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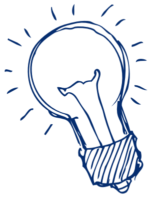

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Impact of Technological and Structural Changes on Total Factor Productivity in the Russian Grain Industry

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Abstract[2]

Grain production – basic branch of the Russian agro-industrial complex, - is one of the few sectors of the Russian economy that have demonstrated sustainable development over the past two decades. What were the main sources of growth in total factor productivity in Russian grain production? On the microdata of agricultural organizations in Russia with help of the data envelopment analysis (DEA) method, the article shows the changes in overall grain productivity that occurred along with the formation of market institutions due to a trade liberalization, land privatization and technical re-equipment, and has resulted in the boost of sector productivity. The fastest growth in total factor productivity occurred between 2002 and 2007 and slowed by 2016. Changes in factor use in the grain subcomplex contributed the most to total factor productivity growth across all periods. At the same time, the technological efficiency of the leading grain farms grew, that is such farms demonstrated a more efficient distribution of available resources. The high increase in total factor productivity in the grain industry in the period from 1995 to 2002 allowed the Russian Federation to enter the world grain market, becoming a key player.

Keywords

Total factor productivity, Russian grain industry, technological changes, trade liberalization, Russia

JEL classification: O13, P23, Q13.

1. Introduction

The modern agri-food sector is one of the most steadily developing sectors of the Russian economy. The production of grain, sunflower, sugar beets has reached historical records: Russia is the leader in exports of wheat and buckwheat, and is among the top ten in terms of exports of other crops. The export of livestock products and value-added food products has begun. Over the past twenty years, progress has been made in the area of food quality and safety.

But that wasn't always the case. Before the reforms of early 90-ties, agriculture in Russia characterized by low labor intensity and heavy subsidization, the land was state-owned during more than 70 years of Communist rule. Liberalization, land reform, and privatization have been implemented more slowly and less vigorously than in other countries of Socialist block. This

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was resulted in weaker individual property rights to land and other assets and provided fewer incentives for effective reorganization of farms. After 2000, this process accelerated, driven by large agribusiness capable of bringing technological change to agriculture. New institutional structure in the agriculture, the abolition of the system of obligatory deliveries to the state, the liberalization of prices and trade have given rise to an economy where agro-exports had a significant impact on domestic production and consumption.

It's well known that initial conditions of economic reforms - changes in property rights, production organization, terms of trade, and the liberalization of the economy, - in many cases induce different output and productivity changes. This has happened in Russia, China and the transition countries of Eastern Europe where a combination of the conditions and reform policy choices has caused the differences in performance and productivity trends. Marcours and Swinnen (2000) have concluded that in the beginning of the transition period in 90-ties there were three 'transition patterns': in Russia, a strong decline in gross agricultural output (GAO) coincides with an equally large decline in agricultural labor productivity (ALP); in Eastern European countries (Czech Republic, Slovakia, and Hungary) a strong decline in GAO coincides with a strong increase in ALP; and in China, a strong increase in GAO coincides with a slower increase in ALP.

Productivity and efficiency analysis is a particularly popular research topic in agricultural economics (Parikoglu et al, 2024). Technological growth and efficiency are seen as the two largest subsections of overall factor productivity. Technological changes stimulate long-term economic growth and raise living standards. Domestic (Shagaida and Uzun, 2019) and foreign researchers (Keyzer et al., 2015) named the main growth drivers as increased labor productivity, technical re-equipment of the industry, and stable government support that appeared in 2000. Nin-Pratt et al (2010) proved that that agricultural growth in China benefited from fundamental institutional and policy reforms in agriculture. There is some evidence that the transformation of industry in China was also important for agricultural TFP growth: manufacture growth absorbed labor and reduced employment in agriculture, creating incentives for capital investment and technical change that kept output per worker in agriculture growing at high rates (Nin-Pratt et al, 2010).

Russia is one of the largest exporters of agri-food products in the world and grain is the main export product in Russian trade. Thus, grain exports from Russia in the season 2023/2024 amounted to 72 million tons, and at the end of the current season 2024/2025, it is expected to reach 60 million tons[3]. Yet before the start of reforms in the 90s, Russia was an importer of grain. To explain the phenomenon of Russia's transformation from a net importer into a net exporter of grain, the goal has been set by the authors to compare the technical efficiency of using factors in the production and sale of grain crops. To achieve this it was necessary to determine the structural components of the change in total factor productivity (TFP), to explain the reasons that influenced its rapid growth in the period from 1995 to 2016[4].

In 2014, the authors of this article analyzed how the technical efficiency (sometimes called technological) of agricultural organizations changed (Saraikin and Yanbykh, 2014) during the reforms. Based on the reporting indicators of agricultural organizations using the DEA method, calculations were carried out and conclusions were drawn about how effectively agricultural organizations began to use their available resources - land, labor, capital, working capital, livestock, etc.

[3] https://tass.com/economy/1876965

4 The period from 1995 to 2016 was chosen because since 2016, the balance sheets of agricultural organizations previously provided by the Russian Ministry of Agriculture have become unavailable.

The main conclusion was that since 1995 there have been positive changes in the agricultural sector: the share of farms whose use of resources has become more efficient has increased significantly, both due to the liquidation of unprofitable farms, and the increase in the technical efficiency of the remaining ones (Saraikin and Yanbykh, 2014).

There are many studies in the scientific literature concerning the technical efficiency of agriculture in foreign countries (e.g. Matijs and Swinnen, 2000; Latruffe, 2010; Čechura and Hockmann, 2010; Čechura, 2012), but in Russia their number is not significant (Brock et al., 2008; Bokusheva et al, 2012; Gataulina and Hockmann, 2014, Saraikin and Yanbykh, 2014). Most of them show how and why technical efficiency has grown over the years of reforms and prove the positive impact of transformation processes on the growth of industry productivity.

As a hypothesis, the thesis was put forward that the increase in grain sales has been caused by a restructuring of the industry's economy under the influence of market signals.

The scientific increment is that for the first time on the microdata of agricultural organizations in Russia it was proved that during the transition from a planned to a market economy, the use of basic resources for grain production was optimized by redistributing them in favor of more efficient agricultural enterprises. It happened due to the liberalization of the economy and the privatization of land and property. As a result, this led to an overall increase in sector productivity.

The article is organized as follows: in the introduction, the authors discuss the relevance of the problem; in the next section, the choice of the DEA method for analyzing the technical efficiency of agricultural organizations is justified and general methodological approaches in assessing changes in total factor productivity are given. The third section presents the methodology for selecting farms and creating a sample for calculations. The fourth section is devoted to assessing changes in TFP using the Malmquist method with obtaining indices of structural changes. The fifth section provides an interpretation of the results obtained and a description of the changes that occurred in the period 1995-2016, as well as a discussion about the impact of technological shifts on productivity growth in agriculture. The study concludes with the main findings about the successful transition of the grain industry of the agro-industrial complex to the market.

2. Conceptual Framework

Building on earlier work by Nishimizu and Page (1982), Bauer (1990), Lovell (1996), and Kumbhakar (2000) developed a theoretical framework for decomposing changes in total factor performance (TFP) into technical changes, technical efficiency changes, and economies of scale. Solow primarily defined technical changes in his 'classical' work (1957) as 'a shift in production function with all input quantities held constant'. This shift can represent both technological progress and regress. Technological progress/regression leads to TFP growth/slowdown.

On the other hand, TFP changes are not affected by technical inefficiency if it's time invariant. If there is no invariance, changes in technical efficiency contribute to the rise/fall of TFP. Therefore, it is not the degree of technical efficiency itself that is important, but its change over time. Finally, the economies of scale are positive/negative as the return to scale increases/decreases as long as the use of inputs increases, and vice versa.

