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HURTOVYI Yurii
https://orcid.org/0009-0005-4047-140X
Postgraduate Student
of the Department of Economic Modeling,
Accounting and Statistics
Oles Honchar Dnipro National University
72, Nauky Ave., Dnipro, 49045, Ukraine
hurtovyi_yu@365.dnu.edu.ua

MODELING OF UKRAINE'S DAIRY PRODUCTION

Ukraine's dairy industry, being in a state of crisis, has faced an aggravation of existing problems due to the full-scale invasion of the russian federation. One of the most substantial factors negatively affecting milk production volumes is the constant reduction in the number of cows, which was especially accelerated due to the entry into force of legislative requirements for the safety and quality of dairy products in 2019. Even though the established norms were supposed to harmonize Ukrainian production standards with European ones, most of the raw milk still does not meet the criteria of extra-quality, remaining unsuitable for export to EU markets. Given the partial lack of statistical data from 2010 to 2023, the research aim is to analyze and forecast resource and technological indicators, as well as behavioral and technological characteristics of households, which affect the increase in milk production volumes and high-quality milk. A hypothesis concerning a statistically significant relationship between the indicators that determine the conditions of dairy industry and the number of cows has been put forward. To test it, linear regression models were constructed. In addition, time series analysis methods (Holt, Brown, ARIMA models) were used to obtain forecast values. Based on the confirmed relationships, the reduction in the number of livestock leads to a decline in the feed base and material and technical equipment, the pace of modernization of which is insufficient to meet the needs of the growing herd without losing its productivity. In particular, milking installations and machines cannot fully service the number of

ГУРТОВИЙ Юрій
https://orcid.org/0009-0005-4047-140X
аспірант кафедри економічного моделювання,
обліку та статистики
Дніпровського національного університету
імені Олеся Гончара
просп. Науки, 72, м. Дніпро, 49045, Україна
hurtovyi_yu@365.dnu.edu.ua

МОДЕЛЮВАННЯ МОЛОЧНОГО ВИРОБНИЦТВА В УКРАЇНІ

Молочна галузь України, перебуваючи у кризовому стані внаслідок повномасштабного вторгнення рф, зіткнулась із загостренням існуючих проблем. Одним з найголовніших факторів, що негативно впливає на обсяги виробництва молока, є постійне скорочення кількості корів, яке особливо прискорилось через набуття чинності законодавчих вимог до безпечності та якості молочної продукції у 2019 р. Попри те, що встановлені норми мали гармонізувати українські стандарти виробництва з європейськими, більшість молока все ще не задовольняє критерії екстраякості, залишаючись непридатним для експорту на ринки країн ЄС. З огляду на часткову відсутність статистичних даних у 2010–2023 рр., метою статті є аналіз та прогнозування ресурсних і технологічних показників, а також поведінково-технологічних характеристик домогосподарств, що впливають на збільшення обсягів виробництва молока високої якості. У ході дослідження висунуто гіпотезу, що між показниками, які визначають умови ведення молочного скотарства, та поголів'ям корів є наявний статистично значущий взаємозв'язок. Для перевірки гіпотези побудовано лінійні регресійні моделі. Окрім цього, для отримання прогнозних значень використано методи аналізу часових рядів (моделі Хольта, Брауна, ARIMA). На основі підтверджених взаємозв'язків встановлено, що зменшення поголів'я призводить до скорочення кормової бази та матеріально-технічного оснащення, темпів модернізації якого недостатньо для забезпечення потреб зростаючого стада без втрати його продуктивності. Зокрема, доїльні установки та апарати не можуть повністю

cows at the enterprises, which will expand by 1 thousand heads. In contrast, the number of milk purifier-coolers grew due to the enterprises' need to meet quality and safety requirements. Households are characterized by technological degradation: according to the forecast, only 1 in 10 households will have a milk separator in 2023. In addition, they will most likely need to make savings for 2–3 years to purchase a separator and a milk quality analyzer. The results obtained can be used to forecast the development of the dairy industry and design a state agricultural policy with a justified priority of state support measures.

Keywords: dairy industry, economic security, the number of cows, forecasting, regression analysis, time series models.

обслуговувати на підприємствах поголів'я корів, що збільшиться на 1 тис. голів. На противагу цьому кількість очищувачів-охолоджувачів молока зростає внаслідок прагнення підприємств відповідати вимогам якості та безпечності. Для домогосподарств характерна технологічна деградація: у 2023 р. молочні сепаратори наявні лише в 1 з 10 домогосподарств. Окрім цього, для придбання сепаратора та аналізатора якості молока домогосподарствам, найімовірніше, знадобиться заощаджувати протягом 2–3 років. Отримані результати можуть бути використані для прогнозування розвитку молочної галузі та розробки державної аграрної політики з обґрунтованою пріоритетністю заходів державної підтримки.

Ключові слова: молочна галузь, економічна безпека, кількість корів, прогнозування, регресійний аналіз, моделі часових рядів.

JEL Classification: C53, O13, Q18.

Introduction

Dairy production is one of the areas of agriculture that plays an essential role in ensuring Ukraine's economic security, entering its production and food components in the form of separate indicators. However, despite the intensification of production systems in livestock farming due to the expansion in demand for dairy products observed on the world market, negative trends are observed in dairy cattle breeding in Ukraine. This situation is associated with a stable drop in the number of cows. Possessing favorable natural and climatic conditions for the development of dairy agribusiness, milk production in Ukraine is constantly decreasing, and most of it does not meet the requirements of extra-quality, suitable for export to world markets.

Kyenko and Symchuk (2019), comparing European and Ukrainian milk quality standards, concluded that the main reason for the low quality of raw milk in Ukraine is the failure to cool it immediately after milking, high bacterial contamination, and the number of somatic cells, which exceed the European thresholds by 4 and 1.6 times, respectively. In addition, the study indicated that Ukrainian milk was considered unsuitable for processing at European enterprises due to its low-fat content (3.4% in Ukraine compared to 4.2% in the EU) and protein content (while the norm is set at 3.4% in Europe, in Ukraine its actual content was 3.0%). It weakens the country's foreign economic security, increasing the gap between actual and potential foreign exchange earnings that could be received in the case of the sector's prosperity.

According to Cherednichenko and Pashchenko (2018), whose article focused on pinpointing the indicators that have the most significant impact on dairy production and the level of population provision, the constant reduction in livestock is one of the most important factors that has negative consequences. In turn, Hladiy and Prosovych (2022), who had a similar goal and studied the development trends of the dairy industry, additionally

highlighted among the difficulties the insufficient amount of financial resources that would allow producers to cover current costs, the dominant share of households in the structure of milk produced, and the inability of products to meet the requirements and standards of EU member states, which is currently the chief market due to the russian invasion. In addition to the fact that the position of livestock is significantly worse than that of crop farming, the authors emphasized that dairy farming is its most problematic direction.

