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Economic Factors in the Development of Kazakhstan's Dairy Sector: An Econometric Analysis

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ABSTRACT

The dairy sector plays an important role in ensuring Kazakhstan's food security, but its development is characterized by structural imbalances, limited technological modernization, and high dependence on production and investment factors. The aim of the study is to evaluate the relationship of investment, price and production factors with the dynamics of milk production in Kazakhstan in 2004-2024, taking into account lag effects and the structural gap in official statistics starting in 2022. The information base was compiled by the annual data of the Food and Agriculture Organization of the United Nations and the Bureau of National Statistics of the Republic of Kazakhstan for 2004-2024. Descriptive statistics, Pearson correlation analysis, ADF and KPSS tests, multiple least squares regression, multicollinearity diagnostics, and alternative specification analysis are applied. The results showed that the preferred model explains 95.3% of the variation in milk production. The most significant positive relationship was found for real investments in agriculture (β = 0.461; p = 0.002) and average dairy productivity of cows (β = 0.305; p = 0.018). The producer price index did not demonstrate a statistically significant relationship with the volume of production (β = 0.021; p = 0.836). Taking into account the revision of official statistics for 2022-2024 has significantly increased the explanatory power of the model. The results show that the main factors in the development of Kazakhstan's dairy sector are investment and increased productivity, while price signals without technological modernization do not ensure a steady increase in production.

KEYWORDS: Agricultural Economy, Agro-Industrial Complex, Agriculture, Dairy Sector, Modernization, Production Efficiency, Fixed Capital, Investment Activity

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Экономические факторы развития молочного сектора Казахстана: эконометрический анализ

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АННОТАЦИЯ

Молочный сектор играет важную роль в обеспечении продовольственной безопасности Казахстана, однако его развитие характеризуется структурными диспропорциями, ограниченной технологической модернизацией и высокой зависимостью от производственных и инвестиционных факторов. Цель исследования оценить взаимосвязь инвестиционных, ценовых и производственных факторов с динамикой производства молока в Казахстане за 2004–2024 гг. с учетом лаговых эффектов и структурного разрыва официальной статистики начиная с 2022 г. Информационную базу составили ежегодные данные Продовольственной и сельскохозяйственной организации ООН и Бюро национальной статистики Республики Казахстан за 2004–2024 гг. Применены описательная статистика, корреляционный анализ Пирсона, тесты ADF и KPSS, множественная регрессия методом наименьших квадратов, диагностика мультиколлинеарности и анализ альтернативных спецификаций. Результаты показали, что предпочтительная модель объясняет 95,3% вариации объема производства молока. Наиболее значимая положительная связь установлена для реальных инвестиций в сельское хозяйство ($\beta = 0,461$; $p = 0,002$) и средней молочной продуктивности коров ($\beta = 0,305$; $p = 0,018$). Индекс цен производителей не продемонстрировал статистически значимой связи с объемом производства ($\beta = 0,021$; $p = 0,836$). Учет пересмотра официальной статистики за 2022–2024 гг. существенно повысил объясняющую способность модели. Полученные результаты показывают, что основными факторами развития молочного сектора Казахстана выступают инвестиции и повышение продуктивности, тогда как ценовые сигналы без технологической модернизации не обеспечивают устойчивого увеличения производства.

КЛЮЧЕВЫЕ СЛОВА: аграрная экономика, агропромышленный комплекс, сельское хозяйство, молочный сектор, модернизация, эффективность производства, основной капитал, инвестиционная активность

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INTRODUCTION

Milk production plays a strategic role in ensuring food security, supporting rural development, and maintaining the sustainability of the agri-food system. In Kazakhstan, dairy farming is an important branch of agriculture, supplying socially significant food products and providing raw materials for the dairy processing industry. According to the Bureau of National Statistics of the Republic of Kazakhstan, the production of all types of milk amounted to 3.63 million tonnes in 2024. However, data from 2022 onward are not directly comparable to earlier observations due to a special revision of official livestock statistics based on updated administrative records (Bureau of National Statistics, 2025). At the same time, the sector has undergone significant structural changes: the share of agricultural enterprises and farms in total milk production increased from 8.9% in 2004 to 38.9% in 2024. Nevertheless, most of the milk production still comes from household farms, which limits the adoption of modern technologies, reduces the marketability of the output, and increases regional disparities in the sector's development (FAO, 2022; OECD, 2023; FAS, 2025).

Previous studies identify investment, herd productivity, and producer prices as important factors associated with the development of dairy production. The productivity of dairy cattle farming, reflected in the average milk yield per cow, is regarded as one of the main drivers of output growth, since improvements in animal productivity make it possible to achieve a sustained increase in production volumes without a proportional expansion of the cattle population. Producer prices send market signals and influence investment decisions and output supply (Han et al., 2022; Náglová & Rudinskaya, 2021). The adoption of digital transformation tools, including supply chain digitization and predictive maintenance, can support the modernization of food production, reduce waste, and improve energy and resource efficiency (John et al., 2025).

Despite the considerable number of studies devoted to dairy-sector development, most examine individual aspects of the industry, such as farm productivity, investment activity, supply-chain organization, government support, and technological modernization (Malik et al., 2022; Headey et al., 2024). In Kazakhstan, published studies primarily focus on assessing the current state of the industry, the challenges of innovative development, and the financial sustainability of agricultural enterprises (Baiguzhinova et al., 2025; Kireyeva et al., 2024; Akhmetova et al., 2026a; Akhmetova et al., 2026b). At the same time, there is a notable lack of research that analyzes long-term official statistical data using a unified econometric model that accounts for the lagged effects of investment and price factors, as well as the structural break in the statistical series caused by the revision of the official statistical methodology after 2021.