The choice of method for calculating indicators for subsequent assessments and characteristics of changes in the grain product sector was dictated by the desire to obtain results based not on summary data of industry production, but on information provided by individual agricultural organizations over a long period.

The database, which included information on the types and volumes of resources, as well as product revenue in physical units and in monetary terms for several thousand units of agricultural organizations, made it possible to obtain a non-trivial result during the analysis, explaining the transformation of the industry both during the transition to the market and in subsequent development.

The Data Envelopment Analysis (DEA) method used in the work is based on an algorithm for constructing a shell of technical efficiency based on data from agricultural organizations. The shell itself is a sample of farms from the total number of those represented, for which the return of each factor reaches its maximum value relative to others in the original set.

The business units selected in this way establish a maximum level of effectiveness, which is taken as 100%, thereby forming the efficiency boundary. The position of all other economic objects within this set is assessed in relation to this boundary and will be less than 100%.

The final result of applying the DEA method will be the representation of all objects in the data base in the form of their scaled arrangement according to the technical efficiency indicator, obtained on the basis of an n-dimensional vector of input variables. This makes it possible to assess the state of the industry from the perspective of best practices for the efficient use of resources in business (benchmarking).

The boundary shell is calculated using two options: on a constant and variable scale. In the first case, the resulting production possibilities frontier reflects the best ratio of output and input under the assumption of constant returns when changing scale (CRS - Constant Returns on Scale).

In the second case, the boundary of 100% efficiency in factor productivity is determined taking into account variable returns when expanding the scale of their use (VRS - Variable Returns on Scale). The latter is also sometimes called the Pareto-optimal frontier in some works. The general methodology for analyzing comparative effectiveness was developed in several books (Farell, 1957; Charnes et al., 1994; Coelli et al, 1998). This article applies the “data shell” analysis described in detail in later work (Brock et al., 2008).

The value obtained by relating the CRS and VRS estimates to each other establishes the influence of the scale of factors on production efficiency. Thus, when solving the problem of calculating technical efficiency using the DEA method, three estimates are calculated. First one characterize the static position of farms in a certain period of time, which, together with the initial data of the resources used, make it possible to characterize the state of the industry (second), and in comparison with other periods - the changes that have occurred (third).

However, the resulting direct comparisons of data will not fully reflect the qualitative changes that occurred during the time interval. Static indicators, although numerous, but taking from different sets of data, do not make it possible to explain the dynamics of the changes that have occurred.

For this purpose, the Malmquist productivity index is calculated, for the assessment of the change in the total factor productivity of the resources used by the industry, as well as the decomposition of the TFP coefficient into indices of general technical efficiency, net technical efficiency, economies of scale and technological changes in dynamics. Characteristics and comparative analysis of the obtained indicators by period allow us to draw conclusions about the influence of factors on changes in TFP.

Since the earliest information on all Russian agricultural organizations is available only for 1995, it was taken as the starting point for calculations and analysis. The same year can be correlated with the beginning of large-scale reforms in agriculture.

The first stage in assessing changes in TFP in the presented work ends in 2002, the date of the final adoption of the law "On the turnover of agricultural land" and "On the financial recovery of agricultural producers." 2007, the year of completion of the priority national project "Development of the Agro-Industrial Complex", was chosen as the boundary value of the second stage. The third stage ends in 2016, the last year when the data was available to researchers.

In general, the resulting breakdown into stages allows us to sufficiently fully assess the changes that have occurred in total factor productivity in the grain product subcomplex of the agricultural sector of the Russian Federation. The main sources of information were databases on farms (agricultural organizations) for 1995, 2002, 2007 and 2016[5].

3. Methodology

Algorithm of selecting farms for calculations

Technical limitations in the program for calculating the maximum number of incoming units determined the need to select a sample not exceeding 1 thousand units from the total number of farms. At the same time, for representative selection it was necessary to observe some of the most important points of organizational differences in the production of grain, such as the targeted use of different crops, or the depth of specialization limited by the farming system used, etc.[6] In general, the sample should reflect the technical characteristics of the state of the industry at a certain time moment, which is especially important for the study.

The process of forming sample populations took place in several stages. On the first stage, farms were selected whose main focus was the production of grains and leguminous crops.[7] To do this, during the first iteration, a cluster of farms was identified from the entire dataset, in which the share of all crop products in the total sales volume exceeded 50%. Thus, crop production farms were identified. In the second iteration, from the formed cluster of crop-growing farms, a set of enterprises were identified whose share of sales attributable to grains and leguminous crops was 50% or more (Table 1). The resulting sample consisted only of the best grain-producing farms with compared indicators.

Table 1. The total number of farms with the main focus on grain production

	1995	2002	2007	2016
Number of farms	2869	6043	4441	6405

Source: Authors' calculations on MoA farms database.

In the second stage the selection of farms was based on two criteria: (1) specialization in grain production, and (2) the level of the share of grain sales by the farm on the domestic market. Pre-labeled farms were divided into decile groups based on the volume of gross harvest, from which 1 thousand units of farms was selected.

At the same time, to eliminate the significant influence of groups with small volumes of grain produced, the calculation took into account its share in the total volume of gross production. For

[5] The results of calculations for 2016 using our methodology were kindly provided by the Center for Agrarian Policy of the Institute of Applied Economic Research of the Russian Presidential Academy of National Economy and Public Administration (RANEPA) under the leadership of Dr. Econ Natalia Shagaida.

[6] In 1995, almost 25.0 thousand farms out of 26.9 thousand were engaged in the production of grain crops, which is 92.9% of the total, while 50% of the gross grain harvest fell on 3960 agricultural enterprises, which shows how different they are in terms of their role in overall grain production.

[7] The focus/specialization is understood as the industry that provides the largest amount of income to the economy (Makarov, 1921).

example, in 1995, the first group included 287 farms (10%), and its share in gross production was 0.7% of the total, i.e. from this group, only 7 farms were included in the final sample of 1000 units; from the second group with a share of 2.3%, 23 farms were selected, etc. As a result, the ratio of the averages for each decile group was preserved, but the average for the entire group was overestimated in various years by 2-2.5 times, which indicates the predominance in the group of farms with large volumes of grain production, and therefore with a greater role in the commodity market (Table 2).

The final selection of farms from decile groups was carried out by the random sampling program of the Access application.

Table 2. Characteristics of sample groups of farms by period

	1995	**2002**	**2007**	**2016**
Number of farms	1002	999	1000	977
Revenue from grain sales, billion rubles	1747*	13	66	172
Share in total grain revenue of all farms, %	21,1	21,8	43,0	33,7
Volume of grain production, million tons	8,0	11,2	16,4	20,3
Share in total grain production of all farms, %	14,5	16,7	32,8	27,3
Sown area of grain crops, million ha	4,8	4,6	6,5	9,8
Share in total area of grain crops in all farms,%	10,1	13,0	25,4	32,4

*before denomination
Source: Authors' calculations on MoA farms database.

The share of selected farms for different years is from 21.1% to 43.0% in sales revenue, from 14.5% to 32.8% in grain production, from 10.1% to 32.4% in sown area (Table 2). The groups formed in this way include the largest business units for the production and sale of grain crops on the Russian domestic market, and therefore the assessment of technical efficiency obtained from them will reflect the state of the industry as a whole.

Constructing an efficient production possibilities frontier.

An input-oriented model with four input and two output data vectors were used. The selected inputs were capital (fixed assets), labor (the number of workers employed in agricultural production), the size of sown areas and current annual material and cash costs; as output – the volume of grain sales and the volume of sales of other crops.

The choice as the output parameter the monetary revenue, rather than the natural volume of production, allows us to assess the influence of market signals on changes in resource productivity in a time interval.

