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## A MECHANISM FOR OPTIMIZING LOGISTICS COSTS IN THE PRODUCTION AND DISTRIBUTION SYSTEM OF A DAIRY INDUSTRY ENTERPRISE

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### Abstract

**Purpose.** The purpose of this study is to develop and substantiate a mechanism for optimizing logistics costs in the production and distribution system of dairy industry enterprises, taking into account sector-specific characteristics and the asymmetric impact of key external and internal factors.

**Design/methodology/approach.** The study is based on a systemic and process-oriented approach integrating diagnostic, analytical, managerial, and control-evaluation blocks. Logistics costs are classified according to functional, factor, and behavioral criteria. To quantify the influence of key determinants, autoregressive distributed lag (ARDL) and nonlinear ARDL (NARDL) models are applied, enabling the assessment of short-term and long-term relationships as well as asymmetric effects of fuel prices, electricity tariffs, and production volumes on logistics costs.

**Findings.** The results reveal a stable long-term relationship between logistics costs and the selected factors. Logistics costs in the dairy industry demonstrate significant inertia and asymmetric sensitivity to changes in energy and fuel prices, with cost increases responding more strongly than cost reductions. The findings confirm that the highest optimization effect is achieved through targeted management of endogenous factors, particularly transport routing, energy efficiency of storage and production processes, and reduction of losses along the supply chain.

**Originality.** The originality of the study lies in integrating a structured logistics cost classification with ARDL/NARDL-based econometric analysis into a comprehensive optimization mechanism tailored to the dairy industry, providing both theoretical contribution and practical applicability.

**Keywords:** logistics costs; dairy industry; supply chain management; ARDL/NARDL; cost optimization.

### Introduction

The dairy industry is one of the basic branches of the agro-industrial complex, ensuring the country's food security and sustainable socio-economic development of the regions. The efficiency of the dairy industry is largely determined by the level of logistical costs incurred at all stages of the production and distribution system – from the procurement and transportation of raw milk to the storage, processing and distribution of finished products.

The industry-specific nature of the dairy industry is due to the perishable nature of products, the need

for strict compliance with temperature conditions, the high energy intensity of production processes and the territorial dispersion of the raw material base. Under these conditions, logistics is becoming strategically important, and logistics costs are becoming one of the key factors in shaping the cost and competitiveness of dairy products.

In recent years, dairy industry enterprises have faced increasing external challenges related to rising fuel and electricity prices, increased transportation costs, and increased requirements for the quality and safety of food products. These factors increase the burden on the production and distribution systems of

enterprises and necessitate the search for new approaches to management and optimization of logistics costs.

Despite the availability of scientific research in the field of logistics and supply chain management, most of them are focused on universal models and do not fully take into account the industry specifics of the dairy industry. In practice, logistics cost management is often fragmented and does not cover the entire set of logistics processes within the enterprise's production and sales system.

In this regard, the development of an integrated mechanism for optimizing logistical costs based on a systematic approach and the integration of diagnostic, analytical and management units is of particular relevance. Such a mechanism makes it possible to ensure consistency of management decisions, increase transparency in the formation of logistics costs and identify reserves for their reduction at all stages of the production and sales system of a dairy industry enterprise.

The purpose of the article is to develop and substantiate a mechanism for optimizing logistics costs in the production and distribution system of a dairy industry enterprise based on the classification of logistics costs and the use of ARDL/NARDL models that take into account short-term, long-term and asymmetric effects of factors.

### Literature review

In modern logistics theory, logistics costs are interpreted as the total costs incurred in managing material, information, and financial flows in the supply chain, including transportation, warehousing, inventory management, order processing, and participant coordination (Christopher, 2016). Within the framework of the supply chain management (SCM) concept, it is emphasized that reducing logistics costs is possible not only through local savings, but also through the coordination of solutions between supply chain links, that is, through system optimization (Chopra & Meindl, 2019).

A separate area of research is devoted to the formation of costs for logistical functions and the search for a compromise between the level of service and costs. The most common approach is to allocate costs by stages: procurement/procurement, production, storage, distribution, and marketing, which helps identify bottlenecks and manage overall supply chain costs (Rushton et al., 2022).

The cold chain is critically important for the dairy industry as a condition for maintaining product quality and safety. Research on the food supply chain shows that temperature violations lead to an increase in losses, write-offs and refunds, which directly increases logistical costs and worsens the economic performance of enterprises (Aung & Chang, 2014). Works on intelligent food logistics indicate that digital monitoring of temperature and product condition can reduce losses and optimize storage and transportation costs (Jedermann et al., 2014).

