Subsidy effects on productivity and technical efficiency of corporate dairy farms in the Russian Federation

Yulia Nikulina[1], Tinoush Jamali Jaghdani[2], Linde Götz[3]; Martin Petrick[4]

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Abstract

The impact of state subsidies on Russia's post-Soviet dairy output remains controversial; this study provides an empirical analysis of that relationship. Using an unbalanced panel dataset of 123 dairy enterprises in the Leningrad Region spanning the period from 2010 to 2023, we employ stochastic frontier analysis to assess these relationships. The results indicate that subsidies have a positive effect on dairy enterprise productivity, while their impact on technical efficiency cannot be clearly identified. Notably, the positive effect of subsidies is confined to a medium range of subsidy levels. The influence of different types of subsidies on productivity is multidirectional, as plant production and investment interest subsidies are associated with productivity gains, whereas breeding subsidies have a negative effect, and other subsidy types show no significant impact. Although our results suggest that milk production in Russia could be further increased through improvements in technical efficiency, the findings also indicate that distributing subsidies to a larger number of enterprises is more effective than allocating large subsidies to a limited number of recipients. Furthermore, the results suggest that dairy subsidy policy should be adjusted in favor of more decoupled and regionally differentiated subsidies at the district level.

Keywords: dairy subsidies, productivity, technical efficiency, stochastic frontier, Russia

[1] National Research University Higher School of Economics, Centre for Productivity Studies, Russia. ORCID: 0000-0003-3348-3259

[2] Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Halle (Saale), Germany. ORCID: 0000-0003-2204-0452

[3] IAMO & Martin-Luther-University Halle-Wittenberg (MLU), Halle (Saale), Germany. ORCID: 0000-0001-8204-4522

[4] IAMO & Justus Liebig University Giessen (JLU), Giessen, Germany. ORCID: 0000-0002-4477-6367

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1 Introduction

As food self-sufficiency is a central objective of Russia's food security policy (Götz et al., 2022; Burkitbayeva et al., 2020) and agricultural and food export growth has become a strategic goal of Russia's agricultural policy (Götz et al., 2022; Wegren, 2020), the expansion of domestic agricultural and food production remains a high priority for the Russian government. Despite an overall increase in Russia's food self-sufficiency across many products (Serova, 2020), Russia did not achieve its political target of 90% self-sufficiency in milk in 2023, reaching 86% instead (Rosstat, 2024a). In 2024, production and export targets were reaffirmed and updated by presidential decree (UPRF, 2024). The new directive envisages a 25% increase in agricultural production and a 1.5-fold increase in exports by 2030 (ibid). The milk-specific target is 39 million tons, compared to an output of 34 million tons in 2024 (Zamglavy, 2025).

Since the onset of post-Soviet period, dairy production in the Russian Federation has declined drastically (Tleubayev et al., 2021). In response, animal husbandry, particularly milk production, has been prioritized to support by the Russian state, especially since the second half of the 2000s (Sedik et al., 2017; Uzun, 2012). Nevertheless, scientific ex post analyses of the impact of agricultural subsidies on Russia's dairy sector remain scarce. Petrick and Götz (2019) provide the only quantitative assessment of subsidy effects in the Russian dairy sector, finding that improvements in herd management and access to milk sales contracts were more effective in stimulating herd growth than existing subsidy payments. Earlier work by Bezlepkina et al. (2005), focusing on the Moscow region during the period between 1995 and 2001, identified positive effects of subsidies on dairy farm profitability and credit constraints. Krivko and Smutka (2020) argue that the importance of direct subsidy payments for agricultural producers

has declined and has been replaced by market price support[5] following the introduction of Western sanctions and the Russian food embargo in 2014. However, there remains a research gap regarding the impact of subsidies on milk output. This study aims to shed light on this under-researched question by investigating the influence of subsidies on the productivity and technical efficiency of dairy enterprises in Russia.

The main channels through which subsidies impact agricultural production are, as well identified in the literature, changes in relative input and output prices, changes in income constraints, changes in risk-taking, and the inducement of structural change (DeBoe, 2020; Minviel & Latruffe, 2017; Kumbhakar & Lien, 2010). The impact of these key pathways on productivity and technical efficiency can be positive, negative, or neutral (Akber et al., 2025; Agostino et al., 2024; Garrone et al., 2019; Latruffe et al., 2017; Minviel & Latruffe, 2017). Although the direction and scale of the impact of subsidies on productivity and technical efficiency in Russian agriculture have been investigated in several studies (Tleubayev et al., 2022; Vasilyeva & Bilko, 2022; Shik, 2020; Svetlov et al., 2019; Epshtein, 2012; Sedik et al., 2000; Sotnikov, 1998), Russian dairy farming has, with the exception of Petrick and Götz (2019), not been addressed.

We focus on corporate milk producers, i.e. agricultural enterprises registered as legal entities, which accounted for 61% of milk output in 2024 (Rosstat, 2024b). Agricultural enterprises may be part of agricultural holdings or be independent. Existing studies have shown that the effect of subsidies varies depending on farm size (He et al., 2022; Staniszewski & Borychowski, 2020). Moreover, Kostov et al. (2025) confirm qualitative differences in the effects of agricultural subsidies on agricultural employment between enterprises and family farms in Russia. In this sense, Russia is an illustrative case highlighting the specific reactions of the corporate agricultural sector compared to a sector dominated by family farms (Rimhanen

[5] Market Price Support is the OECD term for a government policy that creates a gap between domestic producer prices and border prices.

et al., 2023; Loginova & Mann, 2022). We focus on corporate farms because they have become the main milk producers in Russia and thus substantially determine the future development of the industry. We examine eight individual types of dairy subsidies, namely, per kg milk subsidies, breeding, other livestock, capital expenditure, plant production, short-term interest, investment interest, and miscellaneous subsidies.

Since the increase in milk output is a key target for the Russian government (UPRF, 2024; Zamglavy, 2025), we address the following two research questions in this study: (1) Do subsidies impact the quantity of milk production in Russia? (2) Does the type of subsidy (e.g. per-kilogram milk payments, breeding subsidies, etc.) matter for the magnitude of the production effect? We follow Kumbhakar and Lien (2010) in our research approach and consider subsidies as a "facilitating" input, assuming that they impact not only technical efficiency but also the technology itself, and hence the productivity of milk producers. We estimate a translog frontier production model for milk output to simultaneously evaluate productivity and technical efficiency across agricultural enterprises. While productivity refers to the total output per unit of input, technical efficiency represents the extent to which the maximum possible output is achieved given the available resources and technology.

This study contributes to the literature as follows. First, we contribute to filling the aforementioned research gap by building on a novel panel dataset covering 123 milk-producing agricultural enterprises in Leningrad Oblast (Region), one of Russia's leading milk-producing regions, with annual observations for the period from 2010 to 2023. Second, we analyze a variety of subsidy types targeting dairy farming as well as more general subsidies for agriculture. Third, we focus on corporate dairy farms in Russia, whereas the existing literature focuses on family farms in EU agriculture. Fourth, we contribute to the debate on the impact of coupled and decoupled subsidies in transition economies. The results presented can be useful

for agricultural policy in other emerging or developing countries where agricultural production is dominated by corporate farms rather than family farms.

The structure of the paper is as follows. Section 2 provides a brief overview of the development of milk production and dairy subsidies in Russia. Section 3 outlines the hypotheses regarding the impact of subsidies on productivity and technical efficiency. Section 4 describes the econometric modeling approach and the data. Section 5 presents and discusses the econometric results. Section 6 concludes with final remarks.

