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Distribution of Russia's Agricultural Sectors under Global-Warming Conditions

The author's research presented in this article shows that the influence of climate shifts on agricultural development remains a secondary factor for the majority of Russia's regions.

Keywords: *agricultural development, climate shift, spatial distribution of agricultural sectors*

Introduction

Mutually linking the spatial distribution of agricultural sectors across Russia with government regulation and overall economic policy is an objective necessity. On one hand, changes in the territorial distribution of agrarian industries shape the demands of agribusinesses for policy adjustments on food, infrastructure (particularly transport), and foreign trade. On the other hand, the content of state and regional agricultural support programs and measures to protect Russia's national interests has different impacts on production volumes in the same agricultural sector but in different regions.[1]

 "Razmeshchenie otraslei sel'skogo khoziaistva Rossii v usloviiakh global'nogo potepleniia," *Ekonomist*, 2018, no. 10, pp. 70–88.

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Coordination of these causal changes is hampered by a number of unique features of agriculture, including the duration of its production and investment processes, as well as the dependence of production on weather conditions and, in the long run, on climate change. Due to these features, price signals from the agricultural markets are, in the first place, unstable and, second, outdated: they arrive with considerable delay. In some cases, they are less conducive to making the best decisions about investment in regional agricultural sectors than they are disorienting for investors and politicians. The market economy has undoubtedly led to noticeable changes in the distribution of agricultural production in Russia that largely determined its significant increase in competitiveness. Nevertheless, further progress in that direction has been limited by the aforementioned flaws in the signaling system of agricultural markets.[2]

As a result, we face the obvious and objective need for relying on modern information technologies for long-term decision-making. At the foundation of these technologies is mathematical modeling. It allows us to understand which policy measures are most relevant and at what interval we should expect the results of these measures. The principles for applying this method when assessing the industrial and territorial division of labor were developed by V.S. Nemchinov. The research we present in this article is consistent with those principles, which are based on previous studies of Russian agriculture's structural adaptation to climate change and on progress that has been made over the last two or three decades in applying nonparametric methods for optimization of planning.[3]

Among the factors in spatial distribution of industries are natural-climatic and transportation conditions. Traditionally, the former was considered a permanent condition and the latter manageable in the long term. This has been the approach followed, in particular, by the scientific research teams at the All-Russian Scientific Research Institute of Agricultural Economics and the Kursk Agricultural Academy. The monograph edited by A.V. Gordeev was the country's first work of fundamental research on this problem, with central focus on climate change. They believed that changing climate conditions would create new opportunities for agricultural production for the country as a whole, even though these changes would be unfavorable for some regions. However, they formulated this opinion without any detailed account of the impact of regional resource-potential structures, demand factors, logistics, and competition on the effects of climate change. To address this whole complex of factors, we require modeling.[4]

This study seeks to identify strategies for improving the distribution of agricultural sectors under climate-change conditions. Achieving this goal requires comprehensive decisions for most of the tasks involved in instrumental-support programs for agrarian policy aimed at guaranteeing food security for Russia's population. The methodological approach we have developed fully meets this requirement: it provides for a system-wide linkage among food balances, foreign trade, and domestic interregional supplies of agricultural products. This linkage would be valid both for existing climate conditions and under various climate-change scenarios.

At the same time, the list of products with which the mathematical model underpinning this method can operate must be limited to only a few examples, which forces us to use commodity aggregates. This limits the range of tasks to which our tool can be applied. The model's information base would remain sufficiently relevant for no longer than five years. A longer-term analysis is technically possible, but only with the support of other modeling tools that can predict changes in the distant future for the parameters used in the current model.[5]

The work presented in this article was carried out within the framework of two research-and-development projects: "The Formation of Structural and Institutional Prerequisites for Ensuring Russia's Economic Growth Under Conditions of a New, Emergent Technological Order in the Global Economy" (Russian Academy of Sciences Central Economic Mathematical Institute) and "Development of Theoretical Foundations for Adapting the Regional Agro-Production Complex for Long-Term Climate Change" (the A.A. Nikonov All-Russian Institute for Agrarian Problems and Informatics, an affiliate of the All-Russian Scientific Research Institute for Agricultural Economics; hereinafter: VIAPI). The first project includes validation and practical confirmation (based on materials from the Russian agricultural sectors) of the effectiveness of methods for spatial analysis of structural progress based on a linear programming apparatus. This technique will later be applied in analysis of structural implications for the agro-production complex and technologically related industries because of the various factors (including climate change) affecting the process of transitioning to a new technological order. The second project involves the novelty associated with modeling representations of climate shifts and the specific risks to agricultural production, as well as conclusions and assessments that are of practical importance for the development of promising agrarian policies for the country overall and for its federal subjects.

Research methods

For many years, mathematical modeling of the agricultural-sector distribution in Russia's regions has been unsuccessful. The reason lay in the difficulty of understanding, and of subsequently expressing mathematically, the features of agro-production technology in different regions. We can overcome these difficulties by constructing a nonparametric boundary of production ability à la M. Farrell and basing it on statistical data at the regional level. With this approach, the individual sets of regional technological capabilities presented in the model are determined entirely by the amount of certain resources used for agricultural production and available to statistical observation, while the boundary of production capabilities in an imaginary multidimensional space of resources and product types has the same form for all regions.[6]

Another problem—the probabilistic nature of modeling parameters—was addressed by using the ER-Modeling theory. This essentially involves applying a nonparametric representation of the multidimensional probability distribution of those parameters that depend on chance, based on empirical data over a number of years. With a highly accessible empirical base, this kind of approach does not claim that the form of probability distribution obtained is statistically representative, but it at least guarantees the feasibility of an optimal plan under the conditions of any year from among the years whose data was used to construct the model.[7]