From the point of view of operational management, dairy logistics is characterized by (i) a high frequency of deliveries, (ii) seasonality of the raw material base, (iii) territorial dispersion of suppliers (farms), (iv) a high proportion of energy consumption (cooling, storage), which forms a specific structure of logistical costs and increases the requirements for planning routes and capacities (FAO, 2018).

A significant group of studies examines the optimization of logistics costs through a process approach and a more accurate allocation of overhead costs for logistics operations. Activity-Based Costing (ABC) and its development, Time-Driven ABC (TDABC), make it possible to identify "cost drivers" (processing time, distance, number of operations, capacity utilization) and assess the contribution of individual logistics processes to the total cost (Kaplan & Anderson, 2007).

For food industry enterprises, ABC/TDABC are particularly useful in estimating the costs associated with order processing, returns, downtime of refrigeration facilities, uneven loading of vehicles and warehouses. The literature emphasizes that it is the process cost specification that creates the basis for targeted optimization and the correct choice of management decisions (Christopher, 2016; Rushton et al., 2022).

In research on operational SCM methods, routing and supply planning models (Vehicle Routing Problem and its variations) occupy an important place, since transportation costs often account for a significant share of logistics costs in agri-food chains. Route optimization, transportation consolidation, and alignment of supply schedules are seen as cost-cutting tools while maintaining service (Chopra & Meindl, 2019).

In parallel, methods of inventory management and warehouse costs are being studied: optimizing inventory levels, increasing turnover, reducing

delinquency losses, and rationalizing warehouse operations. For dairy products, these tools must be combined with temperature and shelf life requirements, which reinforces the role of regulations and quality control (Aung & Chang, 2014).

Modern literature records that digital technologies are changing approaches to cost management in supply chains. ERP/WMS/TMS systems increase cost transparency and enable end-to-end planning, while IoT sensors and analytics enable real-time cold chain monitoring, loss reduction, and deviation prevention (Ivanov et al., 2019). Research on digital supply chains also highlights that the effect of digitalization is stronger if the implementation is accompanied by a review of processes and KPIs, rather than being reduced to automating individual operations (Ivanov et al., 2019).

In the works on the analysis of costs and price shocks, an approach is widely used that separates the short-term and long-term effects of factors, which methodologically corresponds to the logic of ARDL. For the logistical costs of dairy enterprises, it is especially important to take into account the possible asymmetry of the response to rising and falling prices for fuel and electricity: costs can rise rapidly as resources become more expensive, but decrease more slowly as they become cheaper due to contracts, tariff inertia, capacity constraints and organizational lag. In the works on the analysis of costs and price shocks, an approach is widely used that separates the short-term and long-term effects of factors, which methodologically corresponds to the logic of ARDL. For the logistical costs of dairy enterprises, it is especially important to take into account the possible asymmetry of the response to rising and falling prices for fuel and electricity: costs can rise rapidly as resources become more expensive, but decrease more slowly as they become cheaper due to contracts, tariff inertia, capacity constraints and organizational lags. Nonlinear models (NARDL) make it possible to formalize such an asymmetry by decomposing factors into positive and negative changes and thereby giving the optimization mechanism empirical evidence (Shin et al., 2014).

Thus, the literature offers a wide range of tools for analyzing and optimizing logistics costs: the SCM system approach, ABC/TDABC process methods, optimization models for routing and inventory management, as well as digital cold chain solutions. However, there remains a research gap regarding the development of an integrated, industry-oriented

mechanism that (i) covers all stages of the dairy company's production and distribution system, (ii) links diagnostic, analytical and management circuits, and (iii) is supported by econometric verification of short-term/long-term and asymmetric effects of key factors (fuel, electricity). Filling this gap determines the scientific focus of this research.

## **Methodology**

The methodological basis of the study was the system, process and econometric approaches to the analysis of logistical costs. The object of the research is the production and sales system of dairy industry enterprises, the subject is logistics costs and their management mechanisms.

The proposed mechanism for optimizing logistics costs is based on the integration of diagnostic, analytical and management units and covers all key stages of the production and sales system of a dairy industry enterprise.

At the diagnostic stage, the structure of logistics costs is identified and a system of indicators is formed that reflect the costs of raw material procurement, transportation, storage, processing and marketing of products. The analytical block includes the classification of logistical costs by functional and factorial characteristics, as well as an assessment of the impact of key external and internal factors.