The aim of this study is to assess the relationship between investment, price, and production factors and the dynamics of milk production in Kazakhstan during 2004–2024, accounting for lagged effects and the structural break in official statistics beginning in 2022. The empirical analysis uses annual official statistics, descriptive analysis, Pearson correlation analysis, alternative multiple-regression specifications, multicollinearity diagnostics, and residual diagnostic tests. The estimated coefficients are interpreted as statistical associations rather than definitive causal effects.

The scientific novelty of the study lies in the joint empirical assessment of real agricultural investment, producer prices, and dairy herd productivity within a unified econometric framework that explicitly accounts for the lagged effects of economic factors and the discontinuity caused by the revision of official livestock statistics in 2022–2024. This approach provides a more cautious interpretation of long-term changes in officially recorded milk production. The findings may inform the development of agricultural policy measures to promote investment, increase dairy herd productivity, support technological modernization, and improve the sustainability of Kazakhstan’s dairy sector.

LITERATURE REVIEW

Recent studies consider dairy farming to be one of the key sectors of the agri-food system, contributing to food security, rural employment, and the sustainable development of rural areas. At the same time, the efficiency of the dairy sector is determined not only by production volumes but also by a combination of economic, production, and institutional factors that influence productivity, investment activity, and the

competitiveness of producers (Arvidsson Segerkvist et al., 2020; Fiorillo & Amico, 2024; Adesogan & Dahl, 2020). Studies focusing on Kazakhstan also emphasize the persistent structural problems of the sector, including the high share of household farms, regional disparities in production, an insufficient level of technological modernization, and the need to improve the investment attractiveness of dairy farming (Smagulova et al., 2023; Akhmedyarov et al., 2023; Yesbolova et al., 2025; Jussibaliyeva et al., 2022; Sun et al., 2026). Recent Kazakhstan-specific research also identifies the main prospects for the sustainable development of the dairy sector and emphasizes the importance of technological modernization, investment activity, and institutional support (Baiguzhinova et al., 2025).

Despite the considerable number of publications, research on the factors influencing the development of the dairy sector remains relatively fragmented. A substantial proportion of studies focus on individual elements of the production and distribution chain, including production organization, processing, logistics, supply integration, and risk management (Guarnaschelli et al., 2020; Hassan et al., 2021; Azizsafaei et al., 2022; Vieira et al., 2020; Danese et al., 2020). This approach allows individual processes to be examined in detail; however, it limits understanding of how macroeconomic and production factors jointly determine national-level milk production dynamics. Optimization methods are increasingly applied to improve production planning, logistics, and resource allocation across dairy supply chains (Malik et al., 2022).

Investment is recognized in academic literature as one of the most robust determinants of milk production growth. Economic theory suggests a positive relationship between capital investment and production volume, driven by the modernization of production facilities, the introduction of new technologies, and more efficient resource utilization. Empirical studies confirm that investment contributes to increased productivity in dairy cattle farming, although its impact most often occurs with a certain time lag, since the effects of farm construction, equipment acquisition, and herd renewal materialize gradually (Ma et al., 2020; Olagunju et al., 2022; Świtłyk et al., 2021). More broadly, R&D expenditure and technological innovation are significantly associated with economic growth in Kazakhstan, although the direction and strength of these relationships vary across individual indicators (Kireyeva et al., 2021). At the sectoral level, the sustainability of dairy enterprises' investments is regarded as an important prerequisite for improving the competitiveness of Kazakhstan’s dairy sector (Akhmetova et al., 2024). Accordingly, this study assumes that real investment in agricultural fixed capital has a positive effect on milk production volume.

Recent studies also emphasize the role of digital transformation in improving production efficiency. Supply chain digitization and predictive maintenance can reduce waste and improve energy and resource efficiency in food production and distribution (John et al., 2025). A systematic review by Akhmetova et al. (2026a) demonstrates the importance of agribusiness digitalization for productivity and sustainability, while Akhmetova et al. (2026b) provide dairy-specific evidence on the relationship between digital transformation and the economic efficiency of dairy farms in Kazakhstan.

Another important production factor is dairy herd productivity. Unlike the extensive expansion of the cattle population, an increase in average milk yield reflects improvements in production efficiency, breeding practices, the feed base, and animal housing conditions. A study by Bórawski et al. (2020), conducted across European Union countries, showed that differences in milk production volumes are largely explained by variations in animal productivity and resource availability. Similar conclusions were presented by Bianchi et al. (2022), Kosar et al. (2022), and Klapkiv et al. (2023), who identify productivity growth as the main source of long-term production expansion. Náglová and Rudinskaya (2021) examine the factors influencing the technical efficiency of dairy farms in the European Union, while Han et al. (2022) analyze productive efficiency and trade opportunities for dairy farms in Kazakhstan.

Considerable attention in the economic literature is devoted to price-related factors. According to classical economic theory, an increase in producer prices should stimulate an expansion of product supply by raising the expected profitability of production. However, research shows that this mechanism does not always operate directly. In dairy farming, producers’ responses to price changes are usually delayed, since adjustments in production volumes require time to expand the herd, implement

investment projects, and adapt production processes (Ben Abdallah et al., 2020; Hillen, 2021). In addition, research findings indicate asymmetric price transmission along the value chain, whereby increases in producer selling prices only partially offset rising production costs (Onegina et al., 2022; Rudinskaya & Boskova, 2021). Costa et al. (2022) also note that differences in farm-gate milk prices have varying effects on the efficiency of different types of farms. Accordingly, this study assumes a positive, albeit potentially less pronounced, relationship between the producer price index and milk production volume.