The value of depreciation, increased by 25 times (the average value of the full payback of fixed assets in agriculture), was taken as the input parameter 'the cost of fixed assets spent on the production of grain crops'.

Labor resources were defined as the average annual employment in agricultural production. Current material costs are the sum of crop production costs minus depreciation and labor costs. Land resources - as the total area under crops. Technically we did not have the opportunity to clearly separate the data on capital and labor costs used directly for the production of grain crops, so the inclusion in the model the total volume of resources used and products produced, was methodologically approved. This made it necessary to include in the initial resources the entire sown area of the farm, as well as the sales volume of other crop products minus sold grain.

4. Discussion of the results of DEA modeling

The calculations carried out using the models of Charnes et al. (1994) and Banker et al. (1984) made it possible to obtain CRS and VRS solutions that reflect technical efficiency (TE) at constant and variable scales of resource output.

However, before proceeding to the analysis of the results obtained, we have carried out a recalculation of the efficiency estimates using the bootstrap method. Since initially all DEA estimates are biased upwards, as they are sensitive to sample variations among other things, the bootstrap method is used to overcome this shortfall (Simar & Wilson, 1998; Simar & Wilson, 2000; Simar & Wilson, 2007; Bogetoft & Otto, 2019). The summary comparative results of the efficiency of the original DEA model and the bootstrap approach, along with confidence intervals for efficiency by period, are presented in Table 3.

Table 3. Comparison of statistics for shells obtained using the DEA model and the bootstrap method

Period		average	SD	median	min	max	1 st quartile	3 rd quartile
1995	initial	0,461	0,202	0,430	0,311	0,561	0,065	1
	after bootstrapping	0,413	0,171	0,394	0,286	0,508	0,061	0,905
2002	initial	0,420	0,197	0,392	0,272	0,522	0,074	1
	after bootstrapping	0,369	0,162	0,349	0,243	0,460	0,065	0,952
2007	initial	0,467	0,211	0,434	0,309	0,594	0,032	1,000
	after bootstrapping	0,414	0,174	0,390	0,284	0,525	0,029	0,908
2016	initial	0,497	0,199	0,477	0,363	0,603	0,034	1
	after bootstrapping	0,444	0,169	0,433	0,328	0,544	0,025	0,926

Source: Authors' calculations on MoA farms database.

It can be seen that the efficiency obtained after applying bootstrap is relatively lower than the initial efficiency obtained using DEA. This indicates that there is an upward bias, and as a result of the correction all farms become inefficient. However, since the number of farms in the study is significantly higher than the required criterion (Ozbek et al., 2009), the explanation for the bias based on sample size is excluded. The average efficiency value changed from 0.461 to 0.413 in 1995, from 0.420 to 0.369 in 2002, from 0.467 to 0.414 in 2007, and from 0.497 to 0.444 in 2016 for DEA and bootstrapping, respectively. To illustrate and compare the results, the graphs show the location of farms in descending order of DEA efficiency and adjusted values using the bootstrap method (Figure 1).

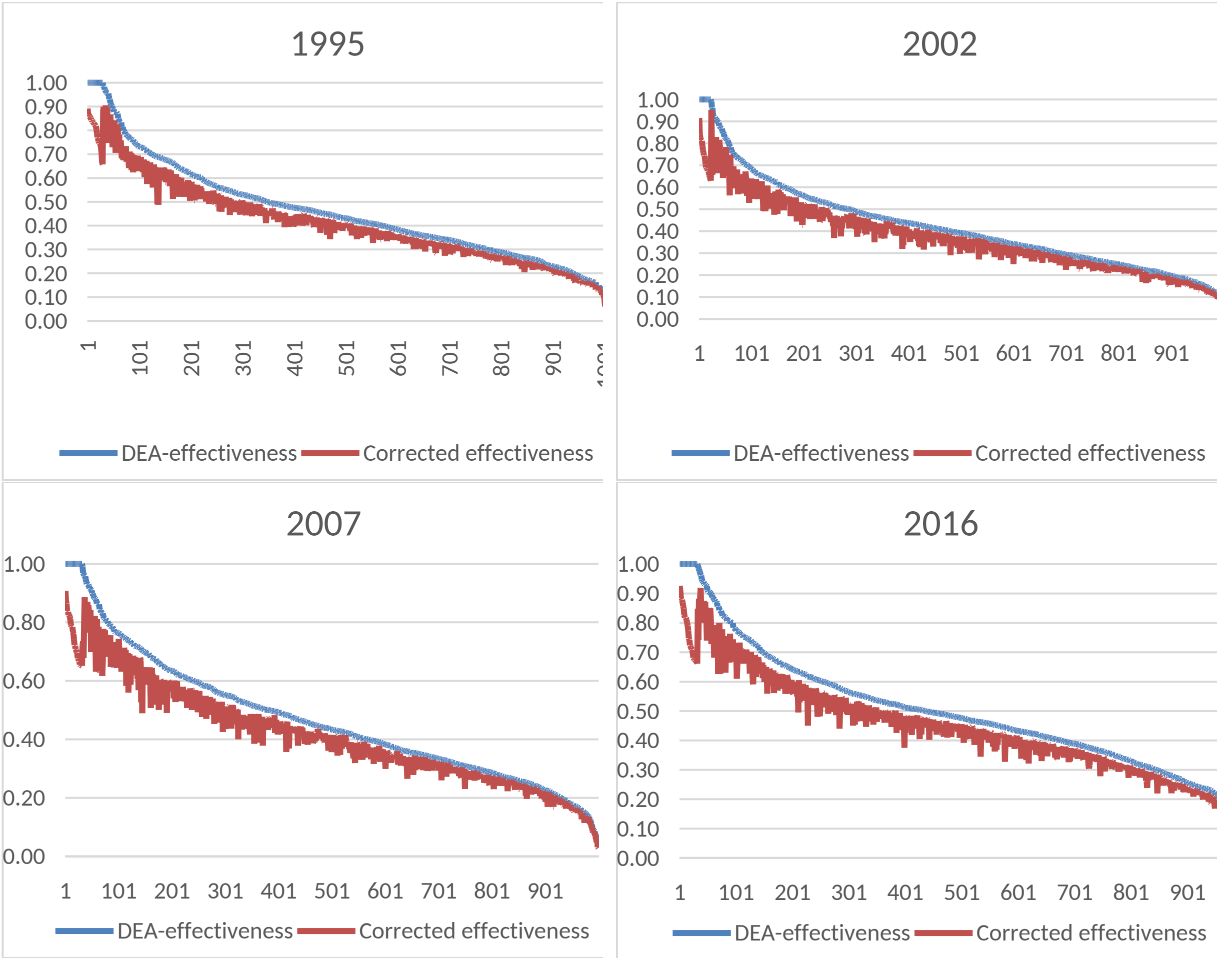

Figure 1. Distribution graphs of DEA-efficiency and adjusted efficiency values for agricultural enterprises by year.
Source: Authors' calculations on MoA farms database.

The location comparison shows the stability of the calculated data obtained using the DEA analysis method (Figure 1).

Comparing the selected groups by year allows us to see the changes in technological efficiency in the grain industry. Since 1995, with the exception of 2002, there has been a constant increase in the technical efficiency of the industry, objectively reflected by a reduction in the share of farms in groups with low TE values and an increase in groups with high TE values (Figure 2). And although the growth in number of farms in groups over 75% is not significant and ranges from a few fractions to a few percent, changes in the groups "25-50%" and "50-75%" show a steady movement of farms in the industry towards an increase in the efficiency of the factors used.

In fact, steady growth in the total return of factors per unit of sales in the production of grain crops is visible (Figure 2). A 7% decrease in the share of farms in 2016 compared to 1995 in the "25-50%" group and an almost 11% increase over the same period in the "50-75%" group indicate a significant increase in technical efficiency.