2 Development of milk production and dairy subsidies in Russia

2.1 Trends in Russian milk production

Agriculture in Russia has undergone sharp declines in output since the collapse of the Soviet Union in December 1991, driven by a harsh reduction in subsidy payments at the beginning of the transition to a market economy (Petrick & Götz, 2019; Uzun, 2012). Milk production in 2024 still falls short of the production level in 1990 by 39%, while poultry and pork production have increased by factors of 3.0 and 1.4, respectively. Milk production has therefore continued to miss the target indicators defined by the government, including the self-sufficiency target. As a result, milk production remains subsidized on a priority basis.

Russia's experience reflects a broader structural decline in dairy production across the former Soviet Union. In the largest milk-producing countries of the former Soviet Union, with the exception of Belarus, milk output has not returned to its 1990 level. Total milk production in the twelve former Soviet Union transition economies was, on average, 28% lower in 2023 than in 1990.

Milk production in Russia exhibits two main trends: (i) a rising share of agricultural enterprises in milk production, and (ii) increasing milk yields per cow. Since the beginning of the study period, the share of agricultural enterprises in raw milk production has increased from 45% in 2010 to 61% in 2024 (Rosstat, 2024b), amounting to as much as 76% of milk production

marketed via value chains (Souzmoloko, 2021). Moreover, the concentration of raw milk production and the development of agroholdings have increased, although to a lesser extent than in the poultry and pork sectors (Uzun et al., 2021).

The average annual growth rate of Russian milk output and milk yield per cow amounted to 0.5% and 1.7%, respectively, while herd size shrank by an average of 1.1% over the study period (Rosstat, 2024b). Milk yield in agricultural enterprises increased considerably from 4.7 tons to 9.1 tons per cow between 2010 and 2024, exceeding the average for all types of producers (Rosstat, 2024b). Together, these trends demonstrate the central role of the corporate sector in raw milk production in Russia, largely determining its future development.

2.2 Dairy subsidies in Russia

Subsidies for milk producers in Russia consist primarily of specialized dairy subsidies and common agricultural subsidies (Table 1). The specialized dairy subsidy is primarily a payment per kilogram of raw milk sold. It is a commodity-based output subsidy that is still applied to raw milk production in Russia. Breeding subsidies include payments for keeping pedigree cows (per head), for the purchase of pedigree young stock (per head), and for semen purchases. "Other" livestock subsidies consist of payments for cattle meat production (per feeder steer), subsidies for fodder purchase, insurance, and related measures. The capital expenditure subsidy refers to state co-financing of capital investments[6] for a selected list of agricultural sectors, including dairy farming. For dairy farming, this subsidy is provided at a higher co-financing rate and was introduced in 2015.

[6] I.e. the government covers part of the expenditures as a grant.

Table 1. Subsidies to milk producers in Russia by type

Type of subsidy	Specialized for dairy farming	Coupled
Subsidy per kg of raw milk sold	yes	yes
Breeding subsidies	yes	yes
Other livestock subsidy	yes	yes
Capital expenditure subsidy	yes	yes
Plant production subsidies (aggregated)	no	no
Short-term interest subsidy (loans up to 1 year)	no	yes
Investment interest subsidy (loans more than 1 year)	no	yes
Miscellaneous (aggregated)	no	mix

Source: Own compilation

The most extensive form of support for agriculture in Russia, available to all types of agricultural producers, is an interest subsidy for short-term and investment loans (OECD, 2020). This subsidy covers a part of the interest costs incurred by agricultural producers. Since 2017, interest subsidies have been replaced by concessional credit, with concessions taking the form of government-fixed reduced interest rates, combined with financial compensation to lending banks. Data on concessional credit for our sample are only available for 2018-2019. Hence, "interest subsidy" is used as a single term throughout the study period, with the understanding that from 2017 onward it also encompasses subsidies for concessional credit. The plant production subsidy consists of payments for seed production and purchase, agrotechnological operations, insurance, and per-hectare subsidy (introduced in 2013), among others. Miscellaneous subsidies are highly heterogeneous and include payments for the reconstruction of reclamation systems, agrochemical inspections and operations, soil liming, infrastructure maintenance, and subsidies under the rural development program.

Among all the subsidies reviewed, only plant production subsidies can be classified as decoupled, while the remainder are classified as coupled. We distinguish between coupled and decoupled subsidies in line with the OECD classification of Russian subsidies (OECD, 2025). Specifically, subsidies based on output or input use are classified as coupled, while those based on the current area planted, with production required, are classified as decoupled.

3. Hypotheses on subsidy effects

Based on the nature of the subsidies under consideration, we make several assumptions about their impact on the productivity and technical efficiency of dairy enterprises. For the group of subsidies aimed at increasing resource intensity (including subsidies per kilogram of raw milk, breeding subsidies, plant production subsidies, and short-term interest subsidies), we assume a positive effect on productivity, as these measures relax constraints on resource use. At the same time, the listed subsidies, with the exception of plant production subsidies, are coupled. We acknowledge that much of the empirical literature finds a negative relationship between coupled subsidies on productivity (Garrone et al., 2019). However, under conditions of market imperfections, coupled subsidies have been shown to mitigate distortions in the agricultural land rental market and enhance farmers' perceived security (Xing & Wang, 2025), thereby potentially improving productive outcomes.

With respect to technical efficiency, we expect subsidies in this group aimed at increasing resource intensity to have a negative effect, as existing empirical studies predominantly report adverse impacts of coupled subsidies, defined as subsidies based on output or input use, on technical efficiency (DeBoe, 2020; Minviel & Latruffe, 2017). Nevertheless, recent studies focusing specifically on dairy farming provide more nuanced evidence. A positive relationship between subsidies and dairy farm technical efficiency has been identified in EU countries that maintained high levels of direct payments even after decoupling (Latruffe et al., 2017). Similarly, in Italian dairy farming, production-coupled subsidies were found to be associated with higher technical efficiency (Agostino et al., 2024). Decoupled subsidies are positively related to milk output technical efficiency (Skevas, 2025), but this type of subsidy is relatively unimportant in the case of Russia. Despite this mixed evidence, our hypothesis regarding the negative impact of subsidies on technical efficiency is further supported by evidence of soft

budget constraints[7] in Russian agricultural support schemes (Vasilyeva & Bilko, 2022; Svetlov et al., 2019) and by a tendency to support less efficient producers, inherited from the Soviet system (Tleubayev et al., 2022; Sedik et al., 2000; Sotnikov, 1998).

Other livestock subsidies are also designed to reduce resource constraints. However, as they primarily consist of payments per feeder steer for meat production, we hypothesize that they negatively impact milk production productivity and technical efficiency, potentially by diverting resources away from dairy activities and diluting managerial control. In contrast, the impact of investment interest subsidies and capital expenditure subsidies is expected to be positive for both productivity and technical efficiency. These instruments are explicitly targeted at production modernization, facilitating technological upgrading toward newer and more productive capital equipment. They may also alleviate income constraints and reduce risk exposure associated with investment and innovation decisions. Moreover, through competitive selection mechanisms in capital expenditure subsidy allocation and bank screening in lending decisions, these subsidies may promote structural change, including the reallocation of resources toward more efficient producers. With regard to miscellaneous subsidies, no a priori assumptions are made about their effects on productivity or technical efficiency. Overall, total subsidies are expected to have a positive impact on productivity and a negative impact on technical efficiency, reflecting their substantial emphasis on policies aimed at intensifying resource use.