Tsvihun and Tsvihun (2023) also focused on the aggravation of the crisis in the dairy sector due to armed aggression, noting that the loss of considerable breeding stock is one of the issues that must be eliminated to ensure the country's food security. Under these conditions, according to the authors, the optimal way to increase production is such an intensive factor as cows' milk productivity. A similar thesis about herd productivity as an intensive factor of gross milk production in the regions was noticed in the study by Boltianska (2021). However, the author detailed that it is also influenced by the fullness of feeding, housing conditions, and both environmental and extensive production indicators. Despite the contribution of the research, the authors focused on the regional analysis of the dynamics of milk production volumes, cow population, and average annual milk yield, not sufficiently assessing the state of the resource and technical securement, which are crucial circumstances for manufacturing high-quality dairy products.

Kolosha (2018), defining the economic efficiency of milk production as the volume of gross output per head, also supported the view that it is much more necessary to analyze the factors that impact the achieved level of cows' productivity or production efficiency. According to the author, low productivity of cows is considered the result of underdevelopment and imbalance of the feed base, which is often used not for milk formation but to support the basic life of the herd, most likely due to a lack of financial and material resources. However, the study did not detail the sources of feed supply formation or its quantitative parameters – the area of hayfields and pastures or the harvest volumes of crops, which limits the possibility of analyzing the state of the feed base as an indicator of milk production in Ukraine.

Bondarenko and Li (2025), studying the problems of the dairy industry development as a result of the war in Ukraine, which complicated the situation and added new obstacles, also identified the growth in the cost of feed due to the increase in the price level of grain and oilseed crops as an indicator in dairy agribusiness. Bednarski and Kupczyński (2024) believed that improving feeding, its composition, or proportions of components can increase milk productivity quite quickly. However, when studying the factors that affect the cows' productivity, according to the authors, technological indicators, in particular hygiene and efficiency of milking cows, as well as ensuring further milk processing, are no less important than nutrition and housing conditions.

The results of the study by Sokoliuk et al. (2022) proved that organizational and technological measures (comfortable housing conditions, proper feeding, and efficient milking of cows) are promising since increasing production volumes, quality, and safety of dairy raw materials. Kulish (2020),

analyzing the impact of macroenvironmental factors on the dairy products market, also focused on both scientific and technical elements, identifying the low level of producers' technological equipment as a threat to the dairy industry. In this context, assessing the dynamics and relationship between the number of cows and the level of producers' provision with milking installations, machines, separators, milk coolers, and feed dispensers for cattle and manure belt and chain conveyors is a reasonable approach to analyzing technological facilities.

The need to estimate the condition and availability of technological tools is reinforced by the analytical monitoring of Uzhva (2024), in which the author emphasized the need for re-equipment with modern milking machines, separators, and milk quality analyzers. Although her conclusion did not consider the necessity for cattle feed dispensers and manure removal conveyors, which not only create high-quality housing conditions but also contribute to compliance with sanitary and hygienic standards, the author rightly noted the importance of these facilities for achieving compliance of Ukrainian products with accepted European quality and safety standards.

The quality of Ukrainian dairy products is an indicator that determines the dairy industry's development, as it affects its competitiveness and sales markets. According to Voliak and Galitska (2018), the low quality of raw milk, which is produced by households in non-sterile conditions with a lingering collection and transportation process, is also one of the biggest challenges. Although the authors justified this situation by low average sales prices, which do not motivate households to modernize and ensure high-quality dairy products, their study did not present behavioral and technological characteristics, in particular, the use of separators by households, sanitary control of milk quality, veterinary inspection or treatment of livestock premises, which would allow for a more comprehensive understanding of the root causes for the low-quality raw milk.

In this context, it is worth noting that new requirements for the safety and quality of milk and dairy products came into force in Ukraine on July 12, 2019, which was aimed at harmonizing Ukrainian and European standards (Government Office for the Coordination of European and Euro-Atlantic Integration, 2019). Since it concerned all market operators, the approved requirements excluded the possibility of second-grade milk, produced mainly by households, entering processing plants. Therefore, the analysis of resource and technological indicators of dairy production, necessary to ensure the competitiveness of Ukrainian dairy products on the global market, takes on particular importance.

Thus, since the studies above did not focus on the relationships between individual sources of cattle feed base, types of technological equipment, behavioral and technological characteristics of households, and the number of cows, the decrease of which directly affects the reduction in milk volumes, further empirical assessments and modeling of factors that potentially affect milk volumes are necessary.

However, despite the outlined scientific need, conducting a full-fledged analysis considering the consequences of a full-scale invasion is

complicated by the partial lack of up-to-date statistical data starting from 2022. According to Derzhstat (2023), business entities during the martial law period and within three months after its end have the right not to submit statistical or financial reporting to protect their interests. Given this, the State Statistics Service of Ukraine has also suspended the publication of individual statistical information. In addition, to reduce the reporting workload, starting in 2020, statistical observation of the agricultural machinery availability has a low frequency, and respondents are required to report only once every five years (State Statistics Service of Ukraine, 2022a). It necessitates the utilization of models to restore data and make forecast estimates based on the identified relationships.

The hypothesis assumed that factors affecting the development of dairy production in Ukraine and the volume of high-quality milk are statistically dependent on the number of cows kept in households, agricultural enterprises, or the country in general.

The research aim is to model resource and technological factors that potentially influenced the development of dairy production in Ukraine in 2010–2023 and to restore absent statistical data by building time series or regression models, which estimate the dependence of indicators on the number of cows.

Statistical yearbooks that have been published by the State Statistics Service of Ukraine served as an information base. It contained data on the social and economic state of agriculture in Ukraine and its resource indicators. Modeling of resource and technological indicators, the time series of which is not covered by disseminated data, was carried out using single-factor regression models 1:

$$y = \beta_0 + \beta_1 x + \varepsilon, \quad (1)$$

where: y – the value of a dependent resource or technological indicator;
x – the number of cows;
β_0, β_1 – estimated parameters of the linear regression model;
ε – random error.

Due to the detected sharp jumps in the dynamics of the number of milk coolers and feed dispensers for cattle, a dummy variable ($Dummy$) was included in the models starting in 2018, which considered the effect of external circumstances and took on the value 1, if $t \geq 2018$. Otherwise, $Dummy = 0$, which is presented in formula 2:

$$y = \beta_0 + \beta_1 x + \beta_2 Dummy + \varepsilon, \quad (2)$$

where: β_2 – estimated structural gap parameter.

The criterion for an acceptable model reliability level was the value of the coefficient of determination (R^2), based on which the model has moderate ($R^2 > 0.5$), high ($R^2 > 0.7$), or very high ($R^2 > 0.9$) explanatory power and the F-test, the values of which confirm the statistical significance of the constructed dependence ($Sig.F < 0.05$). Interpretations of the explanatory

power of the constructed models were carried out according to the Chaddock scale, presented in the study by Mitryasova et al. (2021). The criterion for an acceptable model accuracy level was the mean percentage error ($MAPE$), which should not exceed 5% to ensure high forecast accuracy, but $MAPE < 10\%$ was also considered satisfactory. In addition, statistical characteristics were the standard error of the model estimate (Std. error), which shows how much the actual values are scattered around the regression line on average and is used for constructing confidence intervals (95%), and the maximum percentage error ($MaxAPE$), which is an indicator of marginal accuracy.