These decisions allow us to construct a mathematical model that serves as a tool for addressing the problem examined in this article. The distinctive features of this model are its presentation of technology in the form of nonparametric boundaries of production capabilities; its presentation of resources and output by region; its accounting of interregional product delivery, exports, and imports via existing transportation routes; and its accounting for uncertainty using a stochastic, two-stage ER model. The model includes the 78 constituent entities of the federation that produce agricultural products (except for the Republic of Crimea: the necessary data for developing the model were not available in full), as well as Moscow and St. Petersburg. The model manages the balances of seven resources: agricultural land, arable land, fixed assets, working capital, labor, livestock, feed grain, and four types of agricultural products: grain, milk, livestock and poultry for slaughter, and other agricultural products. It also takes into account interregional transportation access by rail and, in its absence, by waterways or roads.[8]

Our initial data source for constructing this model was the database of regional agri-food complexes developed and maintained by VIAPI. We supplemented this data with geographical information about transportation networks and average transport tariffs. The model takes into account the technological capabilities of Russia's regional agriculture, the food needs of the population, foreign trade, interregional transportation access, regional differentiation of natural conditions, and weather- and market-related risks for agribusinesses.[9]

An optimal distribution of industries would provide a guaranteed food supply to the regional populations covered in our model for economic conditions over the five-year period from 2011 to 2015. These conditions are represented by levels of crop yields and animal productivity in each natural-agricultural group of regions, purchase prices, resource volumes, and the population's food needs. These conditions are implemented with the assumption that climate change will be occurring in accordance with the scenario under consideration —that is, we have used long-term forecasts for global warming in Russia to alter the position of territories where the application of certain production processes with yields and productivity characteristic of the years in question has been appropriate.

Studies of the evolution of long-term agricultural-production distribution suggest the following procedures for applying our mathematical model for distribution of agricultural sectors:

- A forecast of Russia's regional agricultural resources should be created and introduced into the model.
- Different forecasts of technical progress should be created, and the boundaries of production capabilities adjusted to match.
- The distribution of regions by natural-agricultural groupings should be revised on the basis of the climate-change forecast.
- A scenario involving changes in foreign trade prices should be created and introduced into the mathematical model.

This article presents the results of our modeling experiment involving the following conditions. Production technologies were given by the stochastic, nonparametric boundary of production capacity, according to 2011–2015 data. Foreign trade prices were represented by a random vector whose probability distribution was given in nonparametric form based on the UN Food and Agriculture Organization's average annual data for those same years. Anticipated climate changes were reflected by shifting the natural-agricultural groupings of federal subjects (except for mountain and arid groups) to the northeast by 30 percent of the area of the respective regions (Table 1). The Russian population's food needs correspond to 2015 levels. We took the maximum allowable replacement of production processes by more efficient ones as 10 percent: this value is what approximately determines the five-year planning horizon. The agricultural resource base was represented by a random vector whose probability distribution is given in nonparametric form based on 2011–2015 data. Data from 2017 were used to estimate interregional transportation tariffs. We assumed that the existing capacity of communication lines and transportation hubs (railway stations, ports, and their infrastructure) would not limit the volume of traffic: one goal of this modeling is to determine the *required* capacity of existing communication lines and transportation hubs for later adjustment of programs for their reconstruction. Our scenario assumes that transportation of agricultural products would not be subsidized.

All the cost indicators in our model (and thus in our article) are linked to Rosstat price indexes for 2015.

We performed our distribution of the country's regions into the expanded natural-agricultural groups for our baseline scenario by using a method developed at the Center for Agricultural and Food Policy of the Russian Presidential Academy of National Economy and Public Administration, on the basis of data from the monograph edited by A.N. Kashtanov. The climate-change scenario was developed at VIAPI on the basis of cartograms published in an article by S. Kiselev and others.[10]

We first presented the results we obtained from an earlier version of this technique at the April 2018 Saint Petersburg Economic Congress. The new version has improved our method of constructing the boundary of production capabilities: the rate of replacement of regional production processes with more efficient processes (if they are identified) is now regulated for the whole set of replacement processes rather than for each process individually. This technique allows us to identify additional reserves for improving the efficiency of sector distribution, which the earlier version of the model neglected.[11]

Table 1

Natural-Agricultural Groupings of Federal Subjects for Studying the Effects of Global Warming

Federal Subject	Distribution of Agricultural Land by Expanded Natural-Agricultural Grouping: Current Climate (1)	Distribution of Agricultural Land by Expanded Natural-Agricultural Grouping: Changed Climate (2)
Magadanskaia oblast	z1 (polar-tundra): 100%	z1: 70% z2: 30%
Murmanskaia oblast, Kamchatskii krai	z2 (northern taiga): 100	z2: 70% z3: 30%
Karelia Republic, Komi Republic, Arkhangel'skaia, Vologodskaia, Leningradskaia oblasts, Permskii krai, Kirovskaia, Sverdlovskaia, Tiumenskaia oblasts, Krasnoiarskii krai, Irkutskaia and Tomskaia oblasts, Sakha Republic (Iakutiia)	z3 (mid-taiga): 100%	z3: 70% z4: 30%
Brianskaia, Vladimirskaia, Ivanovskaia, Kaluzhskaia, Kostromskaia, Moskovskaia, Riazanskaia, Smolenskaia, Tverskaia, Iaroslavskaia, Kaliningradskaia, Novgorodskaia, and Pskovskaia oblasts, Marii El Republic, Udmurtskaia Republic, Nizhegorodskaia and Omskaia oblasts, Primorskii krai, Khabarovskii krai, Amurskaia and Sakhalinskaia oblasts	z4 (southern taiga, forest): 100%	z4: 70% z5: 30%
Belgorodskaia, Voronezhskaia, Kurskaia, Lipetskaia, Orlovskaia, Tambovskaia, Tul'skaia oblasts, city of Moscow (new territories), Bashkortostan, Mordovia, Tatarstan and Chuvashskaia Republics, Pezenskaia, Samarskaia, Ul'ianovskaia, Kurganskaia, Cheliabinskaia, Kemerovskaia, and Novosibirskaia oblasts	z5 (forest-steppe): 100%	z5: 70% z6: 30%
Krasnodarskii krai	z6 (steppe): 100%	z6: 100%
Rostovskaia oblast, Ingushetiia Republic, Orenburgskaia oblast, Altaiskii krai, Crimean Republic	z7 (dry steppe): 100%	z7: 100%