4 Methods and Data

4.1 Methodology

We follow the approach of Kumbhakar and Lien (2010) and model subsidy payments as an endogenous variable in a productivity model that explicitly incorporates an inefficiency

[7] Excessive reliance on subsidies and reduced incentives to improve technical efficiency, or, conversely, subsidies being directed to those who need them least.

component. This approach allows us to simultaneously identify the role of subsidies in determining productivity and technical efficiency. Subsidies are modeled as an endogenous variable because, in the Russian context, enterprises can, to some extent, influence the amount of subsidies they receive. We therefore adopt a system-of-equations framework to analyze the impact of subsidies on milk output:

$$y_{it} = f\left(\boldsymbol{x}_{it}, \boldsymbol{s}_{it}, \boldsymbol{z}_{it}^{p}, t; \boldsymbol{\beta}\right) + \eta_i + \upsilon_{it} - \mu_{it} \qquad (1)$$

$$s_{it} = f\left(\boldsymbol{z}_{it}^{s}; \boldsymbol{\delta}\right) + c_i + \varepsilon_{it} \qquad (2)$$

where y_{it} denotes milk output (tonnes) for farm *i* at time *t*, $f\left(\boldsymbol{x}_{it}, \boldsymbol{s}_{it}, \boldsymbol{z}_{it}^{p}, t; \boldsymbol{\beta}\right)$ represents the production technology; x_{it} is the vector of inputs; s_{it} denotes the subsidy received; $\boldsymbol{z}_{it}^{p}$ is the vector of control variables; t captures a time-trend; $\boldsymbol{\beta}$ is the vector of parameters to be estimated. Furthermore, η_i denotes an unobserved random effect; υ_{it} is the general error, and μ_{it} represents the stochastic inefficiency component. The inefficiency term is specified as $\mu_{it} = G_t \cdot u_i$, with $G_t = exp(\gamma \cdot \tilde{t})$ where $\tilde{t}$ is a time-trend variable and G(·) is a non-negative function of *t*. Furthermore, u_i, following Kumbhakar and Lien (2010), is assumed to be a time-invariant random variable. It can be defined as $u_i \sim N^{+}(\mu, \sigma_u^2) = N^{+}(\mathbf{z}_i^e\ \varsigma, \sigma_u^2)$, that is, a half-normally distributed random variable. Accordingly, $\mathbf{z}_i^e$ is the vector of explanatory variables determining inefficiency, drawn from different domains of the dairy management system, and ς is the associated parameters to be estimated. In the second equation, which models endogenous subsidies, $f\left(\boldsymbol{z}_{it}^{s}; \boldsymbol{\delta}\right)$ is specified as a function of the variables $\boldsymbol{z}_{it}^{s}$, which capture enterprise characteristics; δ denotes the parameters to be estimated; $c_i \sim N(0, \sigma_c^2)$ represents the unobserved farm-specific effect; $\varepsilon_{it} \sim N\,(0, \sigma^2)$ is the random noise component.

The production function is estimated using the translog form. Before estimating the stochastic frontier function, we estimate the translog production function to determine the appropriate set of variables and to specify the random-effects structure of the panel-data model. The $f\left(\boldsymbol{x}_{it}, \boldsymbol{s}_{it}, \boldsymbol{z}_{it}^{p}, t; \boldsymbol{\beta}\right)$ function in (Equation 1) includes the following input variables: $x_{1,}$

defined as the logarithm of the number of employees; x_2, defined as the logarithm of material costs, measured as expenditures of feed, electricity, and fuel within cow-related expenses; and x_3 is a dummy variable responsible for the type of production technology as a proxy for capital. The number of employees (x_1) is adjusted by multiplying it by the share of revenue from milk sales in total enterprise revenue (revenue excluding subsidies), to ensure consistency between output and labor input. A similar approach is applied, for example, in Mayen et al. (2010) to capital inputs and in Kim et al. (2013) to the allocation of common utilities. The labor adjustment is primarily intended to accurately account for labor use in multi-product farms, particularly those engaged in vegetable and potato production, which are more labor-intensive than milk production. Next, we perform robustness checks to assess this assumption. The production technology type (x_3) equals 1 for free-stall housing systems (with milking parlors or robotic milking systems), which represent a more capital-intensive and advanced technology, and 0 for tie-up housing systems (with pipeline milking systems). The vector $\boldsymbol{z}_{it}^{p}$ includes the number of cows, which is treated as a quasi-fixed factor. In addition, a time-trend index, *t* (1 … 14), is added to account for technical change.

The variables $\mathbf{z}_i^e$ in the inefficiency function $\mu_{it}(\cdot)$ include subsidies received per hectare, a dummy variable indicating agroholding affiliation, and a dummy variable for suburban districts, defined as districts of the Leningrad Region adjacent to St. Petersburg. Other frequently used variables in the literature include farmers' age and education; however, such information is not available for enterprise managers in this study.

Equation 1 is static in nature and does not explicitly model technical efficiency dynamics and persistence. The static stochastic frontier framework is chosen because: (i) the primary objective of the paper is to investigate subsidy heterogeneity and the channels of their impact on milk production (through productivity or technical efficiency), but not to estimate persistence in inefficiency itself; (ii) the dynamic stochastic frontier, as an alternative (Skevas

et al., 2018), exacerbates the existing issue of subsidy endogeneity and may increase the complexity of identification; (iii) given institutional and macroeconomic changes during the study period, a static stochastic frontier model provides a clearer interpretation of current enterprise performance without confounding inefficiency with external shocks.

Before estimating (Equation 2), a formal endogeneity test is performed. If s_{it} is uncorrelated with v_{it}, the OLS and 2SLS estimators should differ only due to sampling error (Wooldridge, 2010: 118). In other words, if the residuals are significantly correlated with the explanatory variable(s), this provides evidence of endogeneity, indicating that 2SLS is required (Ibid., 120).

The set of instrumental variables ($\boldsymbol{z}_{it}^{S}$) in (Equation 2) includes variables related to (i) enterprise size and (ii) enterprise investment activity. In general, larger enterprises are more successful in accessing subsidies in Russia (Shik, 2020; World Bank, 2020; Uzun et al., 2019). This may reflect greater bargaining power, particularly among investment-active enterprises, as well as eligibility for multiple subsidy schemes associated with diversified business activities.

Instruments capturing enterprise size include labor costs, the value of fixed capital and meat sale in tons. Investment activity is characterized by long-term loans, and rate-based indicators, defined as the share of years in which the enterprise received subsidized loans relative to the total number of years observed. The instrument set also includes a dummy variable indicating whether an enterprise produces grain.

All variables are normalized by dividing them by their geometric sample means. Thus, the estimated first-order coefficients of the production factors can be interpreted as elasticities evaluated at the arithmetic sample means. Technical efficiency is defined as the ratio of observed output to the corresponding stochastic frontier output.

The stochastic production function is estimated for both total subsidies and disaggregated subsidy categories. We use the sfaR package (Dakpo et al., 2023) based on the R statistical computing software for estimation. The parameters of the inefficiency function were estimated using the model by Alvarez et al. (2006), which extends the specification of Battese and Coelli (1992) by allowing firm characteristics to influence inefficiency dynamics over time. This enhances model flexibility, permitting a wider range of efficiency trajectories relative to models with a single time trend.

4.2 Study region and data

The analysis is based on the annual standardized accounts of agricultural enterprises producing milk[8], located in Leningrad Oblast (region). This Russian region has a long-standing specialization in dairy farming and ranks among the leading regions in terms of dairy productivity and technological development. In addition, the production structure is dominated by agricultural enterprises. We therefore consider the region under study to be a benchmark for dairy farming in Russia.

