnant dry cows. The latter demonstrates the importance of paying close attention to the efficiency of feed use and increasing their energy value. An increase in subsidies for the development of dairy cattle breeding by 1% led to an increase in the level of the resulting indicator by 0.039%, which proves the need for state support for the sub-industry. On the contrary, an increase in production costs per 100 hectares of agricultural land in the studied set of organizations led to a decrease in the cost of milk produced per cow by 0.112%, which can be explained by the priority of the development of the crop production industry in the region's farms, namely, the production of winter wheat grain as the basis of export. Krasnodar Territory.

3.2.4. Regression with random effects. Regression with random effects was found to be significant. This illustrates the great importance of Wald's statistics: \( \text{Wald chi2 (7)} = 1061.22 \) (table 4). The regressors of this model are not correlated with unobservable random effects, which is confirmed by the value of the expression \( \text{corr}(u_i, x) = 0 \) (assumed).

Econometric evaluation of the regression model with random effects also confirmed the presence of a statistically significant influence of the factorial features selected for analysis on the effective indicator.

| Table 4. Results of an econometric estimation of a random effects regression model for lnY. |
|---------------------------------------------------------------|
| Variable  | Coefficient elasticity | Standard error |
| ln X3     | 0.093\textsuperscript{a} | 0.0342          |
| ln X5     | 0.110\textsuperscript{a} | 0.0277          |
| ln X6     | −0.107\textsuperscript{a} | 0.0277          |
| ln X8     | 0.126\textsuperscript{b} | 0.0556          |
| ln X9     | 0.876\textsuperscript{a} | 0.0375          |
| subsidies | 0.068\textsuperscript{a} | 0.0262          |
| d2018     | 0.386\textsuperscript{a} | 0.0569          |
| const     | −0.447               | 0.3747          |

\( \text{Wald chi2(7)}=1061.22 \)

\( \text{a}, \text{b}, \text{c} — \text{significance levels 1\%, 5\% and 10\%, respectively.} \)

Consider a pairwise comparison of the resulting models for Y - the cost of milk produced per cow - in order to choose between three main regressions (end-to-end, regression with fixed individual effects, and regression with random individual effects). The evaluation of the regression between was of an auxiliary nature.

The fixed effects model was compared with the Wald run-through regression model. Received: \( F \text{ test that all } u_i=0: F(133,261) = 2.80, \text{Prob } > F = 0.0000. \) Since the significance level does not exceed 0.01, the null hypothesis that all individual effects are equal to zero is rejected in this case, and, therefore, the fixed effects model is better suited to describe the data than the end-to-end regression model.

The Breusch and Pagan test allows the comparison of the end-to-end regression model with the model with random effects. Calculations have shown that with a significance level of no more than 0.01, the null hypothesis of the absence of a random individual effect is rejected, i.e., a regression model with random effects describes the available data better than a simple (end-to-end) regression model.

Further, based on the Hausman test, a choice was made between FE and RE models (fixed effects model and random effects model). Studies have shown that the model with fixed individual effects...
allows better description of the initial data, which is objectively due to the constant composition of agricultural organizations.

So, pairwise comparison of the obtained models made it possible to unambiguously single out as the most adequate model with fixed effects. At the same time, according to the analyzed data, the initially put forward hypothesis about a statistically significant effect on the effective factor (the cost of milk produced per cow) of all the characteristics included in the model is confirmed.

4. Conclusions

As a result of an econometric study based on panel data from 126 agricultural organizations in the Krasnodar Territory, it was found that the most statistically significant factors affecting the value indicator characterizing the development of dairy cattle breeding in the region were the following: production costs per head; output of calves per 100 cows and first-calf heifers; availability of subsidies for the development of the sub-sector. This proves the need for further intensification of dairy cattle breeding and its full support from the state.

At the same time, as practice shows, the measures taken are not enough to stabilize the situation in this sector of social production. The main reasons for stagnation in the sub-industry are the underdevelopment of domestic breeding activities, a high degree of physical and moral deterioration of equipment, imbalance in feed rations and the lack of an opportunity for many farms to switch to year-round feeding of the same type. One can also note low levels of staff motivation and investment attractiveness, long payback periods for projects for the construction, reconstruction and modernization of dairy cattle breeding facilities, as well as the poor financial condition of agricultural companies and, as a result, high risks of agricultural lending.

It should be added that the use of econometric modeling has good prospects not only for determining the efficiency of resource use in dairy cattle breeding, but also for predicting gross milk production for a given amount of resources and assessing the reality of fulfilling planned targets.

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