Domestic demand is another important factor in the sector's development. Growth in the consumption of milk and dairy products creates incentives to expand production; however, the impact of demand is primarily reflected in long-term structural changes in the market. Studies by Cheng et al. (2022), Headey et al. (2024), Liang et al. (2020), Jia et al. (2022), and Kimsanova et al. (2024) show that dairy consumption is determined by household income levels, demographic changes, urbanization, and dietary preferences. At the same time, consumption is closely associated with several other macroeconomic indicators, increasing the risk of multicollinearity among the explanatory variables when constructing regression models. For this reason, the consumption indicator was included in the preliminary stage of the analysis, and its effect was assessed alongside multicollinearity diagnostics and comparisons of alternative model specifications.

The official revision of statistical data by the Bureau of National Statistics of the Republic of Kazakhstan is particularly important for interpreting the results (Bureau of National Statistics, 2025). Beginning in 2022, selected livestock statistics for peasant (farm) enterprises and household farms were revised on the basis of updated administrative data from farm household records, in accordance with the Rules for Revising Published Official Statistical Information for Statistical Purposes. This revision resulted in a structural break in the milk production series, reflecting a change in statistical methodology rather than economic processes alone.

Thus, the literature review shows that most studies examine the effects of individual factors influencing the development of the dairy sector-investment, productivity, prices, or consumption-primarily in isolation. In Kazakhstan, there remains a lack of research that integrates macroeconomic and production indicators into a unified econometric model that accounts for the lagged effects of economic factors and the structural break in the official statistical series. Addressing this research gap determines the present study's focus and the selection of explanatory variables.

METHODOLOGY

The empirical dataset comprised official FAO and Bureau of National Statistics data for 2004–2024 on the development of dairy farming in Kazakhstan. The volume of milk production across all types, measured in thousand tonnes, was used as the dependent variable. At the initial stage, an expanded set of macroeconomic and production indicators was compiled, including the producer price index for raw milk, fixed-capital investment in agriculture, per capita consumption of milk and dairy products, the share of agricultural enterprises and farms in total milk production, average milk yield, the number of cows, gross output from dairy cattle farming, foreign trade indicators, the share of agriculture in GDP, pasture area, the GDP deflator, and population size. The final set of factors was determined based on the results of correlation analysis, multicollinearity diagnostics, and the economic interpretation of the models (Table 1).

Table 1. Variables included in the preferred regression model

Variable	Unit of measurement	Transformation
Milk production across all farm categories	Thousand tonnes	Dependent variable
Real fixed-capital investment in agriculture	Million KZT at constant 2024 prices	One-year lag
Producer price index for raw milk	Percent	One-year lag
Average milk yield per cow	Kilograms per cow	Current value
Statistical revision dummy	Binary variable	1 for 2022–2024; 0 otherwise

Note: compiled by the authors based on FAO (2025) and Bureau of National Statistics (2025)

Investment values were expressed in constant 2024 prices using the GDP deflator, thereby removing the effect of inflation. Given the delayed effect of investment, real investment was included in the model with a one-year lag. A similar lag was applied to the producer price index because producers' responses to price changes also occur with a time lag.

To ensure comparability with the data, changes to the official statistical methodology were taken into account. In accordance with the Rules for Revising Published Official Statistical Information, the Bureau of National Statistics of the Republic of Kazakhstan conducted a special revision of selected livestock indicators for 2022-2023 based on updated administrative data from household records (Bureau of National Statistics, 2025). Consequently, a dummy variable was included in the model, taking the value of 1 for the period 2022-2024 and 0 for the preceding years.

The initial dataset included 21 annual observations for 2004–2024. Because of the use of one-year lags, the preferred regression model was estimated with 20 observations. Before estimating the regression models, the stationarity of the time series was assessed using the augmented Dickey–Fuller and KPSS tests.

The study involved the sequential application of descriptive statistics, Pearson correlation analysis, and multiple regression using the ordinary least squares (hereinafter – OLS) method. To assess the robustness of the results, several alternative specifications were estimated, including linear, lagged, and log-linear models, as well as a model accounting for the structural break in the statistical series.

The empirical analysis was conducted in six stages:

(1) data collection and preparation;

(2) descriptive statistical analysis;

(3) stationarity testing using the ADF and KPSS tests;

(4) correlation analysis and multicollinearity diagnostics;

(5) estimation and comparison of alternative OLS specifications;

6) model diagnostics and robustness testing.

The alternative specifications included linear, lagged, and log-linear models, as well as models with and without the statistical revision dummy. Model quality was evaluated using the coefficient of determination (R^2), adjusted R^2, RMSE, and the F-test. Model diagnostics included variance inflation factors (hereinafter – VIF), the Breusch-Pagan test for heteroskedasticity, HC3-robust standard errors, the Durbin–Watson and Breusch-Godfrey tests for autocorrelation, the Ramsey RESET test for model specification, and the Jarque-Bera test for the normality of residuals. In addition, standardized β coefficients were calculated to compare the relative strength of the explanatory factors' effects.

All calculations were performed using MATLAB R2024b. The critical level of statistical significance was set at $p < 0.05$, while results with $p < 0.10$ were considered marginally statistically significant.

RESULTS

An analysis of the data for 2004-2024 indicates that the development of dairy farming in Kazakhstan was characterized by uneven dynamics in both production and macroeconomic factors. Between 2004 and 2021, milk production increased from 4,556.8 to 6,247.2 thousand tonnes; however, beginning in 2022, the official time series shows a sharp decline. This break does not reflect an actual reduction in production but is attributable to the revision of the official statistical methodology and the use of updated administrative data in compiling livestock indicators. Descriptive statistics for the indicators under study are presented in Table 2.