We use an unbalanced panel dataset covering 123 dairy enterprises with 1,225 annual observations from 2010 to 2023. The enterprises in the study sample are highly specialized in raw milk production, as they account for about 89% of regional milk output in Leningrad Oblast. On average, those enterprises generate 92% of their revenues from dairy farming, with 78% derived from raw milk sales, and the remainder from marketing breeding stock, feeder steers, and cull cows.

Table 2 presents descriptive statistics for all variables included in the models, including the instrumental variables. All monetary variables are expressed in constant 2010 prices and deflated using a regional inflation index.

[8] The source of these annual reports is the Committee for Agriculture of Leningrad Oblast. Regional enterprises are obliged to submit annual reports to it, especially if they are receiving subsidies.

Table 2. Descriptive statistics

Variable	Short code	Unit	Mean	Median	Min	Max
Number of cows	Heads	heads	761	750	1	3 005
Milk production	milk_output	tonnes	6 192	5 711	1	31 705
Share of milk sales in total farm revenue	milk_share	%	78	84	2	100
Land cultivated	Land	ha	2 026	1 874	1	7 911
Number of employees	Empl	heads	90	88	1	264
Material costs	material_cost	1000 Rubles	77 059	64 943	18	449 542
If free stall housing of cows = 1	free_stall_d	(1/0)	0.41	0	0	1.00
Subsidy, total	s_tot	1000 Rubles	28 889	21 798	0	216 136
incl. investment interest subsidy	s_invest	1000 Rubles	2 660	0	0	79 190
short-term interest subsidy	s_short	1000 Rubles	487	0	0	10 529
plant production subsidies	s_plant	1000 Rubles	4 312	2 988	0	45 509
subsidies per kg of raw milk sold	s_milk	1000 Rubles	7 754	5 939	0	70 310
breeding subsidies	s_breed	1000 Rubles	4 353	3 714	0	27 171
other livestock subsidies	s_livestock_other	1000 Rubles	1 226	263	0	45 767
capital expenditure subsidy	s_capex	1000 Rubles	432	0	0	129 476
miscellaneous subsidies	s_ miscell	1000 Rubles	7 665	2 582	0	115 601
If enterprise belongs to agroholding = 1	agrohold_d	(1/0)	0.3	0.0	0.0	1.0
If enterprise located in suburban district = 1	suburb_d	(1/0)	0.3	0.0	0.0	1.0
Labor cost for a month	labor_cost	1000 Rubles	2 294	2 055	3	13 984
Fixed capital	capital	1000 Rubles	154 611	93 847	80	1 794 911
Long-term loan debt	long_cred_sum	1000 Rubles	81 051	8 538	0	1 892 956
Long-term loans rate	invest_rate	coeff.	0.41	0.43	0	0.93
Cattle meat sales	meat_sale	quintal	1 728	1 415	0	12 857
If enterprise produces grain =1	grain_d	(1/0)	0.59	1.00	0	1.00

5 Results and Discussion

5.1 Productivity effects of subsidies

The preparatory steps of modeling include testing the baseline translog frontier production function, selecting subsidy types, and formal tests for endogeneity. Estimation results for the subsidy (Equation 2), in which the logarithms of endogenous subsidy variables serve as the dependent variables, are reported in Appendix A-(Table A1). The specifications include all exogenous variables from (Equation 1) as well as the instrumental variables are estimated using a random-effects regression framework. Instrument relevance is assessed using a Fisher test comparing the restricted model (exogenous variables only) with the full model that includes the instruments. A large significant F-statistic indicates strong explanatory power of the instruments The obtained estimates passed the test for instrument exogeneity and the Durbin-Wu-Hausman endogeneity tests.

Table 3 presents the final results of the stochastic production frontier estimation using instrumental variables for subsidies (Equation 1). Models 1 and 2 report specifications in which observed subsidies are replaced by their predicted values at the enterprise level, obtained from the first-stage subsidy equations (Equation 2). The two models differ in whether subsidies enter the productivity component in aggregate form or are disaggregated by type. For comparison and robustness purposes, Table 3 also reports Model 3 (excluding subsidies entirely) and Model 4 (including subsidies without instrumenting), allowing for an assessment of coefficient stability following the application of instrumental variables. As we use normalized variables, the estimated first-order coefficients can be interpreted as output elasticities evaluated at the sample means.

The elasticities of milk output with respect to labor, technology type, herd size, and subsidies are all statistically significant (see Table 3). The sum of elasticities equals 0.95[9], which is statistically different from 1 and indicates decreasing returns to scale. These scale limitations are

[9] Sum of elasticities of variables (empl), (material cost), free_stall_d, (heads), (s_tot) in the Model 1.

likely driven by region-specific structural constraints, most notably land fragmentation, compared to other regions of Central Russia and the Black Earth Region. Land fragmentation raises production costs and reduces revenue, profitability, and technical efficiency (Demirdogen, 2025; Latruffe & Piet, 2014). Similar results of decreasing returns to scale were obtained for dairy farming in European countries operating in similar natural conditions to those in Northwest Russia (Madau et al., 2017).

Table 3. Estimates of the parameters in the translog frontier production function for milk output (Equation 1)

	Model 1 subsidies total_IV	**Model 2 subsidies by type_IV**	**Model 3 no subsidies**	**Model 4 subsidies total**
Production frontier				
(Intercept)	0.131***	0.258***	0.217***	0.171***
	(0.039)	(0.070)	(0.037)	(0.034)
log(empl)	0.143***	0.235***	0.200***	0.177***
	(0.031)	(0.038)	(0.029)	(0.029)
log(material_cost)	0.041	0.067	0.196***	0.163***
	(0.051)	(0.057)	(0.042)	(0.042)
free_stall_d	0.070**	0.064**	0.048*	0.062**
	(0.028)	(0.029)	(0.029)	(0.026)
log(heads)	0.577***	0.664***	0.636***	0.640***
	(0.060)	(0.056)	(0.055)	(0.055)
log(s_tot)	**0.117*** **			**0.020***
	(0.024)			(0.010)
log(s_milk)		**-0.007**		
		(0.020)		
log(s_breed)		**-0.030***		
		(0.015)		
log(s_livestock_other)		**0.003**		
		(0.002)		
log(s_invest)		**0.008*** **		
		(0.003)		
log(s_plant)		**0.056*** **		
		(0.013)		
t	0.024***	-0.024**	0.020***	0.018***
	(0.006)	(0.012)	(0.006)	(0.005)
0.5 * log(empl)^2	-0.008	-0.086*	-0.022	-0.014
	(0.036)	(0.044)	(0.036)	(0.036)
0.5 * log(material_cost)^2	0.055	-0.145*	-0.102	-0.058
	(0.075)	(0.088)	(0.062)	(0.061)
0.5 * log(heads)^2	0.087	-0.221**	-0.073	0.001
	(0.105)	(0.107)	(0.087)	(0.088)
0.5 * log(subs_std)^2	**0.012*** **			**0.002**
	(0.003)			**(0.002)**
0.5 * log(s_milk)^2		0.022***		
		(0.004)		
0.5 * log(s_breed)^2		-0.004		
		(0.003)		

