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in Transition Economies

Maria Belyaeva

A Comprehensive Analysis of Current State and Development Perspectives of Russian Grain Sector: Production Efficiency and Climate Change Impact

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ABSTRACT

The aim of this study is to conduct a comprehensive analysis of Russian grain production, to determine country's production potential and its possibility to remain one of the major grain producers on the world market. On the one hand we estimate the technical efficiency during the period of transition to the market economy. By applying a novel approach to the estimation of production efficiency on a regional level, we assess the grain production potential and determine factors that influence productivity beyond the control of the farmers. On the other hand we conduct a detailed analysis of the climate change impact on grain production. We base our study on panel fixed-effect regressions of grain yields on a set of crop specific weather indicators. Furthermore, we use climate change projections for the medium and long terms to estimate the effect of global warming on grain productivity in different regions of the country.

Empirical results of the production efficiency model are based on a balanced panel of Russian regions which were involved in grain production during the period 1995-2011. We rely on a production function that accounts for the effect of labour, land, capital, and variable inputs. In addition, we construct specific variables to control for factors that remain outside of the farmers' control, i.e. the level of human and infrastructure development and climate and soil conditions. In the climate change model we use yields of three the most popular grain types – winter wheat, spring wheat, and spring barley – on a regional level to determine their relation to indicators that account for climate conditions during the vegetation period, specific for each grain type. Specifically, we approximate the distribution of daily temperatures using a trigonometric sine curve to construct measures of growing and heat degree days. The data covers the period from 1955 to 2012. In order to estimate the effect of future climate change we rely on the latest available projections, provided by the Intergovernmental Panel on Climate Change (IPCC 2014) for the medium and long terms.

The analysis of technical efficiency demonstrates that an average farm in a Russian region is functioning at its full production capacity, and further development and productivity increases depend on factors that are not directly related to technical aspects of production and that remain beyond the control of farmers, namely the level of human and institutional development, access to infrastructure and climate conditions. We indicate that further exploitation of natural production possibilities has a positive impact on the process of agricultural improvement.

We then conduct an examination of the climate effect to analyse the historical dependence of grain production on temperatures and precipitation levels, and project this dependence to estimate the productivity of studied grain types in the medium and long terms, given four different greenhouse gas concentration pathways. We find that altering temperatures have an equivocal effect on agriculture. The most productive zones of the southern black soil belt is projected to face considerable declines in yields, due to insufficient precipitation levels and high probability of heat waves during the summer vegetation period. The northern part, on the contrary, can experience increases in productivity as a result of milder and drier winters and warmer springs.

Obtained empirical results allowed us to determine that climate plays a major role in grain production in Russia. Although northern regions will experience considerable increases in yields in the medium and long terms, projected falls in productivities in the southern part of the country cannot be compensated by production increases in the North: insufficiently developed infrastructure, low productivity of soil and lack of investments to safely reintroduce the abandoned lands into the agricultural process prevent substantial agricultural growth. Accordingly, in order to maintain sufficient production levels more efforts should be concentrated on adaptation measures to breed more drought-resistant grain varieties and to adopt soil moisture accumulating and preserving technologies.

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LIST OF ABBREVIATIONS

CC	Climate change
CCS	Carbon capture and storage
DEA	Data Envelopment Analysis
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
Faostat	Food and Agriculture Organisation of the United Nations, Statistics Division
GDD	Growing Degree Days
GDP	Gross Domestic Product
GHG	Greenhouse gas
GRP	Gross Regional Product
HadGEM2-ES	Hadley Global Environmental Model 2 – Earth System
HDD	Heat Degree Days
IPCC	Intergovernmental Panel on Climate Change
Mineconomrazvitiya	Russian Ministry of Economic Development
OECD	Organisation for Economic Co-operation and Development
PSE	Producer Supply Equivalent
RCP	Representative Concentration Pathway
RUK	Russia, Ukraine and Kazakhstan
Rosstat	Russian Federation Federal State Statistics Service
SAT	Single Agricultural Tax
SFA	Stochastic Frontier Analysis
TE	Technical Efficiency
TFP	Total Factor Productivity
TsSU	Central Statistical Directorate of the Soviet Union
USSR	Union of Soviet Socialist Republics
US	United States of America
USDA	United States Department of Agriculture
VAT	Value-added Tax
WTO	World Trade Organisation

INTRODUCTION

Grain is the foundation of the human diet and the most prominent type of crops in most regions of the world. Today it occupies larger share of agricultural land than any other crop, and its trade levels are the highest in comparison to other agricultural plants combined (Dixon et al. 2009). During the last 20 years the world production of grain has significantly increased: in 2013 the level of the world production was estimated at 2 759 million tonnes, which is around 40% above the 1990 record. Driven by changes in technologies, designed to increase yields and improve production efficiency, by 2020 the global production is projected to be 14% greater than in the period 2012-2014 (FAO 2015). However, this growth is unevenly distributed across the world and is subject to the risk of harvest failures due to unstable conditions during vegetation periods. Predictions of the climate change impact on grain production suggest potential problems for most grain producing regions and benefits only for some. Changes in climate conditions caused irregularities in weather, alterations of vegetation periods and harvesting seasons, as well as constant risk of flooding or drought, placing in danger grain harvests. Given the role of agriculture in the economic stability, population growth and rural development and considering the role of grain in the global food supply, it is of the utmost importance to identify and implement sustainable strategies to maintain current levels of grain output and to increase further the production volumes across the world.

The structure of the world grain market substantially transformed after the transition to the market economy in the majority of the post-Soviet countries. Each state was undergoing its own systematic change and transformation, and, as a consequence, the recovery of the GDP in general and agricultural output in particular was following different pace and speed (Csaki 2000). However, at some point all countries of the former Soviet Union recuperated from the agricultural decline and became important producers of grain crops. Soon Russia, Ukraine and Kazakhstan (RUK) emerged among the key players and occupied stable positions on the world grain market. Already in 2002 both Russia and Ukraine considerably increased their share on the world market: Russia exported almost 14 million tonnes of grain in contrast to 4 million tonnes in the previous year, while Ukraine increased its exports from 5 to 12 million tonnes. Later, in 2007, Kazakhstan exported almost 9 million tonnes of grain. Existing studies name two main reasons behind the emergence of the RUK region on the world grain market (Fellmann, Helaine, and Nekhay 2014; Liefert and Liefert 2015b). First, this group of countries invested significant efforts to restore and restructure the overall agricultural production and trade during the process of transition to free trade and open market economy. Second, in the beginning of the 2000s favourable weather in combination with stable economic and political situation and the emergence of vertically-integrated operators, specific for the RUK region, resulted in large increases in productivity of the region, which created surpluses for foreign trade. Already by the year 2009 gross grain exports of the RUK region amounted to more than 49 million tonnes, contributing 14% to the total world export (Faostat 2016), in contrast to the predecessor of the region, the Soviet Union, that was a major grain importer. For example, in the last decade of its existence, 1981-1991, the Soviet Union imported on average almost 20 million tonnes per year and exported 1.7 million tonnes of wheat annually (Faostat 2016).

The presence of new producing countries has a potential to reduce risks for the world food security, provide solutions for problems that became crucial in view of recent trends of the global economic and social development, i.e. how to maintain stable production to feed the growing population. At the same time, the participation of the RUK region could, on the contrary, seriously distort or damage the existing world market. It has been noted that the export restrictions imposed in these countries were in fact the main source of the price volatility and made a significant contribution to spikes in international food prices during 2006-2008 and 2011-2012 (Fellmann, Helaine, and Nekhay 2014). In other words, current production and export volumes already became decisive for reducing the volatility of the world grain prices and maintaining the stability of the market. In this context many observers see the RUK region as potentially the strongest in strengthening the global food security due to available land with favourable soils and possibility to increase agricultural yields, and a significant number of studies is indeed concentrated on examining production potential and production organisation of this region (see e.g. Fellmann, Helaine, and Nekhay 2014; Lerman, 2001; Liefert and Swinnen, 2002).

One country that is particularly interesting for the analysis of grain production and world market supply is the Russian Federation. It has appeared as a large player on the world grain market only recently, in the early 2000s, and by 2006 it managed to enter the top five wheat-exporting countries (Faostat 2016). The presence of Russia on the world grain market is important in the sense that it can be decisive in either easing or hardening the already extremely tense situation on global market of food, determined by instability of prices and high production volatility (Visser, Spoor, and Mamonova 2014). It is a widespread opinion in the literature that Russia can gain the status of the world breadbasket due to increasing yields by means of efficient use of production factors (Grazhdaninova and Brock 2004; Osborne and Trueblood 2006; Salputra et al. 2013; Schierhorn, Müller, et al. 2014; Voigt 2015) or engaging in production process the agricultural land that is currently not used or abandoned (Uzun et al. 2014).

Indeed, the significance of Russia to the market is often attributed to its large agricultural areas, most part of which was left behind or abandoned during the transition period. Schierhorn, Faramarzi, et al. (2014) point that from 1990 to 2011 the total cropland in Russia has decreased by 35%, or, in absolute terms, from 117.7 to 76.6 million hectares. Although it is widely recognised that Russia can increase its production potential by means of abandoned areas recultivation, significant financial costs and damage to environment can prevent the development of this process (Schierhorn et al. 2012), urging the need to find other means to increase production. Among other major problems that prevent or impede further development the researchers point to the limited access to external finance (Arnade and Gopinath 2000; Bezlepkina et al. 2004) and production inputs (Brooks and Gardner 2004); inefficient state regulation, underdeveloped institutions and export policies (Götz, Glauben, and Brümmer 2013; Salputra et al. 2013); limited ownership rights of agricultural land (Lerman and Shagaida 2007); underdeveloped or old infrastructure (Renner et al. 2014), and potential adverse effects of changing climate (Alcamo et al. 2007). In general, regardless of positive development trends that took place in Russian agriculture in recent decade, current production level is still well below its potential.

The objective of this research is to conduct a comprehensive analysis of the Russian grain production to determine whether Russia has possibilities to remain a major grain producer on the world market or it steps back to give way to other, more prominent and efficient, players. The existing body of literature on Russian agricultural development is very broad and analyses various aspects of production. Using increasingly available data at various aggregation levels from statistical agencies and private surveys and in view of the country’s size and predominance of grain production, most studies focused the analysis on grain production on a regional level. In general, we can distinguish several groups of related studies. First group applies econometric methods to estimate technical efficiency and total factor productivity. The significance of technical efficiency of Russia on a regional level was first emphasised by Sotnikov (1998). The study applies productivity analysis techniques to conclude that initial agricultural reforms that took place in the beginning of transition period had a positive effect on productivity developments, but the growth was not homogenous across the country and it varied depending on the region. Sedik, Trueblood, and Arnade (1998) point to the divergence of technical efficiency on a regional level as a result of various economic and institutional factors. The analysis of financial constraints, conducted by Arnade and Gopinath (2000), determined stringent expenditure constraints that are directly linked to farm inefficiency, observed in the majority of regions. Bokusheva and Hockmann (2006) analyse technical inefficiency of Russian farms further and suggest that the indicator results in higher variability of agricultural production, determined by production risk. The later study by Bokusheva, Hockmann, and Kumbhakar (2012) measures regional productivity and technical efficiency in relation to producers' decision regarding resource allocation, and shows that efficiency and technical change became positive after the Russian financial crisis in 1998.

Second group of studies estimates potential for production increases through a set of production factors. Prishchepov et al. (2013) analyse the process of land abandonment during the transition period and conclude that lower agricultural yields and lack of subsidies coerced farmers to leave behind vast areas of cropland. Visser, Mamonova, and Spoor (2012) describe the problem of land grabbing and its impact on agricultural development in rural areas. Schierhorn, Faramarzi, et al. (2014) and Schierhorn, Müller, et al. (2014), while studying yield gaps in Russia, provide evidence that solution to increase production potential lies in more efficient usage of fertilisers and more intensive irrigation. Few studies that analyse labour force in agriculture (Bogdanovskii 2005; Lerman and Schreinemachers 2005) indicate that farms, both individual and in form of agricultural enterprises, became labour sinks for rural population and industrialisation of agriculture that started in the 2000s. This process can alleviate the social consequences of unemployment in rural areas and maintain high levels of agricultural productivity. The importance of investments and investment behaviour of Russian farms was investigated by Bokusheva, Valentinov, and Anpilogova (2007), who argue that the financing activity of agricultural enterprises entirely depends on three factors, namely individual characteristics of a farm, macroeconomic conditions and institutional environment. Later study by Bokusheva, Bezlepkina, and Lansink (2009) highlights the significance of access to market of inputs and regional specifics to determine the investment behaviour of enterprises.

Third group of studies describes the role and functioning of agricultural enterprises. For example, Bezlepkina et al. (2004) analyse the economic behaviour and financial performance of agricultural enterprises that remained as a heritage of collective and cooperative farms. Other studies concentrate specifically on investigating the phenomena of agroholdings – large vertically-integrated enterprises that brought financial support and integrated small-scale farms into single value chain and pushed productivity on higher levels (see e.g. Hahlbrock and Hockmann 2011a; Hockmann, Bokusheva, and Bezlepkina 2007; Matyukha et al. 2015). Another group analyses the price related impacts on grain production and pricing behaviour of producers (Friebel, Perekhozhuk, and Glauben 2015; Götz, Glauben, and Brümmer 2013; Pall et al. 2013, 2014). While numerous studies have been conducted to analyse the production and export potential, recent developments in agricultural productivity and its connection to changes in climate remain insufficiently investigated. To our best knowledge, at the moment there is no research that forecasts levels of grain production based on the latest available climate change projections for the medium and long-terms (IPCC 2014).

The present research is twofold. On the one hand, we estimate technical efficiency of Russian agriculture during the period of transition to the market economy. We assess the grain production potential at the regional level by applying a novel approach to the estimation of regional efficiency based on conventional stochastic frontier analysis (Coelli, Rao, and Battese 1998) that, in addition, accounts for unique characteristics of each region that, without control of the farmer, influence production levels and efficiency. Our analysis demonstrates that farms are functioning at the full capacity of their potential, and further development depends on other factors, not directly related to technical aspects of production, that remain outside of the control of farmers, namely the level of human and institutional development, access to infrastructure and climatic conditions. We indicate that further exploitation of so-called natural production possibilities can have a positive impact on the process of agricultural improvement and lead to a successful development of regions. On the other hand, we examine the impact of climatic conditions and analyse historical dependence of Russian cereal production on weather, and then project this dependence to estimate the grain productivity in the medium and long runs, applying different scenarios and outcomes of climate change, given altering concentrations of greenhouse gas emissions in the atmosphere as projected by IPCC 2014. This part of the study demonstrates that increasing temperatures have an equivocal effect on agriculture. Currently the most productive zones of the southern Russia can face significant declines in yields as a result of insufficient precipitation levels and frequent heat waves. Accordingly, adaptation measures in these regions should focus on breeding new–more drought-resistant–grain varieties and adopting soil moisture accumulating and preserving technologies. Northern part, on the contrary, will experience increases in productivity: winters are expected to become milder and drier, creating favourable conditions for winter grains, while summers are projected to be warmer, extending the growing period of spring grains and leading to higher yields. However, insufficiently developed infrastructure, low soil productivity, and lack of investments to safely reintroduce the abandoned lands into the agricultural process creates obstacles for increases in production in the North of the country.

The thesis consists of four chapters. The first chapter provides an overview of the Russian agricultural production, describes the institutional and economic framework that shapes agricultural development in the country, and analyses agriculture in view of the ongoing economic and political crisis started in 2014.

The second chapter assembles the analysis of production potential and technical efficiency during the period of transition to the market economy, using a modified approach to stochastic frontier analysis to account for factors that determine production efficiency on the regional level. The third chapter considers climate as one of the most important determinants of agricultural productivity. The analysis includes the estimation of the relationship between weather conditions and agricultural yields, and considers potential changes in climate to estimate its impact on productivity in different parts of the country. The final part summarises the main findings of the research, discusses main contributions and limitations of the conducted analysis, and establishes various pathways for the future research.

1 OVERVIEW OF RUSSIAN AGRICULTURAL DEVELOPMENT

The Russian Federation is one the largest countries of the world, characterised by diverse natural, climatic and economic conditions. According to the most recent estimates of the World Bank, in 2014 it was the 11th biggest world economy, contributing 2.4% to the world GDP (World Bank 2016). Although active economic development took place in the period 2000-2013, showing prospects of the further GDP increase, in 2014 this growth decelerated as a result of geopolitical problems that led to the country's economic isolation. However, despite a forecasted economic decline, caused by low oil prices and a limited access to the world financial market and consequent lack of investments and capital (World Bank 2015), Russian officials indicate that depreciation of the currency and import ban might be beneficial for the development of certain economic sectors, especially agriculture, bringing back the topic of the actual efficiency of the sector and its potential for development. Currently farming constitutes 4.8% value added of the GDP and employs 6.7% of the active population as of 2014 (Rosstat 2016).

Modern Russian agriculture is characterised by an active development of large agricultural producers and a consequent increase of the country's share in the world agricultural market. However, farming in Russia has been always considered as an unsettled, unattractive and problematic sector that impeded economic development during the transition from centrally planned to market economy that began in 1991. The painful period of retreat from controlling the economy, the subsequent transformation and the structural adjustment severely affected agricultural sector, due to traditionally enhanced farming by means of state support and input and output price policies (Liefert and Liefert 2012). Due to the budget deficit and the incessant economic recession state subsidies were removed or significantly reduced during the first 10 years of transition to the market economy; the agricultural sector was inevitably left behind and remained in stagnation until the beginning of the 2000s, coinciding with the country's overall economic recovery. Despite previously made attempts of the Russian government to restore the sector through the number of agricultural reforms and development projects, only the financial crisis of 1998 and the following devaluation of the rouble fostered the revival of Russian economy in general, and of the agricultural sector in particular: prices for the imported agricultural products increased up to a critical level, urging producers to stimulate domestic supply of raw agricultural materials and to improve contracting arrangements, thus encouraging the development of agricultural chains and the entrance of Russian agricultural products, especially grain, on the world market.

Russian agricultural landscape is characterised by a large share of abandoned or not cultivated land. As a result of the Soviet Union's centrally planned economy, production was very often forcedly and, in most cases, inefficiently induced, and was maintained artificially by the government policies to secure the development, employment, and self-sufficiency of each region, even when geographical location and soil quality hindered efficient production, and served as an instrument to reduce famine and eliminate economic stagnation only to a small extent. Transition to the market economy and the following institutional reforms unavoidably resulted in the emergence of abandoned agricultural lands (Schierhorn, Faramarzi, et al. 2014) and, consequently, in the reduction in the number of regions, involved in agricultural production. At present, agriculture has more segmental development that previously, due to the inevitable shift from production, the aim of which was to secure balanced development across the country, to the production oriented predominantly at economic profit.

The overall objective of this thesis is to analyse the most important component of Russia's agricultural production, that is, grain production, and to estimate present and future production potential of the country, taking into account its segmented development and diverse initial conditions in different parts of the country. In order to accomplish the goal of this research we first analyse the state and trends of Russian agriculture, and then proceed with an empirical analysis of different production aspects. This chapter therefore provides an overview of the agricultural development of Russia that allows the reader to gain an understanding of the processes behind the recent growth in production volumes. In the first section of this chapter we examine historical trends of grain production in Russia, in the context of political and economic development of the country during the period of transition to the market economy, analyse shifts in the agricultural production structure, describe structural changes in the agricultural sector that led to the dominating position of the country on the world grain market, and provide brief insights in the current economic situation given political crisis of 2014-2016 and its impact on grain production in Russia. The second section describes economic and institutional framework in Russia that determines certain features of the agricultural development, specific only to some post-Soviet states.

1.1 Evolution of Russian agriculture during the transition period

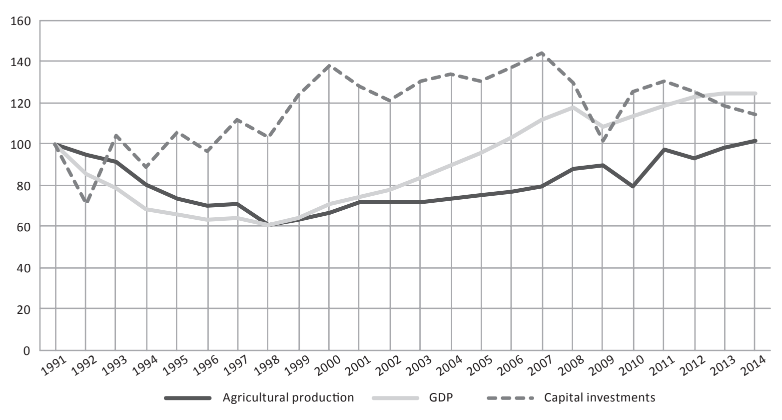
The transition process, initiated with the collapse of the Soviet Union in December 1991, resulted in major institutional, economic and legislative changes, aiming to adapt the previous system of central planning to the realities of the free market, to develop market institutions, to remove the price and market control, to privatise stately-owned enterprises and to introduce the system of property rights that previously did not exist. The following subsections analyse trends in the agricultural development during different stages of transition and adaptation to the market economy.

1.1.1 Initial years of transition and agricultural stagnation (1991-1998)

Initial years of transition are characterised by a general economic decline and a sharp decrease in agricultural output. As shown on Figure 1-1, both gross domestic product and agricultural production were declining at an average rate of 5% p.a., in 1998 resulting in a 40% decrease in comparison to 1991. Numerous studies were conducted in attempts to identify drivers behind such a rapid and sharp decrease in economy (see e.g. Bokusheva, Bezlepkina, and Oude Lansink 2009; Liefert and Swinnen 2002; Liefert, Gardner, and Serova 2003; Visser and Spoor 2011; Brooks and Gardner 2004). The beginning of the 1990s is characterised by a major price disparity: prices on variable agricultural inputs sharply increased, while prices on agricultural goods were limited by the decline in consumers' purchasing power. Nefedova (2013) provides a vivid example of this price disparity: one litre of milk directly from the producer costed less than one litre of petrol and less than one litre of mineral water. Price liberalisation and terms of trade deterioration resulted in a major sharp fall in farm output and a consequent drop in demand for agricultural inputs, especially for machinery and equipment (Bokusheva, Bezlepkina, and Oude Lansink 2009; Liefert and Swinnen 2002). Despite attempts of the sector to adapt to the market liberalisation, the disparity of prices together with the reduction of subsidies, the restricted access to external finance, and the lack of private investments in agricultural sector were the main driving forces behind the stagnation of the sector (Liefert, Gardner, and Serova 2003). Agriculture was not the most attractive aim for investments, because the value of the farmland was usually underestimated in contrast to other natural resources, such as oil and gas (Visser and Spoor 2011). The observed decline in agriculture could have also stemmed from the ideological legacy of the central planning and the lack of knowledge regarding the efficient functioning of agricultural markets: decision-makers focused their attention predominantly on restoring large-scale farming that in reality was often too sluggish to adapt to the changing needs of the market (Brooks and Gardner 2004).