Table 2. Descriptive statistics of the study variables for 2004–2024

Variable	N	Mean	Median	Std. Dev.	CV, %	Minimum	Maximum
Milk production, thousand tonnes	21	5,028.7	5,182.4	768.73	15.29	3,354.6	6,247.2
Producer price index, %	21	109.77	109.60	7.16	6.53	97.80	127.70
Real agricultural investment, million KZT	21	565,480	413,240	269,170	47.60	285,450	1,103,500
Per capita dairy consumption, kg/year	21	224.86	227.20	20.53	9.13	189.10	261.30
Total dairy consumption, thousand tonnes	21	4,062.3	4,019.4	664.12	16.35	3,008.4	5,053.7
Organized-sector share, %	21	20.05	18.13	10.17	50.75	8.90	38.90
Average milk yield, kg/cow	21	2,295.2	2,280.0	111.17	4.84	2,108.0	2,542.0
* Monetary indicators are expressed in constant 2024 prices.							

Note: authors' calculations based on official statistics and MATLAB estimates

The indicators presented in the table show that real investment in agricultural fixed capital and the share of agricultural enterprises and farms in total milk production exhibited the greatest variability, reflecting the scale of the sector's structural modernization. By contrast, the producer price index and average milk yield changed much more gradually. Per capita consumption of milk and dairy products also showed relatively low variability, indicating stable domestic demand throughout the period under review.

Figure 1 shows that until 2021, growth in milk production was accompanied by a steady increase in average milk yield per cow.

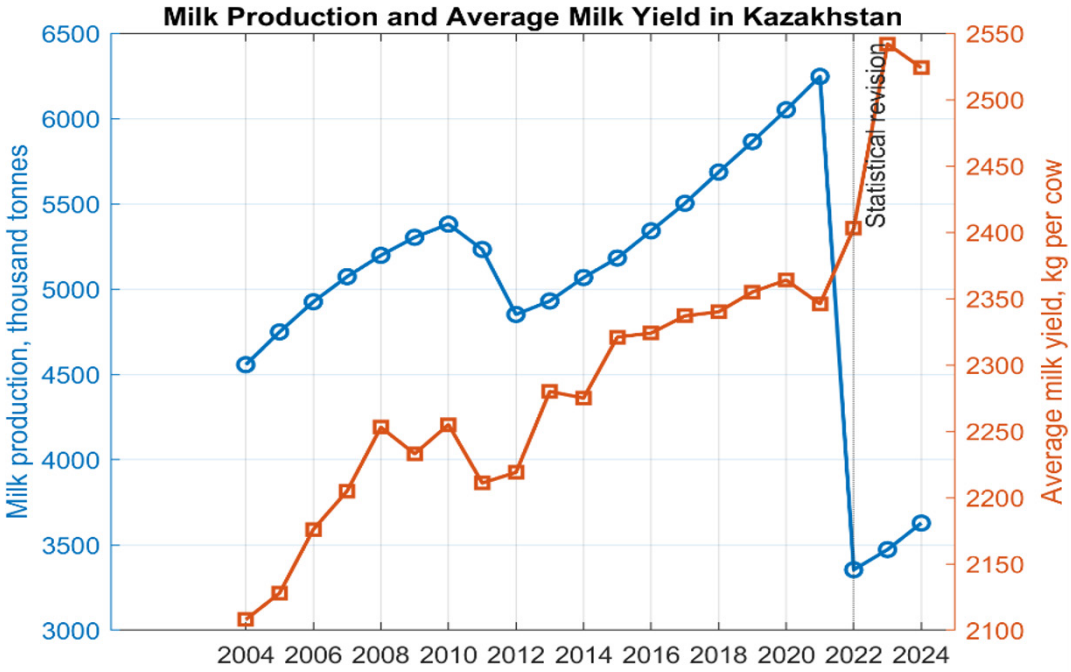


Figure 1. Dynamics of milk production and average milk yield in Kazakhstan for 2004-2024

This indicates a gradual shift in the sources of sectoral growth from the extensive expansion of the cattle population toward improvements in animal productivity. After 2022, despite the sharp decline in officially reported production volume due to a change in statistical methodology, the average milk yield continued to increase, further confirming the absence of any actual deterioration in production efficiency.

To provide a preliminary assessment of the relationships among the variables, a correlation analysis was conducted, and the results are presented in Table 3.

Table 3. Pearson correlation matrix

Variable	Milk production	Producer price index	Real investment	Total consumption	Milk yield	Organized share	Dummy 2022
Milk production	1.000	-	-	-	-	-	-
Producer price index	−0.140	1.000	-	-	-	-	-
Real investment	−0.083	0.120	1.000	-	-	-	-
Total consumption	0.111	−0.091	0.824***	1.000	-	-	-
Milk yield	−0.315	−0.009	0.757***	0.829***	1.000	-	-
Organized share	−0.298	−0.027	0.894***	0.890***	0.936***	1.000	-
Dummy 2022	−0.840***	0.187	0.539*	0.367	0.732***	0.719***	1.000
***p < 0.001; **p < 0.01; *p < 0.05. Pearson correlation coefficients are reported							

Note: compiled by the authors

The correlation matrix reveals that the full-sample pairwise relationships between milk production and real investment (r = −0.083), average milk yield (r = −0.315), and the organized-sector share (r = −0.298) are weak and negative. These coefficients should not be interpreted as evidence of adverse economic effects, since they are strongly influenced by the structural break in the official production series after 2022. This interpretation is supported by the strong negative correlation between milk production and the statistical revision dummy (r = −0.840; p < 0.001). By contrast, real investment is strongly correlated with total consumption (r = 0.824), average milk yield (r = 0.757), and the organized-sector share (r = 0.894), while the organized-sector share is closely associated with average milk yield (r = 0.936). These relationships indicate that capitalization, productivity growth, market expansion, and organizational transformation occurred simultaneously, thereby creating a potential multicollinearity risk that was addressed through alternative model specifications and VIF diagnostics. The producer price index exhibits only weak correlations with the other variables.