Volgogradskaia oblast, Dagestan Republic, Stavropol'skii krai, Saratovskaia oblast	z8 (semi-desert): 100%	z8: 100%
Kalmyk Republic, Astrakhanskaia oblast	z9 (temperate desert): 100%	z9: 100%
Khanty-Mansiiskii Autonomous Okrug—Iurga	y1 (mountain-tundra): 100%	y1: 100%
Altai, Buryatia, Tyva, Khakasiia Republics, Zabaikal'skii krai, Evreiskaia Autonomous Okrug	y5 (mountain-meadow): 100%	y5: 100%
Adygeia, Kabardino-Balkarskaia, Karachaevo-Cherkasskaia, Severnaia Osetiia–Alaniia, and Chechenskaia Republics	y6 (foothill steppe and subtropical): 100%	y6: 100%

Anticipated changes in the distribution of agricultural sectors under global warming

The computer experiment we performed under the scenario just described showed the following deviations from the present day.

In terms of territory, we see a tendency to shift production away from traditional regions: grain to Southern Siberia and the non–Black Earth regions, and livestock and poultry to Kuban, Tatarstan, and central European Russia. This trend is a fairly weak one: the three primary producers of *grain* would remain Krasnadorskii krai (11 million tons, or 93.5 percent of its present average annual 2011–2015 levels), Rostovskaia oblast (7.84 million, or 99.5 percent), and Stavropol'skii krai (7.49 million, the same as its present level). Altaiskii krai would rise to fourth place (3.82 million tons, or 102.7 percent of its present level), beating out Voronezhskaia oblast (3.42 million, or 91.9 percent), which would drop from fourth place to fifth. For Russia as a whole, the average annual volume of grain production would be 90.91 million tons, which is 1.92 million lower than present levels, and the need for grain feed would increase by 142,000 tons. The model suggests that revenue from grain sales will drop by an average of 2.1 percent from current levels. With these figures in mind, we should emphasize that we are interested in only those changes that arise for two reasons: first, because of climate change itself, and second, because of the agricultural-industrial structure's best adaptations to climate change. To assess the impact of climate change separately from other factors, our model's calculations set the resource potential for each federal subject at 2011–2015 levels. The same applies to domestic and foreign trade prices.

Thus, the conditions of our scenario, including those related to climate change, are generally not conducive to further growth in production volumes in the grain industry, which is currently the engine of Russian agricultural development. However, as we show next, this situation is due less to climate change than to the objective competitive advantages of the livestock and poultry sectors. At present, these advantages are being fully realized only in certain Russian regions, and our model shows that beef-cattle breeding will continue its development in other regions.

The five largest *milk* producers, according to the modeling results under climate-change conditions, would remain unchanged, but milk production would slightly decrease in each of these federal subjects. The five are the Republic of Tatarstan (1.73 million tons, or 96.1 percent of present levels), the Republic of Bashkortostan (1.69 million, or

97.6 percent), Altaiskii krai (1.40 million, or 99.0 percent), Krasnodarskii krai (1.29 million, or 95.9 percent), and Rostovskaia oblast (1.04 million, or 97.0 percent). In this scenario, Russia as a whole would produce 30.5 million tons (0.5 million less than today), which is not enough to fully meet the population's needs for dairy products. Profits from dairy sales would decrease by 1.7 percent. The main reason for this situation is that, despite the impressive progress made since the beginning of the century in the expansion of milk production and industry efficiency, foreign competitors remain able to supply dairy products to the markets of many regions at prices that are more beneficial to customers than the analogous products from Russian producers.

There would not be any changes among the five largest *livestock*- and *poultry*-producing regions, though the trends among these five would differ. The largest producer of livestock and poultry would remain Belgorodskaia oblast, which has achieved significant successes in those sectors over the previous decades. For the sake of objectivity, we should note that a study by researchers at Russian Presidential Academy of National Economy and Public Administration has shown that the environmental and social costs of these achievements are, in some respects, excessive. According to the results of our calculations, production of these products would not change in this region, remaining at 1.431 million tons (in live weight). Krasnodarskii krai would remain in second place, though it would also demonstrate the greatest increase in production of these products among all regions under this scenario: an increase of 10.4 percent from 515,000 to 569,000 tons. Tatarstan would remain in third with a total production volume of 498,000 tons and 8.8-percent growth over present levels; fourth is Cheliabinskaia oblast (420,000, or a 0.7 percent decline) and fifth is Bashkortostan (382,000, or an increase of 0.2 percent). Russia as a whole would sell 12.6 million tons (in live weight) of livestock and poultry, which exceeds present levels by 396,000 tons and would lead to a 3.3-percent increase in revenue from sales. This would allow Russia to achieve complete self-sufficiency in meat products, with exports of meat and meat products exceeding imports.[12]

Thus, the greatest benefits of climate change would accrue in the beef-cattle industry, while the grain sector, unlike in alternative forecasts, would be under pressure from competition with livestock producers for resources. Climate change would allow Russia to become a net exporter of meat (997,000 tons in live weight annually) and to deliver an average of 42.8 million tons of grain abroad per year, but with the trade-off in dairy products in the form of 16.9 million tons of raw milk purchased from abroad. Milk would be imported mainly across the borders of Smolenskaia (5.3 million tons), Leningradskaia (4.3 million), and Brianskaia oblasts (3.7 million).