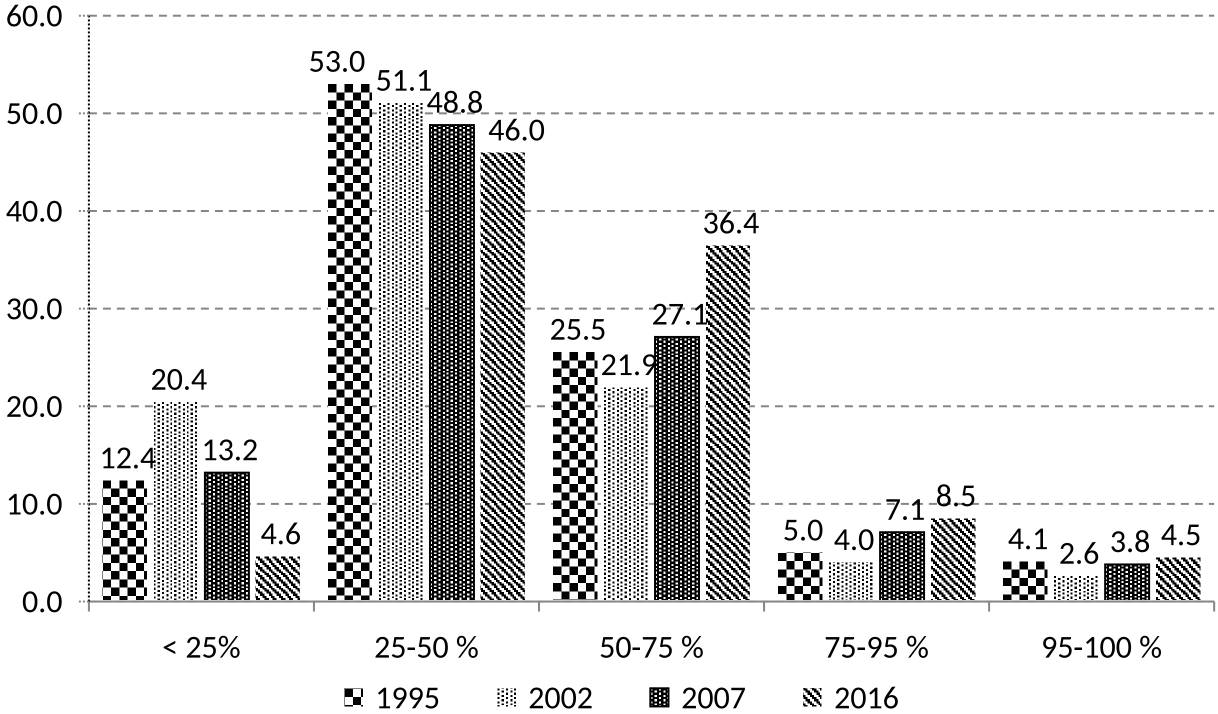

Figure 2. Distribution of farms by technical efficiency with constant returns to scale (%). Source: Authors' calculations on MoA farms database.

A similar pattern is typical for variable returns to the scale of resources. The redistribution in groups in 2016 stands out especially, when the share of farms with technical efficiency from "50-75%" and "95-100%" sharply increases, thereby showing significant changes in the grain industry (Figure 3).

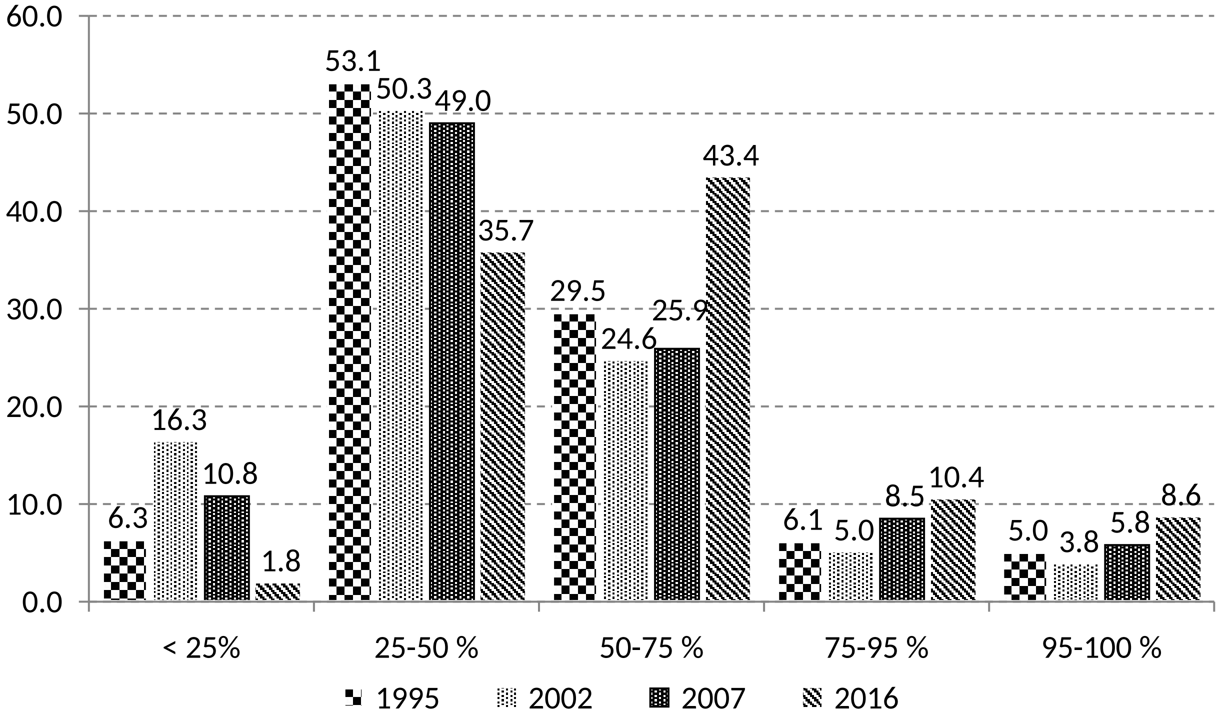

Figure 3. Distribution of farms by technical efficiency with variable returns to scale (%). Source: Authors' calculations on MoA farms database.

A comparative assessment of changes in the distribution of farms according to the technical efficiency shows that during the entire period under review, a qualitative transformation took place within the grain production industry itself, which ultimately influenced the country's level of grain supply and the possibility of its sale on the world market.

However, structural changes in the use of farm resources and the revenue they receive from the perspective of the calculated indicator of technical efficiency are of greater interest. A comparison of the share indicators of the distribution of farms by groups of technical efficiency, the resources used, the revenue received from the sale of grain and other crop products, presented separately for each year (Table 4), allows us to assess the restructuring of the industry in the direction of increasing its efficiency.