	Model 1 subsidies total_IV	Model 2 subsidies by type_IV	Model 3 no subsidies	Model 4 subsidies total
0.5 * log(s livestock_other)^2		-0.001		
		(0.002)		
0.5 * log(s_invest)^2		-0.001		
		(0.001)		
0.5 * log(s_plant)^2		-0.006**		
		(0.003)		
t^2	0.000	0.003***	0.000	0.000
	(0.000)	(0.001)	(0.000)	(0.000)
log(heads) * log(material_cost)	-0.106	0.154*	0.074	0.017
	(0.086)	(0.089)	(0.067)	(0.067)
log(empl) * log(material_cost)	0.035	0.092*	0.096**	0.094**
	(0.041)	(0.051)	(0.040)	(0.039)
log(empl) * log(heads)	-0.071	-0.097*	-0.125***	-0.133***
	(0.046)	(0.051)	(0.045)	(0.045)
t * log(material_cost)	0.014***	0.017***	0.011**	0.012**
	(0.005)	(0.005)	(0.005)	(0.005)
t * log(empl)	-0.003	-0.009**	-0.004	-0.004
	(0.004)	(0.004)	(0.004)	(0.004)
t * log(heads)	-0.009	-0.003	-0.007	-0.008
	(0.006)	(0.006)	(0.006)	(0.006)
Inefficiency part [a]				
Zu_(Intercept)	-1.209***	-1.437***	-1.157***	-1.552***
	(0.220)	(0.224)	(0.186)	(0.209)
Zv_(Intercept)	-3.825***	-3.856***	-3.810***	-3.877***
	(0.044)	(0.045)	(0.044)	(0.044)
Zg_agrohold_d	-0.432**	-0.308*	-0.360**	-0.337**
	(0.183)	(0.185)	(0.170)	(0.165)
Zg_suburb_d	-0.388**	-0.337**	-0.372**	-0.317**
	(0.159)	(0.156)	(0.154)	(0.155)
Zg_log(s_per_ha)	**0.047**	**-0.079**		**-0.133*** **
	(0.054)	(0.049)		(0.036)
AIC	-784.976	-816.038	-762.960	-865.258
BIC	-667.429	-657.606	-660.746	-747.712
log-likelihood	415.488	439.019	401.480	455.629
Num. obs.	1225	1225	1225	1225

*** p < 0.01; ** p < 0.05; * p < 0.1

[a] A negative sign on a parameter indicates a positive impact on technical efficiency

Source: study finding

As expected, herd size has the largest marginal effect on milk output. Material costs are statistically significant in the baseline stochastic frontier production function specification, but lose significance once the model is re-estimated using instrumented subsidies. This result likely reflects the fact that a substantial share of material inputs consists of feed, which is partially subsidized, thereby altering input cost relationships in the baseline model. Technological progress, captured by the coefficient on the time-trend variable (t), is positive and statistically significant. Overall productivity demonstrates a steady upward trend, with an estimated annual growth rate of

approximately 2.5%. This magnitude is consistent with productivity growth estimates from European dairy farms (Latruffe et al., 2017).

The output elasticity with respect to subsidies is positive and statistically significant (0.117). In other words, a 100% increase in subsidies is associated with a 11.7% increase in milk production, supporting our hypothesis that total subsidies positively affect productivity. In marginal terms, an additional thousand rubles of subsidies[10] generates approximately 25 kg of milk (about 33 US dollars[11]). Equivalently, producing one additional kilogram of milk requires 40 Rubles in subsidies (approximately USD 1.3), which is 1.7 times the average milk price. The distribution of subsidy elasticities is negatively skewed, indicating that enterprises with relatively low subsidy responsiveness substantially reduce the sample mean (Figure 1). Thus, the weighted average elasticity exceeds the simple mean and amounts to 0.131.

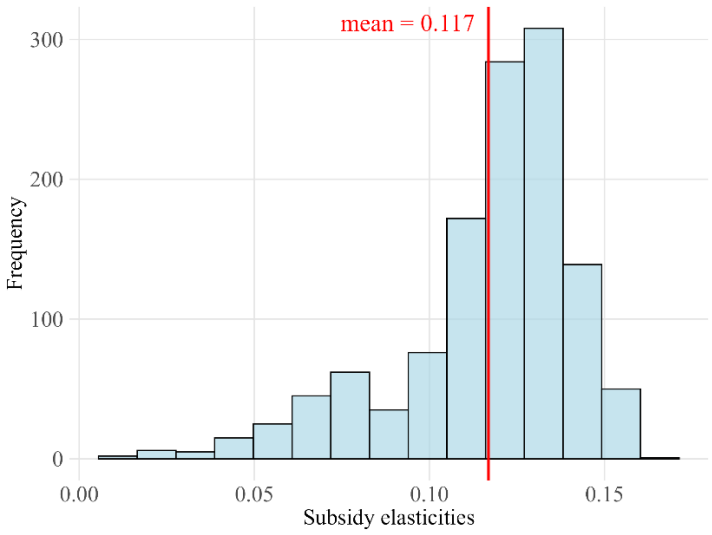
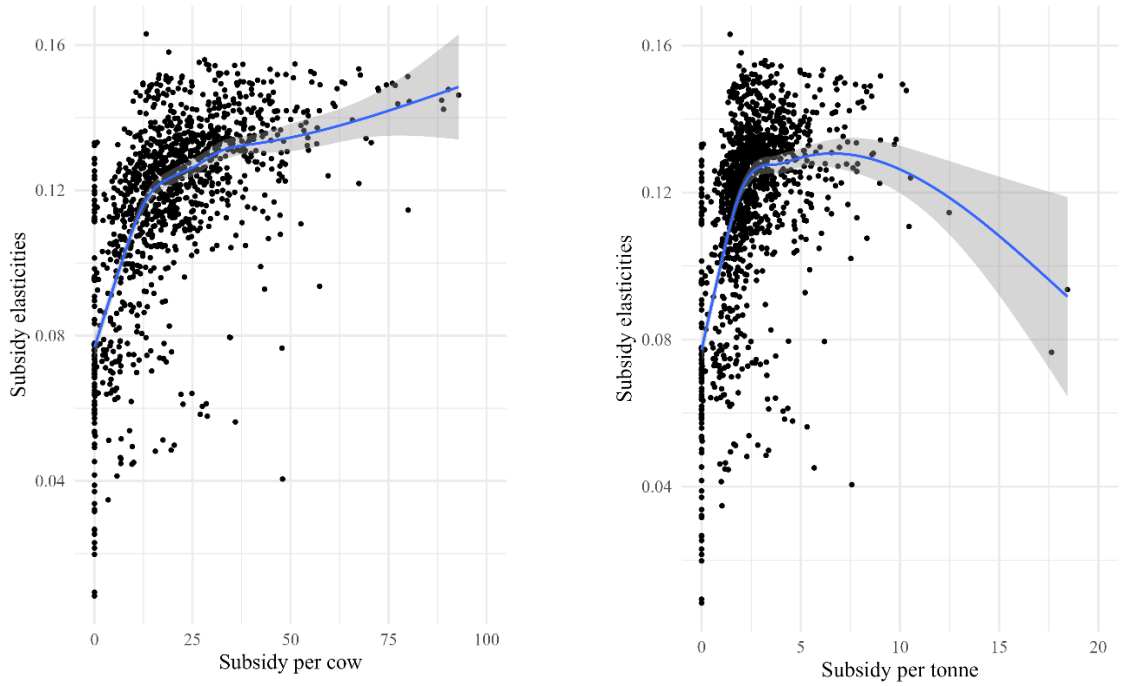


Figure 1. Distribution of subsidy elasticities within the sample of dairy enterprises
Source: study findings

The coefficient on the square of subsidies is significant and positive (0.012). The subsidy impact on productivity increases rapidly as the subsidy level increases, followed by a plateau or

[10] The marginal effect is calculated from the sample mean using the following formula: $MP_s = \varepsilon_s * \frac{\bar{Y}}{\bar{S}}$, where $\bar{Y}$ refers to the estimated sample mean of milk output; $\bar{S}$ refers to our sample mean of subsidy (see table 2); ε_s is estimated output elasticity towards subsidy (see table 3).
[11] Using 2010 exchange rates, since the subsidies are expressed in constant 2010 prices.

decline (Figure 2). From a subsidy payment of around 12 thousand rubles per cow, the elasticities are in a relatively narrow range of 0.12-0.15. A more than twofold increase in subsidy, to 30 thousand rubles per cow or even higher, does not lead to a significant increase in milk output. For a subsidy amount per milk tonne, the level at which efficiency depreciates is around 2,000 rubles per ton. A non-linear effect of subsidy payments in Russian dairy farming on herd growth was also confirmed in Petrick and Götz (2019).