The model predicts that the five regional leaders in agriculture in terms of revenue from sales of agricultural products would be Krasnodarskii krai (340 billion rubles, or 2.7 percent less than today), Rostovskaia oblast (229.4 billion, a decline of 1.6 percent), the Republic of Tatarstan (224.6 billion, a decline of 1.2 percent), Belgorodskaia oblast (198.1 billion, unchanged), and Voronezhskaia oblast (189.8 billion, a decline of 2.7 percent). It is not the conditions of the scenario that lead to the changes these five regions would face in comparison to their present situation, but neither would any of them benefit from the anticipated changes. Either the climate conditions would not change (as in Krasnodarskii krai) or would improve (the other four), but farms in other regions would gain certain comparative advantages: the impact of improved climate conditions would be felt more greatly in regions where the transportation situation is already better and where the larger volume of unused reserves would improve the efficiency of agricultural production (see Figure 1).

For Russia as a whole, the model predicts that revenues from the sale of agricultural products would amount to 5.0243 billion rubles, an increase of only 0.07 percent, though the opportunity costs of agricultural production should decline by 2.5 percent.

The cartogram clearly represents *the anticipated change in distribution of agricultural sectors in European Russia and the Urals under changing climate conditions*. It shows that the increase in livestock production and poultry production would be near-universal, with the most significant increases in Krasnodarskii krai (10.4%) and Tatarstan (8.8%). These numbers suggest that agriculture in the country's two most significant agrarian regions would face a highly sensitive structural adjustment. Rural entrepreneurs there would have the opportunity to earn good money by reprofiling their agricultural production toward livestock and poultry.

In the traditional grain regions of western European Russia—Krasnodarskii krai and Kurskaia, Voronezhskaia, Orlovskaia, and

Figure 1. **Structural Changes in Agricultural Production in European Russia and the Urals under a Climate-Change Scenario, Compared with Annual Average Levels in 2011–2015** (in billion rubles).

Lipetskaia oblasts—grain production declines even though our scenario does not anticipate that the climate conditions in these territories would worsen. The operating factor behind that change is the increase in opportunity costs of resources diverted to the meat industries, along with a simultaneous improvement of the competitive position of the grain industry in northern territories, including the non–Black Earth region, because of climate change.

For other regions pictured in the cartogram, including the southern Volga region and the Urals, where grains occupy significant areas of land, the volumes of grain production show very little change and without any pronounced, system-wide trends. The greatest increase among areas pictured in the cartogram is expected in Orenburgskaia oblast, but this would not entail any major changes in the region's industrial structure, since the result would be only 3.6 percent higher than present day. The trend of grain production shifting to the north and the east is not limited to European Russia and the Urals: the model predicts a significant increase in gross grain harvest in Altaiskii krai as well. Climate and economic conditions for the production of grain would be sufficiently favorable there to compensate for the region's inaccessibility to transportation (see Table 2).

In a number of oblasts in the non–Black Earth region, the increase in grain production would be relatively significant: 78.8 percent in Arkhangel'skaia, 53.7 percent in Tverskaia, 22.5 percent in Smolenskaia, and 16.5 percent in Pskovskaia, while in the Republic of Karelia it would increase by a factor of more than eight. However, very little grain is produced in those regions today, so the absolute increments are either tiny on the cartogram's scale (as in Tverskaia and Smolenskaia oblasts) or completely indistinguishable from zero.

Changes in milk production would be similar to those of grain production in the sense that they are minor in most regions, but there would be a significant decline in production among the largest regional producers, Krasnodarskii krai and Tatarstan, at 4.1 percent and 3.9 percent, respectively.

The cartogram highlights two regional belts with different types of structural changes in relation to other agricultural products—in particular, vegetables, perennial products, potatoes, oilseeds, and industrial crops. In the arc-shaped northeastern belt, production of these products would increase. This belt includes Pskovskaia oblast, Karelia, Arkhangel'skaia oblast, Vologodskaia oblast, the Komi Republic, Kirovskaia oblast, Permskii krai, Bashkiria, and Orenburgskaia oblast. The situation is the opposite for the remaining territories of European Russia and the Urals, with the exception of a narrow belt formed by Chuvashia, Mordovia, and Penzenskaia oblast. The decline would be most significant in Voronezhskaia oblast (−3.9%), Tatarstan (−3.8%), and Krasnodarskii krai (−3.0%). As with grains, the situation for each

Table 2

Federal Subjects with the Highest Absolute Growth in Production of Agricultural Products

Grain		Milk		Livestock/Poultry		Other Products		All Products	
Federal Subject	Thou. Tons	Federal Subject	Thou. Tons	Federal Subject	Thou. Tons	Federal Subject	Mill. Rubles	Federal Subject	Bill. Rubles
Altaiskii krai	101.2	Volgogradskaia oblast	17.14	Krasnodarskii krai	53.61	Altaiskii krai	3,633	Altaiskii krai	3.619
Orenburgskaia oblast	80.96	Cheliabinskaia oblast	15.34	Tatarstan	40.28	Penzenskaia oblast	2,192	Chechnya	2.945
Chechnya	60.15	Lipetskaia oblast	8.06	Voronezhskaia oblast	23.78	Chechnya	2,044	Penzenskaia oblast	2.476
Tverskaia oblast	52.00	Primorskii krai	4.23	Moskovskaia oblast	20.35	Ul'ianovskaia oblast	1,773	Pskovskaia oblast	2.126
Smolenskaia oblast	48.50	Kurskaia oblast	3.79	Nizhegorodskaia oblast	18.97	Bashkortostan	1,604	Kirovskaia oblast	2.053

Note. Thou. = thousand.

belt is explained by the types of products that gain competitive advantages under the new climate conditions, given the region's existing resource potential and optimal transportation of products.

Beyond the Urals, the main source of revenue growth for agricultural producers would be livestock and poultry. Meat production would increase in Novosibirskaia oblast by 16,900 tons, in Tiumenskaia by 13,500 tons, in Krasnoiarskii krai by 8,600 tons, in Sverdlovskaia oblast by 6,700 tons, in Amurskaia by 5,600 tons, and in Primorskaia by 3.4 million tons. Other agricultural sectors in Siberian and far-eastern regions would not undergo any significant changes, with the exception of Altaiskii krai, which we discuss next, and Buryatia, where production of other agricultural goods would increase by 1.31 billion rubles (16.3 percent higher than today).