Table 4. Changes in the share of resources and revenue by farms by TE by year

Groups	Average value of TE	Number of farms		Group share by indicator, %					
		Units	% of total	Fixed assets	Labor resources	Sown area	Current costs	Revenue from crops	Revenue from other products
1995									
95-100%	0,993	50	5,0	5,0	6,5	5,4	7,4	11,5	14,8
75-95%	0,825	61	6,1	5,6	6,8	6,0	6,8	10,3	11,3
50-75%	0,602	296	29,5	29,7	30,8	29,1	31,0	35,7	39,7
25-50%	0,386	532	53,1	51,8	49,5	51,6	48,5	39,8	32,4
<25 %	0,210	63	6,3	7,9	6,5	8,0	6,2	2,8	1,8
Total	**0,496**	**1002**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
2002									
95-100%	0,996	38	3,8	5,1	4,5	4,1	6,9	9,6	12,9
75-95%	0,840	50	5,0	3,9	5,9	5,1	6,6	8,6	11,2
50-75%	0,601	246	24,6	28,3	30,3	28,3	29,9	36,1	38,5
25-50%	0,370	502	50,3	50,0	48,0	48,2	46,0	40,3	33,7
<25 %	0,198	163	16,3	12,6	11,3	14,3	10,6	5,4	3,7
Total	**0,446**	**999**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
2007									
95-100%	0,998	58	5,8	10,3	6,7	8,7	13,0	15,1	15,8
75-95%	0,833	85	8,5	9,1	10,0	8,3	9,8	13,5	16,2
50-75%	0,605	259	25,9	26,6	28,1	25,1	28,7	32,3	37,8
25-50%	0,376	490	49,0	45,6	45,2	46,1	40,2	34,9	28,2
<25 %	0,191	108	10,8	8,4	10,0	11,8	8,2	4,2	2,0
Total	**0,490**	**1000**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
2016									
95-100%	0,994	84	8,6	11,1	9,6	10,8	13,3	16,7	19,8
75-95%	0,835	102	10,4	10,9	9,4	9,0	11,7	13,7	17,2
50-75%	0,603	424	43,4	37,3	38,4	36,8	39,2	42,0	41,8
25-50%	0,403	349	35,7	36,6	40,1	40,1	32,7	26,3	19,9
<25 %	0,206	18	1,8	4,0	2,6	3,3	3,1	1,3	1,3
Total	**0,582**	**977**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: Authors' calculations on MoA farms database.

In the initial year 1995, the intergroup distribution of fixed assets, labor resources, sown area and current costs, with a small difference of 1.5-2.0%, corresponds to the proportion of the number of farms in the groups.

This important nuance indicates that at the initial moment of market transformations in Russian agriculture and, in particular, in the grain industry, there was an approximately equal distribution of resources between farms, i.e. farms, regardless of their level of technical efficiency (total output of resources), had on average approximately the same number of necessary types of resources.

In this case, the differences in technical efficiency obtained in the calculation are explained only as a consequence of the existing difference in the volume of product sales. Thus, the "95-100%" group, which includes 5% of farms and has a slightly larger share in other resources, grain sales, was equal to 11.5%; the "75-95%" group, numbering 6% of farms and almost the same amount in share of all resources, was equal to 10.3% in grain sales.

A similar situation can be observed for the remaining groups, with the only adjustment being that in groups with a lower-than-average TE, the share of revenue will be less than the share of available resources. Thus, the resulting difference in TE with equal resources used across groups is most likely a consequence of the influence of natural and climatic conditions.

The situation changed noticeably by 2002, when market signals became the main determinant of the use of production factors and the choice of economic activity areas. During that time some farms were increasing investments in capital, others - in the acquisition of land, technology improvement, etc.

According to the presented distribution of resources in groups of farms, it can be seen that the most technically efficient farms have increased the volume of use of all resources. For example, in the first group, 3.8% of farms had 5.1% of fixed assets, 4.5% of labor resources, 4.1% of crop area, 6.9% of the amount of current production costs (Table 4). As a result, the share in the revenue of grain crops of the first group reaches 9.6%, which exceeded their share in quantity by more than 2.5 times.

The "75-95%" and "50-75%" groups also increased their shares in resources and in product revenue. Despite the fact that the average value of TE for the dataset has decreased (0.446), the role of factors in productivity growth has become more noticeable, especially when comparing the allocation of resources and results.

The resulting decrease in the average value of TE in the dataset is explained by a significant difference in the number of those for whom it increased and those for whom it decreased.

By 2007, the concentration of resources in the farms of the first group increased even more, as evidenced by their weights. This was noticeably reflected in productivity growth: 5.8% of the best grain-producing farms with a share of 10.3% in the value of fixed assets, 6.7% in the number of agricultural workers, 8.7% in crop area and 13.0% in current material costs, received 15.1% of the total revenue of grain crops (Table 4).

The first two groups of TE (8.8% of the number of farms) had a share of 28.6% of revenue, while the farms of the third group "50-75%" (25.9%) - 32.3% of total revenue. In the industry as a whole, 35% of farms accounted for almost 61% of the total revenue from grain sales.

In 2016, the average TE value increased even more, with the share of the cross-border "95-100%" group amounting to 8.6% in number, and its share in revenue reaching an almost fifth of total sales (Table 4).

In general, by 2016, the technical efficiency of resource use in grain production had increased so much that the Russian Federation became the leader in its sales on the foreign markets. The increase in gross grain production, as a resource for the production of compound feed, also had an impact on the rapid formation and development of other branches of agriculture: pig farming and poultry farming.

The DEA method provides another estimate that shows the impact of conditions on performance. The resulting calculations of TE values with constant returns to scale, determine the total technical efficiency. TE calculations with variable returns to scale show net, Pareto-optimal, technical efficiency, characterizing the quality of the business process of the business units themselves.

Their ratio, defined as economies of scale, reflects the conditions that limit the ability of farms to improve technical efficiency. The influence of conditions in the functioning of the grain production industry can be judged by changes in the share of farms in groups in different years (Figure 4).

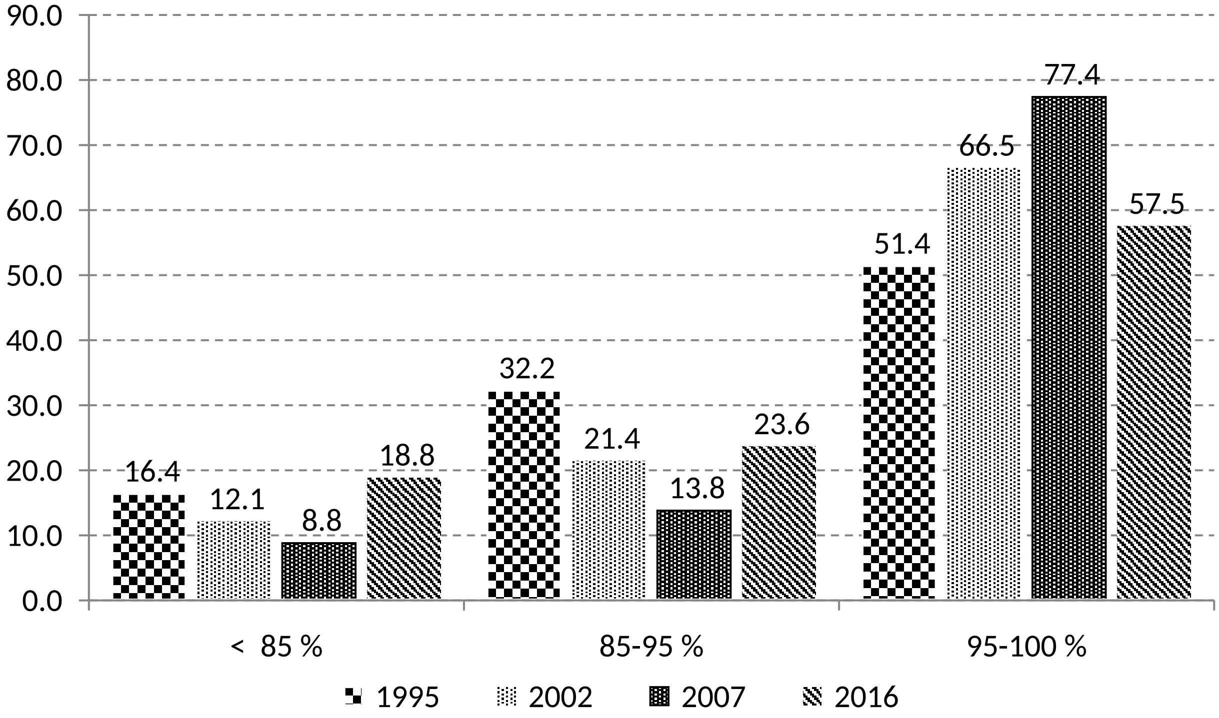

Figure 4. Dynamics of changes in the share of farms in groups according to the value of the scale effect.
Source: Authors' calculations on MoA farms database.