Panel A. Subsidy payment, thou. rubles in constant prices per cow

Panel B. Subsidy payment, thou. rubles in constant prices per milk tonne

Figure 2. Subsidy effectiveness within the sample of dairy enterprises
Source: study findings

The average elasticities of subsidies over time are relatively stable (Figure 3). Testing the temporal stability of elasticities using a random-effects panel model with a linear time trend revealed a statistically significant but very weak negative trend. The corresponding coefficient for the time trend variable is -0.0003 with significance $p < 0.05$. Some decline in the interquartile range was observed after the introduction of the food embargo in 2014, which marked a period that was favorable for Russian agriculture (Kotyrlo & Zaytsev, 2024). Since 2022, an increase in the interquartile range has been observed again. This could be a sign of increasing polarization

among enterprises against the backdrop of restricted access to imported inputs and technologies, as well as rising input costs (Wegren, 2024).

In the existing literature, estimated subsidy elasticities for Russian agriculture in general vary from 0.03-0.04 (Vasilyeva & Bilko, 2022; Epshtein, 2012) to 0.12 (Shik, 2020), while subsidy elasticities for the Russian dairy sector are not available. However, subsidy elasticities for North European countries, which share similar agricultural conditions with Leningrad Oblast as a Northwestern region of Russia, amount to 0.43 for Northern Sweden, 0.15 for Eastern Finland, 0.11 for Southern Finland, and 0.05 for Denmark (McCloud & Kumbhakar, 2008). Thus, our estimated subsidy impact on dairy enterprises' productivity in Leningrad Oblast lies in the medium range of the estimates for the North European countries. Moreover, our results are consistent with Vasilyeva & Bilko (2022), Kalinin & Samohvalov (2020), Svetlov et al. (2019), confirming a positive but very moderate effect of subsidies on the output of Russian agriculture as a whole.

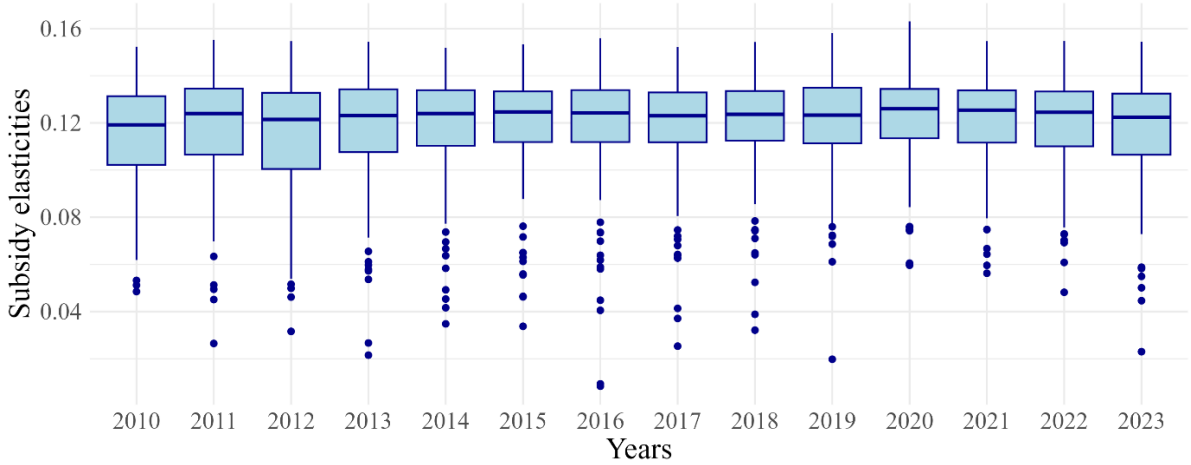


Figure 3. Box plot of annual subsidy elasticities within the sample of dairy enterprises
Source: study findings

The subsidy effect might be curtailed by several factors. First, not all of the subsidy funds may be used to expand production. In addition, a substitution effect is possible, when some enterprises use subsidies instead of their own funds without changing production parameters. Furthermore, the instability of the subsidy allocation and payment rules may also reduce their effectiveness. This effect has been previously discussed for the state support in the Russian agricultural sector as a whole (Vasilyeva & Bilko, 2022; Serova, 2020). Perceived policy

uncertainty may affect dairy producers' decisions to postpone expansion plans even more than earning capacity (Yanore et al., 2024).

The impact of disaggregated subsidies is multidirectional. Milk producer productivity is positively affected by subsidies for plant production and investment interest and the coefficients are 0.056 and 0.008 respectively (Table 3). Plant production subsidies appear to reduce limitations on the use of resources (seeds, agrochemicals, fuel for agro-technological operations, etc.) in feed production. This helps to reduce the gap between the intensity of the feed production and livestock divisions within dairy farming, which is identified as a significant issue in Russian milk production (Evdokimova & Surovtsev, 2022). Plant production subsidies have become even more important amid current restrictions on access to imported inputs. In addition, plant production subsidies are often aimed at forage grain production, which ultimately affects milk production intensity and enterprise productivity. The investment interest subsidy has a modest but positive and significant impact on productivity. This may be explained by the fact that investment loans are primarily used for the purchase of machinery, equipment, and the renovation or construction of livestock facilities. The modest impact on productivity might be related to the delayed effects of the investment interest subsidy and its relatively small share in total subsidies.

The subsidy per kilogram of raw milk sold is insignificant. This may be explained by the fact that direct product subsidies, such as a per kilogram subsidies, lead to a proportional increase in resource use, primarily purchased feed, and can, in fact, be captured by the processor through adjustments in purchase prices. The negative impact of breeding subsidies on the productivity of dairy enterprises (-0.030) might be traced back to the cost and value of breeding cattle. Specifically, it is more profitable for an enterprise to increase a cow's total lifetime milk yield rather than to maximize its productivity in the short term (current year). Therefore, such optimization may hinder productivity in a given year. The estimated parameter for other livestock subsidies is found to be statistically insignificant. As other livestock subsidies mainly include

subsidies for feeding steers, which require intensive production of own feed and qualified personnel, this may induce a limited positive effect on the milk production system, offsetting the possible negative effects of resource dispersion.

Thus, the results obtained for different subsidy types confirm the hypothesis of their positive impact on productivity in the case of plant production and investment interest subsidies. However, they do not confirm it for per kg of raw milk subsidies (which are statistically insignificant) and breeding subsidies (which have a negative coefficient). As for other livestock subsidies, a negative impact on productivity was expected, but the results show that they are statistically insignificant. It should be noted that short-term interest and capital expenditure subsidies were excluded from the analysis for methodological reasons. The two subsidy types found to have a positive effect on productivity fall under support measures common to all agricultural sectors, meaning they are not specific to dairy farming.