Because the cartogram covers only European Russia and the Urals, we have supplemented it with the data in Tables 2 and 3, which presents those federal subjects that will face the largest-scale structural changes because of the effects of global warming. The tables show that, like certain regions of European Russian and the Urals presented in the cartogram, Altaiskii krai would scale down its production of livestock and poultry in favor of grain and other products, whereas Primorskii krai would show significant increases in milk production.

Grain production would relocate from traditional regions to territories where climate conditions are improving, or to locations that already possess reserves for expanding grain production today. Beef cattle production would move to regions where resources are released from grain production (Krasnodarskii krai, Voronezhskaia oblast) or from production of other products (Tatarstan, Nizhegorodskaia and Moskovskaia oblasts). Four of the acknowledged leaders in levels of agricultural development—Krasnodarskii krai, Rostovskaia and Voronezhskaia oblasts, and Tatarstan—would be forced to yield some of their position to competing regions, although the scale of production among these large agricultural producers is so extensive that the decrease (−2.7%, −1.6%, −2.7%, and −1.2%, respectively) would barely be felt.

We located significant reserves for the expansion of agricultural production under climate-change conditions in federal subjects with greatly diverse geographies: the northern non–Black Earth region, southeastern Siberia, the northern Black Earth region, the Northern Caucasus, and

Table 3

Federal Subjects with the Highest Absolute Decrease in Production of Agricultural Products

Grain		Milk		Livestock/Poultry		Other Products		All Products	
Federal Subject	Thou. Tons	Federal Subject	Thou. Tons	Federal Subject	Thou. Tons	Federal Subject	Mill. Rubles	Federal Subject	Bill. Rubles
Krasnodarskii krai	–778.34	Tatarstan	–71.23	Altaiskii krai	–5.40	Krasnodarskii krai	–5,300.0	Krasnodarskii krai	–9.34
Voronezhskaia oblast	–300.06	Krasnodarskii krai	–54.68	Cheliabinskaia oblast	–3.05	Voronezhskaia oblast	–4,704.9	Voronezhskaia oblast	–5.16
Kurskaia oblast	–217.63	Bashkortostan	–41.04	Komi Republic	–0.64	Tatarstan	–4,462.3	Rostovskaia oblast	–3.69
Lipetskaia oblast	–187.77	Rostovskaia oblast	–31.56	Volgogradskaia oblast	–0.33	Rostovskaia oblast	–3,289.0	Tatarstan	–2.63
Orlovskaia oblast	–186.52	Nizhegorodskaia oblast	–29.04	Arkhangel'skaia oblast	–0.04	Moskovskaia oblast	–2,615.7	Samarskaia oblast	–2.12

Note. Thou. = thousand; mill. = million; bill. = billion.

Penzenskaia oblast. The common feature uniting these regions can be found in the All Products column of Table 2: a relatively low level of efficiency in existing agricultural production, a lag in technological upgrading, and a consequential underutilization of resource potential.

Altaiskii krai represents the exception: it is well known for the technological progress it has achieved in raising dairy cattle. The sector receives support from the local dairy industry, effectively using the 2014 food embargo as impetus for development. Nevertheless, the volume of agricultural production in the krai still lags behind what it could achieve with the existing resource potential and may increase only by 2.5 percent over the next five years through technological improvements. It is important to note that this figure is not due to climate change: it remains the same both for the warming scenario and for the actual climate today.

Table 4 presents the federal subjects characterized by the greatest *changes in domestic transportation flows of agricultural products*. With transportation figured into the modeling, the table includes the five federal subjects with the largest absolute growth and the largest absolute decline in net shipment for each of three products.

The data in Table 4 represent the net shipment of products from one Russian federal subject to other regions. In most cases, the changes in supply volumes are not very large and do not place a critical burden on the transportation infrastructure: in fact, the changes tend to reduce the burden on the most heavily loaded routes.

According to Table 4, shipment of grain to other regions will increase largely thanks to the country's eastern regions: Altaiskii krai, Orenburgskaia, and Cheliabinskaia oblasts. In these three regions, the main source of additional volumes of grain for shipment will be production growth. We should emphasize that the increased grain shipment to other regions would be beneficial to Altaiskii krai despite its highly disadvantageous transportation situation, even with nonsubsidized transport tariffs included in the modeling.

In European Russia, Rostovskaia oblast would increase its domestic grain shipment by reducing foreign exports through its ports, and Bashkortostan would do so by reducing its production of milk, which would save on feed grain. The traditional grain suppliers—Krasnodarskii krai, Voronezhskaia, Kurskaia, Orlovskaia, and Lipetskaia oblasts—

Table 4

Net Shipment of Agricultural Products from Individual Federal Subjects to Other Regions (in thousand tons)

Region	Planned	Present-Day	Difference
Wheat			
Altaiskii krai	1,519.5	1,370.6	148.9
Rostovskaia oblast	4,605.4	4,482.5	123.0
Bashkortostan Republic	133.3	17.1	116.2
Orenburgskaia oblast	996.4	883.5	112.8
Cheliabinskaia oblast	166.6	110.3	56.3
Lipetskaia oblast	1,507.1	1,663.0	–156.0
Orlovskaia oblast	1,763.7	1,919.8	–156.1
Kurskaia oblast	2,202.9	2,372.7	–169.9
Voronezhskaia oblast	2,230.8	2,459.7	–229.0
Krasnodarskii krai	8,076.9	8,669.8	–592.9
Dairy products[a]			
Volgogradskaia oblast	–333.2	–349.8	16.7
Cheliabinskaia oblast	–668.9	–684.1	15.2
Lipetskaia oblast	–122.3	–130.5	8.2
Primorskii krai	–536.4	–540.7	4.2
Kurskaia oblast	–18.0	–21.9	3.9
Nizhegorodskaia oblast	–528.5	–499.7	–28.8
Rostovskaia oblast	–407.0	–375.3	–31.7
Bashkortostan Republic	306.3	347.8	–41.5
Krasnodarskii krai	–567.8	–512.9	–54.9
Tatarstan Republic	422.2	493.3	–71.1
Meat[b]			
Krasnodarskii krai	159.3	106.3	53.0
Tatarstan Republic	208.7	169.0	39.7
Voronezhskaia oblast	183.5	159.0	24.4
Moskovskaia oblast	–250.6	–270.7	20.1
Nizhegorodskaia oblast	–95.2	–113.9	18.8
Arkhangel'skaia oblast	–52.0	–51.8	–0.2
Volgogradskaia oblast	21.0	21.5	–0.5
Komi Republic	–34.3	–33.8	–0.6
Cheliabinskaia oblast	157.8	160.9	–3.1
Altaiskii krai	143.9	149.5	–5.6

[a]Calculated in raw cow's milk.
[b]Calculated in live-weight livestock and poultry.

would reduce their deliveries of grain more sharply rather than compete with the new grain-producing regions.