Since 1995, the economic conditions for the functioning of grain farms have contributed to the convergence of net and total technical efficiency, that is, a decrease in the share of enterprises in the "< 85%" and "85-95%" groups and their growth in the latter group (Figure 3).

This trend continued until 2007. In 2016, the opposite picture is observed - the influence of conditions widens the gap between net and total technical efficiency in the industry. With a high degree of probability, this can be attributed to the consequences of international sanctions and retaliatory measures introduced by the Russian Federation.

5. Estimation of changes in total factor productivity using the Malmquist method

***Selecting farms for calculations*.**

To carry out calculations characterizing the change in overall factor productivity in the industry using the Malmquist method, it is necessary to construct a sample consisting of the same farms throughout the entire analyzed period. To obtain it, all sample datasets formed after the first stage of selecting agricultural organizations (farms) were connected to each other using a unique OKPO code[8]. As a result, a group of farms was compiled that operated without changing registration data during the period 1995-2016. It included 115 farms (Table 5).

Table 5. Total indicators of a group of 115 farms

	1995	2002	2007	2016
Revenue from grain sales, billion rubles	326,9*	2,9	8,3	21,6
Share in total grain revenue of all farms, %	3,9	4,9	5,4	4,2
Volume of grain production, million tons	1506	2247,9	2130,7	2882,0
Share in total grain production of all farms, %	2,7	3,4	4,3	3,9
Sown area of grain crops, million ha	732,7	759,6	778,6	1110,2
Share in total area of grain crops in all farms,%	1,5	2,1	3,0	3,7

* before denomination.

Source: Authors' calculations on MoA farms database.

The farms included in the sample were fairly stable production units throughout, as evidenced by their share in total grain revenue, in the volume of its production and in the sown area under the crop. Regarding the latter, we can note the insignificant growth rate of grain area on these farms throughout the entire period.

Thus, in 1995, with their share of 4.0% in number, their share in revenue was 3.9%, in grain production - 2.7%, in the area of grain crops - 1.5%. In 2002, with a share in number 1.9%, their share in revenue increases to 4.9%, in production volume to 3.4%, and in sown area - to 2.1%. In other words, in 2002, the same 115 farms produced 1.5 times more grain with an increase in sown areas of only 3.7%.

In 2007, with a slight decrease in the total number to 2.6%, the share in the group's total revenue increased to 5.4%, in gross grain production - to 4.3%, and in sown area - to 3.0%. However, compared to 2002, the production volume was lower by 5.2%, and the area was larger by 2.5%.

In 2016, the share of farms in the total number was 1.8%, in total revenue and production volume it decreased by 0.8 and 0.4%, respectively, but in the sown area it increased by 0.7%, i.e. compared to 1995, the area has increased by more than one and a half times. Thus, in 2016, these farms used significantly more land resources in grain production than in all previous years.

***Justification of using of the Malmquist coefficient*.**

The use of the Malmquist coefficient to solve TFP determination problems has been described in many scientific papers (Wang and Lan, 2011; Kosterin et al., 2007; Forsund, 2015). It is based on the calculation of the TFP index and its decomposition into components: (a) total technical efficiency (TTE), (b) net technical efficiency (NTE), (c) economy of scale (ES) and (d) technological change (TC). The relationship between them is expressed as follows:

TTE = PTE * ES

TFP = NTE * TC

TFP = NTE * ES * TC.

All components were calculated using the DEAP program and the Win4DEP interface. When loading, four time periods were specified for the same objects, four input and two output

[8] Russian Classifier of Enterprises and Organizations (abbreviation in Russian - OKPO). Rosstat.

variables. As in previous calculations, data on capital, labor, land and annual current material costs were used as input variables, and sales of grain crops and sales of other crop products were used as output variables.

Results of the analysis of the Malmquist coefficients.

Before moving on to the analysis of the obtained calculated values of the indices of changes in total factor productivity, let us consider the distributions of 115 farms by technical efficiency indicators.

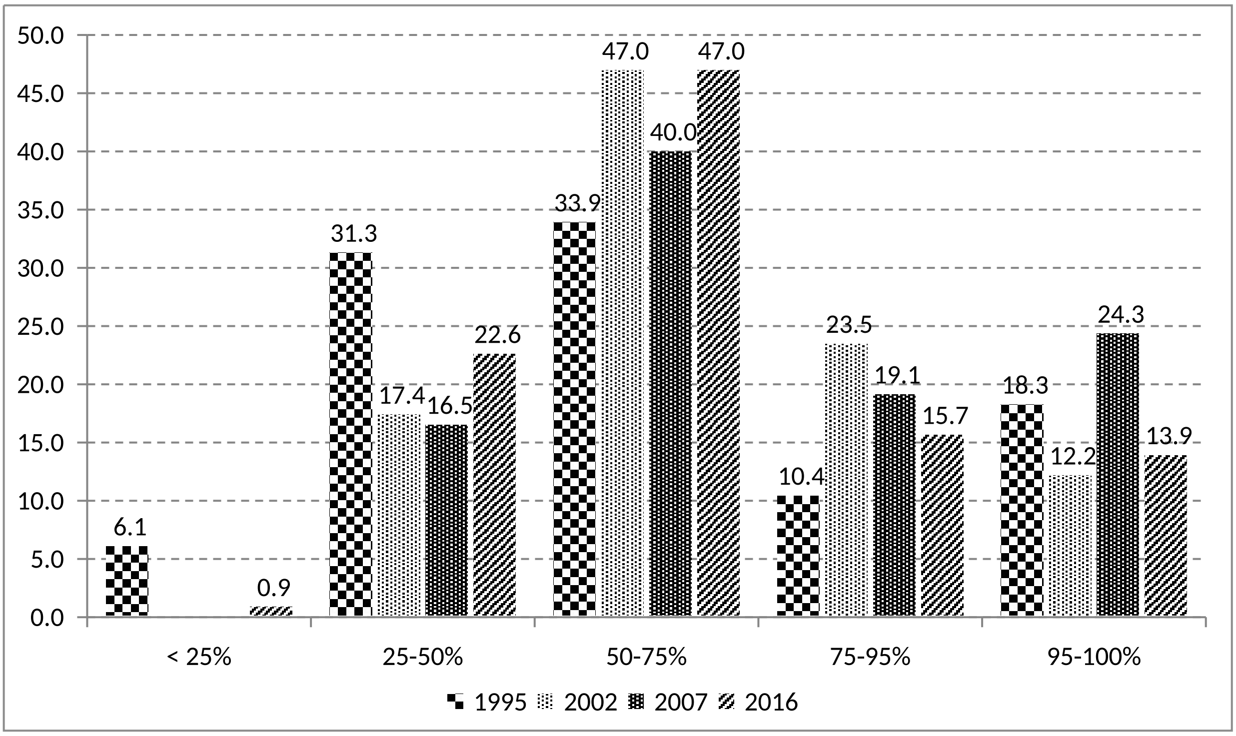

Figure 5. Distribution of 115 farms by technical efficiency with constant returns to scale (%). Source: Authors' calculations on MoA farms database.

As we can see, a distinctive feature of the resulting distribution, in comparison with a sample of 1000 units, is a significant right-sided asymmetry (Figure 5).