Agricultural crisis was followed by changes in the input use patterns, predominantly in ways of land cultivation and usage of labour, marking the change from extensive to intensive development. Overall, Russian farms experienced major contractions in the application of agricultural inputs. As Figure 1-2 shows, country's sown area declined at the rate of 2.6% p.a. in the period from 1991 to 1998. Resulting from the land reform aimed to reorganise cooperative farms, the land

Figure 1-1 Dynamics of GDP, agricultural product, and capital investments 1991-2014.



Note: Dynamics is calculated on the basis of 1991 (1991=100).

Source: own representation based on Rosstat (2015b).

that previously belonged to kolkhozes and sovkhozes[1] was divided between former workers and pensioners of each agricultural entity on conventional land shares. The size of the share depended on the workers' experience and the size of the wage received. The owner of the share theoretically could get either the capital "in kind", or in monetary terms, equivalent to the amount of share, alternatively sell it, give it as a gift, or contribute to the authorised capital of a new agricultural enterprise. However, uncertainty in the land regulation and the absence of property rights on agricultural land had an impact on the land market, distorting the efficient allocation of plots and resulting in massive land abandonment. The problem of agricultural land abandonment sharpened because of high transaction costs (costs of registration, sale/purchase and allotment), leaving over 90 million hectares of abandoned land (Uzun et al. 2014). These plots are usually located in Northern and North-Eastern regions of Russia and predominantly belonged to former cooperative farms, some family farms and households that left them for reasons of low fertility and efficiency of land and high costs of maintenance and cultivation.

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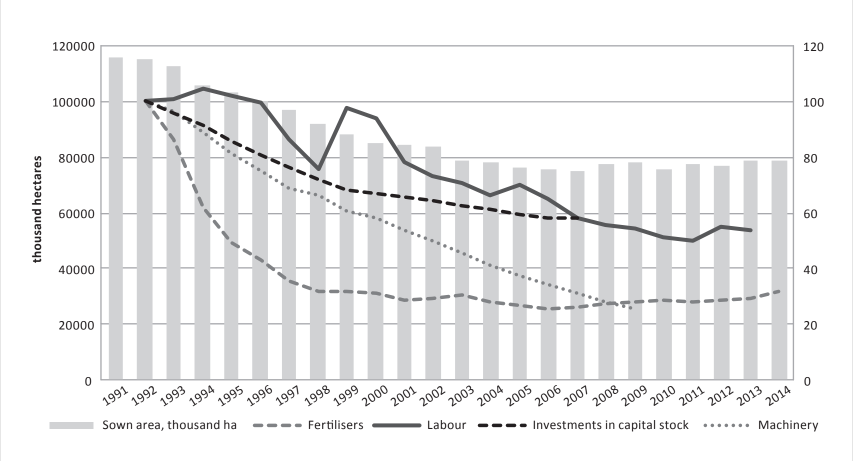
[1] Large scale stately-owned enterprises with appointed managers reporting to the administrative bodies of the state (Serova 1998).

The decreasing amount of sown area was accompanied by a constant fall of fertiliser application and changes in the level of agricultural employment, which was expressing a decreasing trend until the financial crisis in 1998 (Figure 1-2). Indeed, the beginning of the transition period was characterised by an unreasonably high number of workers engaged in agricultural production. This trend is explained by the social function that collective and cooperative farms played in rural areas during the USSR. As a soviet institution, a collective farm was designed to maintain a stable level of the population in villages and rural zones. In many remote regions, farms are still expected to perform this function in order to slow down inevitable depopulation of rural areas. In addition, Bokusheva, Hockmann, and Kumbhakar (2012) explain this unusual in contrast to other inputs development by the fact that agricultural sector apparently served as a buffer for labour released from other economic sectors. These trends underline aspects of agricultural transformation and adjustment, specific for the transition period not only for Russia, but for all countries of the post-Soviet space.

Despite numerous attempts to control and support the sector, the decline of agricultural output was accompanied by reductions in input use and deteriorating

Figure 1-2 Sown area and dynamics of input use, 1991-2014.

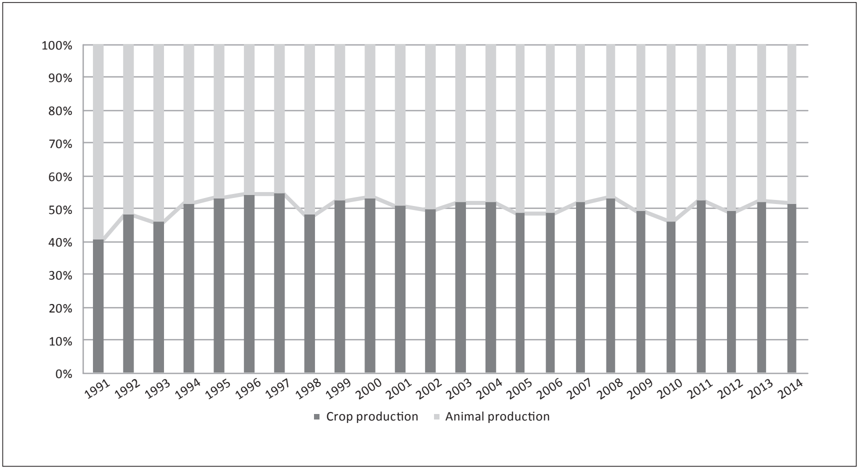


Note: Sown area is presented in absolute values (thousand hectares). Fertilisers' use is calculated as a ratio of fertiliser input to land input. Indicator of Investments in capital stock is calculated in constant 2005 prices. In some cases, data for 1991, and 2008-2014 was not available as of the moment of the latest access to the database. Dynamics is calculated on the basis of 1995 (1995=100).

Source: own representation based on Rosstat (1992-2015); Rosstat (2015b); Faostat (2016).

terms of trade, as depicted in Figure 1-2, despite numerous attempts to control and support the sector. Perhaps the most irresponsive to forthcoming changes was the sector of animal production. Before the collapse of the Soviet Union it occupied the largest share of agricultural production (Figure 1-3), but it was also the biggest recipient of the state support, as a result of the soviet policy aimed to increase domestic meat production by all means possible (Johnson and Brooks 1983). After the opening of the market to foreign production and considerable contractions of the subsidies, animal production encountered major problems. First, animal production showed demand and income elasticity: higher real prices and lower incomes resulted in the further decrease in demand (Serova 1998). In addition, Russian meat produce faced significant cost disadvantages in comparison to imported meat (Liefert 2002). Second, the sharp fall in demand for meat products negatively affected supply. The crisis in the animal sector dictated the distortion of the market and the existing consumption pattern. As a consequence, crop production experienced a corresponding decline in the first years of the transition period, particularly notable in grain production (Figure 1-4). However, in contrast to animal sector, it managed to recover at a faster pace by reorienting to other markets and occupying other niches, thus showing signs of awakening already shortly after the financial crisis in 1998.

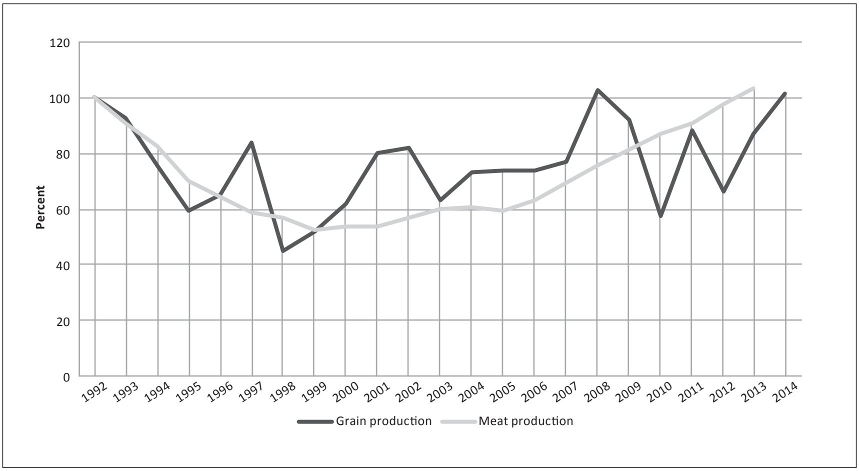
Figure 1-3 Structure of production, percent of the total agricultural product, 1991-2014.



Source: own representation based on Rosstat (2015b).

Deteriorating terms of trade, lack of investments and general imperfections of the newly established financial market that caused high indebtedness of agricultural producers drove the agricultural sector to a long period of stagnation, concluded by the financial crisis and currency devaluation in 1998 that staggered domestic market of agricultural products and created competitive conditions for Russian producers on the world market.

Figure 1-4 Dynamics of grain and animal production volumes, 1992-2014.



Note: Dynamics is calculated on the basis of 1992 (1992=100).

Source: own representation based on Faostat (2015).

1.1.2 Economic recovery and agricultural growth (1998-2014)

The end of the 1990s symbolises external and internal problems that influenced Russian economy. Internally, microeconomic stability was severely affected by declining productivity, constant fiscal deficit and fixed exchange rate between foreign currencies and the Russian rouble. Externally, country's economy was challenged by the spillover from the Asian financial crisis (1997) and the sharp drop in world prices on crude oil. These factors triggered economic problems and uncertainty in the future development, and pushed the Russian government to stabilise the situation by announcing a default on country's domestic debts, moratorium on the repayment of foreign debts and currency devaluation (Desai 2000; Kaminsky, Reinhart, and Vegh 2003). Although the first inevitable impact of the crisis was the reduction in food demand and consumption as a result of high agro-food prices and simultaneous decrease in population wealth, the medium- and long-term effect of economic crisis and devaluation of the rouble on agricultural sector cannot be underestimated (Brooks and Gardner 2004). Notwithstanding the fact that the main effect of the crisis on agricultural development was the reduction of subsidies[2] as a consequence of budget cuts, the currency devaluation fostered an increase of the price competitiveness of almost all products, including that of agricultural goods (Liefert and Liefert 1999), production of which grew by 40% in 1999 compared to 1998 (see Figure 1-1), symbolising a turning point for the revival of the sector. The following changes in the legislative system and favourable trade conditions triggered the interest of non-agricultural enterprises in agro-business and attracted significant inflow of investments that induced the creation of large agricultural enterprises, otherwise known as agroholdings, that restored the balance in economy, helped to speed up the adjustment processes and to increase productivity of the sector through technical innovations and efficient input use[3]. A rapid increase in investments, including that in agriculture, resulted in major productivity shifts and structural changes in the sector. Accompanied by the GDP growth, agricultural production was continuously increasing from 1998 up until 2014, with the exception of the drought that took place in 2010 and drastically reduced the volumes of agricultural output (see Figure 1-1).

Figure 1-5 and Figure 1-6 demonstrate the volumes of domestic production, export and import of meat and cereal, respectively. Although levels of domestically produced meat in the second period of transition (1999-2005) were still relatively high (Figure 1-5), the inefficiency of the sector, elevated prices and poor quality were the factors that prevented the consumers from choosing domestic meat products and soon resulted in their replacement by imported goods. Thus, instead of implementing advanced breeding and feeding technologies to maintain existing livestock, Russia was keeping its position as a major buyer of meat (Liefert and Liefert 2012). The active development of the animal sector started only in 2006, symbolised by an increase in production due to subsidies inflow aimed to stabilise the sector within federal projects that were designed for the renewal of agricultural sector[4]. The state support together with the agroholdings'

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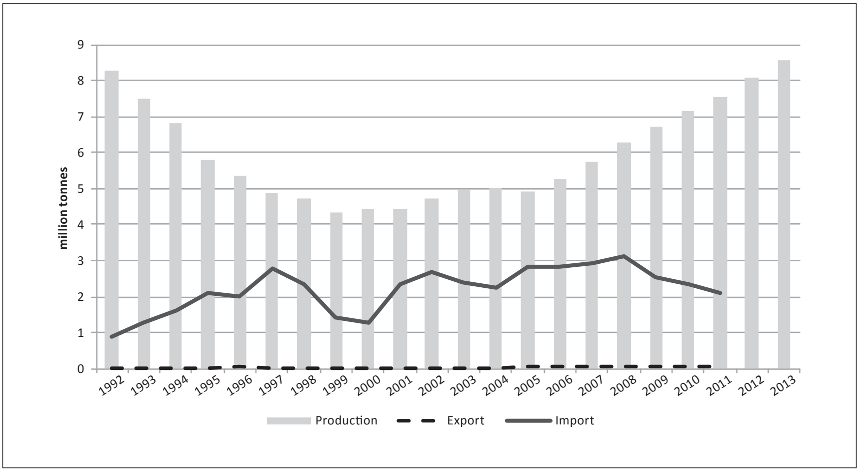
[2] According to Liefert and Liefert (1999), federal subsidies to the agricultural sector fell by about 80% in 1998 in comparison to 1997.

[3] A detailed overview of agroholdings and their impact on agricultural development is presented in subsection 1.2.1.

[4] For a detailed examination of programmes of agricultural development see subsection 1.2.2.

engagement in the animal production developed the market of domestic meat and pushed consumers to switch back, at least partially, to Russian products.

Figure 1-5 Meat production, import and export volumes, 1992-2013.



Note: Import and export data for 2012-2013 were not available at the moment of writing the monography.

Source: Faostat (2015).

The sector of crop production showed signs of awakening earlier than animal sector. Figure 1-6 shows a U-shaped development of total crop output, with an upward slope after 1999. Indeed, sudden growth trend, especially notable in 1999-2002, was triggered not only by favourable weather conditions that Russia experienced during this period, but also resulted from state efforts to restore the sector, including changes in the legislation, designed to maintain the stability of the market[5], higher subsidies and the preferential credit system[6]. Because

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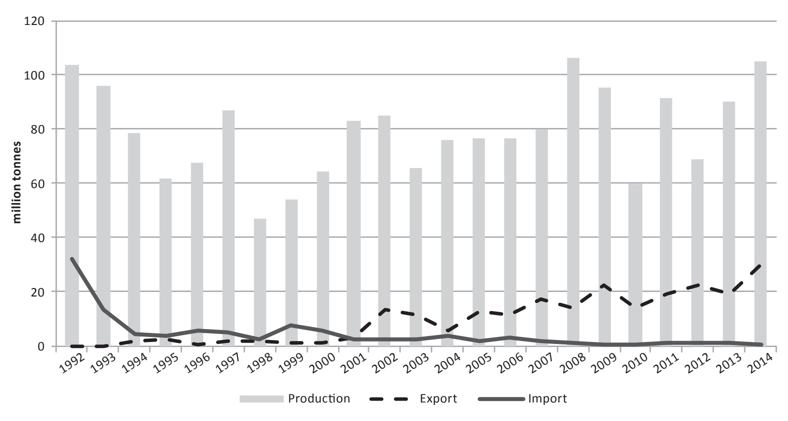
[5] See e.g. the *Federal Law on State Regulation of Agro-Food Production* (1997) that introduced the concept that was previously a common practice in the USSR – guaranteed prices, at which the state was purchasing agricultural products from farms that experienced economic difficulties when the market prices were lower than the threshold prices.

[6] The reformation of the credit system in 1997 led to the establishment of the Soft Farm Credit Fund. Its main goal was to secure short-term credits, necessary for agricultural producers.

of the relative inefficiency and inflexibility of agricultural producers towards institutional changes and modernization, an increase in grain production was slower than expected, but anyway resulted in the development of crop market.

Figure 1-6 Cereal production, import and export volumes, 1992-2014.



Source: Faostat (2016).

Russian crop production is heavily concentrated in the Southern and South-Eastern parts of the country: the biggest share of production comes from regions, rich of Chernozem (black soil), predominantly found in the southern part of the Central Federal District, the Southern and Volga Districts (Table 1-1). In 2014 more than 70% of Russian grain was harvested in those areas, while only 12% of grain originated from territorially larger South Siberian part of the country.[7] Moreover, Southern regions are engaged in production of high-quality grain for human consumption, while Northern and Southern Siberian regions specialise in less productive forage grain.

Started as a grain importing country in 1992, after financial crisis of 1998 Russia managed to replace the import share with domestic production (Figure 1-6) and later enter the world grain market. Soon it gained a foothold as a major

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[7] For an overview of Russian regions, including a detailed data on crop production, see Table A.1 in Appendix A.

Table 1-1 Federal Districts of the Russian Federation and their shares in grain production, 1995-2014.

	Share in grain production							
Federal District	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**
Central	18,4%	16,9%	18,8%	15,9%	18,1%	25,7%	24,4%	24,9%
Northwestern	1,2%	0,9%	0,7%	0,8%	0,6%	0,9%	0,7%	0,9%
Southern	25,6%	26,5%	34,3%	30,9%	24,1%	25,3%	24,3%	25,9%
North-caucasian				13,8%	10,7%	9,4%	10,4%	10,6%
Volga	25,5%	29,6%	24,6%	10,7%	22,5%	20,5%	18,4%	20,1%
Ural	6,7%	6,0%	6,2%	5,5%	7,8%	4,8%	4,7%	4,4%
Siberian	21,9%	19,6%	15,0%	21,9%	15,5%	12,7%	16,6%	12,5%
Far Eastern	0,8%	0,5%	0,5%	0,5%	0,7%	0,8%	0,5%	0,7%
Total	**63405,4**	**65505,7**	**77803,3**	**60959,4**	**94212,8**	**70908,1**	**92384,8**	**104211,8**

Note: *Before 2010 regions of the now Northcaucasian Federal District were part of the Southern Federal District.

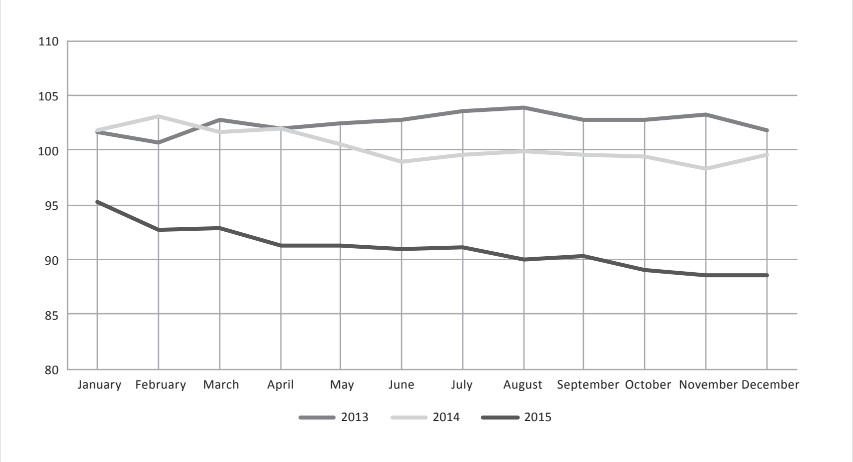
Source: Rosstat (2016).

grain exporter, among the United States, Canada, France, and Australia (Faostat 2016). Already in 2013 Russia accounted for 7.78% of the total world production of grain, and contributed 10.24% to the world grain export (Faostat 2016). According to the estimates provided by the US Department of Agriculture, during the agricultural year 2015-2016 Russia exported 25 000 tonnes of wheat and wheat products, thus becoming the second largest supplier of grain to the world market after the European Union (USDA 2016). Existing studies highlight a number of reasons for such a rapid and successful transformation process from the import-oriented to the export-oriented country that took place in 1999-2013. First, the rapid decline in the overall domestic grain consumption (Nefedova 2013), which was caused by the long-term effect of a) the collapse of the inefficient livestock production that was maintained by the state budget during the period of planned economy; and b) the subsequent development of a more efficient, technically equipped and less fodder consuming animal production, arising from the modern technologies that became available with more private investments in the sector and pushed the animal production on a higher level. Second, Russian grain producers that entered the market profited from the world prices that in 2006-2008 were higher than the domestic ones (Liefert and Liefert 2012). Finally, first years of the existence of the new grain market are notable for the absence of major state interventions in the functioning of the market, providing companies with the opportunities to operate on the international market without significant export quotas.

1.1.3 Political and economic crisis (2014-2016)

Geopolitical instability that started in 2014 entailed structural shocks for the Russian economy and resulted in the ongoing economic stagnation and financial crisis. The economy of the country became vulnerable and volatile due to unexpectedly fast deteriorating terms of trade and unstable prices on gas and oil, which constitute the main source of income for the country and are directly linked to the Russian currency. Unstable situation on the market, vagueness of the political activity and highly volatile exchange rate negatively influenced the inflow of investments that continued to plummet in the following years of the crisis, as well as purchasing power of Russian consumers that experienced fast inflation against sharp recession in real incomes and salaries. The process of personal income depreciation happened quickly and did not allow for the corresponding price adjustment: for instance, in the period of January-August 2015 real income and wages shrank by 9 and 3% respectively compared to the same period in 2014 (Grishina and Kirillova 2015). The instability of incomes and price uncertainty is inevitably tied to a sharp fall in commodities trade, as presented on Figure 1-7. In 2015, in contrast to previous years, trade level considerably augmented in comparison to previous years, expressing tendencies for the further decline.

Figure 1-7 Commodities turnover index (food and beverages), percent, 2013-2015.



Note: Indexes for each year are calculated as percentage for the same period in the previous year.

Source: Rosstat 2016.

The events of 2014 significantly changed the economy of Russia, besides everything else resulting in a disrupted supply of food and agricultural products (Liefert and Liefert 2015a). In response to sanctions applied against Russia and approved by most of the western countries, including the European Union and the United States, Russia introduced a product embargo. Sanctions, imposed on Russia, mainly implied banning certain companies and individuals from conducting business transactions abroad. Russia's embargo, in contrast, prohibited imported food and certain types of agricultural produce. Among sanctioned products were listed meat and meat products, fish and seafood, vegetables and fruits from such major suppliers as the USA, the EU, Canada, Australia, Norway and the UK (*Federal Law Regarding Special Economic Measures to Provide Security of The Russian Federation*, 2014). Later, in 2015, the list was extended to other countries such as Albania, Montenegro, Iceland, Lichtenstein and Ukraine, prolonging the ban at least until August 2016. Sanctions, although hurting agricultural producers of the banned countries (Szczepanski 2015) as it was initially planned by the government, affected predominantly Russian consumers, resulting in reduced purchasing power: imported food supply was about 40% of consumption

(Liefert and Liefert 2015a), forcing the population to switch to a lower quality and often more expensive domestic products. In addition, given high dependency of agricultural sector on imported technologies and taking into account rapid devaluation of the Russian rouble, prices on agricultural goods plummeted, once the stock from previous years was over. Despite rather pessimistic estimations of the current situation on agricultural market, many government officials announced that the ongoing crisis and import ban will provide support for domestic producers, who, in the absence of foreign competitors, are expected to occupy the currently empty niche on the market or take active part in the programme of import substitution.[8] Indeed, this process can already be seen in some most developed regions of Russia, where not only agroholdings, but also small, local farmers enter on the market with high-quality, often biological or organic products. Nevertheless, prices of domestic products are elevated, and, in view of decreasing earnings of the population, the existence of such producers on the Russian market outside the country's richest regions can be rather doubtful. Product sanctions brought no competitive advantages to Russian agricultural producers, banned importers were substituted with importers from other countries, usually at considerable higher prices, damaging especially consumers and not providing much support for producers (Shagaida and Uzun 2016).