If at least one of the established conditions was not satisfied ($R^2 < 0.5$, $Sig.F > 0.05$ or $MAPE > 10\%$), time series models were built using IBM SPSS 25, namely Brown (exponential smoothing that considers the trend), Holt (modification of exponential smoothing that considers both the level and the trend components) and low-order ARIMA models to achieve greater explanatory power and accuracy compared to regression models with the number of cows as an independent factor.

If none of the models were acceptable, an alternative way to build a forecast was a univariate regression model with time t as the independent variable, which was used to forecast the share of households using veterinary inspection (Model 20.2).

Given the large number of models and the auxiliary nature of the forecast, a limitation of the approach is the lack of autocorrelation analysis of residuals, which, however, should be eliminated in further studies that will focus on modeling the relationships between several factors and the volume of extra-quality or higher-grade milk in 2010–2023.

The main part of the study consists of four interconnected sections. The first section forecasts dairy production indicators based on regression models in which the number of cows is the independent variable. It also provided an economic interpretation of the coefficients obtained. The second section contains models that confirmed the statistical dependence of production indicators of enterprises on livestock size, considering the structural gap. The third section covered the indicators of enterprises' dairy production, but the forecast of their dynamics is based on time series models. However, their relationships with the number of cows are non-random and statistically significant. The fourth section analyzes the behavioral and technological characteristics of dairy production in households, for which the hypothesis of statistical dependence on livestock size was partially confirmed.

1. Assessment of the dependence of resource and technological indicators of dairy production on the number of cows: forecasting based on regression models

As a result of the forecasting of indicators that have a potential impact on the development of dairy production in Ukraine, the hypothesis of a high level of dependence of indicators on the total number of cows or their number kept at enterprises and households was confirmed. The single-factor

regression models presented in *Table 1* are characterized by moderate (Models 5–7), high (Models 3–4), and very high (Models 1–2, 8–9) explanatory power since the variation in the number of cows explains from 57% to 97% of the variation in the corresponding dependent variables. It indicates the decisive role of livestock in studied agricultural processes.

Table 1

Statistical characteristics of single-factor regression models that confirmed the dependence on the number of cows and have high forecast accuracy

Model No.	Dependent variable, y	Independent variable, x_i	R^2	Std. Error	F	Sig.F*
1	Average annual milk yield per cow at enterprises (kg)	The number of cows at enterprises, x_1 (thousands of heads)	0.96	180.09	256.40	0.000
2	The value of feed costs of enterprises for agricultural production (million UAH)		0.97	2 798.48	303.87	0.000
3	Milking installation and machines (units)		0.71	313.39	19.25	0.002
4	Average annual milk yield per cow in households (kg)	The number of cows in households, x_1 (thousands of heads)	0.81	60.49	41.59	0.000
5	The amount of fodder spent on feeding cows and breeding bulls of the dairy herd (thousand centners of fodder units)	Total number of cows in the country, x_1 (thousands of heads)	0.64	1 148.73	16.21	0.003
6	Gross harvest of feed corn (thousand tons)		0.60	720.31	16.32	0.002
7	Gross harvest of annual and perennial grasses for hay (thousand tons)		0.57	286.45	14.42	0.003
8	Gross harvest of annual and perennial grasses for green fodder, hay, silage (thousand tons)		0.93	332.93	149.35	0.000
9	Gross harvest of hayfield (thousand tons)		0.93	88.74	138.10	0.000

* – p-value of the parameters of one-factor regression models is equal to their Sig.F.

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

Since the constructed Models 1–9 are statistically significant, based on the minimum values of $Sig.F \in [0.000; 0.002]$, and the $MAPE$ on average is 4.07%, not exceeding 6.81%, the established relationships are non-random. For these reasons, these models can be used for further economic interpretation, providing mainly high forecast accuracy (*Table 2*). Even though Model 8 has satisfactory accuracy ($MAPE = 6.81\% < 10\%$), its explanatory power is interpreted as very high ($R^2 = 0.93 > 0.90$), which makes it acceptable for achieving the set purpose.

Table 2

Forecast values of milk production indicators depending on the number of cows in regression models with high forecast accuracy

Model No.	Equation	*MAPE* (%)	*MaxAPE* (%)	Forecast period	Forecast value	Lower limit (95%)	Upper limit (95%)
1	$y = 12\,598.17 - 13.64x_1$	1.93	6.14	2011	4 561.67	4 169.29	4 954.05
2	$y = 169\,431.93 - 259.08x_1$	4.47	14.79	2021	59 607.07	53 509.71	65 704.42
				2022	59 425.71	53 328.36	65 523.06
				2023	67 301.80	61 204.45	73 399.16
3	$y = 5\,999.81 + 8.37x_1$	2.42	5.48	2020	9 670	8 987	10 353
				2021	9 547	8 864	10 230
				2022	9 553	8 870	10 236
				2023	9 298	8 615	9 981
4	$y = 5\,022.67 - 0.336x_1$	0.94	2.08	2011	4 336.53	4 204.73	4 468.32
5	$y = 18\,119.65 + 4.56x_1$	3.47	5.06	2021	25 743.51	23 240.63	28 246.38
				2022	25 155.65	22 625.78	27 658.53
				2023	24 284.36	21 781.48	26 787.23
6	$y = 2\,603.70 + 2.14x_1$	6.34	17.50	2023	5 504.10	3 934.67	7 073.53
7	$y = 2\,374.04 + 0.80x_1$	5.00	15.31	2023	3 457.64	2 833.52	4 081.76
8	$y = -2\,709.93 + 3.00x_1$	6.81	16.48	2023	1 344.41	619.02	2 069.80
9	$y = -311.24 + 0.77x_1$	5.23	23.01	2023	727.71	534.37	921.05

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

Based on the values of the model parameters, the average annual milk yield at enterprises demonstrates a negative relationship: with a growth in the number of cows by 1 thousand, the studied indicator decreases by 13.64 kg, probably due to the limited resources required to care for cattle. It can be the amount of resources, in particular investment or qualified workers, the lack of which leads to a lowering in individual care, or infrastructure (equipment, veterinary services) that is unable to handle such a load without loss of productivity.

This conclusion correlates with the opinion of Boltianska (2021), who emphasized that increasing the livestock population is a capital-intensive process, as it requires investments in technological equipment, updating the herd, and expanding the feed base. However, the author's conclusion about growth in average annual milk yield by 1 000 kg in the case of a reduction in the livestock by 1.7 thousand heads in 2016–2020 contradicts the results of the current study, raising some doubts given the lack of a confirmed statistical

relationship between the indicators in its article. Given that the calculation was based on a comparison of absolute increases in 2020 compared to 2016, without considering cause-and-effect connections in the intermediate periods, and the relationship between the change in the number of cows and their average annual yield appears arithmetically disproportionate, the author's results require a more substantiated method of quantitative data processing.

Although somewhat smaller, the number of cows in households has a similar effect on their average annual milk yield: with an increase in the number per 1 thousand heads, the yield declines by only 0.34 kg. It may be due to the fact that in the family model of care, cows are kept mainly in small groups (1–2), the number of which is determined by the family size that serves them, relying exclusively on their own resources.