Changes in the transport flows of dairy and meat products (calculated as milk and live-weight cattle and poultry, respectively) turned to be in agreement with changes in production volumes, as expected. Significant deviations here would be possible only in border regions in the event of changes in foreign trade routes. The situation is different with grain: in addition to production and export, its product flows would also be also impacted by changes in the need for feed grain in connection with any growth or decrease in the livestock sectors.

Our calculations suggest that all five regions leading in growth of net shipment of milk are net buyers and, consequently, would reduce their purchases. On the other hand, the five regions with the greatest decreases in net shipment include both net buyers whose dependence on the supply of dairy products would increase (Nizhegorodskaia and Rostovskaia oblasts, Krasnodarskii krai) and net sellers who would limit their presence in other regional markets (Tatarstan, Bashkortostan). As for meat products, among the regions with the biggest changes in domestic supply, three net sellers would increase their deliveries (Krasnodarskii krai, Tatarstan, and Voronezhskaia oblast) and three would reduce them (Altaiskii krai, Cheliabinskaia and Volgogradskaia oblasts). That said, the volume of reductions in the latter three would be small compared with the increase in supply from the three that the scenario predicts in the former category. Two net buyers would noticeably reduce their dependence on the supply of meat products: Moskovskaia and Nizhegorodskaia oblasts. On the other hand, Arkhangel'skaia oblast and the Komi Republic would become more dependent, but to an insignificant degree.

Table 5 presents the *geography of transport flows associated with foreign trade*. Unlike in Tables 2–4, which presented the data of only some federal subjects selected by certain criteria, Table 5 shows every region through which foreign trade passes in transportation flows that correspond to our industry-distribution scenario. We should make two important observations in regard to grain. First, it would be advantageous to send more than half of exported grain through Baltic seaports rather than Black Sea ones, substantially because of both the shift of the country's grain belt to northward under the climate-change simulation and the higher (per ton-kilometer) tariffs on Russia's congested southern railway

Table 5

Net Foreign Export of Agricultural Products Across Federal Subject Borders (in thousand tons)

Region	Grain	Diary Products[a]	Meat and Meat Products[b]
Brianskaia oblast	—	–3,752	929
Smolenskaia oblast	—	–5,323	—
Kaliningradskaia oblast	486	–176	–3
Leningradskaia oblast	22,224	–4,283	–9
Murmanskaia oblast	–69	–236	–8
Pskovskaia oblast	—	–14	—
Krasnodarskii krai	8,077	–654	120
Rostovskaia oblast	12,280	–407	15
Primorskii krai	–387	–536	–18
Khabarovskii krai	157	–1,549	–29
Russia, total	42,766	–16,930	997

[a]As raw cow's milk.
[b]As live-weight livestock and poultry.

network. At present, there are serious measures being taken to develop and reconstruct the trans-shipment infrastructure of ports in Leningradskaia oblast that should, in the near future, allow us to optimize transport flows of grain exports. Second, given the existing railway tariffs, it would be more profitable to meet some of the demand for grain in remote areas such as Murmanskaia oblast and Primorskii krai with imports from abroad.

The largest volume of dairy products is expected to cross the border in Smolenskaia oblast. Our model does not predict price differentiation, or any other differentiation of Russia's foreign trade partners, so this result indicates that Belarus has natural competitive advantages on the Russian dairy product market over other foreign suppliers, advantages independent of the country's agrarian policies. These are due to the country's proximity to the capacious Moscow and Moscow-region markets and to convenient transportation access.

Our calculations have shown that, under the climate-change scenario, Russia can not only solve its self-sufficiency problems in relation to meat products but also become a net exporter. We should note that this conclusion holds only for the total volume of meat production. For certain types of meat, particularly beef, the country may remain a net importer under this scenario. Since it operates with aggregated commodities, the model does not allow us to draw final conclusions in that regard. Meat exports are planned mainly along the railway routes through Brianskaia oblast, and in small volumes through Russian ports on the Azov and Black Seas. For a few meat products, imports to Russia's border regions from abroad is more profitable than domestic supplies by rail.

Table 6 presents features of the situation in agriculture as a whole because of the climate-change scenario. Changes in the distribution of agricultural sectors under a changing climate would affect only the structure of output: production volumes would barely be affected. However, modeling does predict another kind of positive effect, a decline in revenue variation under the impact of incidental natural and economic factors.

Structural changes would occur in the trajectory of livestock and poultry production. The decrease in grain production is because, under more favorite climate conditions, our limited agricultural resources would be redirected toward livestock and poultry production, products with higher added value.

As our modeling shows, Russia has competitive advantages in beef-cattle and poultry production, advantages that the anticipated climate

Table 6

Value of Agricultural Production under the Climate-Warming Scenario (in billion rubles at 2015 prices)

Measure	Grain	Livestock and Poultry	Milk	Other Production	Total
Directed production	707.05	1,104.73	622.12	2,590.38	5,024.28
Absolute growth compared to today	−15.12	35.40	−10.62	−6.32	3.33
Percent growth compared to today	−2.09	3.31	−1.68	−0.24	0.07
Growth of variant coefficient (in percentage points)	0.16	0.03	0.55	0.08	−0.11

Note. Our modeling uses statistical data from 2011, so production in the Republic of Crimea is not included in the figures.

change will only strengthen. To a large extent, these benefits are related to transport conditions. That meat products provide more value added per ton-kilometer than grain transport by an order of magnitude often tilts the scales in favor of meat-production sectors, given Russia's enormous spans of distances.