5.2 Technical efficiency effects of subsidies

The distribution of the technical efficiency estimates for the panel sample (Figure 4) reveals substantial potential for efficiency improvements. In particular, the mean technical efficiency score of 0.71 implies that milk production in enterprises could increase by 29% without additional inputs. Furthermore, only 13% of enterprises in the sample exhibit a technical efficiency score of 0.90 or higher, and are therefore close to the technical efficiency frontier. Nevertheless, compared to the period of market reforms, the Russian livestock sector seems to have made considerable progress. Between 1995 and 2008, the technical efficiency of 85% of cattle enterprises ranged between 25% to 75% (Sarajkin & Yanbykh, 2014). Globally, technical efficiency in dairy farming has been reported to range from 57% to 95% (Ma et al., 2019). In this context, the average technical efficiency observed in this study is comparable to that of dairy farms in the North Island of New Zealand (0.70) (Jiang & Sharp, 2015) and extensive farms in Spain (0.72) (Alvarez et al., 2008).

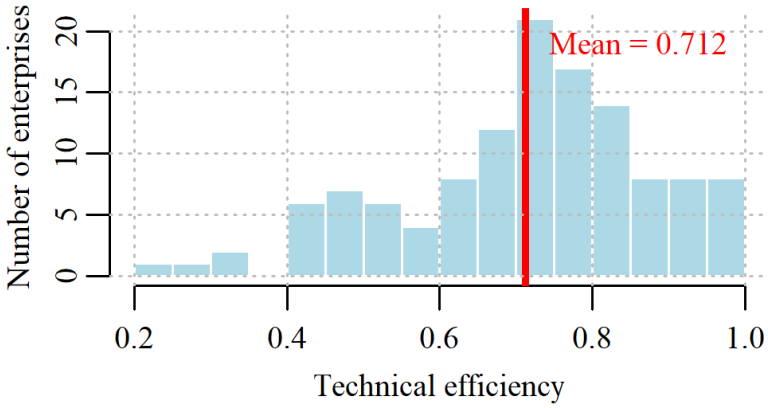


Figure 4. Distribution of technical efficiency levels within the sample of dairy enterprises
Source: study findings

Figure 5 illustrates the spatial dimension of technical efficiency within the sample, indicating that (i) proximity to the metropolitan center of St. Petersburg has a positive effect on technical efficiency, and (ii) enterprise density matters, as technical efficiency increases with the number of enterprises within a district. Together, these patterns suggest a "core-periphery" effect at the intraregional level. The positive relationship between enterprise density on technical efficiency is consistent with previous evidence of spatial spillovers in dynamic technical inefficiency among dairy farms (Skevas & Lansink, 2020).

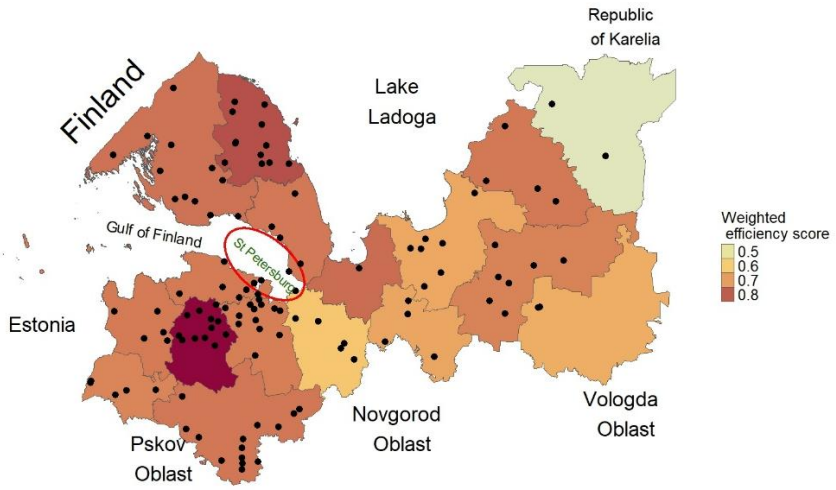


Figure 5. Map of weighted technical efficiency score by the Leningrad Region districts
Note: Milk output was used as a weight to aggregate enterprise-level technical efficiency stores
Source: study findings, produced using a shapefile provided by NextGIS and the ggplot2 package in R (Wickham, 2016)

The determinants of technical inefficiency – subsidies received per hectare, agroholding affiliation (dummy variable), and suburban location (dummy variable) – are reported at the bottom of Table 3. Total subsidy payments are found to be statistically insignificant with respect to the

technical efficiency of dairy enterprises, thus failing to support the hypothesis that subsidies exert a negative effect on technical efficiency. Meta-analysis of the empirical studies shows that nearly one-quarter of papers report no significant relationship between subsidies and farms' technical efficiency (Minviel & Latruffe, 2017). Given the insignificance of total subsidies, in the technical efficiency component, the effects of disaggregated subsidies are not further evaluated. Notably, subsidies also do not exhibit a positive impact on technical efficiency, despite innovation and technological modernization being explicit objectives of agricultural state support in Russia. One plausible explanation could be excessive regulation governing subsidy eligibility, which may constrain enterprises' optimal choices regarding technologies, resource combinations, and scale of operation. Under current conditions, dairy producers must satisfy a complex set of eligibility criteria[12] to access subsidies or otherwise exit the state support system (Minsel'hoz, 2023; Postanovlenie, 2024). In addition, subsidies explicitly targeted at innovation and technological upgrading account for a small share of subsidies, with investment interest subsidies accounting for an average of just 12% over the study period. Moreover, recent studies emphasize that technical efficiency is driven not only by direct financial support but also by access to specialized knowledge (Dewi et al., 2026) and digital information systems that optimize input allocation (Wang et al., 2026).

Technical efficiency does not exhibit a significant linear time trend (Figure 6). Testing the technical efficiency score for a linear trend yields an insignificant coefficient for the time variable. This suggests that the observed dynamics are likely non-linear and dominated by farm-specific

[12] Thus, in order to get a subsidy per kg of milk or breeding head, an enterprise concludes a contract with the Regional Agricultural Committee on keeping and (or) increasing the number of cows / milk output. The subsidy rate depends on the milk yield level / increase in herd size / insurance presence, etc. To receive co-financing of investments (a capital expenditure subsidy), a milk producer's project must pass a competitive selection process and meet a number of requirements, namely a minimum herd size and milk yield, free stall capacity at the time of application (for new farms), and it faces a deadline for reaching the targeted capacity, etc.

heterogeneity and short-term fluctuations rather than a persistent deterministic trend.

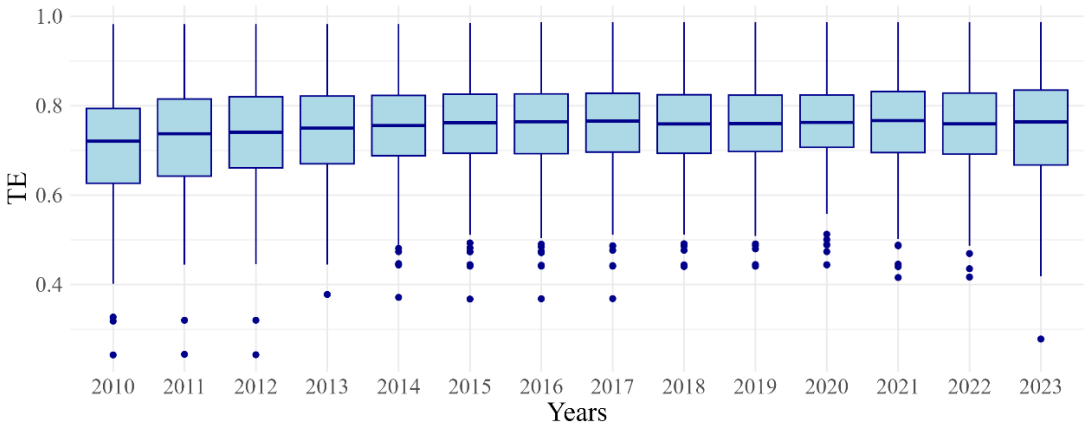


Figure 6. Box plot of annual technical efficiency score within the sample of dairy enterprises
Source: study findings

The negative coefficient on agroholding affiliation (-0.432) indicates higher technical efficiency among affiliated enterprises. This is consistent with earlier findings showing that Russian agroholdings achieve higher total and partial factor productivity than independent farms (Uzun et al., 2021; Epshtein et al., 2013). Similarly, enterprise location in suburban districts is associated with lower inefficiency (-0.388), reflecting a positive effect on technical efficiency. This result corroborates the district-level spatial patterns illustrated in Figure 5.