If the number of cows at the enterprises grows by 1 thousand heads, the number of milking installations and machines (Model 3) rises by 8.37 units. It is consistent with economic logic and the need for more equipment to ensure regular milking. However, this growth rate may not be sufficient for the high-quality service of the new livestock and scaling up production.

Considering the above technical features, a milking machine can serve up to 18 cows per hour (DaMilk Dairy Assistance, n. d.), and a milking installation on average – up to 53 (Tavria State Agrotechnological University, Dmytro Motornyi, n. d.). Assuming a milking session at the enterprise lasts about three hours, then one machine serves 54 cows and one milking installation – about 159. Although under an optimistic forecast, growth in the number of installations of 8.37 units makes it possible to serve almost 1 331 cows, under the pessimistic forecast (with an increase in relatively less powerful milking machines by the same number) – only about 452 cows. Since the production process most likely involves a mix of milking machines and installations, their combination in a 1:1 ratio will allow serving the herd size of 891 heads if the equipment is not damaged or downtime.

Thus, based on the calculated value averaged between the optimistic and pessimistic forecast, it is possible to conclude that the pace of re-equipment of enterprises is insufficient in the case of an enlargement in the number of cows by 1 thousand heads. The results coincide with the conclusions about the limited capabilities of the infrastructure to serve the increased herd size, as evidenced by the reduction in their average annual milk yield due to the need to milk some of the cows manually. The lack of agricultural machinery was also highlighted by Kushnir (2019), who analyzed the impact of technical, energy capacities, and labor resources on the efficiency of farming enterprises' production. In addition, the study noted that even existing machinery does not guarantee high production volumes due to its physical and moral wear and tear.

In the case of an increase in the number of cows at enterprises by 1 thousand heads (Model 2), the value of feed costs of enterprises for

agricultural production decreased by UAH 259.08 million. It may point to economies of scale – optimization of the average cost curve due to more favorable contracts with suppliers or the introduction of an automated feeding system. The risk of reducing the volume of feed per cow is unlikely since, according to Model 5, with an increase in the livestock, the amount of fodder spent on feeding cows and breeding bulls of the dairy herd expands by 4560 thousand centners of fodder units. However, it does not mean that fodder volume is sufficient to ensure high-quality feeding and care.

Models 6–9 confirm the positive impact of livestock on the expansion of the feed base: in the case of an increase in the livestock by 1 thousand, the gross harvest of feed corn growths by 2 140 t, annual and perennial grasses for green fodder, hay, silage – by 3 000 t, annual and perennial grasses for hay – by 800 t, hayfield – by 770 t. The obtained non-negative parameters of the regression models are logical given the growing needs of the herd since corn is one of the main feed components, and green fodder, silage, and hay are considered vital elements of ensuring balanced nutrition, especially in the winter period. The relatively lesser volumes of hay and hayfield are explained by the fact that these parts of the fodder base are dry feeds, which have much lower moisture content than corn or green fodder and, therefore, a smaller tonnage even with the same nutritive value.

The obtained forecast values of average annual milk yields at enterprises (Model 1) and in households (Model 4) are consistent with the statement of Tsvihun & Tsvihun (2023) that the cows' productivity at enterprises is significantly higher, which, according to the authors, was due to their better opportunities to purchase highly productive cows, and high-quality feed, and ensure proper conditions for keeping livestock. In addition, according to the study by Bal-Prylypko et al. (2023), the cows' productivity in households is not only lower but also had a relatively small growth rate in 2010–2022, which was only 1% compared to 5.1% calculated for enterprises.

2. Assessment of the dependence of resource and technological indicators of enterprises' dairy production on the number of cows: forecasting based on regression models considering structural gaps or more economically justified parameters

As a result of the forecasting, the models presented in *Table 3* are characterized by high (Model 11.2) and very high (Model 12.2) explanatory power with R^2 values exceeding 0.80. However, the hypothesis of a statistically significant dependence of milk purifier-coolers and cattle feed dispensers on the number of cows at the enterprises was confirmed only after considering the structural gap observed in the dynamics of these indicators of dairy production.

Table 3

Statistical characteristics of models that confirm the dependence on the number of cows, but require consideration of structural gaps or justified factors to ensure high forecast reliability

Model No.	Dependent variable, y	Independent variable, x_i	R^2	Std. Error	F	Sig.F
10.1	The value of fixed assets put into operation in agriculture (UAH million)	The number of cows at enterprises, x_1 (thousands of heads)	0.87	6 575.46	45.06	0.000
10.2		Capital investments in agriculture, x_1 (UAH million)	0.95	3 995.47	133.99	0.000
11.1	Milk purifier-coolers (units)	The number of cows at enterprises, x_1 (thousands of heads)	0.05	142.20	1.493	0.257
11.2		The number of cows at enterprises, x_1 (thousands of heads)	0.85	64.15	19.83	0.001
		Structural gap, x_2				
12.1	Cattle feed dispensers (units)	The number of cows at enterprises, x_1 (thousands of heads)	0.02	693.98	0.06	0.808
12.2		The number of cows at enterprises, x_1 (thousands of heads)	0.91	219.65	36.75	0.000
		Structural gap, x_2				

Note: p-value of the parameters of one-factor regression models is equal to their Sig.F.

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

Demonstrating a relatively stable trend in 2010–2017, there were sharp jumps in 2018, which were inconsistent with previous tendencies in the number of cattle feed dispensers and milk purifier-coolers. It may suggest a transformation of the methodology for collecting statistical information or instructions for maintaining economic accounting. In light of this assumption, an argument is that, according to the State Statistics Service of Ukraine (2022a), a new form of report on agricultural machinery availability was approved in 2018 with a frequency of once every two years instead of its annual submission. In addition, as an improvement part of the statistical accounting system, the list of agricultural machinery was clarified, the composition and content of indicators were revised in particular, and certain methodological and organizational approaches to information generation were updated. The inclusion of a dummy variable, which in the period 2018–2023 equals 1, allowed for the consideration of structural changes and obtaining F-significant models ($Sig.F < 0.05$) with high accuracy ($< 5\%$).

Despite the reliability of the confirmed dependence of the value of fixed assets put into operation in agriculture on the number of cows at the enterprise, $MAPE = 13.67\% > 10\%$ demonstrates the unsuitability of Model 10.1 for making forecasts of acceptable accuracy (*Table 4*). For these reasons, in the constructed Model 10.2, the independent regression parameter is the volume of capital investments in agriculture, the variation of which explains 95% of

the variation of the dependent variable, showing a more reliable relationship ($F = 133.99 > 45.06$), with a satisfactory $MAPE$, which has decreased almost by half.