Climate change would make production in every sector a bit riskier than before: the coefficients of variation in annual production would increase. However, risks would decrease in agriculture overall: different sectors do not always observe extreme production values in the same years. In years with low production in one industry, another may increase their production. This compensatory effect would be enhanced by optimizing the distribution of production across regions by taking into account the differences between regional climate groupings in relation to weather risks.

In sum, our study shows that the climate changes we face would not increase uncertainty in agricultural activities when viewed across the entire country. Furthermore, improving the regional distribution of agricultural sectors would even reduce that uncertainty. This is true in terms of both the country's food security and revenues for the entire aggregate of agricultural producers, which would affect certain parameters of their activities, such as bank loans and premium rates from insurance companies whose clientele covers the whole spectrum of agricultural sectors. However, investors who operate in a particular agricultural sector would face increased economic uncertainty: they would need either to diversify their investments or to direct more capital than they currently are to self-insurance or to paying for insurance services.

Comparing the optimal distribution of agricultural sectors with and without climate change

Now that we have described the changes that would occur in distribution of agricultural sectors in the process of adapting them to likely climate changes in Russia, we address the following question: to what extent would these changes be due to climate change, and to what extent to the currently untapped reserves for optimizing distribution that sometimes arise from the lack of awareness among the business community, the institutional characteristics of certain regions, and the limitations of the existing infrastructure. To answer this, we compare *the results of a model* that does not include climate change as in the warming scenario we just used. In this mathematical model, using the present-day climate, we used the agricultural land of existing natural-agricultural groupings, that is, the ones that correspond to the first column of Table 1 rather than the second.

The results showed that, on the scale of Russia as a whole, the effect of likely climate warming would be only a fraction of a percent different than the output that would be obtained without climate change. The impact of global warming is generally positive. The difference in average annual marginal income between the two scenarios is 6.85 billion rubles in favor of the warming scenario (1.12 percent greater than in the existing climate scenario, which was taken as a baseline). The difference in average annual cost of goods in terms of sales prices is 7.05 billion rubles, or 0.14 percent in favor of the warming scenario. The only product where global warming would have a negative impact on production is milk, because climate change would enhance the competitive advantages of the grain and meat sectors, redistributing agricultural resources in their favor (Table 7).

The higher marginal income forecasted in the event of global warming is first due to the concentration of production (especially export-oriented production) in regions favorable to transportation, which makes some portion of the resources in traditional agricultural regions uncompetitive and redundant, and second to an increase in exports.

Table 7

Comparison of Forecasted Agricultural Production Volumes in Russia "Without Warming" and "With Warming"

	Volume of Production			
Type of Product	Without Warming	With Warming	Difference	Relative Growth, %
Grain, million tons	90.67	90.91	0.242	0.27
Livestock and poultry, living weight, million tons	12.52	12.56	0.037	0.29
Milk, million tons	30.55	30.50	–0.047	–0.15
Other products, billion rubles	2,588	2,590	2.75	0.11
Total, billion rubles	5,017	5,024	7.05	0.14

Under the warming scenario, the average annual gross export of meat products (in terms of livestock and poultry in live weight) would be 2.88 percent higher, approaching 1.06 million tons, whereas the export of grain would increase by 0.66 percent, approaching 43.26 million tons.

The data in Table 7 suggest that the reduced grain production under the warming scenario in comparison to today would not be related to the warming in itself. The reason, rather, is that the current deployment of agricultural sectors does not fully conform with the competitive advantages of those sectors and regions as they exist today. That unconformity arises because rural entrepreneurs and investors lack timely and complete information about those advantages, and for institutional reasons, including the specifics of agrarian policy within the federal subjects and the presence or lack of business relationships among entrepreneurs in certain regions, relationships that would otherwise facilitate access to foreign markets, to transportation infrastructure, and to new technology. For both informational and institutional reasons, global warming in Russia would represent a relatively weak factor in the volume of production not only of grain but also of other agricultural products.

Table 8 presents the effects of warming in regions that occupy the top two places in absolute growth, both positive and negative, for each type of product. The net effect of climate change on Russian regional grain production does not indicate any marked geographical trends. The industries that would find it most profitable to develop in a given region in the event of warming depends decisively on how the region's agricultural resources relate to one another and to the size of the population, as well as the region's position on the country's transportation network, rather than the natural-agricultural grouping to which the region belonged before the climate warmed. This conclusion is also supported by the fact that, in the event of warming, the production of livestock and poultry would be concentrated more closely to megacities than in the existing climate scenario.

Stability of results

This article presents the results of calculations for only two of the many scenarios and modeling variants we studied. The variants

Table 8

Comparison of Forecasted Regional Volumes of Agricultural Production in the "Without Warming" and "With Warming" Scenarios (regions with the greatest absolute change)