Before estimating the regression models, the stationarity of the time series was tested using the augmented Dickey-Fuller test. The results are presented in Table 4.

Table 4. Augmented Dickey–Fuller unit root test

Variable	ADF p-value, level	ADF p-value, first difference	KPSS p-value, level	Inference
Milk production	0.686	0.001	0.012	I(1)
Real investment	0.615	0.006	0.010	I(1)
Producer price index	0.021	0.001	0.100	I(0)
Total consumption	0.662	0.001	0.013	I(1)
Milk yield	0.503	0.001	0.058	Trend-stationary/ borderline
Organized share	0.598	0.036	0.010	I(1)
For the ADF test, the null hypothesis is the presence of a unit root; for the KPSS test, the null hypothesis is stationarity.				

Note: compiled by the authors

The tests indicated mixed stationarity properties across the variables. Milk production, real investment, total consumption, and the organized-sector share were classified as I(1), while the producer price index was stationary in levels and average milk yield was trend-stationary or borderline. These properties should be considered when interpreting the regression results. In addition, the structural break in the official time series after 2022 was accounted for by including a dummy variable, thereby preserving the economic interpretability of the model and reducing the risk of biased coefficient estimates.

Following the preliminary data analysis, several alternative multiple regression specifications were estimated. These differed in the composition of the explanatory variables, the use of lagged effects, and the method employed to account for the structural break in the official time series. A comparison of the models is presented in Table 5.

Table 5. Comparison of alternative regression models

Model	Main explanatory variables	N	R^2	Adjusted R^2	RMSE	AIC	BIC
M1	Milk yield + lagged real investment + lagged PPI + Dummy 2022	20	0.953	0.940	191.1	271.1	276.1
M2	Real investment + total consumption + PPI + Dummy 2022	21	0.930	0.913	227.3	291.8	297.0
M3	Organized share + total consumption + PPI + Dummy 2022	21	0.920	0.900	243.0	294.6	299.8
M4	Pre-2022 lagged specification	17	0.820	0.778	199.8	231.8	235.1
M5	Milk yield + current real investment + PPI + Dummy 2022	21	0.948	0.934	196.8	285.7	291.0
M6	Real investment + total consumption + milk yield + PPI + Dummy 2022	21	0.948	0.930	203.2	287.7	294.0

Note: compiled by the authors

The comparison shows that all models demonstrate a high goodness of fit; however, model M1 exhibits the best statistical characteristics. This model includes lagged real investment, the lagged producer price index, average milk yield, and a dummy variable accounting for the change in the official statistical methodology after 2022. For this model, the coefficient of determination is $R^2 = 0.953$, the adjusted coefficient of determination is 0.940, and the F-statistic is statistically significant at $p < 0.001$, indicating the model's high explanatory power.

The use of a lag structure proved to be both economically and statistically justified. Unlike current investment, capital investment affects milk production only after the completion of the investment cycle, through the modernization of production facilities and the introduction of new technologies. Similarly, producers' responses to changes in purchase prices are delayed due to the biological characteristics of dairy farming.

The estimation results for the preferred model are presented in Table 6.

Table 6. Regression results for the preferred lagged model

Variable	Coefficient	OLS SE	OLS t-statistic	OLS p-value	HC3 robust SE	HC3 p-value	Standardized β
Intercept	−684.110	2,062.400	−0.332	0.745	2,272.600	0.768	–
Average milk yield	2.264	0.835	2.713	0.016	0.850	0.018	0.305
Lagged real agricultural investment	0.001318	0.000314	4.198	0.001	0.000342	0.002	0.461
Lagged producer price index	2.251	6.626	0.340	0.739	10.714	0.836	0.021
Statistical revision dummy, 2022–2024	−3,091.200	208.020	−14.860	<0.001	194.980	<0.001	−1.450
Model fit statistics							
Observations	20						
R^2	0.953						
Adjusted R^2	0.940						
RMSE	191.1						
F-statistic	75.6						
Model p-value	<0.001						
The dependent variable is milk production, measured in thousand tonnes. Real agricultural investment is expressed in constant 2024 prices and included with a one-year lag. The producer price index is also included with a one-year lag. The statistical revision dummy equals 1 for 2022–2024 and 0 otherwise. OLS SE denotes the conventional OLS standard error, while HC3 robust SE denotes the heteroskedasticity-consistent standard error. Standardized β coefficients are reported only for continuous explanatory variables.							

Note: compiled by the authors

The estimates show that real investment in agricultural fixed capital has the greatest impact on milk production volume. The coefficient on lagged investment remains positive and statistically significant both with conventional standard errors and after the HC3 correction. According to the estimate, a KZT 1 billion increase in real investment is associated with an increase in milk production of approximately 1.318 thousand tonnes in the following year, ceteris paribus. The standardized coefficient ($\beta = 0.461$) is the highest among the continuous factors included in the model, indicating that investment activity plays the leading role in the long-term development of the dairy sector.

Average milk yield per cow is another important factor. An increase of 100 kg in productivity is associated with an increase in production of approximately 226.4 thousand tonnes, while the standardized coefficient ($\beta = 0.305$) confirms the substantial contribution of technological improvement and production efficiency. The joint significance of investment and productivity indicates that sustainable production growth is achieved primarily through sectoral modernization and more efficient use of resources.