Table 4

Forecast values of milk production indicators depending on the number of cows in regression models, but demonstrate high forecast accuracy considering structural gaps or more justified factors

Model No.	Equation	$MAPE$ (%)	$MaxAPE$ (%)	Forecast period	Forecast value	Lower limit (95%)	Upper limit (95%)
10.1	$y = 183\,111.08 - 294.14x$	13.67	31.86	–	–	–	–
10.2	$y = -685.74 + 0.82x_1$	7.01	15.23	2010	8 742.18	36.79	17 447.56
				2011	13 201.04	4 495.66	21 906.43
				2012	15 134.22	6 428.84	23 839.61
				2022	41 237.04	32 531.66	49 942.43
				2023	52 641.42	43 936.03	61 346.80
11.1	–	4.06	7.11	–	–	–	–
11.2	$y = 3\,330.39 - 0.86x_1 - 380.76x_2$	1.47	4.03	2020	2 573	2 433	2 713
				2021	2 586	2 446	2 726
				2022	2 585	2 445	2 725
				2023	2 611	2 471	2 751
12.1	–	13.59	26.40	–	–	–	–
12.2	$y = -1\,006.06 + 8.79x_1\ 1\,957.71x_2$	3.50	11.26	2020	4 806	4 327	5 285
				2021	4 676	4 197	5 155
				2022	4 683	4 204	5 162
				2023	4 415	3 936	4 894

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

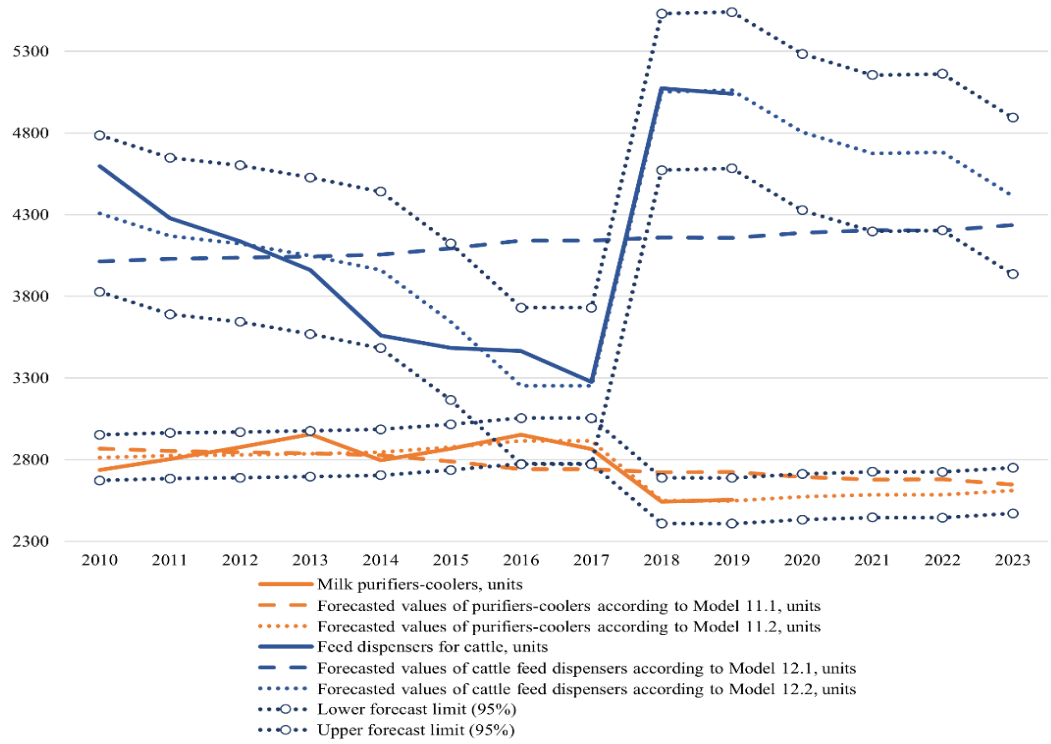
Based on the values of the model parameters, the value of fixed assets put into operation in agriculture declines by UAH 294.14 million in the case of an enlargement in the number of cows by 1 thousand heads. Such results are explained by the reverse trend of the analyzed indicators: against the annual reduction in the number of cows at enterprises in 2010–2023, the value of fixed assets put into operation, on the contrary, increased. Since its notedly rapid upsurge was observed starting from 2014, the probable cause for the obtained coefficient of Model 10.1 obtained was the currency factor, namely the devaluation of the hryvnia, which enormously raised the value of imported machinery, equipment, and materials regardless of the dynamics of the number of cows at enterprises. On the other hand, according to Model 10.2, the dependent variable increases by UAH 0.82 million in the case of growth in capital investments in the industry by UAH 1 million, i.e., not all capital investments were directed at the financing of new fixed assets.

According to Model 11.2, the number of milk purifier-coolers increases by 0.86 units, even if the livestock population decreases by 1 thousand cows. It means that despite the drop in the number of cows, the need for the production

of extra-grade milk suitable for export to the world market is growing, especially in the context of new requirements for the safety and quality of milk and dairy products, which establish the immediate cooling of milk to a temperature of 6–8 °C (in various cases) immediately after milking. Even though the milk purifier-coolers reduced by an average of 380.76 units due to improvements in the statistical accounting methodology in 2018, with a confidence level of 95%, a gradual increase in their number to 2 611 units is expected in 2023.

Cattle feed dispensers are characterized by a positive dependence on the number of cows. If they expand by 1 thousand heads, the amount of equipment that provides animal feeding increases by 8.79 units, which increased rapidly by an average of 1 957.71 units in 2018 after a structural gap. Their positive impact was confirmed by the analysis of modern animal feeding equipment presented in the article by Smoliar et al. (n. d.), according to the results of which it was established that feed dispensers ensure uniformity of their distribution at a level of almost 91% to over 95% and demonstrate efficiency, minimizing fodder losses. Thus, the expansion of technical provision with this equipment is an economically justified enterprise's response to the growing livestock.

However, despite its substantial increase of 54.88% in 2018 compared to the previous period, according to the forecast, a steady decrease in their number will continue, reaching a value of 4 415 units in 2023 (*Figure*), as the number of cows at enterprises showed a lowering of 73.60 thousand heads in 2023 compared to 2018.



Actual and forecasted amount of equipment required for dairy production, considering the structural gap observed since 2018

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

If, when modeling the dynamics of this equipment, the structural gap observed since 2018 is ignored, the forecast trajectories of the indicators deviate significantly from the actual values, which is especially noticeable in 2016–2020. While all the de facto values fall into the confidence intervals of statistically reliable Models 11.2 and 12.2 with a probability of 95%, the values excluding the gap go beyond the lower and upper limits of the forecasts. The underrated factual number of cattle feed dispensers and, conversely, the overrated number of milk purifier-coolers will further distort the estimations of the parameters of the multiple regression models, which are aimed at scrutinizing the impact of factors in 2010–2023 that contribute to an increase in the volume of extra-grade milk suitable for export to foreign markets.

3. Assessment of the dependence of resource and technological indicators of enterprises' dairy production on the number of cows: forecasting based on time series models

Table 5 presents Models 13–17, which confirmed the hypothesis of a statistically significant relationship between the number of cows and resource and technological indicators of the dairy industry, the explanatory power of which varies from 0.44 to 0.89. However, the use of time series models leads to an improvement in the R^2 values and their transition on the interpretation scale of the coefficient to higher quality levels: Model 13, 15 (weak → moderate), Model 14 (moderate → high), Model 17 (high → very high). Although Model 17.1 is characterized by acceptable explanatory power, $MAPE = 6.09\%$, which does not suggest its high accuracy. In Model 17.2, built using the Holt method, $MAPE$ is lower, at 2.79%, and $MaxAPE$ has more than halved to 5.83%, which, together with other time series models used (Holt, Brown, ARIMA), provides highly accurate forecasts, which are especially important in the context of restoring absent statistical data.