If in Figure 1 the main share of farms falls in the "25-50%" group, then in the new sample – in the "50-75%" group, which is understandable, since these farms are economically stronger, they "survived" in the conditions of transition to the market, successfully carrying out its commercial activities throughout the entire 20-year period.

The distribution structure of farms with variable returns to scale (VRS) presented in Figure 5, shows that almost all of them have high technical efficiency of the resources used.

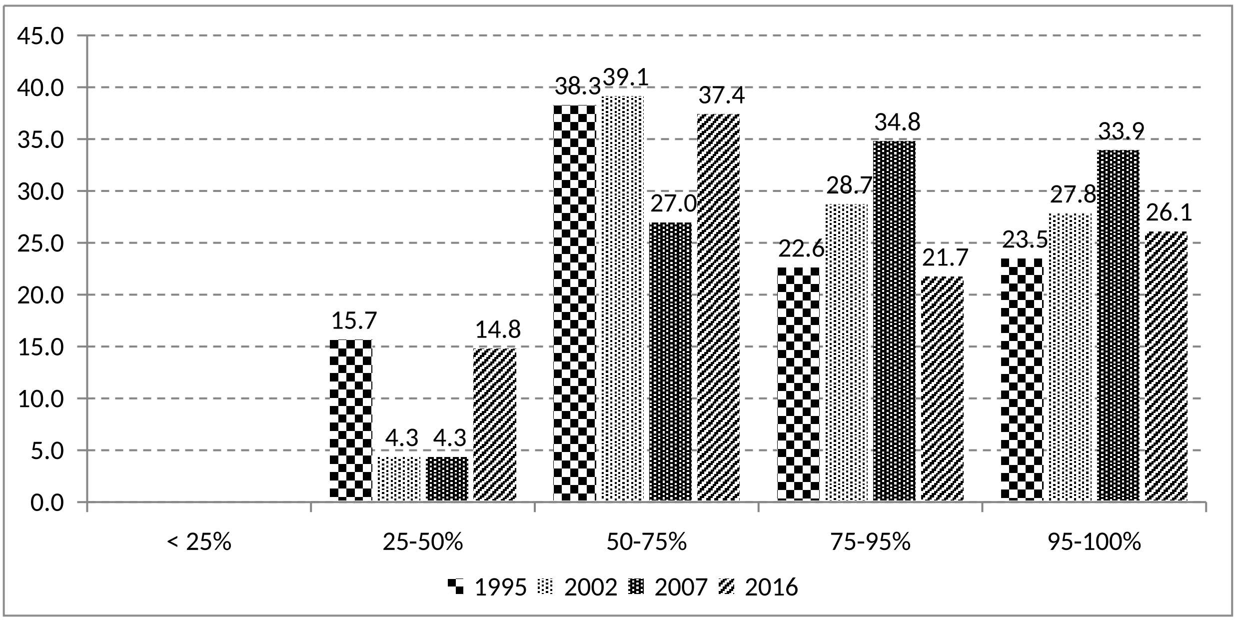

Figure 6. Distribution of 115 farms by technical efficiency with variable returns to scale (%). Source: Authors' calculations on MoA farms database.

Thus, there are no farms with technical efficiency below 25% in all years. Let us note a feature associated with the dynamics of changes in the "25-50%" group, where there is a decrease in the share by 2002 to 4.3%, remaining the same in 2007, and by 2016 there is an increase.

The reverse movement in the groups "75-95%" and "95-100%" shows an increase in the number of groups by 2007 and a decrease by 2016, and characterizes a change in economic conditions, which led to a decrease in overall technical efficiency. In general, we can state a significant increase in the technical efficiency of the industry until 2007 and a subsequent decrease by 2016.

The final solution to the problem was to obtain the values of all indices (TTE, NTE, ES, TC and TFP) for each agricultural organization (farm). The average values of indices characterizing the overall dynamics of the rate of change in TFP in the grain subcomplex are presented in Table 6.

Table 6. Average values of Malmquist indexes for grain industry

	2002 to 1995	2007 to 2002	2016 to 2007
Total factor productivity (TFP)	**3,246**	**1,790**	**1,878**
Total technical efficiency (TTE)	1,148	1,051	0,892
Net technical efficiency (NTE)	1,094	1,045	0,891
Economy of scale (ES)	1,050	1,006	1,000
Technological change (TC)	2,828	1,704	2,106
Average annual value of TFP index	**1,183**	**1,123**	**1,073**

Source: Authors' calculations on MoA farms database.

Based on the calculations obtained, we can conclude that there was a significant increase in the productivity of resource use during the period of agricultural reform, the formation and subsequent development of market institutions, as well as the improvement of the mechanism of economic activity of the agro-industrial complex. That happens thanks also to the implementation of the national project "Development of the Agro-Industrial Complex" in 2006-2007 and two State programs for the development of agriculture during the period 2008-2012 and 2013-2030.

The rapid growth of the TFP index by 2002 in comparison with 1995 (1995 = 1) by more than 3.2 times, or an average annual 18.3% increase in the productivity of the resources used, showed the strength of the influence of market institutions on efficiency in comparison with the system of state planning existing those times. And although later, over the period 2002-2007, the average annual growth rate of the TFP growth index decreased to 12.3%, and in the period 2007-2016 to 7.3%, the role of the market in coordination and motivation still remained significant.

Decomposing the TFP growth index into its components, total technical efficiency and technological changes, allows us to see what influenced the result more. The basis for the rapid growth of the TFP index in all periods was technological changes in the use of farm resources (Table 6).

According to DEA theory, technological changes in productivity are changes resulting from the shifts in the boundary (envelope) in a discrete time interval. In other words, it represents the relative gap between the technologies of "today and yesterday", and it is the potential maximum contribution in measuring productivity (Wang and Lan, 2011). It can be seen that technological changes in the period 1995-2002 provided the main share in the growth of TFP, equal to 282.8%. The index of technological changes, showing the shift in the boundary of industry efficiency under the influence of changes occurred, manifested fundamental processes associated with structural changes in the use of main factors of production.

For example, low wages were the reason for the outflow of part of the workforce from the agro-industrial complex to other sectors of the national economy. At the same time, the opportunity to purchase more modern equipment, hybrid seeds, advanced plant protection and veterinary products etc. appeared in the 90s allowed to increase the volume of production and sales, thereby not only compensating for the loss of labor resources, but also significantly increasing the productivity of the resources used in the industry.

The restructuring of the resources used under the influence of market signals allowed agricultural enterprises to radically change the production technology of almost all crops, in particular grains, in a short time. The same effect has been observed by Parikoglou et al when they investigated the contribution of innovation to farm-level productivity in EU (Parikoglou et al, 2024).

And although this was a largely painful procedure that had an impact on the decline in the standard of living of the rural population, ultimately a completely different type of agricultural production was created. In subsequent periods, the value of the technological change index was slightly lower (Table 6), but it still remained the main factor in the growth of the TFP index of the grain industry.

The second component of the TFP index is an indicator reflecting changes in total technical efficiency, expressed through the ratio of the position of objects relative to the CRS-efficiency boundary in comparable periods of time. It illustrates a virtual catch-up that has also been influenced by technological shift (Wang and Lan, 2011). The change in the average technical productivity of factors in agricultural organizations in 2002 made it possible to obtain an additional increase in the TFP index by 14.8% (Table 6).

This shows that the average value of the index in the number of enterprises has increased, and in 2002 their location relative to the boundary of the CRS envelope was closer than in 1995 (Figure 4). The decrease in the total technical efficiency index observed in the next two periods shows that the influence of the factor of technical change has virtually disappeared.

Moreover, in the period 2007-2016, its value became less than 1, which indicates its opposite effect, aimed at reducing TFP. Nishimizu and Page (Nishimizu and Page, 1982) defined this factor as "other technical changes in productivity - for example, learning by doing, dissemination of new knowledge, improvement of management practices, short-term adaptation to shocks external to the enterprise."