In contrast to the aforementioned factors, the lagged producer price index did not demonstrate a statistically significant independent effect. This indicates that short-term changes in purchase prices alone are insufficient to sustain increases in production volumes without corresponding capital investment and productivity growth.

As shown in Figure 2, the fitted values closely track the long-term dynamics of milk production, including the shift in the level of the time series after 2022.

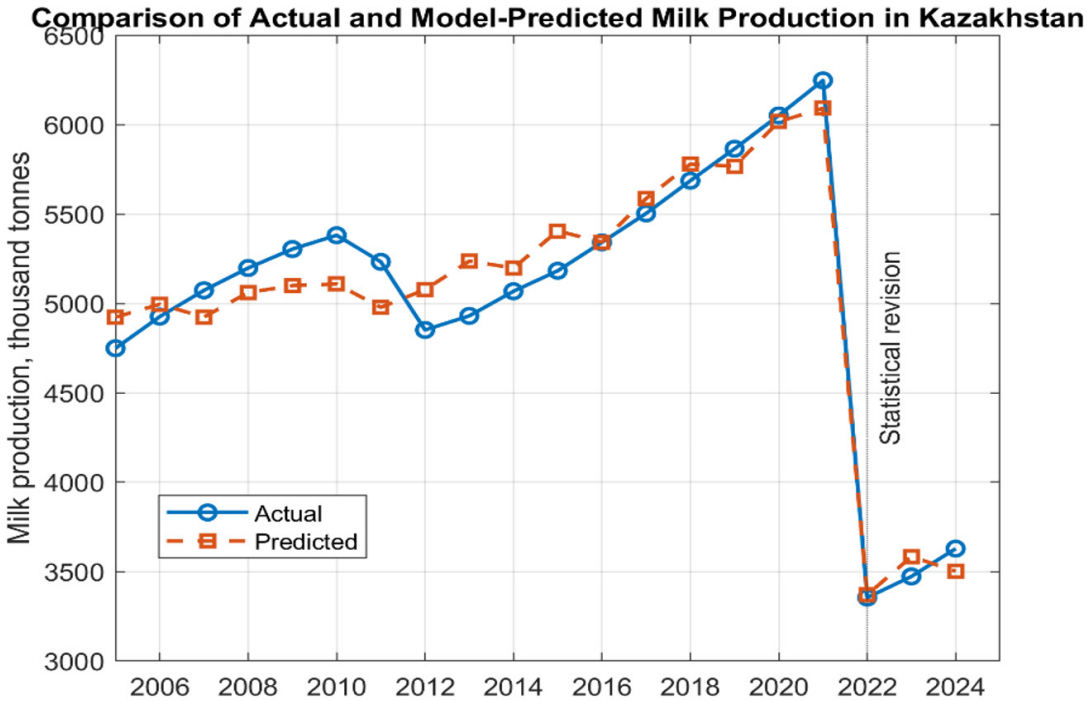


Figure 2. Actual versus predicted milk production

The coefficient on the 2022-2024 dummy variable, which reflects the effect of the change in statistical methodology, is of particular importance. Its negative and highly statistically significant value indicates a structural break in the official time series, attributable to the revision of administrative data rather than to an actual decline in milk production. Consequently, ignoring this effect would have resulted in substantial bias in the model parameters.

The absence of systematic deviations between the actual and predicted values confirms the adequacy of the selected specification and the correct treatment of the structural break in the official statistics. The reliability of the estimates obtained was additionally assessed using a set of diagnostic procedures, the results of which are presented in Table 7.

Table 7. Regression diagnostic tests

Diagnostic	Statistic	Result	Interpretation
Maximum VIF	4.013	< 5	No severe multicollinearity
Breusch–Pagan LM	5.458	$p = 0.243$	Homoskedasticity is not rejected
Jarque–Bera	0.996	$p = 0.408$	Residual normality is not rejected
Durbin–Watson	1.005	Below 2	Possible positive residual autocorrelation
Ramsey RESET	5.204	$p = 0.022$	Possible functional-form incompleteness
Maximum Cook's distance	0.439	< 1	No single observation is overwhelmingly influential
Observations above Cook's 4/n threshold	1	–	Sensitivity check recommended
HC3 robust inference	Applied	–	Coefficient inference robust to heteroskedasticity

Note: compiled by the authors

The inclusion of a dummy variable reflecting the change in official statistical methodology in 2022–2024 allowed the structural break in the time series to be accounted for and reduced the risk of biased parameter estimates. The diagnostic procedures indicated no severe multicollinearity

or heteroskedasticity and did not reject residual normality. However, the Durbin–Watson statistic suggested possible positive autocorrelation, while the Ramsey RESET test indicated possible functional-form misspecification. Therefore, the estimated coefficients should be interpreted as robust statistical associations rather than definitive causal effects.

The robustness of the results was further assessed through a sequential comparison of alternative specifications. In model M2, the positive effect of dairy product consumption persists; however, after applying HC3 robust standard errors, its statistical significance becomes marginal. In model M3, the inclusion of the share of agricultural enterprises leads to a substantial increase in multicollinearity, indicating a strong interrelationship among the processes of capitalization, productivity growth, and institutional transformation within the sector. Models M4 and M5 confirm the robustness of the positive effect of investment regardless of whether the period of statistical revision is considered, whereas the inclusion of additional factors in M6 provides virtually no improvement in model quality and only strengthens the interrelationships among the regressors. Overall, the comparison results confirm that model M1 provides the most robust and economically interpretable estimates.

The estimation results of the log-linear model are presented in Table 8.