The process of import substitution takes places, but slowly and selectively for some sectors. Shagaida and Uzun (2015) distinguish two types of import substitution: quantity and price substitution. Quantity substitution takes place when imported products are replaced with the same quantity of similar, domestically produced good, while price substitution implies that consumers reduce their consumption of imported goods but increase expenditures on the same quantity of similar, domestically produced goods. Exactly price substitution of import is observed in Russia, resulting in consumption decreases in most agricultural products, with exception for poultry and vegetables (Shagaida and Uzun 2016). What Russian agricultural producers really benefited from in the first period of crisis was devaluation of the currency, similar to that of 1998, allowing agroholdings to become competitive on the world market: although physical quantities of export have decreased, in 2015 the price of exported agricultural products was 35% higher than in 2014 and 92% higher than in 2013 (Shagaida and Uzun 2016). However, increasing prices on foreign technology and variable inputs soon will negatively affect the financial situation of most agricultural producers and shake their already unstable position on the world market. Overall, the impact of current economic crisis on agriculture can be summarised in the following five points:

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[8] http://www.rbc.ru/rbcfreenews/5612dfdc9a794761616be4b6.

1. Higher risks and economic uncertainty led to high barriers in obtaining the bank credit, resulting in outflow of investments and postponement of the implementation of some planned and developing agricultural projects.

2. The crisis showed the weak sides of the food sector and highlighted the segments that completely depend on imports, such as vegetables, fish, milk, some meat products (predominantly veal, considering higher development levels of poultry and pork production).

3. Russian agricultural production depends on imports from the technological point of view (seeds, crops protection, and agricultural machinery). However, the ban of foreign seeds practically did not affect the grain market, because the biggest share of grain seeds is domestically produced[9].

4. Underdeveloped infrastructure, lack of storage facilities and equipment aggravated the impact of sanctions that, in many cases, became the barrier for the fast and efficient development of the domestic agricultural market.

5. According to the recent estimates by Lobell, Schlenker, and Costa-Roberts (2011), in view of changing climate Russia faces decreases in yields and losses in harvest. The negative impact can be softened with the help of advanced agricultural technologies, the access to which is temporarily closed for the Russian agricultural producers.

Despite many fears and uncertainty, the first year of sanctions did not have an effect on the grain production: given high grain harvest in spring and autumn 2014, followed by the fast devaluation of the Russian currency, the export of grain was almost twice as high as in 2013, and in 2014-2015[10] reached 30.1 million tonnes (Figure 1-6), with main destinations of Turkey, Egypt and Yemen. At the same time, recent estimates by the US Department of agriculture indicate that in agricultural year 2014-2015 Russia became the second biggest after the European Union exporter of wheat only on the market, reaching 24.5 million tonnes (USDA 2016). In order to keep the market under control and to prevent excessive export of grain and its loss in domestic market the government made a decision to extend existing policy to control agricultural production within the

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[9] According to the estimates, presented by the Russian Agricultural Center (Rosselkhozcenter), only 15% of grain seeds have foreign origins, and these seeds are mainly elite types (http://www.agroinvestor.ru/analytics/article/print/22504/).

[10] During the agricultural year (from July 2014 to July 2015).

country and to introduce several new control instruments, the application and consequences of which are discussed in the following subsections.

In the short term agricultural sector is expected to develop against low investment activity, decrease in real incomes, limited possibilities to attract credits, and worsening of financial indicators of agricultural producers. In the medium term grain production and trade could decrease, given lower prices and higher price risks, and diminishing investments in the grain sector (Götz et al. 2015). At the same time, according to the forecast of socio-economic development for 2016-2018, prepared by the Russian Ministry of Economic Development, positive dynamics of investments will be observed again after 2017 in optimistic scenario and after 2018 in conservative pathway (Mineconomrazvitiya 2015). Overall, the development of the sector in the medium and long run entirely depend on the recovery of the economy, on the growth of investment activity and higher rates of return, as well as increased consumption.

1.2 ECONOMIC AND INSTITUTIONAL FRAMEWORK FOR AGRICULTURAL DEVELOPMENT

1.2.1 Farm structure and the role of agroholdings

Before the retreat from controlling the economy switch towards market reforms took place in the beginning of 1990s, agricultural structure was characterised by two major groups of players: collective and state farms (kolkhoz and sovkhoz respectively)[11] and family or individual household plots. During the process of land reforms soviet-type collective farms were transformed into stately- or privately-owned agricultural enterprises or production cooperatives. In addition, reforms introduced a concept of family farm that did not exist during the USSR. Already in 1990-1994 around 275 000 family farms emerged (Bezlepkina et al. 2004). This farm type played a minor role in the agricultural development during the initial period of transition: despite high quantity, family farms contributed only a small share in agricultural production and cultivated considerably smaller agricultural areas. This group of producers developed at slow pace, hindered by bureaucratic

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[11] State farms were usually located around cities and were significantly bigger than collective farms. However, Serova (1998) and Bezlepkina et al. (2004) indicate that in the pre-reform period these two types of farms became hardly distinguishable from one another and are often placed in the same group as a contrast to household plots.

and financial difficulties and the shift of budget funds distribution towards more efficient and profitable large-scale enterprises (Davydova and Franks 2015). Currently the structurere of agricultural production consists of three pillars, meaning that large- and medium-scale commercial farms coexist with small family plots that produce predominantly for household consumption and increasing number of family and individual farms (Table 1-2). Together family farms and household plots contribute almost equal shares to the total agricultural output as large agricultural enterprises (OECD 2015). Large farms produce mostly grain and technical crops, while family plots are specialised in potato and vegetable production.

Table 1-2 Structure of agricultural production by producer type, 1995-2014.

	1995	2000	2005	2010	2011	2012	2013	2014
				Agricultural enterprises				
Share in agricultural production	50.2	45.2	44.6	44.5	47.2	47.9	47.6	49.5
Animal production	56.0	42.2	45.2	47.6	49.1	50.7	51.8	55.6
Crop production	45.1	47.9	44.0	40.8	45.5	45.1	43.8	43.8
				Household plots				
Share in agricultural production	47.9	51.6	49.3	48.3	43.8	43.2	42.6	40.5
Animal production	42.7	56.0	52.0	48.6	46.7	44.9	43.5	39.7
Crop production	52.4	47.8	46.5	48.0	41.0	41.4	41.7	41.3
				Individual farmers and family farms				
Share in agricultural production	1.9	3.2	6.1	7.2	9.0	8.9	9.8	10.0
Animal production	1.3	1.8	2.9	3.9	4.2	4.5	4.7	4.7
Crop production	2.5	4.4	9.6	11.2	13.4	13.5	14.5	14.9

Note: Data presents percentage shares in corresponding production of all three farm types.

Source: Rosstat (2002, 2015b).

The distinctive feature of Russian agricultural model is the presence of large agricultural companies, otherwise known as agroholdings, who play an important role in the economic and agricultural development. The prerequisites, necessary for the emergence of agroholdings, appeared in the end of the 1990s. During that period, Russian economy experienced stagnation and most agricultural enterprises found themselves on the edge of bankruptcy. At that moment the government of the Oryol oblast[12] decided to establish in each municipal unit one or several agricultural companies that inherited the existing bankrupt farms and food processing companies in the region (Uzun, Shagaida, and Saraikin 2012). The newly created agricultural companies were the receivers of the financial support from the state as well as of all the necessary production equipment and machinery. In spite of what appeared to be a foundation for a successful development, many of the companies eventually found themselves in significant debts as a result of inefficient state management and lack of strategic innovation. Thus, the experience of the Oryol oblast did not spread immediately across the country. Another example comes from the Belgorod oblast[13], where the government provided support for several agricultural firms, in which the head company was formed with the help of the private investors. By the year 2000 the Belgorod oblast already accounted for 18 agroholdings that included 44% of all agricultural enterprises of the region (Uzun, Shagaida, and Saraikin 2012). However, the experience of the Belgorod Oblast with private investments was unique in that period, and the practice did not receive a wide-spread application in other parts of the country, until two important changes in the legislative system took place.

Prerequisites for the development of vertical integration

The beginning of the 2000s is characterised by important changes in the land legislation: the newly introduced *Land Code* (2001) finally provided the possibility for individuals and legal entities to own agricultural land. Basically, it granted rights to any non-agricultural companies to purchase agricultural land that before could only be rented or inherited from former cooperative or state farms. The price of land was understated, thus providing businesses with an ample opportunity to expand the scope of their operations fast and at low costs (Uzun, Shagaida, and Saraikin 2012). Later, in 2002, another law came into force - the *Federal Law on Financial Recovery of Agricultural Producers* (2002), accord-

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[12] Oryol oblast forms part of the Central Federal District and is specialized on industrial and agricultural production. In 2013 the share of agricultural product n GRP was more than 30% with more than half attributed to crop production (see Table A.1 in Appendix A for a detailed overview of socio-economic and agricultural indicators of the region).

[13] Belgorod oblast as well forms part of the Central Federal District, and is located in the Chernozem area, bordering with Ukrainian regions of Luhanks, Kharkiv, and Suma. Despite large share of chernozem soils, region is the country's leader in animal production (72% of total agricultural production). See Table A.1 in Appendix A for a detailed overview of socio-economic and agricultural indicators of the region.

ing to which agricultural producers were allowed to repay their debts without otherwise obligatory fees and penalties. In order to be subject to this law, the enterprises-debtors were supposed to demonstrate a financially stable plan to secure a profitable activity. The legislation resulted in a controversial situation for farmers: to accomplish these plans the companies needed some primary investments that could not be easily received from banks, due to numerous barriers for enterprises with debts to be granted a loan. These circumstances created perfect conditions for non-agricultural producers to enter the market and bring investments to the sector. Rylko and Jolly (2005) point out the sharp increase in the amount of vertically integrated companies that can be observed during the period 2000-2003. According to the survey, conducted by the authors, 585 companies entered the market already in 1999-2000, while in 2001-2003 the number of new players reached 727. Existing studies on the nature of agroholdings name at least two main reasons why agricultural sector suddenly became so attractive for the non-agricultural companies (Matyukha, Voigt and Wolz 2015; Wandel 2011; Wegren 2005). First, forming part of the existing value change brings significant advantages in form of higher profit opportunities, especially in the new, emerging market. In general, participation in agroholdings can reduce a country-specific transaction costs given high uncertainty in institutional and economic environment (Hockmann, Wandel, and Nedoborovskyy 2005). The successful experience of some companies resulted in positively changing business environment that created economic incentives for the further spread of agroholdings. Second, the emergence of agroholdings was somewhat triggered by the state policy: through political support the government intended to keep the rural population engaged in labour activity, and agroholdings were very often persuaded to take over unprofitable and stagnating farms or farms on the edge of bankruptcy. In addition, certain financial and legal advantages of using holding as a business model make it more attractive (Uzun, Shagaida, and Saraikin 2012). First of all, vertical integration allows for a reduction of financial risks, thus, firms that are parts of a holding are legally independent and bear their own responsibility. Second, according to the *Federal Law on Agricultural Lands Turnover* (2002), an oblast government has the right to limit the amount of land owned by one firm, while in case of agroholding this limit may be overcome, because the head company can own land through smaller subsidiaries.

In general, vertical integration in Russia brought a significant inflow of capital in the agricultural sector, which allowed for the modernisation of machinery and infrastructure in the most productive regions of the country (Dries et al. 2009). Nevertheless, the lack of flexibility and the size of such corporations often raise questions regarding their relative efficiency and performance.

Efficiency of agroholding as a business structure

Since no legislation exists on agroholdings, there is no legal definition of this type of a business structure, and vertical integration is therefore considered as a business model rather than a legal entity. This complicates researchers' attempts to estimate the performance and the role of agroholdings on the Russian agricultural market. Uzun, Shagaida, and Saraikin (2012) conducted the study on the basis of 2006 agricultural census and defined 318 non-government head companies that owned 1089 agricultural enterprises, in contrast to 413 state and municipal agroholdings. In total, agroholdings owned around 21% of all large and medium-sized agricultural companies that were producing 26.5% of agricultural output from all agricultural enterprises in the country. In 2006 agroholdings owned 6.6% of the sown land and produced 7.7% of grain. Given such a large share of agricultural products, created by agroholdings, it is important to analyse the efficiency and production potential of these companies in order to justify their existence. Uzun, Shagaida, and Saraikin (2012) indicate that productivity in these companies was 18% higher than in enterprises that were not forming part of agroholdings. Another study by Hockmann and Kopsidis (2007) suggests that vertically integrated enterprises in many cases may not be as efficient as usually presented, predominantly because of the lack of knowledge regarding the integration process and the requirement for the efficient decision-making. However, the Total Factor Productivity (TFP) analysis conducted by Hahlbrock and Hockmann (2011b) highlights that independent farms are worse equipped than farms affiliated to agroholdings. Apparently, the technical change was the driving force of TFP growth among the members of agroholdings. Nevertheless, the authors conclude that technological and managerial innovations introduced by farms affiliated to agroholdings do not necessarily increase the efficiency of those farms. Similarly, Matyukha, Voigt, and Wolz (2015) suggest that the farm size is not directly related and is even insignificant for the growth. The authors failed to find any proof that farms, forming part of agroholdings, have any economic advantages in comparison to their independent counterparts.

Usually vertically integrated enterprises are perceived by the general public and decision-makers as the most optimal solution for the efficient grain production. However, a number of studies suggest otherwise. Despite official estimates that agroholdings can produce between 40 and 50% of the gross country grain output, Visser, Spoor, and Mamonova (2014) provide evidence that agroholdings may not be the most optimal solution to maintain the current level of production or to increase it any further. Besides questions regarding productivity and efficiency, already discussed above, expectations and official forecasts might be overestimated. As already mentioned, according to Uzun, Shagaida, and Saraikin (2012) agroholdings accounted for 6.6% of the sown acreage for grain and 7.7% of the total grain production, while studies of the Institute for Agricultural Market Studies (Rylko 2010) suggest that agroholdings account for 25% of grain output. At the same time, Uzun, Shagaida, and Saraikin (2012) point out that despite more investment and advancements in technology in agroholdings, and fertiliser use that was 260% higher than in other agricultural companies, grain yields were only 13% higher. The diversity of data, lack of additional information, and legal definition of agroholding as a business entity create obstacles for the estimation and feasible conclusions regarding the efficiency of agroholdings.

Nevertheless, vertically integrated enterprises have been an important driver of the Russian agricultural development, promoting Russian grain on the world market and annually increasing country’s share in it. However, the lack of small- and medium-scale farmers on domestic market creates substantial obstacles for the further development of agricultural production and, in view of introduced in 2014 product embargo, limits the competition on the domestic market by the presence of only large, almost monopolistic entities. Admitting the need for development of the family farms Russian authorities made it the priority within the bounds of State programmes of agricultural development, designed to set direct aims for the distribution of budget funds.

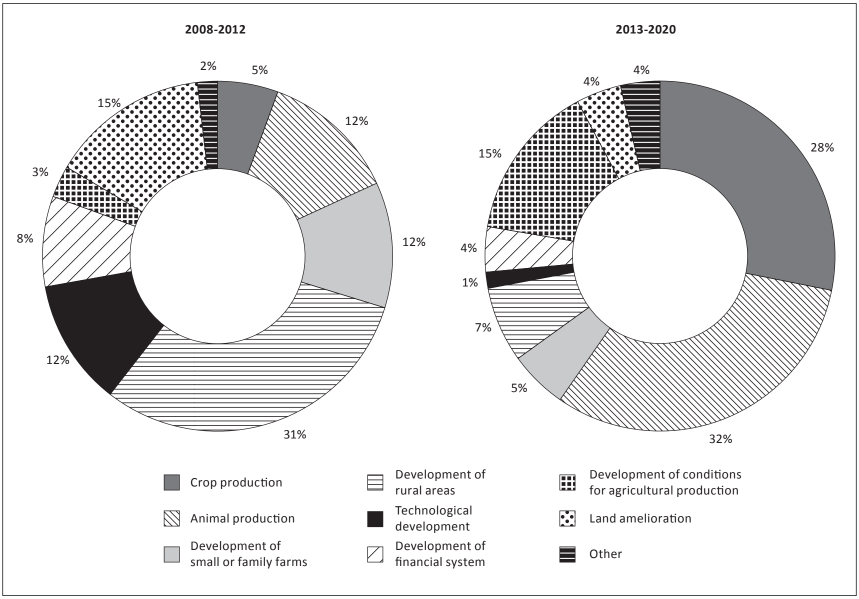
1.2.2 State programmes of agricultural development

The indicative sign of forthcoming changes in the sector appeared in 2005, when the Russian state government announced the reorganisation of the agro-industrial complex as a part of the two year National Priority Project (Barsukova 2007). The project aimed to develop the social welfare system, together with health-care, education, and housing recovery. The authors of the project intended to stimulate an increase in livestock production by 7% by the end of 2007, as well as to provide support for individual and small-scale farmers. It highlighted the importance of the rural development in Russian economy, indicated the direction of agricultural progress and build the basis for the legislation, designed to impose control over the market. In 2008 the agricultural portion of the National Priority Project was replaced by the *State Programme of Agricultural Development and Agricultural Markets Regulation for 2008-2012* (2007). The Programme envisioned the development of agriculture for the subsequent 15 years through the accomplishment of three main goals, namely:

- development of rural areas;
- increase of competitive capacity of domestically produced agricultural products;
- conservation and reproduction of agricultural lands.

Livestock production sector was provisioned to be among the most important targets of the governmental support, given its low development stage at the time the programme was designed. The meat self-sufficiency was expected to reach 70% by 2012 and the annual meat consumption to increase from 55 kg per person in 2005 to 73 kg in 2012. In fact, the programme proved to be effective and yielded astonishing results: already in 2011 the share of domestically produced meat on the market was 78%, while meat consumption reached its peak of 75 kg in 2013 (Rosstat 2016).

Figure 1-8 Comparison of funds distribution between the 2008-2012 and 2013-2020 programmes of agricultural development.



Source: own illustration of the State Programme of Agricultural Development and Agricultural Markets Regulation for 2008-2012 (2007); the State Programme of Agricultural Development and Agricultural Markets Regulation for 2013-2020 (2012).

Introduced later the *Food Security Doctrine* (2010) supplemented the Programme of agricultural development for 2008-2012 and set a number of goals to be achieved by the year 2020, including an increase in meat and cereal production in order to reach the aim of 85% and 95% of self-sufficiency level, respectively. The targets, defined in the *Food Security Doctrine*, were later used to shape the *State Programme of Agricultural Development and Agricultural Markets Regulation for 2013-2020* (2012) that was designed as the continuation and the supplement of the development plan for 2008-2012. It encompassed almost all the goals from the previous programme, including ambitious targets of animal sector development[14]. However, the drastic difference was in the distribution of funds, as depicted in Figure 1-8. While in 2008-2012 the biggest share of funds was directed at the development of rural areas (31%), in 2013-2020 it received only 7% of the programme financing. In contrast, the emphasis in the new plan was predominantly placed on crop production (28%), alongside with animal production (32%) that previously received only 5 and 12% of all the funds, respectively. Overall, the new programme was expected to trigger an increase in grain production, which was consequently to be followed by an increase in animal production. Noteworthy, the new programme and its targets were designed in a way that the sector could fast and easily adapt to the rules, imposed under the WTO regulation, signed by Russia in 2012. However, in view of introduced in 2014 sanctions and product embargo and the resulting need to strengthen the orientation towards self-sufficiency of the agricultural production, the following changes in the supply required structural changes in the financing scheme. This process resulted in the redistribution of funds and appearance of additional five subprogrammes, aimed to adapt and develop fast import substitution of meat, milk, vegetables, potatoes and fruits (Sinelnikov-Murylev and Radygin 2015). Moreover, in order to support the access of population to agricultural products and to increase demand for domestically produced goods, the government made the decision to create the system of internal support for consumers that implies the direct food supply or subsidies to low-income population. This measure was consequently expected to increase the demand for domestically produced food. In addition, in 2015 Russian officials announced that due to state support the rate of return for agrarian producers have increased up to 22% (Minselkhoz 2016). Meanwhile, without the state subsidies it would have remained at the level of 11%, which would have been too low to increase the attractiveness of the sector for new investors.

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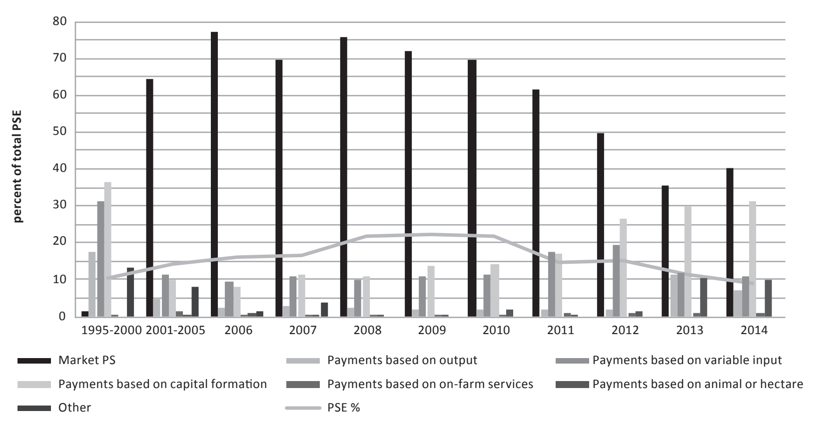
[14] The programme provisions an increase in meat self-sufficiency to 91.5% and cereal self-sufficiency – up to 99.7%.

One of the biggest hindrances and shortcomings of both described above programmes of agricultural development is the doubling of subsidies. For example, the current programme for 2013-2020 is designed in a way that milk production is supported by two subprogrammes. This overfinancing does not stimulate the efficient exploitation of government funds and, moreover, very often results in a complete lack of expected subsidies: given high level of bureaucratic procedures, end users might never receive it. Another problem arises from the fact that most subprogrammes stimulate the quantitative increase in production, which in certain areas of agriculture might result in the crisis of excess supply. Instead, it would be beneficial for agricultural sector if the programme was designed to develop the production quality at lower costs. In view of the ongoing crisis, it is also important to maintain the stable situation on the market and to avoid mistakes, made previously in attempts to support agricultural producers. For example, the crisis already caused an increase in prices of variable inputs, consequently increasing prices of domestic products. However, artificially maintaining low prices on food will eventually result in product deficit, similar to the country faced in 1990-1991. It is essential for agricultural producer to sell products at a price, close to the world price in order to maintain stable demand and push production further (Sinelnikov-Murylev and Radygin 2015). One should also keep in mind that increasing prices on agricultural products will cause a decline in demand and changes in consumption patterns that, in turn, may result in financial damages to large agricultural enterprises, leading to their inevitable bankruptcy. In this case it might be beneficial to further develop small farming due to its flexibility to changing consumption patterns and ability to adapt fast.