6 Conclusions and policy implications

This study examines the relationship between agricultural subsidies and milk production in the Leningrad Region of Russia. The main finding is that subsidies have a positive effect on productivity, while their impact on technical efficiency cannot be confirmed for dairy enterprises in the region. Furthermore, the estimated elasticities for subsidy and estimated technical efficiency parameters are not varying in different years. In particular, the estimated elasticity of subsidies is 0.12, suggesting that subsidy levels need to be doubled to increase milk output by 12%. The subsidy cost of producing one additional kilogram of milk exceeds the average milk price by more than one and a half times. More specifically, productivity is positively affected by plant production subsidies and investment interest subsidies, while breeding subsidies have a negative impact.

Furthermore, four subsidy types are found to have no statistically significant impact on productivity: subsidies per kilogram of raw milk, short-term interest subsidies, other livestock subsidies, and capital expenditure subsidies.

The analysis further shows that subsidies are effective only within a limited range of medium-sized subsidy rates (per cow or per ton of milk). Whether subsidy effects vary systematically across producers remains an open question.

No statistically significant effect of subsidies on technical efficiency is identified. The mean technical efficiency score of 71% indicates considerable potential for increasing milk production in Russia through efficiency gains. Higher technical efficiency is associated with enterprise proximity to a metropolitan area, affiliation with an agricultural holding, and greater enterprise density within a district.

The findings have several implications for the adjustment of dairy subsidy policies. First, relatively smaller subsidies distributed across a larger number of enterprises appear to be more effective than larger subsidies concentrated among fewer recipients, confirming Petrick and Götz (2019)'s findings. Second, the results support adjusting the structure of dairy subsidies, namely increasing the share of decoupled plant production subsidies and subsidies aimed at increasing long-term credit, such as investment interest subsidies. Third, to enhance the potential impact of subsidies on technical efficiency, it may be beneficial to grant enterprises greater autonomy in choosing technologies and resource combinations, increase the share of investment-oriented subsidies, and adopt subsidy policies differentiated across districts.

The results and conclusions of this paper are particularly relevant for the corporate segment of dairy farming and may be informative for agricultural policy design in other emerging and developing countries. They illustrate both the directions and magnitude of subsidies' effects on production in large-scale farming systems, which is especially relevant for countries with a dominant corporate sector or a rapidly expanding segment of large farms (Cai et al., 2025). The

study thus contributes to the broader discussion on agricultural subsidy reform in transition economies, including the scope for reducing input- and output-coupled subsidies while prioritizing credit-related support mechanisms.

One limitation of this study is its reliance on empirical data from a single Russian region. Given the substantial regional heterogeneity of dairy farming in Russia, the findings cannot be directly generalized to other regions. In addition, the applied model does not capture long-term subsidy effects, which are particularly relevant for investment-oriented support measures (e.g., investment interest subsidies, capital expenditure subsidies, and subsidies for maintenance of reclamation systems). Another limitation is the selection of instruments, which is constrained by data availability and specifics. More well-founded instruments based on institutional allocation rules such as program eligibility thresholds, district-level budget variation over time, or administrative payment timing are either constant or absent within a single region. We therefore view the current instrument set as a reasonable first-best given data limitations, while fully acknowledging that stronger identification could be achieved in a multi-region setting. Future research should prioritize the development of dynamic modeling and the collection of additional empirical data to address these limitations.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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Appendix A

Table A1. Estimates of the parameters in the Equation (2)

	s_tot	s_tot_per_ha	s_milk	s_breed	s_plant
Exogenous variables					
(Intercept)	-0.211	-0.224	-0.594**	-2.990***	-3.535***
	(0.289)	(0.126)	(0.305)	(0.299)	(0.259)
log(empl)	0.225	-0.284	1.382***	0.985	-0.244
	(0.308)	(0.119)	(0.338)	(0.348)	(0.317)
log(material_cost)	1.143	0.474*	0.640	2.068**	1.579**
	(0.417)	(0.162)	(0.463)	(0.487)	(0.432)
free_stall_d	-0.319	-0.056	-0.470**	-0.289	-0.358
	(0.230)	(0.098)	(0.240)	(0.302)	(0.226)
log(heads)	0.278	-0.443*	-0.324	-0.545	0.721
	(0.538)	(0.212)	(0.597)	(0.634)	(0.559)
t	0.024	0.072**	0.074	-0.105	0.806***
	(0.058)	(0.022)	(0.066)	(0.068)	(0.061)
0.5 * log(empl)^2	-0.198	0.187	-1.002**	0.141	-0.649
	(0.348)	(0.138)	(0.389)	(0.416)	(0.364)
0.5 * log(material_cost)^2	-1.845	-0.268	-3.088***	-1.829*	-2.367**
	(0.622)	(0.241)	(0.700)	(0.724)	(0.655)
0.5 * log(heads)^2	-2.497	-1.142	-3.309**	-0.877	-1.636
	(0.877)	(0.341)	(0.983)	(1.031)	(0.921)
t^2	-0.005	-0.007***	-0.007	0.008	-0.043***
	(0.004)	(0.001)	(0.004)	(0.004)	(0.004)
log(heads) * log(material_cost)	2.330	0.651	3.034***	1.637*	2.114*
	(0.671)	(0.261)	(0.752)	(0.788)	(0.704)
log(empl) * log(material_cost)	0.342	-0.264	1.393**	1.222*	1.245
	(0.388)	(0.150)	(0.437)	(0.453)	(0.409)
log(empl) * log(heads)	-0.306	0.300	-0.760	-1.293	-0.941
	(0.459)	(0.177)	(0.519)	(0.530)	(0.485)
t * log(material_cost)	-0.029	-0.015	0.056	-0.075	-0.001
	(0.049)	(0.019)	(0.055)	(0.058)	(0.052)
t * log(empl)	-0.039	-0.029	-0.121	-0.030	0.010
	(0.038)	(0.015)	(0.042)	(0.043)	(0.040)
t * log(heads)	0.048	0.039	0.073	0.117	-0.042
	(0.058)	(0.023)	(0.065)	(0.068)	(0.061)
Instruments					
log(labor_cost)	0.805**	0.842***			
	(0.166)	(0.068)			
invest_rate	1.052**	0.278	1.586***		
	(0.475)	(0.226)	(0.463)		
log(meat_sale)			0.245**		
			(0.056)		
log(capital)				0.435**	
				(0.095)	
log(long_cred_sum)				0.088***	
				(0.017)	
grain_d					1.255***
					(0.165)
s_idios	1.551	0.564	1.823	1.799	1.692
s_id	1.100	0.544	1.031	1.847	1.023
R2	0.346	0.275	0.341	0.338	0.483
Adj. R2	0.337	0.265	0.332	0.329	0.476
Num. obs.	1225	1225	1225	1225	1225
Instruments strength test: Fisher test for the models with and without the instruments					
F-statistic	14.90***	32.66***	21.64***	12.55***	22.36***

*** p < 0.01; ** p < 0.05; * p < 0.1 according to robust standard errors

Source: study finding