Table 8. Log-linear robustness model

Variable	Coefficient	Standard error	t-statistic	p-value
Intercept	−4.1965	2.6817	−1.565	0.137
Producer price index	0.001868	0.001329	1.405	0.179
Log of real agricultural investment	0.065632	0.031913	2.057	0.056
Log of average milk yield	1.5155	0.3762	4.028	0.001
Statistical revision dummy, 2022–2024	−0.60945	0.03791	−16.075	<0.001
Model fit statistics				
Model statistic	Value			
Observations	21			
R^2	0.953			
Adjusted R^2	0.942			
RMSE	0.0405			
F-statistic	81.6			
Model p-value	<0.001			
The dependent variable is the natural logarithm of milk production. Real agricultural investment and average milk yield are also expressed in natural logarithms. Accordingly, their coefficients can be interpreted as elasticity. The producer price index is included in levels. The statistical revision dummy equals 1 for 2022–2024 and 0 otherwise.				

Note: compiled by the authors

The logarithmic specification confirmed the robustness of the conclusions obtained from the linear model. The coefficient on the logarithm of average milk yield was 1.5155 and was statistically significant at the 1% level ($p = 0.001$), allowing it to be interpreted as an elasticity coefficient: a 1% increase in average milk yield is associated with an approximately 1.52% increase in milk production, ceteris paribus. The elasticity with respect to real investment was 0.0656 and was statistically significant at the 10% level ($p = 0.056$), indicating a positive, although comparatively moderate, effect of capital investment. As in the linear model, the producer price index did not demonstrate a statistically significant independent effect.

The dummy variable for the period 2022–2024 remained highly statistically significant ($p < 0.001$), confirming the robustness of the structural break in the time series. Given the logarithmic form of the model, the corresponding coefficient is equivalent to a decrease of approximately 45.6% in the conditional level of officially recorded production, reflecting the consequences of the change in statistical methodology and the updating of administrative data rather than an actual decline in milk production. Thus, the log-linear model supports the conclusions of the main specification and demonstrates the robustness of the results regardless of the functional form of the relationship.

To assess the effect of accounting for the structural break, models with and without the dummy variable were directly compared (Table 9).

Table 9. Effect of accounting for the structural break on model performance

Model performance statistic	Without structural dummy	With structural dummy (2022–2024)	Change
Observations (N)	21	21	—
Adjusted R^2	0.050	0.934	+0.884
RMSE (thousand tonnes)	749.13	196.79	−73.7%
AIC	341.15	285.73	−55.42
BIC	345.33	290.96	−54.37
Note: The model without the dummy variable ignores the statistical revision of official livestock data introduced in 2022. The second specification includes a dummy variable equal to 1 for 2022–2024 and 0 otherwise. Lower values of RMSE, AIC and BIC indicate superior model performance.			

Note: compiled by the authors

Accounting for the structural break caused by the revision of the official statistical methodology in 2022 substantially improves the fit of the econometric model. The inclusion of the dummy variable increases the adjusted coefficient of determination from 0.050 to 0.934, reduces the model's root mean square error by almost 74%, and substantially lowers the AIC and BIC values. The results show that omitting the structural-break dummy substantially worsens model fit and may bias the estimated coefficients. Therefore, the use of a dummy variable is a necessary for reducing specification bias and improving comparability of the factors influencing the development of milk production in Kazakhstan.

The positive effect of investment identified in this study is consistent with recent research on the technological modernization of dairy farms, while also allowing the temporal mechanism of this effect to be specified more precisely. Using data from 251 dairy farms in China, Yu et al. (2025) found that a 1% increase in digital investment raises technical efficiency by an average of 0.029%. After accounting for potential endogeneity and conducting robustness checks, the estimated effect ranged from 0.015% to 0.085%. In the present study, the elasticity of milk production with respect to real investment was 0.0656 ($p = 0.056$), while the standardized coefficient of lagged investment in the linear model reached $\beta = 0.461$ ($p = 0.002$). Despite differences in the dependent variables, the direction of the results is consistent, and the elasticity estimated for Kazakhstan falls within the range reported by Yu et al. (2025). An important distinction is the identified one-year lag: capital investment affects output after equipment has been commissioned, farms have been modernized, and the production base has been renewed. This interpretation is consistent with the dynamic analysis by Ali (2021), according to which the average productivity growth of Dutch dairy farms was 1.1% per year, including 0.5% attributable to technical progress, while the returns to quasi-fixed resources depended on the intertemporal costs of their adjustment.

The substantial effect of average milk yield is also consistent with the findings of international studies; however, in the present research, this effect is quantitatively assessed for the first time at the level of Kazakhstan's national milk production. Based on an analysis of more than 5,400 observations from Swiss dairy farms, Schorr and Lips (2018) found that an increase in milk yield of 1,000 kg per cow raised annual income per family worker by an average of CHF 2,660, or approximately 6%. For the most successful group of farms, the effect reached CHF 7,210, or about 16%, whereas for the least efficient farms, further increases in milk yield did not necessarily improve financial performance. In the model for Kazakhstan, a 100 kg increase in average milk yield is associated with an increase in production of approximately 226.4 thousand tonnes; the standardized coefficient is $\beta = 0.305$ ($p = 0.018$), while the logarithmic specification yields an elasticity of 1.5155 ($p = 0.001$). Therefore, improvements in herd productivity represent a significant source of growth in aggregate output, although the findings of Schorr and Lips (2018) indicate that the economic return from higher milk yields at the individual farm level may depend on management quality and the farm's initial level of efficiency.