1.2.3 Agricultural policies and state support

Agricultural sector is characterised by a number of policy instruments that provide support for producers. These instruments are designed to maintain the stable level of production, to encourage businesses to engage in agricultural activities and to regulate prices on the domestic market. The analysis of agricultural policies traditionally relies on policies evaluations, provided by OECD and presented as a set of standardised indicators to measure the level and composition of producer and consumer support. A scrupulous analysis of agricultural policies in Russia indicates an intensive level of support, particularly observed during the transition period. Indeed, Producer Support Estimate (PSE), as calculated by OECD, showed a decreasing trend in 2013-2014 (Figure 1-9), reflecting reductions in the support from budgetary funds and signalling changes in the intensity of the agricultural platform and transition to a more competitive agricultural market. The most commonly used instruments and policies in Russia include preferential tax regimes, domestic price regulation policies, export control and federal and regional subsidies for agricultural production, as described in Figure 1-10. However, about two thirds of producer support volumes derives from import tariffs, export quotas and duties and tariff rate quotas, while the remaining part is dominated by budget support (Sedik, Lerman, and Uzun 2015).

Figure 1-9 Producer Support Estimate, 1995-2014.



Source: own representation based on OECD (2016).

Figure 1-10 Structure of agricultural support policies.

Concessional credits and subsidies	Tax policy	Price regulations and income support	Border protection
• Concessional credit in form of subsidy to interest rate • Direct subsidies for variable inputs and investment • Discounted leasing of agricultural machinery	• Single Agricultural Tax • Preferential tax regimes	• Market interventions • Per tonne payment • Per animal and hectare payment	• Export measure • Import measures

Source: own illustration.

Concessional credits and subsidies

Concessional credits and direct subsidies are the most important and the most commonly used types of agricultural support in Russia. Concessional credit usually takes form of subsidies for the interest rates on loans. Its size is calculated on the basis of the Russian Central Bank refinancing rate, it depends on the type of loan, as well as financial stability of the borrower, and it is financed from federal or regional budgets. Originally designed for the short-term support for large agricultural producers, in the beginning of the 2000s the measure was expanded its focus to provide financial help small- and medium-scale farmers and, in addition, to give loans for long-term investment (OECD 2013). Another widespread type of financial support is subsidy for leasing, operated through the Federal State Company Rosagroleasing, which obtains its funds from the federal budget and provides subsidies in form of preferential rates for agricultural machinery and pedigree cattle. Subsidies for leasing imply leasing of agricultural machinery for farmers at preferential rates. As opposed to a leasing support, direct variable inputs subsidies constitute a major part of agricultural support; in 2014 they accounted for more than 10% of the PSE (Figure 1-9). Usually this group of subsidies includes payments for purchasing fertilisers, fuel, feed and equipment, subsidies for transportation, as well as crop insurance premiums. The main problem that arises along with direct subsidies, just as with most types of agricultural support, introduced in Russia, is the unequal distribution of funds. Producers based in already developed from an agricultural point of view regions, such as Krasnodar and Stavropol krais[15], receive high subsidies in addition to existing profits, while farmers from other, less developed, regions receive only the remaining part of the budget that is not substantial enough to make significant changes and achieve production levels, high enough to compensate expenses[16]. In addition to the problem of unequal distribution, the major concern of economists still remain high levels of corruption and bureaucracy that prevent efficient and transparent redistribution of funds.

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[15] Located in the Southern and Northcaucasian Federal Districts, respectively, both regions are the country's largest agricultural producers. In 2013 the share of agricultural production in Krasnodar krai was almost 18% of the GRP, while the neighbouring Stavropol krai accounted for 31% of the regional economy. See Table A.1 in Appendix A for a detailed overview of socio-economic and agricultural indicators of regions.

[16] According to expert interviews (http://www.agroinvestor.ru/investments/article/print/22558).

Tax policy

Agricultural producers in Russia benefit from favourable tax regimes, including zero income tax and tax concessions for certain types of agricultural production. In 2001 a new tax policy was introduced to stimulate the development of the agro-food sector. Within this policy farmers received the possibility to either adopt the Single Agricultural Tax (SAT) that amounted to 6% of the difference between value of revenues and costs, or to maintain the traditional tax regime. Producers that opted for the SAT were exempt from traditional VAT (18%), income (20%) and property taxes (2.2%) that in total could sum up to more than 40.2% (*Tax Code of Russia* 1998). In 2016, despite already low rates of the SAT, the government announced its plans to reduce the tax further and create preferential tax regimes for certain categories of agricultural producers that can vary between 0 and 6% depending on the type of agricultural activity (Ekonomika i Zhizn 2016). This measure is expected to ease the tax burden for agricultural producers and increase the attractiveness of the sector for new investors. In case an organisation chooses not to adopt the SAT, they can still benefit from a zero tax on income from agricultural activities, including primary production and processing. In addition, preferences in VAT are envisaged for certain agro-food items, for example poultry and live cattle (OECD 2013).

Market intervention and income support

Market intervention is a process, by means of which the government can purchase or sell a certain quantity of agricultural products (usually applied to cereals) in case the price on the market falls behind or exceeds the predefined maximum and minimum price boundaries. These interventions are intended to provide help for farmers in case of lack of demand, reflected in low prices, or to ease the effect of prices, elevated as a result of unfavourable climate conditions impact. This type of support constitutes the biggest share of PSE, as demonstrated on Figure 1-9. The per tonne payments are usually provided from regional budgets in contrast to federal budget to support producers of animal products, such as meat, milk, eggs and wool. This measure is considered to be the most effective way to stimulate domestic production and increase in agricultural outputs, and it is being widely implemented within current governmental programmes of agricultural development (OECD 2013). In 2014 the per output payments contributed more than 7% to the overall producer support, in contrast to an average of 3% in the period 2000-2012 (Figure 1-9). In contrast, the per hectare payments is a relatively new type of agricultural support, designed to replace certain subsidies for variable inputs, i.e. fertilisers, fuel etc. The main idea of the per hectare payment is to differentiate subsidies based on the quality of land, climate conditions and productivity, so that more productive areas receive higher payments. This measure became widespread only in recent years (2013-2014), and its mechanism is still being developed.

Border protection and trade policies

Initial years of transition were marked by a market liberalisation and a lack of border restrictions. Later, trade policies started to heavily rely on border protection, which soon became the most commonly and widely used measure of controlling the domestic market in Russia. Usually it is expressed in form of export duty or tax, or in form of export ban, introduced in order to maintain the stable supply on domestic market. For example, in view of extremely high world market prices and in order to limit consequent increases in domestic prices, in November 2007 Russia introduced a 10% wheat export tax, which was increasing in the following months up to 40% and was abolished later in 2008 (Rude and An 2015). As a result of unexpectedly low grain harvest due to drought that affected almost all wheat producing regions, in 2010-2011 Russian authorities introduced a complete ban on wheat export in order to maintain domestic supply at sufficient levels (Götz, Glauben, and Brümmer 2013). In February 2015 Russian government reintroduced export duties that were equal to 15% of the price, adjusted to the exchange rate between euro and rouble[17] and eliminated shortly after, on May the 15th.[18] Later that year, on July the 1st, it was decided to switch from manual regulation of export to the automatic one, and a so-called Argentinian duty[19] on grain was implemented: the duty is automatically switched on once the export price exceeds the domestic price. The current maximum price is 6 500 roubles per tonne, and everything higher is subject to 50% export tax minus 6 500 roubles but not less than 10 roubles per tonne (Government of the Russian Federation 2015). However, in view of current financial crisis this measure cannot be considered efficient and is being widely criticised by producers and experts for several reasons.[20] First, the tax is calculated on the basis of a stable exchange rate between Russian rouble and the world currencies, as well as low

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[17] According to the press release by the Ministry of Agriculture of the Russian Federation: http://mcx.ru/news/news/show/32886.355.htm

[18] http://www.gazeta.ru/business/news/2016/02/11/n_8239547.shtml

[19] Since the middle of 2000s Argentina, in many attempts to control inflation of food prices, introduced different types of export restrictions, including fluctuating export duty, which, in fact, resulted not only in expected decrease of wheat exports, but also in a drastic fall in wheat production (Nogués 2008).

[20] According to expert interview, conducted by news agency RBK (http://www.rbc.ru/opinions/economics/23/06/2015/5589650a9a794723997dfb8f).

world prices on grain, which is a very unrealistic assumption given current trends and state of the world grain market. Second, in case world grain prices reach unexpectedly high levels, prices on variable inputs consequently increase, leading to high production costs. Third, the inability of producers to increase revenues during peaks of the world grain prices prevent them from making significant developments from technological point of view, leading to a sharp decrease in quality in comparison to other world producers. Finally, the set amount of tax will damage prevailingly those regions that export the most, i.e. most productive Southern, rich of black soil regions. Most share of Russian meat production is subject to measures of import protection, i.e. tariff rate quotas. These quotas usually apply to beef and poultry. After the Russian Federation joined the WTO import tariffs for pork was reduced to 0%. Besides tariff measures, Russia introduced temporary non-tariff restrictions, banning certain imported products as a result of failures to meet the sanitary standards. In view of recent geopolitical events, Russia started to apply frequently non-tariff measures and restrictions on imported food, already described in subsection 1.1.3.

Discussed above policy instruments are introduced within the state programmes of agricultural development that describe country's agricultural framework, set aims for the future agricultural development, shape the plan for the future federal and regional regulation and design mechanisms to boost the production, including the distribution of federal funds among various agricultural sectors. Another source that determines Russian agricultural policy is the World Trade Organisation, characterised in the following subsection.

1.2.4 Agricultural regulation within the WTO

Russia accepted the membership in the World Trade Organisation on August the 22nd, 2012. Within the agreement Russia was expected to lower its import tariffs on most agricultural products and introduce tariff bindings to some specific products groups (e.g. dairy and cereals). The changes were planned to be finally introduced by the end of 2020. The advantages and disadvantages of the WTO conditions for the Russian agriculture are widely discussed in academic and professional communities (see e.g.Chowdhury 2003; OECD 2013; Sedik, Lerman, and Uzun 2015), naming among the negative instruments the obligation to reduce or remove import quotas on some meat products. The consequences of this reduction were expected to put at risk domestic producers: before the WTO agreement the policy supported domestic farming through consumers that paid higher prices for domestically produced agricultural goods. Due to the WTO obligations the support of domestic producers was put at risk and many feared a decline of national agriculture. Despite debates and fears that the new trade conditions would have a negative short-term consequences for the agricultural sector, the membership in the WTO did not yield any negative results for the level of domestic production shortly after its introduction. For example, in 2013, after the implementation of the WTO, the market did not experience any considerable shocks and growth of imports, just as well as expansion of Russian production to foreign markets. However, the WTO has long-term perspectives, aimed at increasing the competitiveness of farmers, at creating conditions for the natural selection of efficient producers, developing appropriate and adequate measures of export control, as well as at changing the direction of the agricultural policy towards a more liberal one by adjusting agricultural policies away from production- and trade-distorting measures (Sedik, Lerman, and Uzun 2015).

1.3 CONCLUDING COMMENTS

During the period of transition to the market economy Russia evolved from the net importer to the net exporter of grain, becoming an important player on the world agricultural market. In the course of 10 years Russia increased its production from 76 thousand tonnes of cereals in 2004 up to 104 thousand tonnes in 2015 (Rosstat 2016). The biggest driver behind that growth were agroholdings, large agricultural enterprises that included the whole value chain in their production process, minimising transaction costs and augmenting production volumes. Although numerous studies raise doubts concerning the relative efficiency of vertically integrated companies, their impact on domestic grain production cannot be underestimated: inflow of investments in the sector allowed agricultural producers to reach new level of technological and infrastructural development, otherwise not attainable without additional funds.

Despite current political tensions and economic crisis Russian grain producers remain active in international trade. Current projections of future grain harvest suggest a further constant increase due to high grain yields because of increased investments in production technology, stimulated by the growth of prices on grain on the world market. At the same time Russian agricultural production was always vulnerable to climate conditions, risking to lose the whole harvest of the season due to unstable weather. The ambiguity of grain production in Russian leaves at least three questions open: what determines, what drivers are behind productivity and efficiency on the regional level and what role does climate play in past and future productivity of grain.

2 ECONOMETRIC ANALYSIS OF GRAIN PRODUCTION EFFICIENCY AND PRODUCTION POTENTIAL DETERMINANTS

A broad number of studies has been conducted to analyse the development of agricultural production and technical efficiency in transition economies (see e.g. Brümmer 2001; Cechura 2012; Lerman et al. 2003; Lissitsa and Odening 2005; Lissitsa and Rungsuriyawiboon 2006; Macours and Swinnen 2000). Usually these studies focus on the analysis of technological change impact on agricultural growth, expressed in production frontier shifts, and changes in technical efficiency as a measurement of production frontier adjustments. From this point of view Russia represents an interesting case study for the productivity analysis: available datasets allow for an estimation of technical efficiency not only on the farm level, but also on the level of regions, thus permitting a researcher to analyse development and trends within the whole country. As demonstrated in the overview of Russian agricultural development, presented in the previous chapter, during the transition period Russia experienced significant changes in agricultural production structure that led to an overall flourishing of the sector. Macroeconomic stability, higher demand for domestically produced food, favourable weather conditions and attractiveness of agricultural sector for investors were among the factors that contributed to this process. Crucial questions though remain the same: did technical efficiency contribute to the increase of production and how do natural conditions, i.e. those that farmer cannot control, determine productivity?

Given these questions, the following chapter therefore aims to estimate the performance of Russian agriculture from the efficiency point of view. The main objective of this part of the study is to assess the grain production on the oblast level through the measurement of production potential. This chapter introduces a novel approach to the estimation of efficiency, based on traditional stochastic frontier model that, in addition, accounts for unique characteristics, such as climate, level of regional development, and infrastructure that potentially influence efficiency. The remainder of the chapter is organised in the following way: the first section provides a detailed review of recent research concerning the efficiency of Russian agricultural production. The second section gives an overview of methodology applied. The third section describes data and the empirical model, while the fourth section presents the obtained results.

2.1 OVERVIEW OF STUDIES ON EFFICIENCY OF RUSSIAN AGRICULTURE

An analysis of the efficiency of agricultural production in transition economies has been a popular research topic in the last twenty years, especially focusing on

Russia because of its vast production potential and land resources. Table 2-1 presents an overview of selected studies that estimate efficiency and production potential of Russian agriculture. Several studies concentrated on the measurement of farm-level efficiency (e.g. Bezlepkina 2003; Bokusheva and Hockmann 2006). However, given the size of the country, the disparity of the country's development, various climatic zones and soil quality, it becomes more reasonable to conduct the efficiency analysis on a regional level, estimating the production potential of the whole country rather than of each separate region. In fact, there are several studies that focus on estimating the efficiency of production on a regional level (Arnade and Gopinath 2000; Sedik, Trueblood, and Arnade 1999; Sotnikov 1998). These studies analyse changes in technical efficiency of Russian agricultural during the first years of transition. For instance, Sotnikov (1998) reports an increase in technical efficiency in the early 1990s, interrupted by a decline of efficiency scores in 1993-1995. The author concludes that an increase in technical efficiency took place primarily due to improvements in the input use, together with notable changes in technologies, while a following decrease in efficiency scores resulted from price controls and subsidies from the side of the government. These results go in line with further findings of Sedik, Trueblood, and Arnade (1999), who, in addition, explain decreasing technical efficiency scores in the begining of transition period by price changes for agricultural inputs, as well as by subsidies, given to the most inefficient farms. Furthermore, these findings allow the authors to conclude that specialisation leads to higher efficiency scores. In other words, the less diversified is the production within one oblast, i.e. the more the production is concentrated on one single crop, the higher is the productivity.

Arnade and Gopinath (2000) expand the analysis to estimate production functions by measuring financial efficiency in addition to technical efficiency of Russian agriculture. They indicate that only six out of 73 examined Russian oblasts managed to maintain high levels of technical efficiency, and only 19 oblasts experienced financial efficiency in 1994-1995. Such poor efficiency scores result from inefficient terms of trade, as well as unstable weather conditions that cause interruptions in agricultural production. Arnade and Trueblood (2002) confirm the common finding that efficiency tends to be responsive to input prices, and find the prevalence of technical and allocative efficiencies in the Russian agricultural production. Based on a regional level data, Osborne and Trueblood (2006) note a decreasing pattern of technical and allocative efficiency scores in the period from 1993 to 1998. Later, Voigt and Hockmann (2008) observe a considerable decrease in the original production possibilities during this period, and indicate that a positive development and restructuring of the sector can only be observed starting from 2003. In addition, the authors find evidence that production technologies differ across oblasts due to the diversity and different development paths on the

Table 2-1 Selected studies on efficiency of Russian agricultural production.

Name	Sector	Level	Period	Main findings
Sotnikov (1998)	Agricultural production	Regional	1990-1995	Productivity improved in 1991-1993 and declined in 1995
Sedik,Trueblood, and Arnade (1999)	Crop production	Regional	1991-1995	Initial conditions are important in predicting efficiency performance
Arnade and Gopinath (2000)	Agricultural production	Regional	1994-1995	Most oblasts experienced profit losses as a result of inefficiency
Arnade and Trueblood (2002)	Agricultural production	Regional	1994-1995	Technical and allocative inefficiencies are widespread
Bezlepkina (2003)	Agricultural production	Farm (medium and large enterprises)	1995-2000	Agricultural enterprises operate under liquidity constraints
Bokusheva and Hockmann (2006)	Crop production	Farm (large enterprises) in Krasnodar, Oryol and Samara	1996-2001	Risk and technical inefficiency describe production technology
Osborne and Trueblood (2006)	Crop production	Regional	1993-1998	Declines in technical and allocative efficiencies determined reduction in economic efficiency
Voigt and Hockmann (2008)	Agricultural production	Regional	1993-2003	Technical efficiency did not improve over the observed period
Bokusheva, Hockmann and Kumbhakar (2012)	Agricultural production	Regional	1991-2008	Economic and institutional reforms fostered the exploitation of production potential

Source: own compilation.

level of regions. Bokusheva, Hockmann, and Kumbhakar (2012) confirm results of previous studies and find a decreasing trend of regional efficiency until 2000, followed by a steady improvement afterwards. Based on the TFP calculations, the authors point out the heterogeneity of economic and institutional environment across the country. This is the crucial finding that outlines almost all the studies mentioned above: production in Russia is influenced by external factors rather than by efficient (or inefficient) use of production inputs. Therefore, the current study aims first to measure the production potential of Russian agriculture, and then identify factors that determine heterogeneity of the country and thus influence productivity of the agricultural sector. We distinguish three indicators that could serve as proxies for factors that determine heterogeneous development of the country, precisely: level of human development, level of infrastructural development, and climate and soil conditions. We then implement them in our empirical model to estimate the production function.

2.2 METHODOLOGICAL APPROACH TO THE EFFICIENCY ESTIMATION

2.2.1 Production function estimation and theoretical concept of technical efficiency

The estimation of production potential of a production unit (company or farm in case of agricultural economics) in relation to other production units that express a so-called best practice of the economic sector has been widely used to obtain insights into the efficiency levels. Farrell (1957) suggested an approach that allows for the measurement of technical efficiency through the frontier estimation, i.e. production functions of the fully efficient and best in the sector companies. Production functions can then be estimated, using one of the two techniques: the mathematical programming and the econometric estimation. The mathematical programming approach, named Data Envelopment Analysis (DEA), did not receive a widespread usage in agricultural economics (Coelli and Battese 1996), unlike the econometric estimation, that is otherwise known as the Stochastic Frontier Analysis (SFA). The reason behind this is that the DEA assumes that deviations from the frontier are a priori related to technical efficiency, which is a rather unrealistic assumption in the agricultural field, given influence of weather, crop diseases, lack of farmer's education etc. The SFA, although having its disadvantages[21], gained popularity among agricultural economists due to availability of two error terms, one to account for inefficiency and another – to account for other factors that can result in the deviation from the frontier. Aigner, Lovell, and Schmidt (1977) and Meeusen and van Den Broeck (1977) were the first two studies to develop the basics for the SFA. These works were followed by a number of additions to the model in attempts to provide a clearer defini-

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[21] Among the most influential disadvantages the researchers usually name the importance of functional form and the distributional assumptions.

tion of technical efficiency and the error term (see Battese (1992) for a detailed overview of the method development).

The dominant functional form in the SFA studies is based on the works of Battese and Coelli (1992, 1995). Specifically, the Battese and Coelli (1995) model is the most commonly used and it can be generally expressed as follows:

$$Y_{it} = f(X_{it};\beta)\exp(v_{it} - u_{it}) \tag{2-1}$$

$$i \in (0, N) \forall N = (1, \dots, N),$$

where Y_{it} is the estimated output, X_{it} is the production input, β is set of parameter coefficients, v_{it} is the two-sided random error term with $v_{it} \sim iid\ N(0, \sigma_v^2)$, u_{it} is a random variable that represents inefficiency, $u_{it} \sim iid\ N(\mu_{ut}, \sigma_u^2)$. The technical efficiency from the model is then calculated as the ratio of observed production over the maximum obtainable production (without the inefficiency term):

$$TE = \frac{f(X_{it};\beta)\exp(v_{it} - u_{it})}{f(X_{it};\beta)\exp(v_{it})} = \exp(-u_{it}) \tag{2-2}$$

In order to estimate the parameters of the stochastic frontier the authors propose to use the maximum likelihood methodology, and then base the technical efficiency predictions on conditional expectations of the assumptions of the model.