The management unit of the mechanism is aimed at developing and implementing management solutions for optimizing logistics processes based on the results of analysis and modeling. The effectiveness of the mechanism is assessed using a system of logistics KPIs that provide feedback and correction of management decisions.

The research uses methods of classification, structural and functional analysis, economic and statistical analysis and econometric modeling. The econometric justification of the optimization mechanism is carried out using ARDL and NARDL models, which allows taking into account short- and long-term effects, as well as the asymmetry of the response of logistical costs to changing factors.

## **Results and discussions**

The results of the study showed that effective optimization of logistics costs in the production and sales system of a dairy industry enterprise is impossible without their preliminary systematization and structuring. In this regard, within the framework

of the diagnostic and analytical blocks of the proposed mechanism, a classification of logistical costs was developed, reflecting their economic nature, functional role and manageability.

The classification of logistics costs of dairy industry enterprises is presented in Table 1 and is used as a methodological basis for identifying cost sources and choosing ways to optimize them.

**Table 1** – Classification of logistics costs of dairy industry enterprises

Classification criteria	Types of logistical costs	The economic essence	ARDL/NARDL variables	Role in the optimization mechanism
By function (stages of the supply chain)	Raw milk preparation	Costs of collection, primary cooling and milk delivery	$LC$	Formation of the basic level of logistics costs and identification of priority optimization areas
	Production logistics	Intra-factory movement, energy supply	$LC, PROD$	Optimization of internal flows and scale of production
	Storage and warehousing	Cold storage, losses, depreciation	$ELEC_{\pm}$	Reduction of energy consumption and storage losses
	Transportation	Fuel, transport maintenance, carrier services	$FUEL_{\pm}$	Optimization of routes and transport schemes
	Sales and distribution	Delivery of finished products, refunds	$LC$	Improving the efficiency of distribution logistics
By factor conditioning	Endogenous	Costs that depend on the organization of logistics and enterprise solutions	$PROD, LC_{t-1}$	The main object of managerial influence
	Exogenous	Costs generated under the influence of external prices and tariffs	$FUEL_{\pm}, ELEC_{\pm}$	Accounting for external constraints and price shocks
By behavior over time	Permanent	Depreciation, lease of warehouses	$LC_{t-1}$	Accounting for the inertia of logistical costs
	Variables	Fuel, electricity	$FUEL, ELEC$	Assessment of short-term cost sensitivity
	Conditional variables	Operation of refrigeration equipment	$PROD, ELEC_{\pm}$	Search for reserves of flexibility of logistical costs
According to the degree of controllability	Managed	Transportation routes, delivery schedules	$PROD$	Implementation of targeted management measures
	Partially managed	Energy consumption, loss rate	$ELEC_{\pm}$	Improving efficiency through technology
	Poorly controlled	Tariffs, energy prices	$FUEL_{\pm}$	Minimizing environmental risks
By the nature of the reaction to the factors	Symmetrical	Proportional cost response	$ARDL(X)$	Using linear management tools
	Asymmetrical	A stronger reaction to the growth of factors	$NARDL(FUEL^{\uparrow/}, ELEC^{\uparrow/})$	Justification of adaptive and preventive solutions

Note – compiled by the author based on Christopher (2016), Rushton et al. (2022), Shin et al. (2014).

where:

- LC is the total logistical cost;
- $FUEL^{\uparrow/}$  – increase/decrease in fuel prices;
- $ELEC^{\uparrow/}$  – increase/decrease in electricity tariffs;
- PROD – the volume of production.

The logistical costs of dairy industry enterprises are classified according to functional, factorial and behavioral characteristics. The costs of procurement logistics, production logistics, storage and

warehousing, transportation and distribution are distinguished by functional feature. The totality of these costs forms a dependent variable of the model – the logistics costs of the enterprise ( $LC_t$ ).

According to factor conditioning, logistical costs are divided into endogenous and exogenous. Endogenous costs depend on the organization of logistics processes and management decisions of the enterprise and are reflected through production

volumes ( $PROD_t$ ). Exogenous costs are formed under the influence of the external environment and are represented by fuel prices ( $FUEL_t$ ) and electricity tariffs ( $ELEC_t$ ).