Whether the obtained result and the provision of "the other technical changes" are the basis for the assumption that agricultural organizations specializing in grain production have reached the upper limit in the growth of TFP, requires additional study of the constituent factors of TFP.

However, it is important to note here that in the period 2007-2016, the decrease in the net technical efficiency index may have been a consequence of the introduction of agro-food sanctions by EC and counter-sanctions by Russia.

The result of the changes that took place in the agricultural sector of Russia, which led to structural changes in the production of grain and leguminous crops, was:

1. Entry of the Russian Federation into the world grain market in 2000 and a gradual increase in sales volume, which by 2016 reached almost 34 million tons and their subsequent growth beyond the time frame of this analysis (Figure 7).

2. A significant increase in meat production volumes in industrial livestock sectors that use concentrated feed as the main source of nutrition, thereby increasing the added value of products in the agro-industrial complex - pig farming and broiler and egg poultry farming (Figure 8).

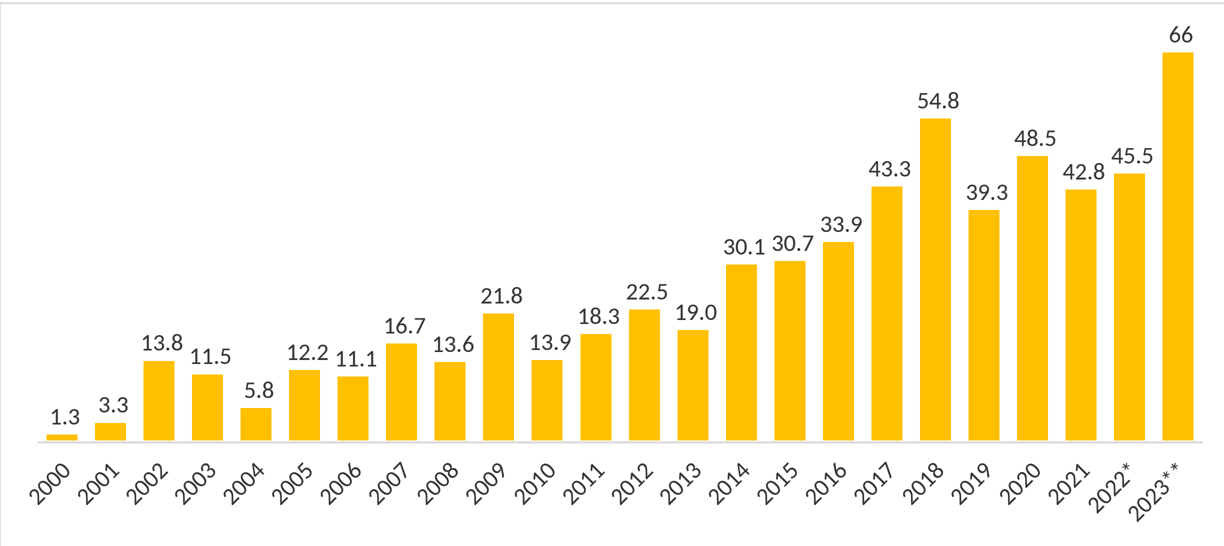

Figure 7. Grain export without processed products, million tons.
Source: Rosstat, food resource balances, 2000-2021.
*2022. https://xn--e1alid.xn--p1ai/journal/publication/2042
** 2023. Portnews. https://portnews.ru/news/359906/

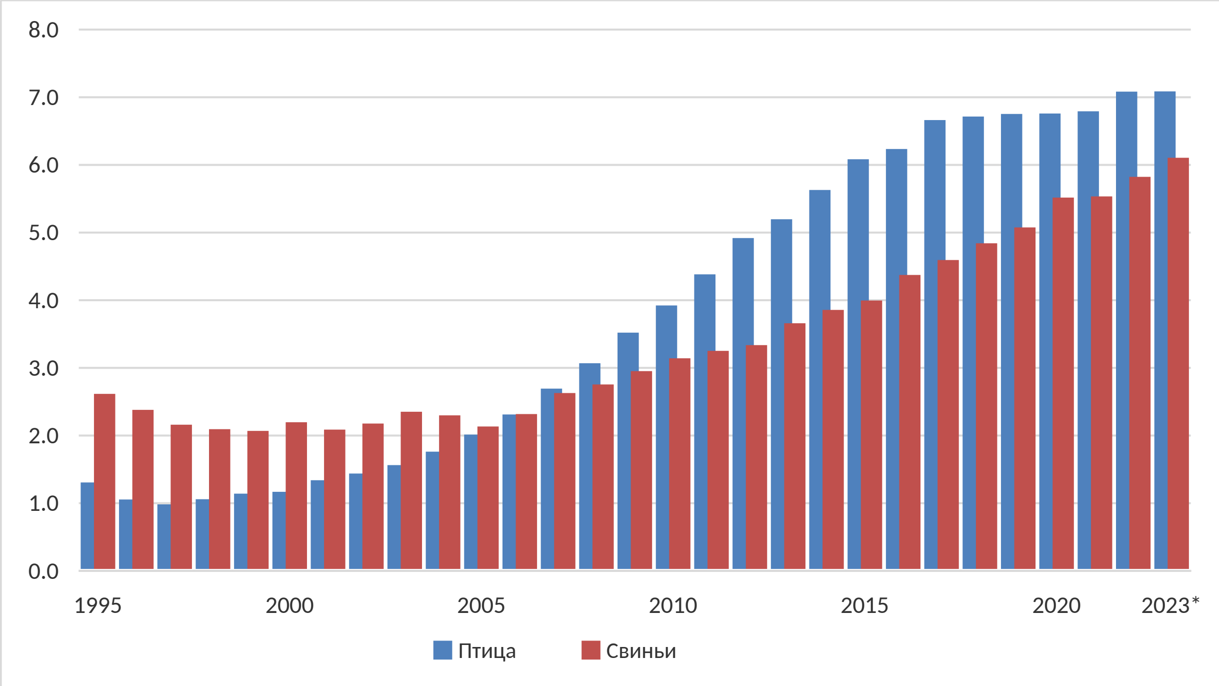

Figure 8. Production of pig and poultry meat for slaughter (in live weight) in farms of all categories, million tons.
Source: Rosstat, 2023 – assessments of national unions of pig and poultry farmers.

6. Final conclusions

This study confirmed the conclusions of previous studies about the rapid growth of technical efficiency and productivity in agriculture compared to 1995. Under the influence of market signals, the bulk of resources were gradually concentrated in farms with higher productivity. These farms have become benchmarks for other economic units in the industry. According to calculations, in 1995, farms with technical efficiency above 50% accounted for 57.5% of total sales of grain crops, in 2016 - already 72.4%.

A comparison of group distributions of farms by technical efficiency and the availability of resources over the years showed, how under the influence of market signals a redistribution of production factors took place from less efficient to more efficient.

The rate of change in total factor productivity in the grain product subcomplex in the period from 1995 to 2016 was different. They reached a maximum of 18.3% annual growth in the period from 1995-2002, decreased to 12.3% in 2002-2007 and decreased further to 7.3% in 2007-2016.

The high increase in total factor productivity in the grain industry in the period from 1995 to 2002 allowed the Russian Federation to enter the world grain market in 2000, becoming a key player. We believe that the main role in increasing total factor productivity was played by the transition to a market economy and the subsequent structural changes both in the agro-industrial complex as a whole and in the grain subcomplex. This conclusion is very important, since Russia is a big player in world food markets, and changes in its productivity can greatly affect the balance of world grain reserves. But of course this still needs to be proven by more in-depth methods.

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Disclaimer

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