2.2.2 Modified approach to the production potential estimation

Conventional stochastic frontier theory implies that production units, e.g. farms, are primarily inefficient rather than influenced by institutional, economic, and climatic factors. In addition, traditionally calculated efficiency scores are estimated assuming that all producers have access to homogeneous technology. However, this assumption cannot be the case while estimating production potential on the regional level (especially on the regional level of Russia, where the size of the country and its diversity from climatic and development point of view simply cannot allow for this kind of assumption). Therefore, choosing an incorrect model can result in overestimated efficiency scores, while factors that potentially influence efficiency the most are left without attention and counted as an error term. Moreover, with the appearance of more advanced technologies and more experienced workers, production is more likely to be efficient, and therefore diversity of regional conditions becomes the factor that could have negative impact on the production of the country. We construct a stochastic frontier model focusing on the diversity of regions and following the approach developed by Alvarez, Arias, and Greene (2004) and later applied by Wang, Hockmann, and Bai (2012). We assume that production possibilities can be described by the translog output distance function. Using the homogeneity property of the latter we can describe the optimal production as follows:

$$\ln y_{j,it}^{opt} = \beta_0 + \boldsymbol{\beta}'_{\mathbf{x}} \ln \mathbf{x}_{it} + \tfrac{1}{2} \ln \mathbf{x}'_{it}\, \boldsymbol{\beta}_{\mathbf{xx}} \ln \mathbf{x}_{it} + \alpha_m m_i^{opt} + \boldsymbol{\alpha}_{m\mathbf{x}} m_i^{opt} \ln \mathbf{x}'_{it} \qquad (2\text{-}3)$$

or

$$\ln y_{j.it}^{opt} = f(\mathbf{x}_{it}, m_i^{opt}) \qquad (2\text{-}4)$$

where y_{it}^{opt} is the optimal reference output and x_{it} denotes the vector of inputs. The oblast effect is captured by m_i^{opt}. Similar to the trend variable, it has an impact on the production possibilities not only through a shift of the production function, but also through a turn of the marginal products curves. We use this formulation to take into account that regions' production possibilities differ in ways of applying production technologies. However, farms (or, in our case, regions) generally do not exploit their full production capacities indicated by y^{opt}. Due to various institutional, technical, climate and economic effects, they are only able to realise an output y^{opt}. This statement allows us to define the technical efficiency as follows:

$$TE_i = \frac{y_{j,it}^{act}}{y_{j,it}^{opt}} \qquad (2\text{-}5)$$

The observed output $y_{j,it}^{act}$ is then modelled using the same structure as $y_{j,it}^{opt}$, see equations 2-3 and 2-4. The only difference is that farms are not able to use their full capacities resulting from farm heterogeneity (m_i^{opt}). Instead, we assume that farms can realise m_i^{act} (with $m_i^{act} \leq m_i^{opt}$). We can then define the actual output as:

$$\ln y_{j,it}^{act} = \beta_0 + \boldsymbol{\beta}'_{\mathbf{x}} \ln \mathbf{x}_{it} + + \frac{1}{2} \ln \mathbf{x}'_{it}\, \boldsymbol{\beta}_{\mathbf{xx}} \ln \mathbf{x}_{it} + \alpha_m m_i^{act} + \boldsymbol{\alpha}_{m\mathbf{x}} m_i^{act} \ln \mathbf{x}'_{it} \qquad (2\text{-}6)$$

Using the definitions of production possibilities in equations 2-3 and 2-4, technical efficiency (TE) can be defined as follows:

$$\begin{aligned} \ln TE_{it} &= \ln \frac{y_{j,it}^{act}}{y_{j,it}^{opt}} = \ln y_{j,it}^{act} - \ln y_{j,it}^{opt} \\ &= (\alpha_m + \boldsymbol{\alpha}_{m\mathbf{x}} \ln \mathbf{x}'_{it})(m_{it}^{act} - m_i^{opt}) \end{aligned} \qquad (2\text{-}7)$$

Moreover, from equation 2-5 it follows that

$$\begin{aligned} -\ln y_{j,it}^{act} &= -\ln y_{j,it}^{opt} - TE_{it} \\ &= f\left(\mathbf{x}_{it}, t, m_i^{opt}\right) - (\alpha_m + \boldsymbol{\alpha}_{m\mathbf{x}} \ln \mathbf{x}'_{it})\left(m_{it}^{act} - m_i^{opt}\right) \\ &= f\left(\mathbf{x}_{it}, t, m_i^{opt}\right) + u_{it} \end{aligned} \tag{2-8}$$

where u_{it} is defined as $-(\alpha_m+\boldsymbol{\alpha}_{mx}' \; ln\boldsymbol{x}'_{it})(m_i^{act} - m_i^{opt}) \geq 0$ and $f(\boldsymbol{x}_{it},t,m_i^{opt})$ is given as in equations 2-3 and 2-4. Compared to the conventional use of distance functions where the output (input) distance function provides the estimation of output- or input-oriented efficiency, our procedure allows us to combine the input-oriented inefficiency with the output distance function. The difference from the conventional interpretation of efficiency is that the proportionality factor for all output or inputs captures the inefficiency regarding the reference output only.

For estimation purposes we add the usual two-sided error term to equation 2-8:

$$-\ln y_{j,it}^{act} = f\left(\mathbf{x}_{it}, m_i^{opt}\right) + u_{it} + v_{it} \tag{2-9}$$

The likelihood function can therefore be developed after the standard assumptions regarding the inefficiency term and error term are introduced, namely:

$$\begin{aligned} &u_{it} \sim iid\; N^{+}(0, \sigma_u^2) \\ &v_{it} \sim iid\; N(0, \sigma_v^2) \end{aligned} \tag{2-10}$$

The likelihood will have the same structure as in conventional stochastic frontier analysis:

$$f(\varepsilon) = \frac{2}{\sigma}\phi\left(\frac{\varepsilon}{\sigma}\right)\Phi\left(-\frac{\varepsilon\lambda}{\sigma}\right), \tag{2-11}$$

with ε = - ln $y_{j,it}^{act}$ - $f(\boldsymbol{x}_{it}\; m_i^{opt})$, $\lambda = \dfrac{(\alpha_m + \boldsymbol{\alpha}_{m\mathbf{x}} \ln \mathbf{x}'_{it})\sigma_u}{\sigma_v}$, and $\sigma^2 = (\alpha_m + \boldsymbol{\alpha}_{mx}\; ln\; \boldsymbol{x}'_{it})^2\; \sigma_u^2 + \sigma_v^2$. Further, ϕ and Φ are the density and the cumulative distribution function of the standard normal distribution, and $f(\boldsymbol{x}_{it}\; m_i^{opt})$ is given by equations 2-3 and 2-4. Considering that m_i^{opt} is an unobservable variable, Alvarez, Arias, and Greene (2004) propose a simulated maximum likelihood function and assume that m_i^{opt} is standard normally distributed, i.e. $m_i^{opt} \sim N(0,1)$. We can then take R draws from this distribution, plug in the values of m_i^{opt} into equation 2-8 and construct the simulated maximum likelihood function as follows:

$$\ln L = \sum_t \ln\left(\frac{1}{R}\sum_r \prod_i f(\varepsilon)\right) \tag{2-12}$$

The expectation of the random parameter can be computed via the Bayes formula:

$$\mathrm{E}\left[\widehat{m}_i^{opt} | y, \mathbf{x}_{it}\right] = \frac{\frac{1}{R}\sum_r m_i^{opt} \prod_i \hat{f}(y|m_i^{opt}\ \mathbf{x}_{it})}{\frac{1}{R}\sum_r \prod_i \hat{f}(y|m_i^{opt}\ \mathbf{x}_{it})}, \tag{2-13}$$

where $(y|m_i^{opt}\boldsymbol{y}_{it,} \boldsymbol{x}_{it,}\ t)$ denotes the value of the transformed distance function (2) for given input vector $\boldsymbol{x}_{it}$ and regional effect m_i^{opt}. The inefficiency scores can then be calculated using the formula derived by Jondrow et al. (1982):

$$E(u_{it}|\varepsilon_{it}) = \sigma_* \left[\frac{\phi\left(\frac{\varepsilon_{it}\lambda}{\sigma}\right)}{1 - \Phi\left(\frac{\varepsilon_{it}\lambda}{\sigma}\right)} - \frac{\varepsilon_{it}\lambda}{\sigma}\right], \tag{2-14}$$

using the property that $\frac{u_*}{\sigma_*} = -\frac{\varepsilon\lambda}{\sigma}$ with $\sigma_* = \frac{(\alpha_m + \boldsymbol{\alpha}_{m\mathbf{x}} \ln \mathbf{x}_{it})\sigma_u\sigma_v}{\sigma}$.

Moreover, equation 2-7 proves that technical efficiency depends on input vector $\boldsymbol{x}_{it}$, time t, and the difference between the optimal and actual values of regional effect (m_i^{opt} - m_{it}^{act}). The original version of this model faces one crucial econometric problem: the assumption of independence of u and x does not hold, so the estimated results are not necessarily consistent (Kumbhakar and Lovell 2000). We therefore reformulate the model to allow for a more consistent estimation.[22] We use the output distance function to formulate the production structure in the translog form. However, the translog specification of the model requires a further modification in order to fulfil requirements of theoretical consistency

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[22] We define the model by deleting the squared term from the original version of the model. Due to this modification the impact of regional characteristics can be cancelled out, and the model can be estimated by a procedure developed by Kumbhakar (2002) for the risk production function.

from an economic point of view, i.e., monotonicity and curvature properties (Coelli, Rao, and Battese 1998; Fuss and McFadden 1978).

The translog specification used in the empirical application fulfils the requirements only locally (Diewert and Wales 1988). Usually the desired properties are checked for the approximation point (mean of the data) only. The lack of global consistency prevents production far apart from the approximation points from being consistently interpreted. We overcome this problem by forcing the estimation to provide theoretically consistent results for a number of approximation points by applying corresponding linear and nonlinear inequality restrictions. First, we calculate the standard deviation (σ) for each variable. For each variable, all observations not within the $\mu \pm \sigma$ range are excluded from the dataset. For the resulting data sets the mean of each variable is computed. These means in the new data set are used as new approximation points[23]. This procedure gives us consistent results from an economic point of view for a wide range of observations. All variables are normalised by their geometric means in order to facilitate their estimation and allow the interpretation for of parameters as elasticities estimated at the geometric mean. The endogeneity problem can be an important issue in production functions, and we partly overcome it by using the output ratios in the functional form (Coelli 2000). We then develop the model further and assume that production in each region is defined by a set of specific characteristics that indicate the level of regional development and are most likely to influence the implementation of production technologies. Among such characteristics we can name the level of economic and social development, system of transportation and infrastructure, and climate and soil conditions and their suitability for agricultural production.

2.3 DATA AND MODEL SPECIFICATION

The data used in the empirical analysis consists of a balanced panel of 61 Russian territorial units which were involved in grain production during the examined period. The study intentionally had to exclude several oblasts whose data caused validity concerns and therefore could have significantly distorted the estimation results. The data comes from statistical publications of the Russian Federation

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[23] Since we have 6 exogenous variables we constructed 12 approximation points. For each point we have 6 linear monotonicity restrictions and 11 nonlinear curvature restrictions, formulated by determinant criterion (Diewert, Avriel, and Zang 1981). Such a definition results in a large number of restrictions, but very few of them were binding.

Federal State Statistics Service (Rosstat), and covers the period from 1995 to 2011. Summary statistics of the main production characteristics of the country are presented in Table 2-2. In general, there is no clear specialisation of regions according to the type of agricultural production. Since the dominant type of farm is the large enterprise (or agroholding) in the majority of regions, production tends to be combined in order for a farm to maintain self-sufficiency.

Table 2-2 Descriptive statistics: agricultural output and production factors.

Variable	Notation	Unit	Mean	SD	Minimum	Maximum
Gross harvest of grain	y_1	1000 tonnes	11648.50	16246.52	57.38	116343.50
Gross animal production	y_2	mln roubles	5737.92	4531.34	158.43	29389.33
Gross crop production (excl. grain)	y_3	mln roubles	3023.36	2711.46	76.09	19219.68
Labour	x_1	1000	106.02	84.59	4.04	485.12
Land	x_2	1000 ha	1257.55	1265.06	20.40	5832.60
Capital	x_3	bn roubles	14610.17	20917.74	66.06	180622.50
Variable inputs	x_4	mln roubles	4799.90	4422.16	19.11	25598.74

Source: own calculations based on Rosstat (1992-2015).

The group of variables used in the analysis consists of output and input vectors. Output vector is defined by gross harvest of grain as the dependent variable and by gross animal production and production of other crops as independent variables. The vector of inputs consists of the amount of cultivated land, the number of workers involved in agricultural production, and the amounts of capital and variable inputs used in agriculture. Capital is defined as the net value of agricultural capital, and variable input costs are measured as the difference between gross agricultural production and gross regional agricultural product.

Our study focuses on identifying sources and defining, to what degree factors other than production inputs influence the production efficiency. In other words, we need to separate factors that might have an impact on the agricultural development of each oblast. For this purpose we use three indices that could reflect specific attributes and characteristics of each region:

- Climate index (z_1) is set to identify the level of climate and soil conditions. It is calculated as a cumulative mean of average temperature and precipitation in each region during the observed period.

- Stable economic and social development is presented by an index of the human development (z_2), defined following the methodology introduced by UNDP (UNDP 1990) and further developed by Klugman, Rodríguez, and Choi (2011). It is composed as a geometric mean of three normalised indicators of populations' achievements, i.e. life expectancy at birth, gross regional income per person, and the number of children enrolled in school each year[24].

- As a proxy for transportation system we used a normalised index of railways density in each oblast (z_3). Density of railways is not a perfect indicator of transportation development since there exist several regions with no railway connection at all, but unavailability of data prevents us from using a more precise indicator.

These indices combined serve as an aid in determining the level of differences across regions within Russia. Table 2-3 provides a brief overview of the distribution of average indices' values across federal districts[25], accompanied by Figure 2-1 that presents the map of Russia in the context of share of agricultural production in gross regional product of federal subjects. The climate index shows that oblasts located in the European part of the country (Central, North-West, and most part of the Southern Federal districts) on average tend to have better conditions for agricultural production that than those located beyond the Ural Mountains. Moreover, regions with high density of railroads are located in the European part of the country, where the density of the population is high as well. The highest level of human development have oblasts located in the Ural district that connects the Asian and the European parts of Russia and is considered to be the main mining district in Russia.

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[24] Lately, it has been recommended to use expected years of schooling as a more precise measure of education dimension (Klugman, Rodríguez, and Choi 2011), but lack of data limits the possibility to calculate desired indicators.

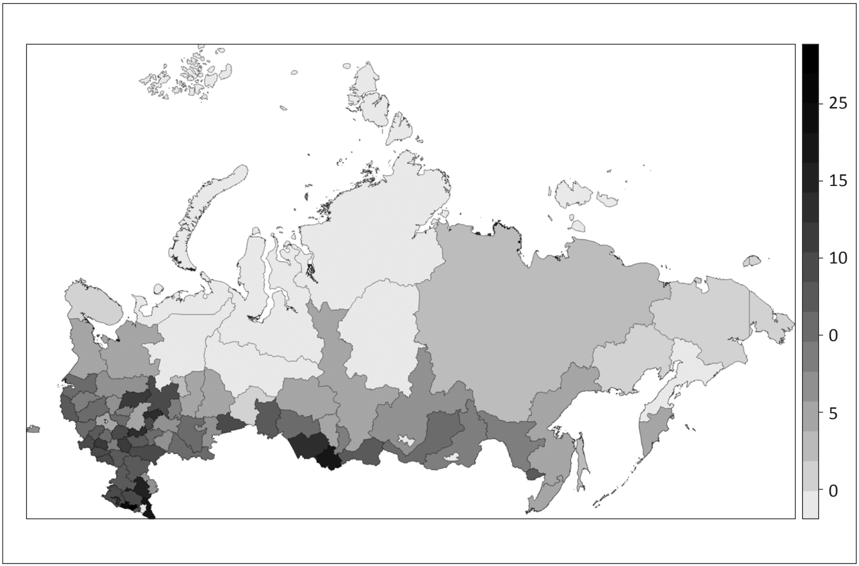
[25] Federal districts in Russia present groups of federal subjects (oblasts, republics, krais, and cities of federal importance, autonomous oblasts and autonomous okrugs). Hereinafter in the text for the sake of simplicity we refer to federal subjects of Russia as oblasts.

Table 2-3 Average indices of determinants of regional diversity.

Federal district	Climate index (z_1)	Human development index (z_2)	Transportation and infrastructure index (z_3)
Central	0.572	0.353	0.465
Northwestern	0.623	0.295	0.494
Southern	0.663	0.351	0.238
Volga	0.482	0.386	0.283
Ural	0.391	0.436	0.217
Siberian	0.335	0.341	0.102
Far Eastern	0.356	0.262	0.113

Note: see Table B.1 in Appendix B for a detailed overview of indices' volumes on a regional level.
Source: own calculations.

Figure 2-1 Share of agricultural product in GRP, 2013.



Source: own interpretation based on Rosstat (2014).

Following the available data and the production function, described in previous subsection, we can present the first model to be estimated as follows:

$$\begin{aligned}-\ln y_{1it}^{act} \quad &= \beta_0 + \beta_t t + \beta_{\mathbf{y}} \ln \mathbf{y}_{\boldsymbol{it}} + \beta_{\mathbf{yt}}\, t \ln \mathbf{y}_{it} + \beta_{\mathbf{x}} \ln \mathbf{x}_{\boldsymbol{it}} + \beta_{\mathbf{xt}}\, t \ln \mathbf{x}_{it} \\ &\qquad + \frac{1}{2}\beta_{\mathbf{yy}} \ln \mathbf{y}_{it} \ln \mathbf{y}_{it} + \frac{1}{2}\beta_{\mathbf{xx}} \ln \mathbf{x}_{it} \ln \mathbf{x}_{it} \qquad\qquad , \quad (2\text{-}15) \\ &\qquad + \alpha_m m_i^{act} + \alpha_{mt} m_i^{act} t + \alpha_{m\mathbf{x}} m_i^{act} \ln \mathbf{x}'_{it} + u_{it} + v_{it}\end{aligned}$$

where y_{1it}^{act} is the actual gross production of grain, $\boldsymbol{y}_{it}$ = (y_{2it}, y_{3it}), with y_{2it} being the gross animal production and y_{3it} – the gross production of other crops. We define the vector of inputs as $\boldsymbol{x}_{it}$ = (x_{1it}, x_{2it}, x_{3it}, x_{4it}), where x_{1it} is the labour input, x_{1it} is the land input, x_{3it} and x_{4it} are the capital and material inputs respectively. The time trend variable t permits neutral technical change at a constant rate, allowing for the shift of the frontier.

The model is then extended to account for potential sources of diversity across the country and to include therefore the potential impact of climate, socio-economic and infrastructure development:

$$\begin{aligned}-\ln y_{1it}^{act} \quad &= \beta_0 + \beta_t t + \beta_{\mathbf{y}} \ln \mathbf{y}_{\boldsymbol{it}} + \beta_{\mathbf{yt}}\, t \ln \mathbf{y}_{it} + \beta_{\mathbf{x}} \ln \mathbf{x}_{\boldsymbol{it}} + \beta_{\mathbf{xt}}\, t \ln \mathbf{x}_{it} \\ &\qquad + \frac{1}{2}\beta_{\mathbf{yy}} \ln \mathbf{y}_{it} \ln \mathbf{y}_{it} + \frac{1}{2}\beta_{\mathbf{xx}} \ln \mathbf{x}_{it} \ln \mathbf{x}_{it} \qquad\qquad (2\text{-}16) \\ &\qquad + (\alpha_0 + \alpha_t t + \alpha_{\mathbf{x}} \ln \mathbf{x})\left(\gamma_0^{opt} + \gamma_{\mathbf{z}}^{opt}\mathbf{z}\right) + u_{it} + v_{it}\end{aligned}$$

Potential sources of country's diversity are defined as $\boldsymbol{z}$ = (z_1, z_2, z_3), with z_1 denoting the climate index, z_2 the index of human development, and z_3 the index of infrastructure and transportation. The usual two-sided error term is denoted as v_{it}, while u_{it} is defined as the negative of In TE_{it} (see equation 2-7). We employ constrained maximum likelihood techniques to obtain consistent estimates of β, α and y, and impose convexity restrictions for outputs and quasi-convexity for inputs, following Morey (1986).

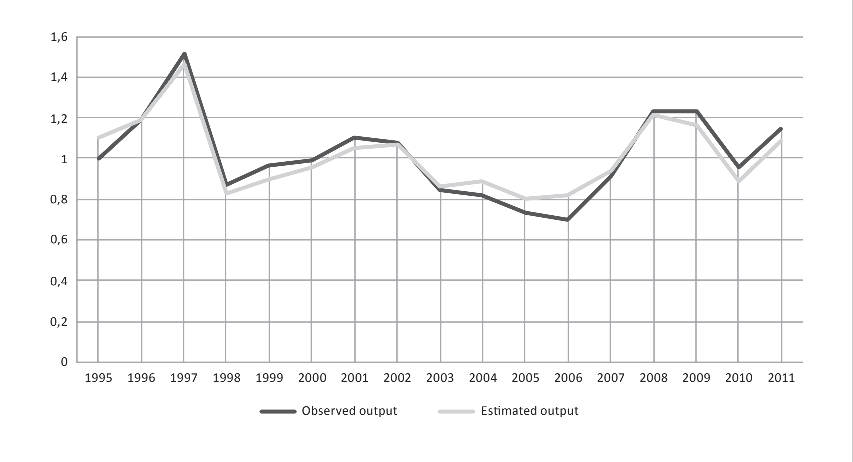
2.4 EMPIRICAL RESULTS

2.4.1 Diversity effect

This subsection presents results of the parameter estimation of the model, presented in the equation 2-15, that accounts for the overall impact of regional diversity on efficiency levels, hereinafter referred to as diversity effect model.

As shown on Figure 2-2, the model was able to capture the fluctuations in the observed output; the average deviation of the estimated output from the observed output is approximately 5%.

Figure 2-2 Observed output vs. estimated output: diversity effect model, 1995-2011.



Source: own calculations.

To prove the validity of the results we analyse the coefficients for output and input variables, presented in Table 2-4. Due to the normalisation procedure described in the previous section we can interpret first-order coefficients of variables included in the output vector as shares of these types of production in country's total agricultural output. Therefore, based on this interpretation, we can say that agricultural production in Russia accounts for, on average, 57% of animal production, 18% of crop production (excluding grain), and 25% of grain production. This finding corresponds to the relative importance of the various production types as reported by the Russian statistics service (see Figure 1-3).

Besides the coefficients for outputs we analyse the parameter coefficients for the input vector variables. Similar to our interpretation of the output parameters, the first-order coefficients of inputs are associated with production elasticities at the sample mean. To obtain information about the input shares, the first-order coefficients are weighted by the elasticity of scale, which is calculated as the negative sum of input coefficients. In our case, first-order input coefficients

Table 2-4 Constrained maximum likelihood parameter estimates: diversity effect, 1995-2011.