Table 5

Statistical characteristics of single-factor regression models that confirm the dependence on the number of cows but have higher forecast accuracy using time series models

Model No.	Dependent variable, y	Independent variable, x_i / Time series model	R^2	Std. Error	F	Sig.F
13.1	Hay mowing area (thousand hectares)	The number of cows at enterprises, x_1 (thousands of heads)	0.44	37.90	6.97	0.027
13.2		Brown	0.54	–	–	–
14.1	Pasture area (thousand hectares)	The number of cows at enterprises, x_1 (thousands of heads)	0.59	51.60	13.08	0.006
14.2		ARIMA (0,1,0)	0.71	–	–	–
15.1	Hay mowers (units)	The number of cows at enterprises, x_1 (thousands of heads)	0.47	411.11	7.19	0.028
15.2		Holt	0.51	–	–	–

End of Table 5

Model No.	Dependent variable, y	Independent variable, x_i / Time series model	R^2	Std. Error	F	Sig.F
16.1	Milk separators (units)	The number of cows at enterprises, x_1 (thousands of heads)	0.76	15.36	25.88	0.001
16.2		Holt	0.83	–	–	–
17.1	Conveyors for cleaning manure (units)	The number of cows at enterprises, x_1 (thousands of heads)	0.89	1 388.73	64.87	0.000
17.2		Holt	0.98	–	–	–

Note: p-value of the parameters of one-factor regression models is equal to their Sig.F.

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

At the same time, regression models remain a source for interpreting reliable and robust relationships between variables. Based on the values of the model parameters (*Table 6*), the hay mowing area increases by 530 hectares if the number of cows expansions by 1 thousand heads, which is natural given the greater need for meadow vegetation, which is necessary for the formation of the feed base – the preparation of hay and green fodder.

Table 6

Forecast values of milk production indicators in Ukraine, calculated using time series models, but demonstrating a statistically significant dependence on the number of cows in regression model

Model No.	One-factor regression equation / Time series model	$MAPE$ (%)	$MaxAPE$ (%)	Forecast period	Forecast value	Lower limit (95%)	Upper limit (95%)
13.1	$y = 2\,106.00 + 0.53x_1$	1.15	2.62	–	–	–	–
13.2	Brown	0.47	4.49	2021	2 249.90	2 177.10	2 322.70
				2022	2 216.70	2 107.70	2 325.70
				2023	2 183.40	2 033.00	2 333.90
14.1	$y = 4\,894.06 + 0.99x_1$	0.69	1.49	–	–	–	–
14.2	ARIMA (0,1,0)	0.46	2.18	2021	5 226.40	5 132.80	5 319.90
				2022	5 202.40	5 070.00	5 334.80
				2023	5 178.50	5 016.40	5 340.60
15.1	$y = 7\,342.16 + 6.71x_1$	3.05	6.12	–	–	–	–
15.2	Holt	2.81	5.35	2020	10 197	9 283	11 111
				2021	10 070	9 156	10 984
				2022	9 943	9 029	10 857
				2023	9 816	8 903	10 730
16.1	$y = 51.09 + 0.48x_1$	3.85	9.22	–	–	–	–
16.2	Holt	3.08	7.17	2020	257	227	287
				2021	248	218	278
				2022	239	208	269
				2023	230	199	260

End of Table 6

Model No.	One-factor regression equation / Time series model	$MAPE$ (%)	$MaxAPE$ (%)	Forecast period	Forecast value	Lower limit (95%)	Upper limit (95%)
17.1	$y = -18\,979.32 + 68.08x_1$	6.09	13.80	–	–	–	–
17.2	Holt	2.79	5.83	2020	10 368	9 003	11 733
				2021	9 073	7 682	10 465
				2022	7 779	6 361	9 197
				2023	6 484	5 040	7 928

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

For similar reasons, pasture areas are also subject to a statistically significant impact, which rises by 990 hectares, as they are used by animals as fodder in the spring and summer. The conclusion obtained is consistent with Moschovas et al. (2023), who, studying the factors affecting milk quality, emphasized the importance of pastures not only for ensuring the natural behavior of cows but also in the context of reducing the prevalence of diseases compared to keeping them in specialized premises.

As with the sources of feed base, the equipment is characterized by a positive dependence on the number of cows: in the case of their enlargement by 1 thousand heads, the number of hay mowers increases by almost 7 units, and manure conveyors – by 68 units. While hay mowers provide the growing need for mechanized mowing of juicy fodder, the manure conveyor system maintains cleanliness and optimal humidity in the premises where animals are kept, ensuring better care and reducing the labor intensity of this production process. Compared to Models 15.1 and 17.1, the number of milk separators, although positive, is only 0.48 units. Although the upsurge in the number of cows drives larger milk volumes for processing and cleaning, enterprises are most likely to use high-capacity separators with a long service life. In addition, depending on the level of technological equipment, separation can be part of an automated line of installations, not a separately built-in element. Based on this, a slight increase in the number of separators when the herd grows by 1 thousand heads is justified from a technological point of view.

The reliability of the forecasts obtained based on time series models is enhanced by the fact that all values from *Table 6* are characterized by a stable negative trend in 2021–2023, which is consistent with Ukraine's general trend toward a reduction in the number of cows in both at enterprises and in households. Similar dynamics are also present in the study by Tkachuk (2019), which noted a significant reduction in the level of enterprise provision in almost all categories of technological equipment necessary for agricultural production.

Thus, the smaller the herd size, the smaller the need for both hay mowing and pasture areas, hay mowers, manure conveyors, and milk separators, given the positive values of the coefficients of the independent variable in one-factor linear regression models.

4. Assessment of the dependence of milk production indicators in households on the number of cows: forecasting behavioral and technological characteristics

Although the share of milk received by processing enterprises from households was only 10.98% in 2023, they keep most cows (958.6 thousand heads), which in the total livestock structure of Ukraine is over 70%. Thus, while maintaining their crucial role in ensuring domestic consumption through local markets, their awareness, technological equipment, and compliance with veterinary and sanitary standards affect the overall dairy high-quality production in the country. Since households do not produce extra-grade milk, and more than 81.67% of milk received by processing enterprises from the population in 2023 was of grade I, the competitiveness of Ukrainian dairy products and their export potential significantly depends on the functioning of family-type farms.

According to Shevchenko and Tabachuk (2019), the concentration of raw milk production in households that do not provide proper conditions for keeping cows and violate sanitary and hygienic standards or milking technology without immediately cooling the milk, as a result, causes high bacterial contamination with undesirable microflora and low milk quality. At the same time, despite the validity of their conclusions, the authors did not analyze and forecast the behavioral and technological aspects of household production activities, which are presented in *Table 7*.