By the nature of the reaction to changing factors, symmetrical and asymmetric logistical costs are distinguished, which leads to the use of the nonlinear NARDL model.

$$LC_t = \alpha_0 + \sum_{i=1}^p \alpha_i LC_{t-i} + \sum_{j=0}^q \beta_j FUEL_{t-j} + \sum_{k=0}^r \gamma_k ELEC_{t-k} + \sum_{m=0}^s \delta_m PROD_{t-m} + \varepsilon_t \quad (1)$$

where:

$\alpha_i$  – reflect the inertia of logistical costs;  
 $\beta_j, \gamma_k, \delta_m$  – short-term effects of factor variables;  
 $\varepsilon_t$  is an accidental error.

Long-term coefficients are calculated based on the estimated parameters of the model and reflect the steady influence of factors on the level of logistical costs.

Taking into account the specifics of logistics costs of dairy industry enterprises, it is assumed that the cost response to rising and falling resource prices may be asymmetric. To account for it, the NARDL model is used, in which exogenous variables are decomposed into positive and negative partial sums:

$$\begin{aligned} FUEL_t &= FUEL_t^+ + FUEL_t^-, ELEC_t = \\ &= ELEC_t^+ + ELEC_t^- \end{aligned} \quad (2)$$

The NARDL model is used to account for the asymmetry:

$$\begin{aligned} LC_t &= \alpha_0 + \sum_{i=1}^p \alpha_i LC_{t-i} + \beta^+ FUEL_t^+ + \\ &+ \beta^- FUEL_t^- + \gamma^+ ELEC_t^+ + \\ &+ \gamma^- ELEC_t^- + \delta PROD_t + \varepsilon_t \end{aligned} \quad (3)$$

The ARDL/NARDL model in this study is used to quantify the short- and long-term, as well as the symmetrical and asymmetric effects of logistics cost formation factors and serves as an analytical basis for their optimization mechanism aimed at improving the efficiency of logistics process management in the production and sales system of dairy enterprises.

The basic ARDL model looks like this:

where:

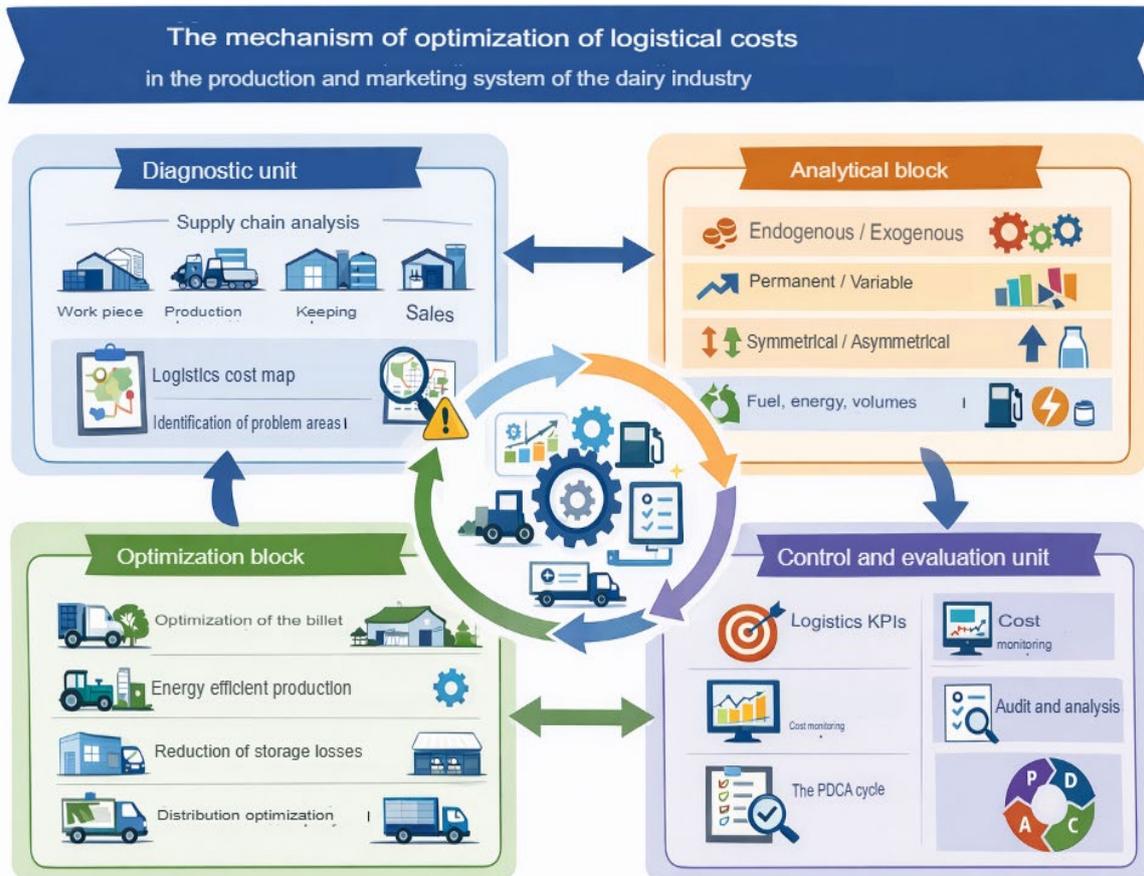
$\beta^+, \gamma^+$  reflect the reaction of logistics costs to rising fuel and electricity prices;  
 $\beta^-, \gamma^-$  – a reaction to their decrease.