Variable	Value	Std. Error	t-Value
β_0	-0.06	0.00	-13.59
Output effects			
β_{y_2}	0.57	0.01	115.88
β_{y_3}	0.18	0.01	27.65
Input effects			
β_{x_1}	-0.17	0.01	-12.86
β_{x_2}	-0.23	0.00	-98.08
β_{x_3}	-0.13	0.01	-13.63
β_{x_3}	-0.38	0.01	-31.93
Technical changes			
β_t	-0.05	0.00	-85.75
β_{tt}	0.001	0.00	6.10
β_{y_2t}	-0.01	0.00	-8.62
β_{y_3t}	0.01	0.00	11.14
β_{x_1t}	-0.01	0.01	-0.76
β_{x_2t}	0.01	0.00	5.40
β_{x_3t}	0.01	0.00	8.02
β_{x_4t}	-0.01	0.00	-2.45
Output-input effects			
$\beta_{y_2y_2}$	0.57	0.02	26.86
$\beta_{y_3y_3}$	0.27	0.01	37.30
$\beta_{y_2y_3}$	-0.21	0.01	-43.18
$\beta_{x_1x_1}$	-0.07	0.05	-1.42
$\beta_{x_2x_2}$	0.03	0.01	3.30
$\beta_{x_3x_3}$	-0.02	0.01	-1.20
$\beta_{x_4x_4}$	-0.11	0.00	-105.06
$\beta_{x_1x_2}$	0.03	0.02	1.51
$\beta_{x_1x_3}$	-0.01	0.02	-0.39
$\beta_{x_1x_4}$	-0.004	0.02	-0.15
$\beta_{x_2x_3}$	-0.01	0.01	-1.38

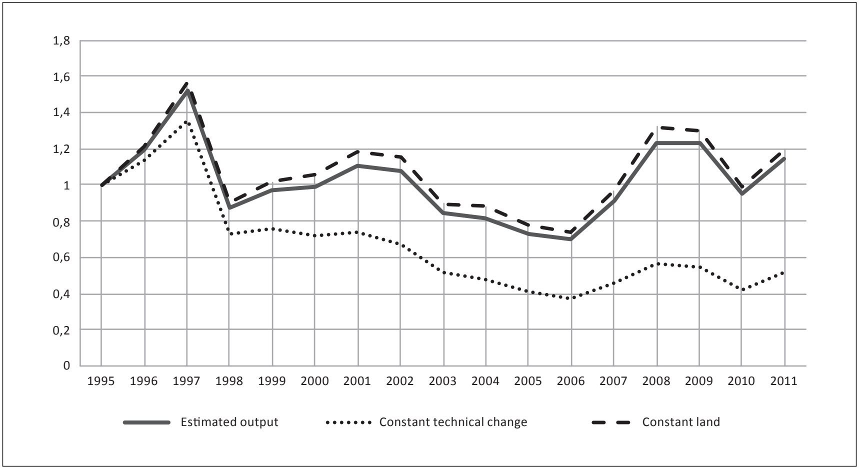
Variable	Value	Std. Error	t-Value
$\beta_{x_2x_4}$	0.01	0.02	0.96
$\beta_{x_3x_4}$	0.02	0.02	1.22
$\beta_{y_2x_1}$	0.02	0.02	0.78
$\beta_{y_2x_2}$	0.21	0.01	23.73
$\beta_{y_2x_3}$	-0.03	0.01	-2.37
$\beta_{y_2x_4}$	-0.25	0.01	-17.68
$\beta_{y_3x_1}$	0.02	0.01	1.35
$\beta_{y_3x_2}$	-0.01	0.01	-0.97
$\beta_{y_3x_3}$	0.02	0.01	1.27
$\beta_{y_3x_4}$	0.11	0.01	7.93
Regional effect			
α_m	-0.07	0.00	-18.25
α_{mt}	-0.02	0.00	-18.33
α_{mx_1}	0.02	0.01	0.18
α_{mx_2}	0.02	0.01	3.16
α_{mx_3}	-0.02	0.01	-2.30
α_{mx_4}	0.02	0.01	1.84
σ_v	0.11	0.00	88.86
σ_u	0.12	0.06	1.91

Source: own calculations.

sum up to 0.91, implying decreasing returns to scale, where more than 40% of the production costs are due to material inputs. This value corresponds to the share of material inputs in gross agricultural production. Unfortunately, for other parameters there exist no empirical values of the cost shares, making it difficult to interpret their estimates. However, accounting for different time and regional horizons, and model used, the estimated values are close to that obtained by previous study that employed similar methodology (Bokusheva, Hockmann and Kumbhakar 2012). Thus, we conclude that the estimated first-order parameters map the input and output structures of Russian agricultural production relatively close to reality and allow us to proceed with the interpretation of the model.

Overall, technical change had a positive impact on production but at a decreasing rate (Table 2-4). About 4.8% of the total increase in agricultural production was due to technical change. Estimation results suggest that animal production is steadily becoming more technologically advanced, while production of other crops is increasing due to factors other than technical change. The coefficient for land variable is positive, suggesting that factors other than land expansion contribute to an increase in production. Indeed, the coefficient for variable inputs indicate that the use of fertilisers and other materials increase throughout the observed period, proving the initial suggestion that production is becoming more land- and capital-saving and less material-saving.

Figure 2-3 Alternative output scenarios: diversity effect model, 1995-2011.



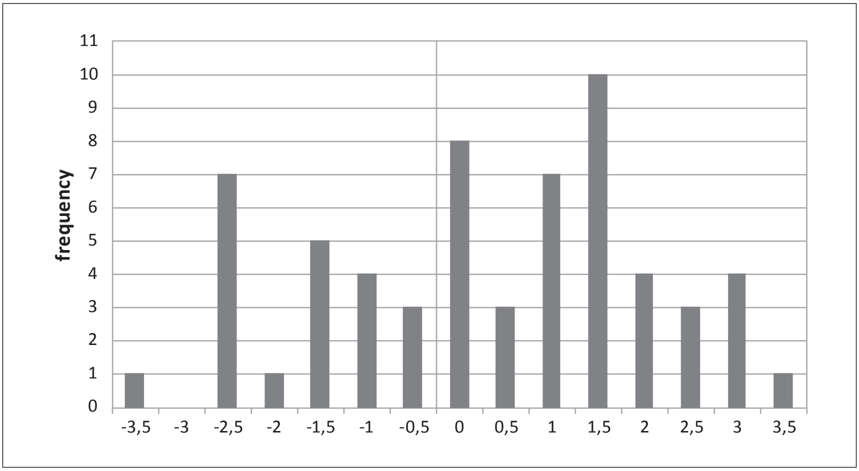
Source: own calculations.

We facilitate further analysis of the overall impact of technical change by representing alternative output scenarios in Figure 2-3. This graph compares the development of estimated output with the grain production that would have taken place if: i) the level of technological change had been constant; and ii) the amount of cultivated land had not been decreasing but rather remained constant. The dotted line represents a scenario with a constant technology, therefore highlighting the role that investments in machinery and/or equipment adoption or improved use of material inputs (seeds, pesticides) played in the observed growth in agricultural production. Without this process, the level of production would have been, on average, 50% lower in recent years. The dashed line, which shows production without a land abandonment throughout the observed period, indicates that given the current technologies of land use, more land does not necessarily lead to a significant increase in production, thereby proving the statement that grain production has become less land- and more material-oriented. Moreover, the small amount of additional output due to the increase of land indicates that mainly less productive land (low quality, deteriorated, poorly connected to the farm centre) was abandoned.

Contrary to other analyses, our estimates show that technical efficiency plays a minor role in explaining various rates of regional development. In fact, σ_u (Table 2-4) is significantly greater that zero, and it explains more than 50% of the total variation of the compound error term. However, when discussing the actual impact on production we have to consider the fact that efficiency also depends on other inputs, see equation 2-7. The estimates for these parameters are moderately small. Nevertheless, besides their impact on efficiency, the parameters presented in Table 2-4 have another interpretation: they measure the impact of regional diversity on regional production structures.

Overall, our results indicate that farms in regions differ not only in their production capabilities, but also in the adoption of technology and suitability of external conditions. As shown in Table 2-4, almost all parameters designed to capture the impact of regional diversity (m) were found to be statistically significant. The parameter a_m indicates that a higher value of m is associated with better suitability of the regions' agricultural production. In addition, each region benefits from technical change in a different way (a_{mt}). Indeed, upon the detailed

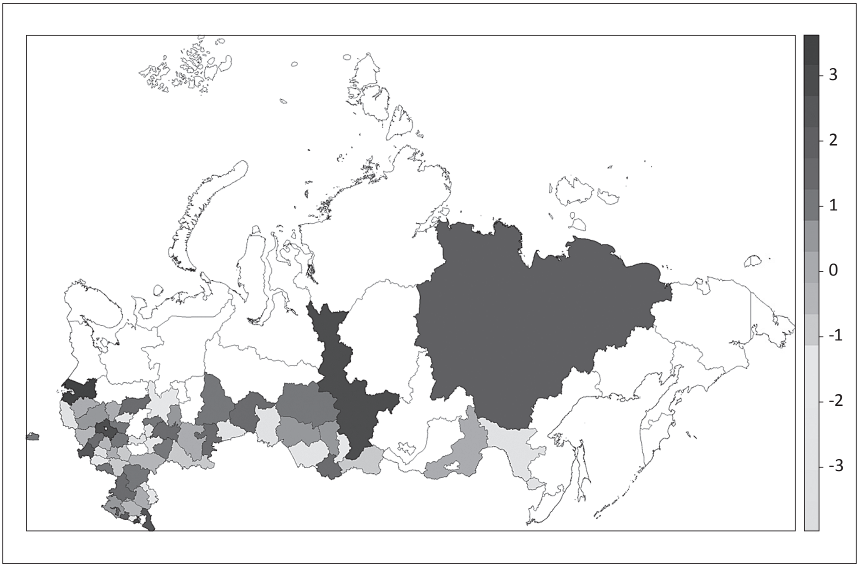
Figure 2-4 Distribution of diversity indicator (m).



Source: own calculations.

examination of the results, the impact of technical change seems to be higher in regions with better production conditions. Furthermore, the value shares of individual inputs vary in a way that regions with higher production and better production conditions tend to use a lower share of land and material inputs, but invest more in capital goods in order to boost production even further (a_{mt_3}).

Figure 2-5 Spatial distribution of diversity indicator (m).



Source: own calculations.

The parameter estimates are then used to generate estimates of a regional diversity effect using the procedure described in subsection 2.2. Figure 2-4 illustrates the distribution of indicators that capture heterogeneity across the country. The higher the value of the indicator is, the more suitable production conditions in a region are. In fact, the examination of the estimation results suggests that the regions with a higher value of m tend to be locations with good soil and favourable weather conditions for grain production; they are mainly located in the southern part of the country (see Figure 2-5). Moreover, economically advanced regions with good infrastructure also have a positive m. On the other hand, regions that are not actively involved in grain production but produce amounts sufficient for local consumption, or because they have facilities for crop production as a Soviet heritage, were found to have negative regional effect indicator values.

In this model regional characteristics add to the role of technical efficiency in traditional stochastic frontier analyses. Our approach suggests that examined regions have already been acting as efficient producers, and their location under the production frontier is explained by a set of external production conditions that characterise each particular region. This implies that the policy implications derived from traditional efficiency models have to be modified in a way that varying across country regional characteristics are more emphasised to better define the goals and implement the corresponding instruments of agricultural policy.

2.4.2 Regional characteristics

This subsection presents results, obtained through the estimation of the model, described by the equation 2-6. The results of the estimation of the stochastic cost frontier by constrained maximum likelihood estimation are shown in Table 2-5. All the explanatory variables were normalised by their geometric mean, thus allowing us to interpret their first-order coefficients as cost elasticities. Therefore, the function is increasing in output and decreasing in input levels. In addition, due to the functional form and normalisation procedure, parameters of output variables indicate the share of each type of output in agricultural output. Consistent with results from previous modelling exercise (subsection 2.4.1), estimation of the model from equation 2-6 suggests that agricultural output in the country on 50% consists of animal output, on 22% of production of other crops, and on 28% of grain production (Table 2-5).

The estimates of the production function indicate the importance of production factors for agricultural production, specifically for grain production. Input elasticities sum up to 90% suggesting the existence of decreasing returns to scale. Similar to the results from the estimation of the diversity effect model (subsection 2.4.1), the highest elasticity is observed for variable inputs (0.40). It indicates the close connection between materials and production without other factors that could potentially contribute to the production. Therefore, reduction in the use of materials such as fertilisers and other variable inputs would considerably reduce gross production of agricultural goods. Moreover, land has an elasticity of 0.21, indicating that production is becoming more material-intensive rather than land-intensive. The estimated elasticities of labour and capital are slightly less intense but still statistically significant, with indicators of 0.16 and 0.13 respectively. The relatively low elasticity of labour with respect to materials and land indicate the decreasing importance of labour in agricultural production

Table 2-5 Constrained maximum likelihood parameter estimates of the frontier: role of regional characteristics, 1995-2011.

Parameter	Estimate	Std.Err.	t-Ratio
β_0	0.025621	0.00956	2.679898
Technical change			
β_t	-0.03165	0.00305	-10.3761
β_{tt}	0.01196	0.000425	28.16434
Output effects			
β_{y_2}	0.4995	0.01643	30.40116
β_{y_3}	0.219853	0.008121	27.07138
β_{y_2t}	-0.01966	0.004006	-4.90632
β_{y_3t}	0.015046	0.003592	4.188822
$\beta_{y_2y_2}$	0.475963	0.047887	9.939359
$\beta_{y_3y_3}$	0.254158	0.007527	33.76737
$\beta_{y_2y_3}$	-0.17296	0.017965	-9.62775
Input effects			
β_{x_1}	-0.16395	0.015052	-10.8926
β_{x_2}	-0.21005	0.015123	-13.8893
β_{x_3}	-0.12908	0.017565	-7.34864
β_{x_4}	-0.40223	0.021381	-18.8121
β_{x_1t}	-0.00469	0.00285	-1.64434
β_{x_2t}	0.007157	0.003586	1.995656
β_{x_3t}	0.00322	0.002143	1.502799
β_{x_4t}	-0.00251	0.001432	-1.75346
$\beta_{x_1x_1}$	-0.0835	0.055784	-1.49679
$\beta_{x_2x_2}$	0.057653	0.021379	2.696682
$\beta_{x_3x_3}$	0.004528	0.018271	0.247829
$\beta_{x_4x_4}$	-0.13554	0.028415	-4.76997
β_{x1x2}	0.042011	0.028891	1.454119
β_{x1x3}	-0.02534	0.015127	-1.67543
β_{x1x4}	0.036849	0.034394	1.071355
$\beta_{x_2x_3}$	-0.0211	0.024411	-0.86446
$\beta_{x_2x_4}$	-0.00741	0.007177	-1.03247
$\beta_{x_3x_4}$	0.033687	0.032762	1.028219

Parameter	Estimate	Std.Err.	t-Ratio
	Output-input effects		
$\beta_{y_2x_1}$	-0.02258	0.030768	-0.734
$\beta_{y_2x_2}$	0.237941	0.029823	7.978497
$\beta_{y_2x_3}$	-0.06294	0.023108	-2.72369
$\beta_{y_2x_4}$	-0.17611	0.023216	-7.58561
$\beta_{y_3x_1}$	-0.03387	0.020712	-1.63517
$\beta_{y_3x_2}$	0.032587	0.01863	1.749115
$\beta_{y_3x_3}$	-0.01607	0.019617	-0.81932
$\beta_{y_3x_4}$	0.101337	0.022231	4.558385

Source: own calculations.

and its replacement with technological advancements. In fact, the coefficient of the correlation between technical change and labour is negative, suggesting the introduction of labour-saving technologies. At the same time, technical change was found to be capital-intensive, thus proving our initial assumption of decreas-

Table 2-6 Technology and determinants of regional diversity.

Parameter	Estimate	Std.Err.	t-Ratio
	Technology		
α_m	0.224796	0.017755	12.66120
α_{mt}	0.137213	0.014970	9.165888
α_{m1}	0.052615	0.039471	1.333005
α_{m2}	-0.00156	0.005526	-0.28319
α_{m3}	-0.03365	0.032908	-1.02242
α_{m4}	-0.03164	0.021196	-1.49253
	Regional diversity		
γ_0	0.013183	0.024183	0.54513
γ_1	0.284270	0.060682	4.68459
γ_2	0.297972	0.048810	6.10471
γ_3	0.196324	0.043218	4.54260
σ_v	0.216769	0.004083	53.0878
σ_u	0.101913	0.152221	0.66950

Source: own calculations.

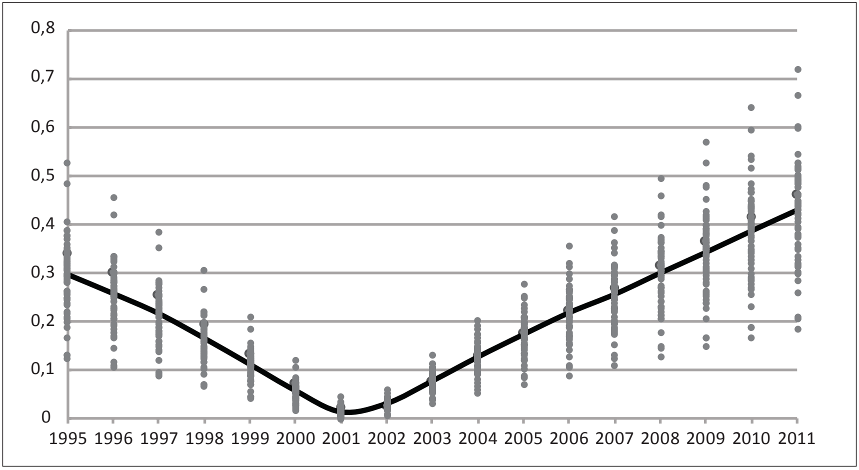
ing use of labour and increasing importance of capital as the part of production technology. Similarly, technical change is land-intensive, demonstrating evidence that production has increased due to increase in yields rather than increase in land used. Overall, the impact of technical change on agricultural production is increasing annually at 3.1% with a decelerating rate of technology development.

The initial model assumption implies that production in the country is primarily determined by specific characteristics of each particular oblast. We measure these characteristics by means of three indices described in the section 2.3. Estimation of technology and regional diversity indicators (Table 2-6) suggests that there are two leading characteristics that shape the technology and determine the level of production, namely climate (z_1) and human development (z_2). The effect of climate was expected to be high due to the country's size and variety of climatic zones, which have a direct impact on agriculture, especially on grain production. The level of economic and social development as reflected by the human development index, is positive and statistically significant, with a value similar to that of climate. Such results indicate that the higher is the level of region's development, the more investments are attracted to the oblast, and the better skills have workers and farm managers, the more efficient will therefore the production be. At the same time, higher economic and human development results in better infrastructure, transportation system and facilities for agricultural production and trade. The indicator of transportation and infrastructure system (z_3) is significant in determining the level of heterogeneity across the country – it plays an important role in agriculture in general, occupying a crucial position in trading and in distribution process. Estimation of technology (Table 2-6) indicates that regions with higher values of diversity effect tend to have higher levels of technical change, suggesting a more advanced development of agriculture in those regions.

As shown on Figure 2-6, diversity effects play a notable part in determining the production potential: with higher values of diversity its impact on the production level increases. It is worth noting that the level of influence of the diversity indicators on production decreased in the period from 1995-2001. Such a tendency can be explained by an overall decrease of actual agricultural production in general, and by lower levels of production inputs in particular, caused by economic instability and the transition to market economy, as described in Chapter 1.

Figure 2-7 provides an overview of the diversity indicator values across the country. The presented map shows evidence that conditions for agricultural production become better in the western and south-western parts of the country, where

Figure 2-6 Influence of diversity effect and inputs on production output on a regional level, 1995-2011.



Note: each dot represents the impact of diversity indicators in combination with input use on grain production in each region in specified year. The black line represents the annual average.

Source: own calculations.

favourable climate results in higher productivity, while development of regions implies better infrastructure and facilities for agricultural production and trade.

Figure 2-8 highlights the contrast between the regional diversity indicator for some selected regions (with favourable and unfavourable conditions for agricultural production). High values of the indicator imply that conditions in a region are better suited for agricultural production than in other regions with a low value of diversity. At first glance, Moscow region[26] is the one with the highest production possibilities among all other regions. However, such a suggestion is ambiguous upon examination of determinants of high value: the highest in the country density of roads provides the most favourable conditions for transportation and trade of grain, but relatively low value climate index suggests that Moscow region maybe not be the best suited for agricultural (especially crop) production. Krasnodar region, on the contrary, has favourable climate conditions, higher than the average value of human development index, and well-developed

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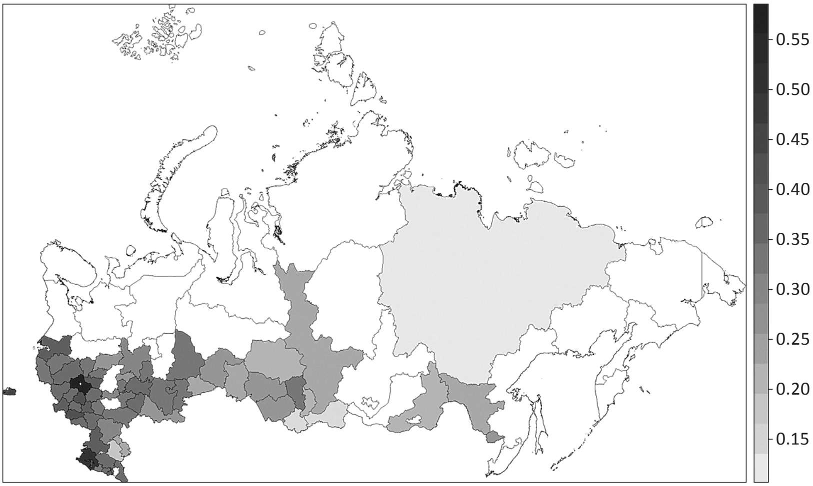
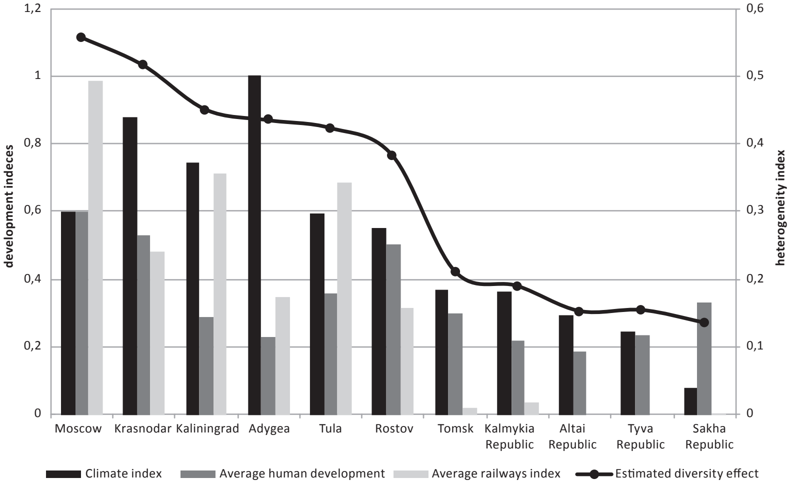
[26] Moscow region does not include the city of Moscow, which is counted in statistics as a separate federal subject.

Figure 2-7 Spatial distribution of the values of diversity indicator across the country.