Table 7

Dependence of household functioning on the number of cows: statistical characteristics of one-factor regression and time series models

Model No.	Dependent variable, y	Independent variable – x_i or t / Time series model	R^2	Std. Error	F	Sig.F
18.1	Share of households with a separator (%)	The number of cows in households, x_1 (thousands of heads)	0.64	1.66	8.92	0.031
18.2		Holt	0.89	–	–	–
19.1	Share of households carrying out sanitary control of milk quality (%)	The number of cows in households, x_1 (thousands of heads)	0.58	0.90	6.88	0.047
19.2		Holt	0.65	–	–	–
20.1	Share of households using veterinary inspection (%)	The number of cows in households, x_1 (thousands of heads)	0.31	0.96	2.27	0.192
20.2		Time, t	0.86	0.49	12.03	0.020
21.1	Share of households carrying out sanitary treatment of livestock premises (%)	The number of cows in households, x_1 (thousands of heads)	0.28	1.47	1.97	0.219
21.2		ARIMA (0,2,0)	0.94	–	–	–

* – p-value of the parameters of one-factor regression models is equal to their Sig.F.

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

Since the 2010–2015 time series is short due to the cessation of data collection and processing by statistical authorities after 2015 and does not satisfy the requirement for the minimum permissible number of observations (n) for building reliable models, the original data set was expanded by adding observations from 2009 so that $n = 7$. Given the riskiness of the long-term forecast until 2023 and the entry into force of new requirements for the safety and quality of milk and dairy products in 2019, which could outcome in meaningful structural transformations of production processes, the upper limit of the forecast horizon was 2018.

The statistical characteristics of Models 18–21 only partially confirmed the hypothesis of the dependence of household milk production indicators on the number of cows kept. Despite the substantial impact of livestock on the share of households with a separator and the share of households carrying out sanitary control of milk quality in regression models, their explanatory power is interpreted as moderate ($R^2 \in [0.5;\ 0.7]$). At the same time, the independent variable is not statistically significant for veterinary inspection (Model 20.1) and sanitary treatment of livestock premises (Model 21.1). Time series models (Holt, ARIMA) and a simple regression model using time t as an independent variable provide mainly high R^2 values and better accuracy based on $MAPE \leq 5\%$, which indicates the feasibility of using these approaches for medium-term forecasting.

Based on the values of the model parameters (*Table 8*), with an expansion in the number of cows in households by 1 thousand heads, the share of households that have a separator or carry out sanitary control of milk quality increases by 0.01%.

Table 8

Forecast values of household characteristics that affect the development of dairy production in Ukraine and calculated using time series models

Model No.	One-factor regression equation / Time series model	*MAPE* (%)	*MaxAPE* (%)	Forecast period	Forecast value	Lower limit (95%)	Upper limit (95%)
18.1	$y = -6.08 + 0.01x_1$	5.21	14.03	–	–	–	–
18.2	Holt	5.09	8.98	2016	15.90	12.30	19.50
				2017	14.90	11.20	18.50
				2018	13.90	10.20	17.50
19.1	$y = 9.76 + 0.01x_1$	2.41	6.55	–	–	–	–
19.2	Holt	2.50	5.43	2016	20.40	18.30	22.50
				2017	19.90	17.80	22.00
				2018	19.40	17.30	21.50
20.2	$y = 48.40 + 1.48t - 0.22t^2$	0.63	1.00	2016	46.38	45.32	47.44
				2017	44.17	43.11	45.23
				2018	41.53	40.47	42.59
21.2	ARIMA (0,2,0)	0.61	1.22	2016	52.10	50.80	53.40
				2017	48.30	45.30	51.30
				2018	43.80	38.80	48.80

Source: calculated by the author based on (State Statistics Service of Ukraine, 2023).

Regression Models 20.1 and 21.1 demonstrate statistical unimportance, i.e., the number of cows in households is not a key factor affecting the share of households that use a veterinary inspection or carry out sanitary treatment of livestock premises.

According to the forecast for 2016–2018, there is a further reduction in households that perform the necessary procedures to ensure milk quality: the share of households with a separator decreased to 13.90% in 2018, i.e., by 2.60 pp compared to 2015, the share of households that carry out sanitary control of milk quality – by 1 pp (19.40%), the share of households that use veterinary inspection – by 6.6 pp (41.50%), the share of households that carry out sanitary treatment of livestock premises – by 11.40 pp, amounting to 43.80% in 2018. These changes are of concern given the growing public interest in cow welfare as a component determining the quality of dairy products. The results of the study by Castellini et al. (2023) showed that consumers equate low-quality milk with the lack of medical treatment and proper veterinary inspection, considering animal welfare as a condition for product acceptability. Given the forecasted lowering in households carrying out veterinary inspection and sanitation of premises, thus neglecting the cows' welfare, some consumers are likely to refuse such products, which in turn may lead to an even more critical situation for individual peasant farms, which are already in a vulnerable economic position.

Against the background of the reduction in the number of cows in households, which was observed throughout the study period, it indicates the departure of not only uncompetitive producers but also those who had the necessary equipment and carried out basic processes to ensure milk quality but probably faced economic barriers: a low purchase price for milk, which does not contribute to a quick return on investment, the lack of infrastructure and processors necessary for the sale of extra-grade milk, limited financial resources for modernization in conditions of economic instability. Bondarenko and Omelianenko (2024), who studied the threats and prospects of the milk market in Ukraine, also highlighted the lack of sufficient funding for investment and innovation projects among the factors that negatively affect its development. In turn, Cwalina et al. (2020) noted that for family farms, the purchase price of milk is the most essential aspect that affects their desire to engage in production activities.

The analysis of the situation with the level of household provision with separators requires special attention since the additional regression model, which examines the relationship between the number of separators and the share of households that possess them (considering their restored values in 2016–2018 using the Holt model), demonstrates extremely high statistical characteristics of reliability and validity. Built on data for 2010–2018, it is statistically significant with $R^2 = 99.85\%$, $F = 5\,216.77$, $MAPE = 0.48\%$. Based on the values of the model parameters, each new separator is associated with an increase in the share of households that own them

by 0.11%. Considering the steady negative absolute growth in the number of separators in 2010–2023, the share of households using them in 2023 is forecasted to be only 8.8%, not exceeding the value of 9.1%, which is the upper limit of the confidence interval. It indicates a technological decline of family-type farms since less than 1 in 10 households use a milk separator, which is incompatible with the growth of extra-grade or higher-quality milk. For these reasons, state support measures aimed at improving the technological provision of households with pivotal equipment for primary milk processing, such as milk separators and milk quality analyzers, are of great importance. Tsvihun and Tsvihun (2023), when agreeing that the development of dairy farming in households requires state support, proposed interest-free loans and tax breaks as possible ways to revive the industry.

An additional argument in favor of the implementation of efficacious tools is the negligible positive coefficients β_1 in regression Models 18.1 and 19.1, which may indicate the lack of incentives for modernization, one of which is the low-income level. Since the monthly cash income of rural households averaged UAH 11 889.69, and cash expenses were recorded at UAH 9 245.44 (State Statistics Service of Ukraine, 2022b) in 2021, the average residual of resources after satisfying various types of needs equals UAH 2 644.25. At the same time, income from entrepreneurial activity, self-employment, and the sale of agricultural products, which in the structure of their total resources was only 12.3% in 2021, equaling UAH 1 462.43 per month. Based on this data, it is possible to determine the terms of accumulation of funds by households on two created scenarios (*Table 9*):

1) optimistic scenario – involves directing 100% of the income received from agricultural activities (UAH 1 462.43) to the needs of dairy production modernization;

2) realistic scenario – involves setting aside a third of the average residual resources (UAH 8 72.60).