Coefficients for  $FUEL^+$  and  $ELEC^+$  reflect an increase in logistics costs with an increase in the cost of resources, while the coefficients for  $FUEL^-$  and  $ELEC^-$  are the effect of their reduction. The significance of lags  $LC_{t-1}$  indicates the inertia of logistical processes.

Thus, the ARDL/NARDL model provides not only a quantitative assessment of the factors of formation of logistical costs, but also forms an analytical basis for making managerial decisions within the framework of their optimization mechanism. The use of a non-linear approach makes it possible to take into account the industry specifics of the dairy industry and increases the validity of strategic and operational decisions on logistics process management.

The mechanism for optimizing logistics costs in the production and sales system of a dairy industry enterprise is a multi-level system of interconnected blocks, each of which performs a specific functional role and ensures the transition from analysis to practical management of logistics processes.

The developed mechanism for optimizing logistics costs is a consistent and interconnected system of blocks aimed at improving the efficiency of logistics process management.



**Figure 1** – A system mechanism for optimizing logistics costs in the production and distribution system of a dairy industry enterprise  
Note – compiled by the author

The structure and logic of the proposed mechanism are shown in Figure 1.

The developed mechanism for optimizing logistics costs in the production and sales system of a dairy industry enterprise is a consistent and interconnected system of blocks, each of which performs an independent function, but at the same time is integrated into a single analytical and managerial logic. The ARDL/NARDL econometric model is organically integrated into this mechanism and provides quantitative justification of management decisions at each stage.

The first block of the mechanism, the diagnostic one, is focused on identifying the structure and dynamics of logistical costs generated at various stages of the dairy industry supply chain, including raw milk harvesting, production, storage, transportation and marketing of finished products. At this stage, a logistics cost map is being formed, which makes it possible to determine their distribution across the functional links of the production and

distribution system and identify areas of the highest cost concentration.

The purpose of the diagnostic unit is to form a holistic view of the structure of logistics costs and their specific weight at each stage of the supply chain. This allows you to determine which logistics operations have the greatest impact on the cost of production, as well as identify problem areas characterized by increased costs. The need for this block is due to the fact that logistics costs in the dairy industry have a complex, multicomponent structure and cannot be effectively managed without prior structuring and systematization.

From the point of view of econometric analysis, the diagnostic unit corresponds to the formation of a dependent variable model – the total logistical costs.

$LC_t$ , as well as accounting for their inertia through lags  $LC_{t-1}$ . The importance of lags in the ARDL/NARDL model confirms that the current level of logistics costs is largely determined by the previously established structure of the production and

distribution system, which justifies the need for phased and systemic optimization.

The second block, the analytical one, is aimed at in-depth assessment of the factors affecting the level of logistical costs and identification of the nature of their impact. Within the framework of this block, logistical costs are classified according to factorial and behavioral characteristics, including the division into endogenous and exogenous, constant and variable, as well as symmetrical and asymmetric with respect to changes in external factors. This allows us to take into account the different reactions of logistics costs to rising and falling fuel and electricity prices, changes in production volumes and raw material supply conditions.

The rationale for the analytical block is related to the need to move from a descriptive cost estimate to the identification of stable cause-and-effect relationships. The use of econometric tools, in particular ARDL/NARDL models, makes it possible to quantify the contribution of exogenous factors ( $FUEL_t$  fuel prices and  $ELEC_t$  electricity tariffs) and endogenous factors ( $PROD_t$  production volumes) to the formation of logistical costs, as well as to distinguish between short-term and long-term effects of their impact.

The use of the non-linear NARDL specification ensures the identification of the asymmetry of the response of logistics costs to changing factors, which is of fundamental importance for an industry with high energy and transport dependence. Thus, the analytical unit forms a scientifically based basis for the subsequent optimization of logistics processes.