Source: own calculations.

Figure 2-8 Comparison of diversity effect and its determinants in selected oblasts.



Source: own calculations.

infrastructure, which makes it the most attractive regions in terms of agricultural, and, in particular, crop production. In contrast to regions with high values of estimated diversity, regions with poor indicators of diversity (e.g. Republics Sakha, Tyva, Altai and Kalmykia, and Tomsk oblast) suffer from severe climate that prevents widespread crop production, as well as a low level of railways density, indicating the slow development of infrastructure across regions and, therefore, bad connection with other regions and trading centres.

2.5 CONCLUDING COMMENTS

In this part of the study, we extend the existing literature by evaluating the impact of regional diversity on production when farms in regions face different time-varying production technologies and time-invariant region-specific conditions. The consideration of heterogeneous regional impact essentially changes the conventional approach to SFA, which implies that production is technically inefficient by default, and it is the inefficiency in technologies that does not allow farms to reach the frontier. Our study, on the contrary, assumes that production is defined by specific characteristics of regions that indicate the level of regional development and influence the implementation of production technologies. The applied approach provides new insights into the analysis of agricultural production of the country, and presents the basis for the consistent estimation of production potential in general. Using regional level data for Russia, we test the hypothesis that grain production grew efficient over the transition years and, at its current condition, entirely depends on production technologies and external production conditions. We provide evidence that climate in combination with the level of human and institutional development and infrastructure have a significant effect on production structure of regions and therefore should not be neglected while assessing regional policies and production potential. Moreover, exploitation of production possibilities potentially has a positive impact on transition process and lead to a successful development of a region and its agriculture, thus helping regional development to become a self-enforcing process.

This part of the research implies that climate conditions remained unchanged over the observed 15 years. Indeed, the influence of climate can only be observed having longer time series at disposal. Through the analysis of past trends we can forecast with higher certainty the future productivity. The next chapter, therefore, provides a detailed analysis of climate change impact on grain productivity in Russia, and presents estimates of crop yields given various scenarios of climate change for the medium and long terms.

3 IMPACT OF CLIMATE CHANGE ON GRAIN PRODUCTION: EVIDENCE FROM PANEL APPROACH

Accumulating evidence suggests that increases in greenhouse gas concentrations will change the world climate and increase the frequency and severity of extreme weather events (IPCC 2013). Projected climate change (CC) is expected to fundamentally alter the average level and variability of temperature during seasons. Due to its direct connection with weather, agriculture is one of the economic activities expected to be most likely and significantly affected by CC (Schlenker and Roberts 2009; Fisher, Hanemann, and Roberts 2012). As a result, successful and effective adaptation of agricultural systems to CC requires knowledge of the mechanism and the magnitude of its impacts, as well as information about the ability and potential capacity of economic agents to adjust to changes in their environment (Burke and Emerick 2013).

Studies on the impacts of CC on agriculture have been based on two major approaches (Ortiz-Bobea and Just 2012). The first approach captures CC impacts by applying processed-based crop simulation models developed and calibrated for specific sites using historical crop yield and climate observations (see e.g. Mearns, Rosenzweig and Goldberg 1992; Semenov et al. 1996; Sirotenko, Abashina and Pavlova 1997; Jones and Thornton 2003; Alcamo et al. 2007). An important advantage of process-based models is their ability to simulate crop yields considering different technology choices, such as crop mix, fertiliser-use intensity, adjustments in sowing dates or use of irrigation. While, in general, processed-based models represent a valuable tool for assessing the likely impacts of CC, a few aspects might affect the accuracy and reliability of projections obtained on their basis. First, most processed-based crop simulation models exhibit a high degree of complexity, which may lead to considerable model prediction uncertainties (Schlenker and Roberts 2009) and represent a constraint for applying processed-based models to a sufficiently large number of representative locations. Second, applying crop simulation models to locations (regions) at high aggregation levels is often associated with a loss in the precision of crop growth modelling processes and an increase in the number of uncertain parameters (Lobell and Burke 2010).

The second approach relies on econometric models estimated using observational data, therefore, better capturing revealed preferences. Mendelsohn, Nordhaus and Shaw (1994) were the first to leverage econometric approaches to estimate the impact of CC on agricultural productivity. Exploiting cross-sectional variation in climate and land values across U.S. counties while controlling for potentially confounding factors such as soil types, they provided Ricardian estimates[27] of the impact of CC on agricultural profitability. Deschênes and Greenstone (2007) drew attention to a serious limitation of the Ricardian approach, namely its vulnerability to the omitted variable problem. To overcome this concern, they applied a panel approach to U.S. census data on agricultural profits with county and state-by-year fixed effects. A number of studies have followed the work by Deschênes and Greenstone (2007) and applied the panel approach to estimate reduced-form statistical crop yield models. Most studies in this line of research have been done in a U.S. context (Schlenker and Roberts 2009; Ortiz-Bobea and Just 2012; Roberts, Schlenker, and Eyer 2012). A careful analysis of CC impacts using the panel approach is still largely lacking for a number of European countries, and thus relatively little is known about the relationship between climate and agricultural productivity in Europe. Some exceptions include studies by Moore and Lobell (2014) for selected regions in the European Union countries and an application of the Ricardian approach in the context of German agriculture by Chatzopoulos and Lippert (2015) and Van Passel, Masetti, and Mendelsohn (2016).

This chapter is organised as follows. The next section provides an overview of studies that analyse the CC impact on Russian agriculture. The second section briefly describes our methodology. The third section provides an overview of the data and climate projections used. It is followed by the presentation and discussion of the main empirical results. Concluding remarks are presented in the last section.

3.1 OVERVIEW OF STUDIES ON CLIMATE CHANGE IMPACT ON RUSSIAN AGRICULTURAL PRODUCTION

The objective of this part of the research is to examine the potential impact of CC on Russian agricultural production. Considering the country's nontrivial role in world food production, described in previous chapters, climate-induced changes in agricultural productivity in Russia could have serious consequences for global food supply and world food prices. From 1976 to 2013, Russia's average annual temperature has increased at a rate of 0.43°C per decade, that is, twice as much as the global rate (Roshydromet 2014). These temperature increases might have been beneficial for areas in northern Russia that exhibit a poor suitability for

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[27] The authors name their method the Ricardian approach because they analyse the impact of climate on the net rent or value of farmland instead of traditional weather-yield relationship.

agricultural production under current climate, but at the same time might have had a damaging effect on agricultural productivity in more important grain-producing regions located in the South of the country. Therefore, on many levels Russia represents an interesting case study for analysing not only the magnitude but also the sign of CC impacts on agricultural productivity.

There have been only a few assessments of potential CC impacts on agricultural productivity in Russia. Most of the existing studies have applied crop simulation models to compute the average country-level impact of CC on the productivity of selected crops, mainly wheat and barley. Based on projections obtained using a process-based crop simulation model, Sirotenko, Abashina, and Pavlova (1997) find that average grain production in Russia might decline by 15% by the year 2030 in comparison to the 1951-1980 period. Alcamo et al. (2007) derive similar estimates of CC impacts on national production. However, when extending their analysis to the regional level, the latter study recognises that potential gains in agricultural productivity due to CC can outweigh potential damages. Alcamo et al. (2007) indicate that the range of CC impacts is very broad – varying from -9% to +12% of the country average grain production compared to the 1961-1990 reference period. These findings suggest that a number of regions in Russia could actually benefit from future changes in climate. Pavlova et al. (2014) develop and apply a crop simulation model for the steppe zones in Russia and Kazakhstan. The results of this study suggest that water scarcity during the growing season represent a major stress factor in these areas. Given that the steppe zones are expected to become more arid in the future, Pavlova et al. (2014) conclude that seasonal water shortages will be a key factor influencing grain productivity in this area. Safonov and Safonova (2013), analysing results presented by the Russian Research Institute of Agricultural Meteorology, indicate a potential decrease in grain crop yields by 9% and 17% by 2030 and 2050 relative to the year 2000, respectively. In addition, the authors point out that North-western regions are more likely to benefit from increasing temperatures and are expected to experience grain yield increases up to 8-9%. In contrast, Dronin and Kirilenko (2007) predict a rather pessimistic future for Russian agriculture. In the South-European regions of Russia that possess the best soils most suitable for crop production (chernozem soils[28]), Dronin and Kirilenko (2007) argue that potential damages to agricultural production are unlikely to be compensated by shifting agricultural production to areas up to the boreal forest zone, due to poor soil quality and hard terrain.

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[28] Black fertile soil that is conductive to high agricultural yield.

To the best of our knowledge, there are only two studies that assess the impact of CC on Russian grain production using a statistical approach. Interestingly, they arrive at contradictory results. In the study of CC impacts on global crop production, Lobell, Schlenker and Costa-Roberts (2011) find that Russia experienced the largest negative overall impact of CC worldwide during the period 1980-2008. According to these authors, recent climate trends have depressed Russian wheat yields by almost 15%. At the same time, as reported by Sirotenko and Pavlova (2012) who conducted their analysis based on a winter wheat time series aggregated at the level of the country's economic regions[29], winter wheat yields have grown at rates varying from 0.4% per decade in the Central economic region to 2.8% per decade in the Volga region over the period 1975-2010. Both studies estimated reduced-form yield models and used analogue model specifications with average seasonal temperatures and rainfall and their squares as dependent variables. The main difference in the modelling approaches of the two studies is that Lobell, Schlenker and Costa-Roberts (2011) use a fixed-effect panel model at the global scale with country-specific quadratic technology trends, whereas Sirotenko and Pavlova (2012) similar to Lobell and Field (2007) apply an econometric approach based on the first-difference time series of yields and weather variables. Moreover, while Lobell, Schlenker and Costa-Roberts (2011) use the country-level crop yield panels and accordingly aggregate the weather data up to the national levels, Sirotenko and Pavlova (2012) estimate weather-yield relationships separately for single economic regions in Russia.

In this study we aim to update projections of CC impacts on Russian grain production by using the most recent yield, weather and climate projections data for single subjects of the Russian Federation and employing a panel fixed-effect modelling approach. We build upon recent advances in the modelling of the yield-weather relationship by accounting for the potentially damaging effects of extreme temperatures (Schlenker and Roberts 2009). To capture smooth technical change, we specify and test economic region-specific time trends. CC is projected to have an equivocal effect across regions in both the medium and long terms. According to our predictions, grain productivity should increase in most of the northern regions, whereas it is predicted to drop in a number of most important grain-producing regions located in the South of the country thus causing an overall negative CC impact on Russian grain production.

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[29] Economic regions of Russia represent federal subjects, grouped according to certain common characteristics, such as geographic location, availability of natural resources and similar climate conditions, and level of social and economic development.

3.2 METHODOLOGICAL APPROACH AND MODEL DESCRIPTION

We base our analysis on panel fixed-effects regressions of crop yields on a set of crop-specific weather indicators controlling for smooth technological progress. In particular, we elaborate on the following basic form of the crop yield model:

$$\ln y_{it} = \mathbf{w}'_{it}\beta_w + u_i + f_s(t) + \epsilon_{it}, \tag{3-1}$$

where y_{it} is the yield in observation unit i (in our case oblast[30]) and year t, $\boldsymbol{w}_{it}$ is the vector of relevant weather variables, and β is the vector of model parameters. Unit-fixed effects (u_i) are used to account for oblast heterogeneity, and economic region-specific time trends $f_s(t)$ capture the effect of technological progress. This specification allows us to identify the weather effect parameters from unit-level weather deviations about the unit average while controlling for region-specific trends.

Taking into account the methodological improvements suggested by recent studies (see e.g. Schlenker and Roberts 2009; Roberts et al. 2012; Burke and Emerick 2013; Tack, Barkley, and Nalley 2015), we include the following indicators in the vector of weather variables $\boldsymbol{w}_{it}$: vegetation period growing degree days (GDD), extreme heat degree days (HDD), growing season total precipitation and its square (P and P^2 respectively) measured for the main vegetation period of a crop. Then, the model in equation (*3-1)* is specified as

$$\ln y_{it} = \beta_1 GDD_{it} + \beta_2 HDD_{it} + \beta_3 P_{it} + \beta_4 P_{it}^2 + \beta_5 HDD_{it} P_{it} + u_i + f_s(t) + \epsilon_{it}, \tag{3-2}$$

and estimated as a regression with standard error adjusted for spatial correlation (Conley 1999; Hsiang 2010). An interaction term between precipitation and HDD are introduced to account for the fact that greater precipitation may mitigate the damaging effects of extremely high temperatures (Schlenker and Roberts 2009).

Additionally, to account for the effect of temperature and precipitation on winter wheat vegetation over the autumn and winter months, we apply the following extension of the model in equation 3-2:

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[30] Oblast and krai are territorial units that can correspond to province, just as autonomous republic, but with a lower level of independence from the federal government. For simplicity, in the text we use the term oblast for all three different types of the subjects of the Russian Federation, and refer to economic regions as regions.

$$\begin{aligned}\ln y_{it} = \quad & \beta_1 GDD_{it} + \beta_2 HDD_{it} + \beta_3 P_{it}^{Spring} + \beta_4 P_{it}^{Spring^2} \\ & +\beta_7 T_{it}^{Autumn} + \beta_8 T_{it}^{Autumn^2} + \beta_9 T_{it}^{Winter} + \beta_{10} T_{it}^{Winter^2} \\ & +\beta_{11} P_{it}^{Autumn} + \beta_{12} P_{it}^{Autumn^2} + \beta_{13} P_{it}^{Winter} + \beta_{14} P_{it}^{Winter^2} \\ & +u_i + f_s(t) + \epsilon_{it},\end{aligned} \tag{3-3}$$

where T_{it} denotes average daily temperatures in the corresponding period. We test the model in equation 3-3 against the model in equation 3-2 for winter wheat to verify if weather in the autumn and winter months can explain a significant part of the variation in winter wheat yields.

Model coefficient estimates are used to predict the impact, I_{cc}, defined as the percentage change in the yields for a projected period against the yields in the baseline period, holding growing areas constant:

$$I_{CC} = \frac{\sum_{i=1}^{N} a_i e^{\mathbf{w}_{i1}' \beta_w + u_i + f_s(t=2012)}}{\sum_{i=1}^{N} a_i e^{\mathbf{w}_{i0}' \beta_w + u_i + f_s(t=2012)}} - 1, \tag{3-4}$$

where a_i denotes the crop sowing area in unit i, $\boldsymbol{w}_{i1}$ is the vector of weather variables for the projected period, $\boldsymbol{w}_{i0}$ is the vector of weather variables for the baseline period (1971-2000). We apply equation 3-4 to obtain estimates of the CC impact on grain production for two projected periods, 2046-2065 and 2081-2100.

3.3 DATA

We conduct our analysis using the data for 62 subjects of the Russian Federation[31] actively engaged in grain production, and group them into 12 economic regions with similar economic, social and natural conditions. We use agricultural data for three major grain crops in Russia–winter wheat, spring wheat, and spring barley–over the period 1955-2012, as reported by the Russian Federation Federal Statistics Service (Rosstat 1992-2014; TsSU 1956-1991). Descriptive statistics for agricultural data and weather variables for the 1955-2012 period are presented in Table 3-1.

We concentrate our analysis on grain production because it covers over 57.8% of the country's total sown area (Figure 3-1), and, therefore, plays a crucial part

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[31] As of 2016, Russia consisted in total of 85 subjects of the Federation.

Table 3-1 Descriptive statistics: grain yields and weather conditions.

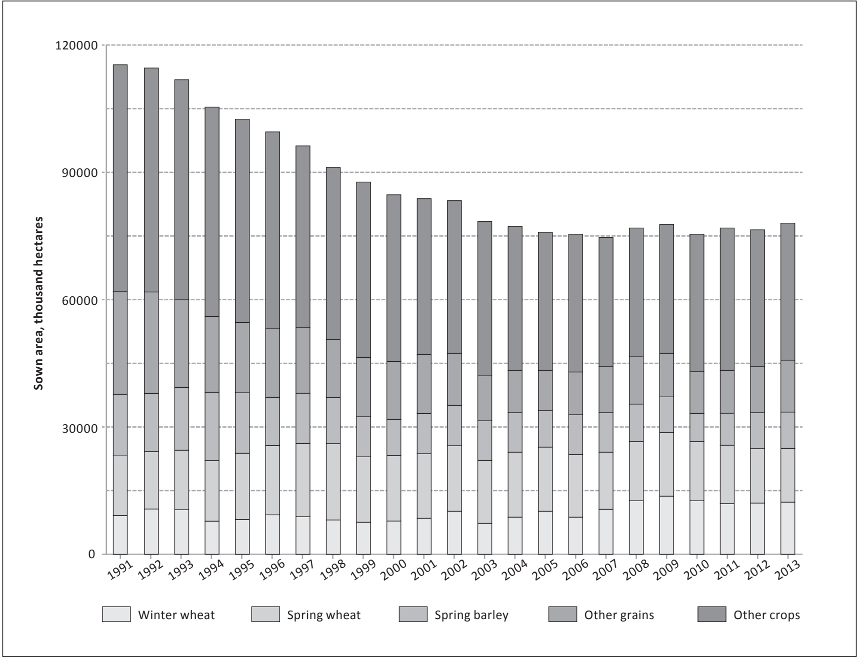
	Unit	Mean	Median	Min	Max	Std. dev
			Agricultural data			
Winter wheat						
Yield	tonnes/ha	1.87	1.77	0.17	5.54	0.79
Sown area	thousand ha	174.83	46.7	0.01	2071.50	337.71
Spring wheat						
Yield	tonnes/ha	1.19	1.13	0.01	4.33	0.53
Sown area	thousand ha	356.77	91.3	0.10	5150.50	646.11
Barley						
Yield	tonnes/ha	1.29	1.20	0.05	4.17	0.61
Sown area	thousand ha	181.82	86.40	0.03	2425.60	262.18
			Weather data			
Winter wheat						
GDD	units	837.89	816.38	187.48	1504.59	216.01
HDD	units	8.76	4.68	0.00	111.55	11.30
Average temperatures Sept-Nov	°C	4.83	4.92	-6.53	14.47	3.70
Average temperatures Dec-Feb	°C	-10.02	-9.09	-30.41	5.47	6.31
Total precipitation March-June	mm	241.22	235.74	56.12	568.30	72.14
Total precipitation Sept-Nov	mm	135.69	129.31	21.81	365.78	50.22
Total precipitation Dec-Feb	mm	97.47	97.33	6.78	342.95	43.26
Spring grains						
GDD	units	1189.21	1189.77	591.55	1753.70	189.60
HDD	units	21.34	12.85	0.04	189.53	24.19
Total precipitation	mm	177.27	176.64	27.37	422.32	56.03

Source: Rosstat (1992-2014); TsSU (1956-1991); Sheffield, Goteti, and Wood (2006).

in Russian agricultural development. The analysis is conducted for three major types of grain, i.e. winter wheat, spring wheat, and spring barley. During the period 2001-2013 winter wheat accounted for 13.9% of the total sown area and 24.1% of the grain sown area. Its average share in the country's total grain production was 35.7% over the same period (Figure 3-2). The shares of areas sown in spring wheat and spring barley were 31.9% and 19.6% from 2001 to 2013. During this period these two crops contributed 22.8% and 18.0% of total grain production, respectively.

The weather variables were calculated using the Global meteorological forcing dataset of 1.0° grid resolution by Sheffield, Goteti, and Wood (2006). Using information on the spatial distribution of crop areas under grains as in 2009 (Bontemps et al. 2010), we derive spatially weighted average, maximum, and minimum daily

Figure 3-1 Structure of sown area, 1991-2013.

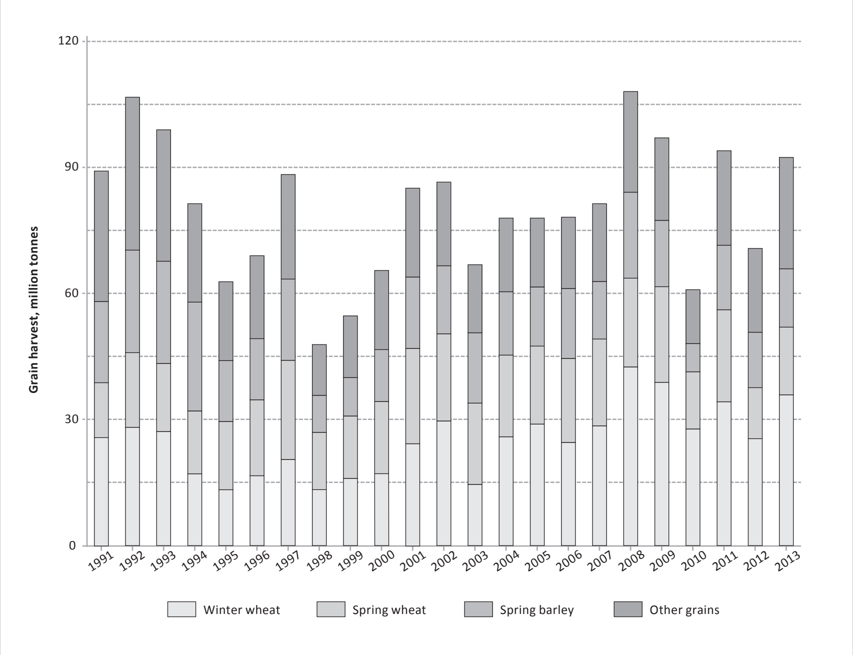


Source: Rosstat (1992-2014).

temperatures and precipitation levels for crop-specific growing seasons. We use these data to calculate necessary weather variables for the models specified in equations 3-2 and 3-3. For winter wheat, we set the summer growing season to the period from March the 1st to June the 30th and also control for weather in the autumn (September the 1st - November the 30th) and winter (December the 1st – February the 28th) months. For both spring grains (spring wheat and spring barley), we define a growing season of totally three months covering the period from May the 1st to July the 31st.

The two previous studies that applied statistical crop yield models to assess the impact of CC on Russian agriculture use average monthly or seasonal temperatures (Lobell, Schlenker and Costa-Roberts 2011; Sirotenko and Pavlova 2012). In our research we build upon recent advances in modelling of the yield-weather relationship and account for the effect of extreme temperatures by distinguishing between growing degree days (GDD) and heat degree days (HDD) temperature measures (Schlenker and Roberts 2009; Tack, Barkley, and Nalley 2015). To com-

Figure 3-2 Structure of grain production, 1991-2013.