			Warming: Growth Compared to "Without Warming" Scenario		
Product	Federal Subject	Production without Warming	Total	% of Region	% of Russia
Grain, thous. tons	Krasnoiarskii krai	2,030.0	63.3	3.12	0.070
	Nizhegorodskaia oblast	1,027.4	61.0	5.94	0.067
	Kirovskaia oblast	580.3	–13.2	–2.28	–0.015
	Sverdlovskaia oblast	636.9	–25.1	–3.94	–0.028
Livestock and poultry in live weight, thous. tons	Moskovskaia oblast	283.0	9.1	3.20	0.072
	Sverdlovskaia oblast	246.7	6.7	2.70	0.053
	Primorskii krai	59.6	–1.3	–2.11	–0.010
	Permskii krai	122.6	–2.2	–1.83	–0.018
Milk, thous. Tons	Kirovskaia oblast	523.9	11.3	2.16	0.037
	Krasnoiarskii krai	700.8	8.3	1.18	0.027
	Vladimirskaia oblast	339.1	–12.8	–3.76	–0.042
	Sverdlovskaia oblast	618.3	–21.6	–3.50	–0.071
Other products, mill. rubles	Arkhangel'skaia oblast	8,934	1,327	14.86	0.051
	Permskii krai	29,699	979	3.30	0.038
	Moskovskaia oblast	69,263	–1,100	–1.59	–0.043
	Nizhegorodskaia oblast	43,935	–1,294	–2.94	–0.050
Total production, mill. rubles	Arkhangel'skaia oblast	15,389	1,253	8.14	0.016
	Permskii krai	52,454	1,125	2.14	0.014
	Moskovskaia oblast	110,252	–450	–0.41	–0.006
	Nizhegorodskaia oblast	77,263	–600	–0.78	–0.008

Note. thou. = thousand; mill. = million; bill. = billion.

differed in assumptions about the possibilities of replacing regional production processes with more efficient ones and about the scale of the predicted climate changes, and in the methods of estimating those modeling parameters where precise data was unavailable. Compared to the other versions, the scenarios presented in this article were the most radical in terms of the scale of climate change and of the possibilities allowed by the model for adapting to those changes. In other words, they represent the strongest impact of those two factors among all the scenarios we calculated. However, in all other respects, these two scenarios were the most conservative of the set.

Once we selected these scenarios from the alternatives, the question arose about the extent to which the freedom to choose these scenarios affects the main conclusions we drew from the calculations.

All the scenarios, including those we ran solely for testing purposes, consistently predicted the same structural changes across the country: a reduction in grain and milk production and an increase in livestock and poultry production. In the variant we used for our report to the St. Petersburg Economic Conference, the production of other products increases in these scenarios, but a more thorough analysis revealed that, in that version of the plan, there would be a shortage of feed grain in some regions of the country, at which point we modified the model to exclude this kind of situation.[13]

In every scenario, the largest-scale changes in regional industrial structure would occur in Krasnodarskii krai, in Tatarstan, and in Voronezhskaia oblast, in each case associated with the development of livestock and poultry in those regions.

At the same time, the scale of industrial changes in Krasnodarskii krai would be much smaller, though it would nonetheless remain a leader, if we assume growth (albeit a small percentage) in grain yield throughout the country over this five-year period beyond the capabilities of production processes observed by statistics, or if we were to limit the export of grain through the Baltic ports.

Unlike these three regions, the *direction* of structural changes in other federal subjects is sensitive to the conditions of the scenario. This is the case, for example, in Novosibirskaia oblast, where, depending on the chosen scenario, the results toggle between production growth of either grain or livestock and poultry. In Altaiskii krai, not all scenarios would increase production of other agricultural products, but milk production always declines (sometimes by much more than in the scenario described above) and grain production grows. Unlike in the warming scenario, there is no change in the size and industrial structure of agriculture in Rostovskaia oblast in other scenarios.

In all the scenarios we calculated, the list of regions occupying the top five positions in terms of volume of production remained unchanged for each of the four product types our study considered.

All of the scenarios supported our conclusions about the very weak impact of climate change on the country's agriculture as a whole and in most of its regions, though the specific list of federal subjects most affected by these changes depends on the particular scenario. Nevertheless, certain regions almost always appeared on this list as unfavorable for agricultural activity: Krasnoiarskii krai, Arkhangel'skaia oblast, and Permskii krai, as well as Moskovskaia oblast, which consistently responds to warming scenarios by increasing production of livestock and poultry because of the reduced cost of supplying feed grain thanks to increased grain production in nearby areas.

The question of the sensitivity of our results to possible changes in transportation tariffs and foreign trade prices remains an open one: we have not yet made any calculations for tariffs outside of the 2017 unsubsidized rates, or for foreign trade prices that differ from the actual prices of the baseline period.

Conclusion

Overall, our study does not provide the Russian Ministry of Agriculture grounds for serious concern regarding likely climate change. Our scenario assumes extreme warming rates that lead to a large-scale shift of natural-agricultural zones toward the north and east over this five-year period, and we can see that this kind of shift would lead to barely noticeable effects both in the country as a whole and in most of its regions. Our conclusion differs significantly from that of a study at the All-Russian Scientific Research Institute for Agricultural Economics on the substantial significance of negative climate-change effects on the country's agriculture, on the significant risks to competitiveness and possibility of material losses.[14]

Meanwhile, farmers in individual regions will have to take measures to bring their industrial structure in line with changing conditions. For that reason, the recommendations provided by the Institute for improving agencies that monitor climate change and respond to anticipated consequences remain relevant in light of our results, with the amendment that the priorities in these recommendations should naturally be differentiated depending on what consequences are anticipated by which particular federal subject.

The most important demand of federal agencies, regardless of any climate change, is to address the development of transportation infrastructure.[15]

Among regions that will face structural changes, we should distinguish between two groups: those in which these changes are necessary regardless of climate change, and those that actually do require slightly different changes in industrial structure than anticipated in plans that do not account for climate. The former group consists primarily of Krasnodarskii krai, Tatarstan, Voronezhskaia oblast, and Altaiskii krai, as well as, with somewhat less certainty (i.e., dealing with scenarios not described in this article), Rostovskaia and Penzenskaia oblasts. The second group consists of those regions listed in Table 8.

No region in the second group will face any radical restructuring of their agricultural structure because of global warming, at least not over this five-year period. Nevertheless, it would be wise for the authorities and entrepreneurs of these regions to make explicit adjustments for upcoming climate change when developing regional agrarian policy and making investment decisions.

As for the majority of Russian regions, our study shows that the impact of climate shifts on agricultural development remains a secondary factor. It should not divert the attention of government and business from other priorities: scientific-technical progress, institutional improvements, infrastructure development, and improved access to information about investment opportunities and to the data needed for qualitative analysis of investment projects.

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