The third block, management (optimization) – provides for the development and implementation of a set of management solutions aimed at reducing logistics costs and improving the efficiency of logistics processes. In this section, the results of diagnostics and econometric analysis are transformed into practical measures for each logistics link, including optimizing the routes for collecting and delivering raw milk, improving the energy efficiency of production and warehouse operations, reducing storage losses and rationalizing the distribution system of finished products.

From the point of view of the ARDL/NARDL approach, the management unit relies on the interpretation of coefficients for the asymmetric variables  $FUEL^{+/-}$  and  $ELEC^{-/}$ . The higher sensitivity of logistics costs to rising resource prices compared with their decrease indicates the presence of

structural limitations of the logistics system and justifies the need for priority management of internal, endogenous factors. Thus, the management unit is focused not on waiting for favorable external conditions, but on actively reducing the vulnerability of logistical costs by optimizing processes.

The fourth block, control and evaluation, is focused on monitoring the results of the implementation of management decisions and evaluating their effectiveness. Within this block, a system of logistics KPIs is used to track the dynamics of logistics costs, the level of product losses, inventory turnover and the energy intensity of logistics processes.

In the econometric context, this block is related to the assessment of the stability of long-term dependence and the rate of adjustment to equilibrium, reflected by the error correction factor (ECM). The significance and the ECM mark allow us to assess the ability of the production and distribution system to adapt to external and internal shocks, as well as the effectiveness of implemented management decisions. The need for a control and evaluation unit is due to the formation of feedback, which ensures the adjustment of the mechanism and its continuous improvement.

Together, the presented blocks form an integrated mechanism for optimizing logistical costs based on the logic of a sequential transition from diagnosis to analysis, then to management and control. The ARDL/NARDL econometric model acts as the analytical core of the mechanism, providing quantitative interpretation of factors and their integration into the management decision system.

The implementation of the proposed mechanism allows us to consider logistics costs not as an isolated cost element, but as a result of the interaction of all parts of the production and sales system. Unlike fragmented approaches, the mechanism provides comprehensive cost management, taking into account the industry specifics of the dairy industry, the high sensitivity of logistics costs to external factors and the need for sustainable enterprise development. The practical significance of the mechanism lies in the possibility of its adaptation to various business scales – from regional processing enterprises to integrated agro-industrial holdings, and the results of the study confirm that the greatest optimization effect is achieved with synchronous management of procurement and sales logistics and the introduction of digital tools for monitoring logistics processes.

## Conclusion

In the course of the research, a mechanism for optimizing logistics costs in the production and sales system of a dairy industry enterprise based on the system integration of diagnostic, analytical, managerial, and control and evaluation units has been developed and substantiated. The proposed mechanism is aimed at improving the efficiency of logistics process management, taking into account the industry specifics of the dairy industry, characterized by high energy and transport dependence, limited shelf life and the need to comply with the cold chain.

The key element of the mechanism is the classification of logistics costs, which allows you to structure costs according to functional, factorial and behavioral characteristics and consider them as the result of the interaction of all parts of the production and distribution system. The use of ARDL/NARDL econometric models provided a quantitative justification of the mechanism and made it possible to identify both short- and long-term dependencies between logistical costs and factor variables, as well as the asymmetric nature of the cost response to changes in fuel and electricity prices.

The results of the study showed that the logistical costs of dairy industry enterprises have a pronounced inertia and react more strongly to an increase in external price factors than to their decrease. This

confirms the limited flexibility of logistics processes and justifies the need for priority management of endogenous factors, including optimizing procurement and distribution routes, increasing the energy efficiency of production and warehouse operations, as well as reducing losses during storage and transportation of products.

The scientific novelty of the research lies in the integration of logistics cost classification, ARDL/NARDL econometric analysis and the block structure of the optimization mechanism, which allows us to move from fragmented management decisions to integrated and adaptive logistics cost management. The practical significance of the work lies in the possibility of applying the proposed mechanism at dairy enterprises of various scales, from regional processing plants to integrated agro-industrial holdings, as well as in using the analysis results to justify management decisions in conditions of price instability and external shocks.

In general, the implementation of the proposed mechanism helps to increase the stability of the production and distribution system, reduce the sensitivity of logistics costs to external factors, and create long-term competitive advantages for dairy enterprises. The prospects for further research are related to the expansion of the set of factor variables, the inclusion of indicators of logistics digitalization and environmental factors, as well as the testing of the mechanism on regional and interregional data.

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