Table 9

Determining the terms of accumulation of funds by households for the modernization of dairy production under two scenarios

The goal of accumulation	Model with a statistically significant factor	Average cost of equipment, UAH	Optimistic scenario (100% of income from agricultural activities), month	Realistic scenario (33% of residual income), month
Milk separator	18.1	6 929.2*	4.74	7.94
Milk quality analyzer	19.1	25 200**	17.23	28.88

* – calculated for Ukrainian-made equipment of Motor Sich as of April 21, 2025, and averaged according to data (ProTek, n. d.), (Byrenka.com.ua, n. d.), ** calculated for Ukrainian-made equipment of IKF Agroservice as of April 21, 2025, and averaged according to data (IKF Agro, n. d.).

Source: calculated by the author based on (State Statistics Service of Ukraine, 2022b).

Thus, households in rural areas planning to purchase both a milk separator and a milk quality analyzer will need from 1 year and 10 months if they accumulate 100% of their income from agricultural activities to over 3 years if they save 33% of their average monthly residual budgets in 2021. While purchasing a separator is a relatively achievable goal in the short term for households, a milk quality analyzer, which is a principal condition for producing premium milk, is scarcely available.

By ensuring control of somatic cell counts, fat, protein content, and compliance with requirements for the absence of traces of antibiotics or bacterial contamination, households should sell high-quality products at higher prices (Bal-Prylypko et al., 2023). However, according to the study by Voliak and Galitska (2018), the payment of extra-quality, premium, and first-grade milk in previous years had minimal differences within 2–3%, which does not contribute to a quick return to households of funds spent on the purchase of separators or milk quality analyzers. For these reasons, investment by households in these types of technical equipment is not only inaccessible due to limited financial capabilities but also unlikely, given the lack of economic incentives for the modernization of production processes.

Even though the scenario modeling is based on household incomes in rural areas in 2021, since it is the latest data published by state statistics bodies, according to the study by the United Nations in Ukraine (2023), 65% of households reported a decrease in income since February 2022. Based on this, it is unlikely that the difference between the actual income and expenditure in 2022–2023 will exceed the value in 2021, especially in the context of a slow growth in state social standards due to a full-scale invasion.

Therefore, the conclusions about the need to accumulate for 2–3 years for households to purchase this equipment can be considered reliable. If the state seeks to boost the volume of export-oriented extra-grade milk, programs for partial compensation of costs for separators and milk quality analyzers can positively affect the development of dairy production in Ukrainian households. At the same time, Shpychak et al. (2022), justifying ways to overcome problems in dairy production, on the contrary, advocated the introduction by the state of incentives for the reorganization of production and concentration of cow herds on the farm.

Given the results of the study, to increase the volume of high-quality dairy products, the government should introduce additional state support measures within the framework of the budget program "Financial support for agricultural producers", under which expenditures of UAH 1 205 million are planned in 2025 (Pavlenko, 2025). In this context, a special tax-free investment account, similar to the Canadian AgriInvest program, to which dairy producers would contribute their funds in the form of a set percentage (for example, % of income from the sale of milk and dairy products), is promising. By adding another 50% or the full amount to this contribution, the state would help stimulate targeted investments, which are allowed to be directed only to the purchase of high-cost equipment or modernization, which is critically necessary to produce extra-quality milk. In addition, within the

framework of the budget program "Support for farms and other producers of agricultural products", to which about UAH 4 726 million should be allocated in 2025, it is possible to develop a system of additional payments for households for high and extra-quality milk. Providing for the availability of basic equipment as a prerequisite for receiving compensation for 2–3 years would encourage family farms to improve their technical equipment. To modernize their material and technical base, households may show greater interest in obtaining interest-free loans under the budget program "Provision of loans to farms".

The practical value of the proposed measures lies in shifting the focus from direct support of producer incomes to reducing their dependence on subsidies, which in turn will reduce the budget burden.

In any case, increasing the production of high-quality raw milk in Ukraine requires effective state policy that will help the industry overcome the crisis during the post-war recovery period and strengthen food sovereignty, which is especially important given the reduction in the level of population provision with milk and dairy products (from 107.71% in 2017 to 95.21% in 2021) and the increase in the share of their imports in consumption (from 1.55 to 9.37% in the same periods), as was determined in the article by Ivanov and Hurtovyi (2023).

Conclusions

The results of a comprehensive analysis of the constructed regression and time series models allowed for the restoration of the absent data, confirming the main study hypothesis about the presence of a statistically significant relationship between the number of cows and resource and technological indicators of dairy production both at enterprises and in households. The negative relationship between the number of cows and the average annual yield at enterprises indicates a probable limitation of resources and infrastructure capability to provide proper care for the growing livestock without losing productivity. It is confirmed by insufficient technical modernization since the combination of milking machines and installations, according to the average scenario, will allow servicing the size of the herd, which includes 891 heads but not 1,000 cows, without considering damage and downtime of equipment.

The number of cows positively impacts the expansion of the fodder base. Nonetheless, given the nationwide reduction in the number of cows in 2010–2023, their decline is expected by 2023 with a probability of 95%. Compared to 2022, in 2023, the gross harvest of feed corn is expected to decrease by 7.25%, hayfields by 24.68%, and annual and perennial grasses for green fodder, hay, and silage by 27.84%. Compared to 2019, the number of hay mowers in 2023 will fall by 3.73%, milking machines by 7.81%, cattle feed dispensers by 12.40%, and milk separators by 13.86%.

However, unlike other equipment, despite the drop in the number of cows, the number of milk purifier-coolers is forecasted to increase by 2.19% – from 2 555 units in 2019 to 2,611 in 2023. It hints at a certain level of enterprise modernization and their focus on compliance with the requirements for the quality and safety of milk and dairy products, which establishes the immediate cooling of milk to an established temperature immediately after milking.

The technological degradation of dairy production in households is of great concern: in 2016–2018, there was a further decline in households that carried out the necessary procedures to ensure milk quality, veterinary inspection, and sanitation of premises. According to the forecast, the share of households using a separator in 2023 will be no more than 9.1%. It indicates the unavailability of primary equipment for family-type farms since only 1 in 10 households uses a milk separator. In the case of saving a third of the monthly residual income and even assuming the accumulation of entire income from agricultural activities, it will take 2 to 3 years for rural households planning to purchase a milk separator and a quality analyzer.

Given the limited households' possibilities for purchasing milk separators and quality analyzers in the short term and the need to increase the volume of high-quality milk, urgent state support measures are needed for producers within the framework of which technical re-equipment is partially compensated by the government. One of the ways may be the mechanism of the Canadian state support model, in which producer funds in a tax-free savings account (in a defined %) are supplemented by state contributions that can be directed only to investments.

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