The absence of an independent effect of the producer price index does not contradict research on price transmission, since price changes along the value chain and the response of physical output represent distinct economic processes. Using monthly data from the South African dairy industry for 2000–2024, Ramakgasha and Thaba (2026) identified asymmetric price transmission among

the farm, processing, and retail levels. The speed of adjustment toward long-run equilibrium was approximately 32%, while the transmission of price changes from the farm level to retail was about 51%. In the present study, the lagged producer price index has a very small standardized coefficient of $\beta = 0.021$ and remains statistically insignificant after the HC3 correction ($p = 0.836$); its effect is also insignificant in the logarithmic model ($p = 0.179$). This means that price changes may be transmitted among participants in the dairy value chain, but they do not, by themselves, ensure an expansion of production in the absence of investment, technological upgrading, and productivity growth.

The findings regarding domestic demand also require a differentiated interpretation. Applying the Almost Ideal Demand System model to panel data from rural households in Bangladesh, Mahfuza et al. (2024) obtained positive expenditure elasticities for liquid, powdered, and condensed milk of 1.013, 1.856, and 1.060, respectively. These estimates indicate that an increase in household purchasing power can substantially raise the consumption of dairy products. In the present study, the models that included aggregate consumption demonstrated lower quality than the preferred specification incorporating lagged investment and herd productivity (Table 4). After accounting for production factors in the final model, real investment ($\beta = 0.461$; $p = 0.002$) and average milk yield ($\beta = 0.305$; $p = 0.018$) retained the strongest effects, while the consumption indicator was not included in the final specification. This suggests that domestic demand determines the size of the dairy market, whereas long-term production growth is driven to a greater extent by investment activity and improvements in animal productivity.

The increase in the share of agricultural enterprises and farms from 8.9% to 38.9% indicates the continuing organizational transformation of Kazakhstan's dairy sector. The institutional significance of this process is supported by the findings of Kaliyeva et al. (2021): the adjusted willingness of Kazakhstan's citizens to pay for a policy supporting the establishment of dairy cooperatives amounted to KZT 86.61 per litre, or approximately 29% of the market price, while the aggregate public valuation of such a policy reached approximately KZT 267 billion per year. At the same time, the results of the correlation analysis show a strong relationship between the share of the organized sector and real investment ($r = 0.894$), as well as average milk yield ($r = 0.936$), indicating that the processes of organizational concentration, capital accumulation, and technological modernization occur simultaneously. Therefore, the development of organized forms of farming should be regarded primarily as an institutional foundation for increasing investment activity and productivity rather than as an independent factor driving growth in production volumes.

Overall, comparison with international studies shows that the long-term growth of milk production is driven not by a single factor but by an interconnected process of capital accumulation, technological change, and productivity improvement. In Kazakhstan, the strongest continuous factor is lagged real investment ($\beta = 0.461$; $p = 0.002$), followed by average milk yield ($\beta = 0.305$; $p = 0.018$), whereas the lagged producer price index has no independent effect ($\beta = 0.021$; $p = 0.836$). An additional feature of the Kazakhstani time series is the statistical revision of data after 2022: including the corresponding dummy variable increases the adjusted R^2 from 0.050 to 0.934 and reduces the RMSE by 73.7%. Therefore, the estimated coefficients should be interpreted in light of the fact that the sharp change in officially recorded production primarily reflects the updating of administrative data and statistical methodology rather than a comparable economic decline in physical output. Official publications of the Bureau of National Statistics also indicate that special revisions of livestock indicators were conducted on the basis of updated administrative data from farm records.

CONCLUSION

The study provided a comprehensive economic assessment of the factors determining the dynamics of milk production in Kazakhstan, based on official statistical data for 2004-2024. Unlike most previously published studies, the analysis focused on the joint consideration of macroeconomic and production factors, taking into account the specific features of national statistics and the structural revision of data conducted beginning in 2022.

The results showed that real investment in the fixed capital of agriculture and average milk yield per cow have the greatest influence on milk production volume. The use of a lagged specification confirmed

that the effect of investment is not immediate but occurs with a time delay, which is consistent with the economic nature of the investment process. By contrast, the producer price index did not demonstrate a statistically significant independent effect after production factors were considered, indicating that price signals alone do not ensure sustainable production growth without improvements in the sector's technological efficiency.

The inclusion of a dummy variable reflecting the change in official statistical methodology in 2022–2024 allowed the structural break in the time series to be explicitly accounted for and reduced the risk of biased parameter estimates. The diagnostic procedures indicated no severe multicollinearity or heteroskedasticity and did not reject residual normality. However, the Durbin–Watson statistic suggested possible positive residual autocorrelation, while the Ramsey RESET test indicated possible functional-form incompleteness. Therefore, the estimated coefficients should be interpreted as statistically robust associations rather than definitive causal effects.

The findings can inform government support measures for the dairy sector aimed at stimulating long-term investment, increasing dairy cattle productivity, and promoting technological modernization. The proposed approach also makes it possible to account for the effects of changes in official statistical methodology when analyzing long-term time series.

A limitation of the study is its reliance on aggregated annual national-level data, which do not capture regional heterogeneity in dairy farming or differences among producer categories. A promising direction for further research is the development of panel data models for the regions of Kazakhstan, as well as the inclusion of additional indicators characterizing government support for the sector, foreign trade activity, climatic conditions, and the technological level of agricultural enterprises.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: YD and LA; research design: YD, LA, AB, AA and ID; data collection: YD, LA, AB, AA and ID; analysis and interpretation: YD, LA, AB, AA and ID; writing draft preparation: YD, LA, AB, AA and ID; supervision: AB, AA and ID; correction of article: YD, LA, AB, AA and ID; proofread and final approval of article: AA and ID. All authors have read and agreed to the published version of the manuscript.

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