Source: Rosstat (1992-2014).

pute GDD and HDD, we approximate the distribution of daily temperatures (T_i) within each day using a trigonometric sine curve connecting daily minimum and maximum temperature records (Snyder 1985).[32]

Following Stöckle (2013) we set the baseline temperature for all three grain crops to 3°C (T_b) and the upper bound temperature to 25°C (T_u), and calculate GDD and HDD based on the following principle:

$$GDD = \begin{cases} T_b & if\ T_i \leq 3 \\ T_i - T_b & if\ T_b < T_i < T_u \\ T_u & if\ T_i \geq T_u \end{cases} \tag{3-5}$$

and

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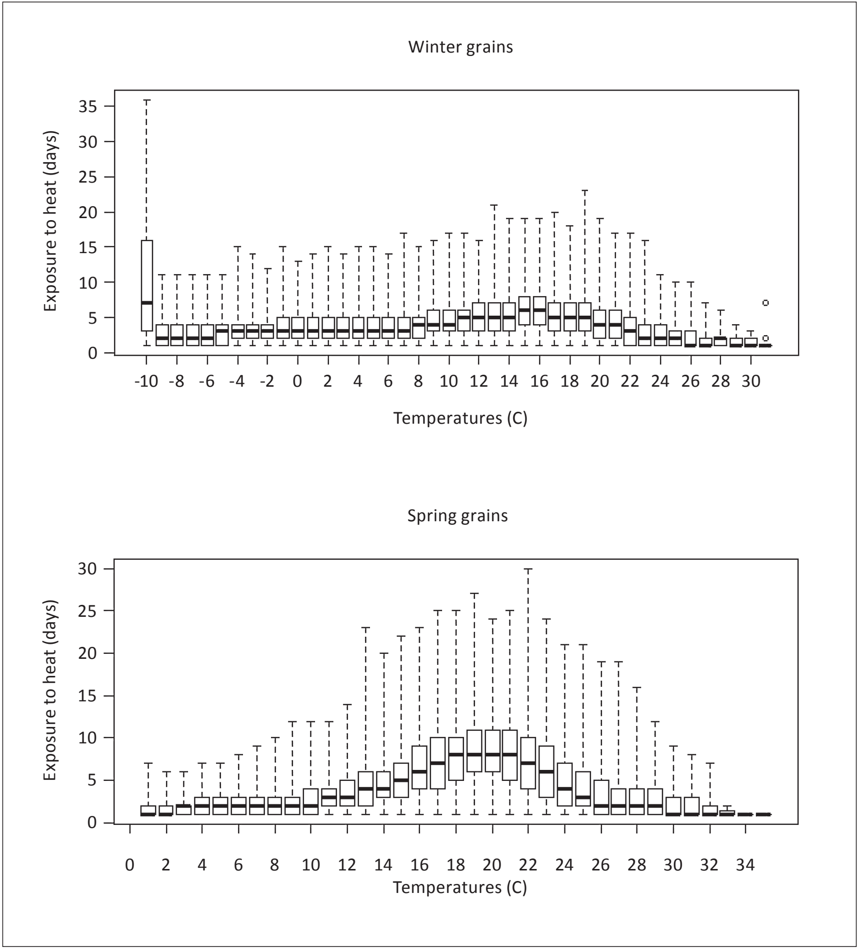
[32] For a detailed explanation of method, used to compute growing and heat degree days measures, see Appendix C.

$$HDD = \begin{cases} 0 & if\ T_i \leq T_u \\ T_i - T_u & if\ T_i > T_u \end{cases} \tag{3-6}$$

Figure 3-3 shows the distribution of days when winter and spring grains were exposed to each 1°C temperature interval during the growing season using all historical observation (for single years and oblasts). It demonstrates that spring grains are more likely to be exposed to extreme heat events than winter grains. This finding suggests that the former might be more vulnerable to potential increases in summer temperatures. In contrast, winter wheat is more likely to avoid exposure to extreme temperatures because its vegetation starts much earlier in spring, thus helping the plant to finish its formation to a larger extent before the period with the hottest days of the year in June and July.

Predictions of climate change were derived from the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2014). We use the climate model developed by the Hadley Centre for Climate Prediction and Research (HadGEM2-ES), and obtain monthly model output for four representative concentration pathways (RCP)–RCP2.6, RCP4.5, RCP6.0 and RCP8.5–relying on different assumptions of future development paths, such as economic, technological or demographical changes, which, in turn, result in different levels of greenhouse gas emissions in the atmosphere (IPCC 2014). Table 3-2 presents main characteristics of the representative concentration pathways, used in the current study. The most optimistic pathway–RCP2.6–assumes a rapid economic growth, a moderate increase of global population until the middle of the century and a decline afterwards, a balanced use of different energy sources, and aggressive CC mitigation strategies that result in peak emissions in the short run and their gradual decline until the end of the century. This storyline projects an increase in mean global temperatures by 0.3 to 1.7°C in the long run relative to 1986-2005. RCP4.5 (medium-low pathway) and RCP6.0 (medium-high pathway) adopt fast economic growth, related to changes in economic structure and the switch to information technology with clean and energy-saving technologies in order to stabilise emission levels by the end of the 21st century. According to both medium RCPs, emissions are expected to reach their peak only in 2070-2100 and decrease thereafter. The resulting changes in global temperatures are projected to range from 1.1 to 2.6°C for RCP4.5 and from 1.4 to 3.1°C for RCP6.0. Finally, RCP8.5 implies that the global economy continues its business-as-usual development, resulting in a very heterogeneous and fragmented world with temperature changes varying between 2.6 and 4.8°C. Therefore, we consider RCP8.5 as the worst-case scenario and RCP2.6 as the best-case outcome. For all four pathways and both time horizons, based on the daily projections provided by IPCC (2014), we compute 20-year averages of daily minimum temperature, daily maximum temperature and monthly total precipitation and use these data to derive necessary weather variables for the projected periods.

Figure 3-3 Descriptive statistics: Growing season temperatures, 1955-2012.



Note: Graphs show the distribution of temperatures during the growing season (March-June for winter wheat, and May-July for spring wheat and spring barley). Whiskers show the maximum and minimum exposure to the selected temperature range. Box marks observations that fall into the 25-75% percentile range, and the bold line indicates the sample median.

Source: own representation of data by Sheffield, Goteti and Wood (2006).

Figure 3-4 presents the differences in the projected and baseline temperatures distribution for the growing seasons of winter and spring grains for all four RCPs and two projected periods. The number of days with an average daily temperature above 25°C is projected to increase practically in all 62 oblasts covered in our study. However, the magnitude of the exposure to extreme temperatures varies substantially across individual oblasts. In addition, the differences between baseline and projected temperatures are in general much higher for spring grains than for winter wheat. Except for the best-case scenario (RCP2.6), projections of the other three RCPs suggest an increase in the exposure to heat degree days in the long term compared to the medium term.

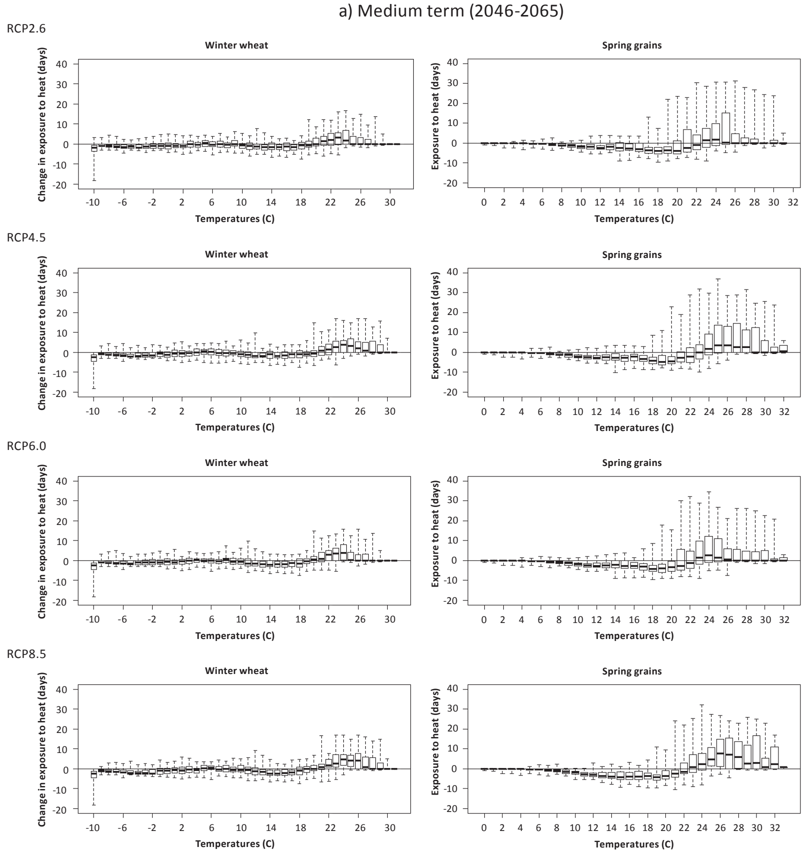
Available climate projections provide estimates of average minimum and maximum daily temperatures for each month. Using changes in average monthly maximum and average monthly minimum temperatures relative to the baseline period, we reconstruct the course of daily temperatures by employing the same procedure as when using historical data, and successively derive the two degree days measures. Total seasonal precipitation values are constructed using projections of daily precipitation. Descriptive statistics for baseline and projected periods for each of the four pathways, including indicators of degree days and precipitation, constructed for winter and spring crops, are presented in Tables 3-3 and 3-4.

Table 3-2 Main characteristics of representative concentration pathways.

RCP	Radiative forcing	Temperature change (baseline 1986-2005)				Change in CO2-eq emissions compared to 2010 (in %)		Pathway of CO2-eq concentrations	Main energy source	Air pollution	Land-use
		2046-2065		2081-2100							
		Mean	Likely range	Mean	Likely range	2050	2100				
2.6	2.6 Wm^2 by 2100	1.0	0.4-1.6	1.0	0.3-1.7	-72 to -41	-118 to -78	Peak and decline	Bio-energy and CCS	Medium-low	Medium for crop-land and pasture
4.5	4.5 Wm^2 post 2100	1.4	0.9-2.0	1.8	1.1-2.6	-38 to 24	-134 to -50	Stabilisation without overshoot	Fossil fuels	Medium	Very low for crop-land and pasture
6.0	6 Wm^2 post 2100	1.3	0.8-1.8	2.2	1.4-3.1	18 to 54	-7 to 72	Stabilisation without overshoot	Fossil fuels	Medium	Medium for crop-land and low for pasture
8.5	8.5 Wm^2 in 2100	2.0	1.4-2.6	3.7	2.6-4.8	52 to 95	74 to 178	Rising	Fossil fuels	Medium-high	Medium for crop-land and pasture

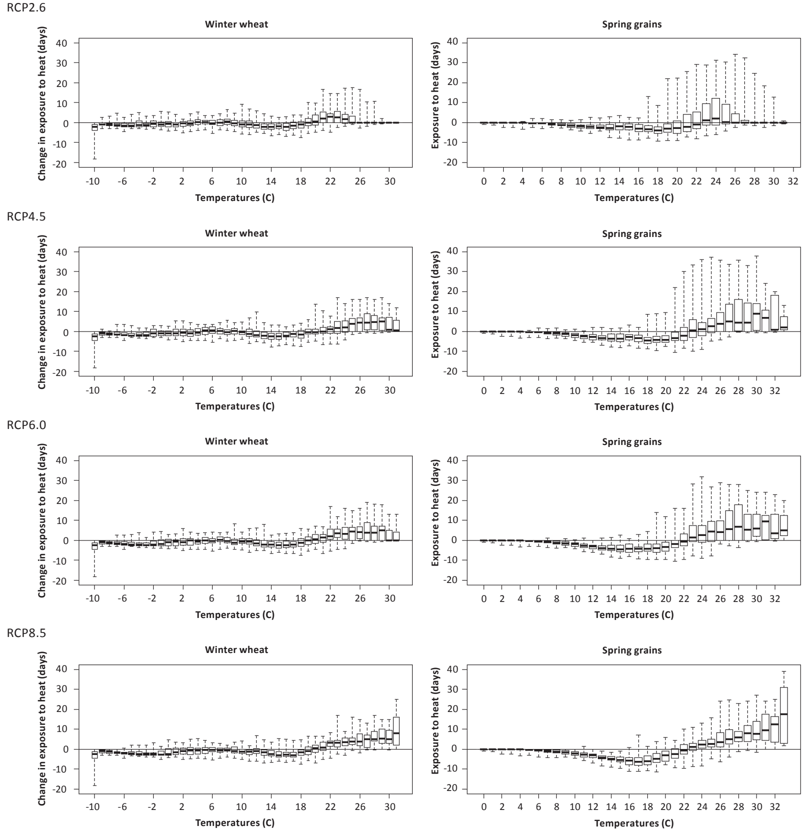
Source: own illustration based on IPCC (2014); van Vuuren et al. (2011).

Figure 3-4 Differences in baseline temperatures (1971-2000) and climate change projections under HadGEM2-ES for four selected representative concentration pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) for (a) medium term and (b) long term projected periods.



a) Medium term (2046-2065)

b) Long term (2081-2100)



Note: Graphs show the changes in the distribution of mean temperatures during the growing season (March-June for winter wheat, and May-July for spring wheat and spring barley). Whiskers show the maximum and minimum exposure to the selected temperature range. Box marks observations that fall into the 25-75% percentile range, and the bold line indicates the sample median.

Source: Own calculation based on IPCC (2014) and Sheffield, Goteti and Wood (2006).

Table 3-3 Descriptive statistics: Weather variables for the winter wheat vegetation season in the baseline period and under four representative concentration pathways in the medium term and long term projected periods.

Pathway	Period	Variable	Mean	Median	Min	Max	St.dev
Baseline	1971-2000	GDD	887.76	848.10	646.91	1274.85	168.49
		HDD	10.21	8.14	0.61	44.67	8.76
		Average daily temperatures Sept-Nov	5.41	4.93	0.73	12.30	2.82
		Average daily temperatures Dec-Feb	-8.42	-7.90	-16.52	1.12	4.25
		Total precipitation March-June	240.56	237.99	100.72	408.92	58.79
		Total precipitation Sept-Nov	141.92	147.75	55.67	205.82	35.28
		Total precipitation Dec-February	101.88	104.05	47.71	208.43	30.27
RCP2.6	2046-2065	GDD	1103.01	1091.81	749.32	1500.31	202.47
		HDD	21.39	14.15	0.00	89.00	21.64
		Average daily temperatures Sept-Nov	8.55	7.64	2.58	15.56	3.52
		Average daily temperatures Dec-Feb	-5.69	-6.26	-17.28	5.58	5.92
		Total precipitation March-June	228.00	214.75	83.01	454.39	68.77
		Total precipitation Sept-Nov	158.67	155.96	107.72	216.30	27.70
		Total precipitation Dec-Feb	167.39	169.96	88.18	343.00	41.64
RCP2.6	2081-2100	GDD	1097.56	1089.73	748.50	1478.61	189.49
		HDD	19.29	12.20	0.00	84.41	20.78
		Average daily temperatures Sept-Nov	8.18	7.20	2.43	15.30	3.51
		Average daily temperatures Dec-Feb	-6.27	-6.57	-17.42	4.98	5.92
		Total precipitation March-June	240.91	236.47	90.68	450.92	65.80
		Total precipitation Sept-Nov	174.44	175.49	107.77	254.58	29.30
		Total precipitation Dec-Feb	154.90	158.55	85.88	297.30	34.57
RCP4.5	2046-2065	GDD	1171.85	1157.99	795.98	1553.70	194.01
		HDD	34.88	26.73	0.04	112.26	27.34
		Average daily temperatures Sept-Nov	8.98	8.01	2.85	16.40	3.61
		Average daily temperatures Dec-Feb	-4.83	-4.81	-16.05	5.65	5.70
		Total precipitation March-June	234.04	227.23	88.05	441.65	64.35
		Total precipitation Sept-Nov	146.19	141.56	92.40	218.77	28.59
		Total precipitation Dec-Feb	166.07	170.77	88.03	327.64	41.30
RCP4.5	2081-2100	GDD	1219.45	1217.81	835.88	1594.56	189.00
		HDD	51.14	45.13	0.04	144.58	36.53
		Average daily temperatures Sept-Nov	9.85	8.85	4.59	16.81	3.39
		Average daily temperatures Dec-Feb	-4.81	-5.28	-15.09	5.74	5.47
		Total precipitation March-June	224.62	212.99	78.98	429.47	65.42
		Total precipitation Sept-Nov	163.87	168.00	105.87	237.58	27.70
		Total precipitation Dec-Feb	159.32	162.01	92.14	325.63	37.92

Pathway	Period	Variable	Mean	Median	Min	Max	St.dev
RCP6.0	2046-2065	GDD	1173.13	1173.32	786.51	1548.16	189.53
		HDD	28.74	20.09	0.01	104.80	25.97
		Average daily temperatures Sept-Nov	8.56	7.58	2.98	15.85	3.56
		Average daily temperatures Dec-Feb	-5.44	-5.76	-15.66	4.94	5.58
		Total precipitation March-June	234.69	234.44	87.57	428.11	61.81
		Total precipitation Sept-Nov	165.29	162.97	110.13	256.00	30.52
		Total precipitation Dec-Feb	163.28	163.06	93.34	335.27	40.19
RCP6.0	2081-2100	GDD	1295.05	1294.61	939.41	1666.35	188.15
		HDD	41.97	37.51	0.31	135.47	33.00
		Average daily temperatures Sept-Nov	10.66	9.85	5.08	17.46	3.36
		Average daily temperatures Dec-Feb	-3.19	-3.39	-13.14	6.89	5.30
		Total precipitation March-June	219.22	206.39	77.53	405.85	64.24
		Total precipitation Sept-Nov	147.99	148.10	97.09	221.14	26.14
		Total precipitation Dec-Feb	167.77	171.89	92.91	312.41	38.27
RCP8.5	2046-2065	GDD	1220.20	1213.83	866.45	1573.36	186.79
		HDD	39.26	33.39	0.05	129.62	31.21
		Average daily temperatures Sept-Nov	9.44	8.44	4.08	16.61	3.45
		Average daily temperatures Dec-Feb	-4.17	-4.64	-14.28	5.82	5.30
		Total precipitation March-June	214.71	201.37	74.94	427.30	68.19
		Total precipitation Sept-Nov	151.20	147.99	99.66	240.10	28.70
		Total precipitation Dec-Feb	171.78	175.26	90.19	340.82	41.52
RCP8.5	2081-2100	GDD	1430.33	1436.50	1063.18	1780.65	177.28
		HDD	92.51	82.29	13.13	216.81	50.37
		Average daily temperatures Sept-Nov	12.99	12.15	7.94	19.61	3.23
		Average daily temperatures Dec-Feb	-1.37	-1.63	-10.97	8.04	5.02
		Total precipitation March-June	224.88	221.94	81.30	403.35	59.29
		Total precipitation Sept-Nov	164.08	160.01	106.39	236.35	35.14
		Total precipitation Dec-Feb	188.88	192.85	103.42	366.77	43.42

Source: own calculations based on IPCC (2014) and Sheffield, Goteti and Wood (2006).

Table 3-4 Descriptive statistics: Weather variables for the spring wheat and barley vegetation season in the baseline period and under four representative concentration pathways in the medium term and long term projected periods.

Pathway	Period	Variable	Mean	Median	Min	Max	St.dev
Baseline	1971-2000	GDD	1183.73	1185.37	710.89	1567.63	166.06
		HDD	20.42	15.29	1.99	90.82	17.09
		Total precipitation	179.33	181.51	105.49	268.75	34.29
RCP2.6	2046-2065	GDD	1411.25	1431.43	970.81	1750.02	187.29
		HDD	49.92	36.66	0.00	217.60	53.44
		Total precipitation	192.82	172.78	61.32	427.27	80.82
RCP2.6	2081-2100	GDD	1423.79	1456.36	959.40	1757.08	186.72
		HDD	46.51	29.76	0.00	203.45	49.76
		Total precipitation	232.43	216.96	82.76	474.00	86.76
RCP4.5	2046-2065	GDD	1489.68	1528.35	1020.10	1789.04	186.02
		HDD	80.30	68.23	0.00	267.67	67.00
		Total precipitation	189.72	166.46	61.88	453.46	81.94
RCP4.5	2081-2100	GDD	1546.90	1576.37	1098.86	1819.03	175.88
		HDD	108.40	108.14	1.34	330.97	85.82
		Total precipitation	180.15	156.79	53.19	443.44	82.69
RCP6.0	2046-2065	GDD	1487.61	1534.46	987.06	1799.57	193.95
		HDD	67.50	58.75	0.06	250.77	63.31
		Total precipitation	203.34	192.20	75.28	420.30	70.60
RCP6.0	2081-2100	GDD	1570.29	1594.01	1174.99	1830.06	151.03
		HDD	95.29	87.64	1.00	314.53	76.98
		Total precipitation	173.49	150.42	51.23	440.00	86.47
RCP8.5	2046-2065	GDD	1544.81	1569.37	1113.54	1832.03	171.05
		HDD	96.11	86.69	2.66	313.73	77.70
		Total precipitation	182.45	161.54	57.02	437.05	87.03
RCP8.5	2081-2100	GDD	1664.82	1716.16	1303.02	1855.16	149.05
		HDD	202.05	197.91	40.61	486.65	111.92
		Total precipitation	169.92	144.84	53.69	486.48	85.89

Source: own calculations based on IPCC (2014) and Sheffield, Goteti and Wood (2006).

3.4 RESULTS AND DISCUSSION

The following section presents estimates of the relationship between grain productivity and climate and provides discussion of obtained results. The first subsection demonstrates the results of model estimation and discusses them in terms of past yield outcomes, while the second subsection shows the application of obtained estimation results to calculate the impact of climate change on future agricultural productivity.

3.4.1 Past yield outcomes

The model estimation results are presented in Table 3-5. Our estimates indicate a positive response of grain yields to GDD. The respective coefficient estimates are of about the same magnitude for all three crops, and indicate that an additional growing degree day (i.e. day when temperatures remain above 3°C and do not exceed 25°C) increases the yield by 0.12% for winter wheat, by 0.10% for spring wheat and by 0.11% for barley. Similar to the results obtained by Schlenker and Roberts (2009) we find a negative impact of extreme temperatures on grain yields in Russia.

Additionally, the HDD coefficient is higher for both spring grains than for winter wheat. Each additional heat degree day (i.e. exposure to temperatures above 25°C) reduces the yield of winter wheat by 0.8%, of spring barley by 0.9%, and of spring wheat by 1.3%. The probability of daily temperatures exceeding the 25°C threshold is considerably higher for spring wheat and spring barley than for winter wheat (Tables 3-3 and 3-4), since a larger part of their vegetation period (phenology phases such as tillering, heading, earing and grain formation) takes place in June and July. This explains a higher elasticity of yields in HDD for these two crops. In addition to accumulated temperatures during the summer season, the model for winter wheat includes average daily temperatures and total precipitations for the autumn and winter months. The model estimates suggest an inverse U-shaped response of winter wheat yields on both average temperature and total precipitation in autumn with the optimal seasonal temperature of 12.6°C and the optimal precipitation in the autumn months of 262 mm. Considering that the average daily temperature was varying between 0.7 and 12.3 in the baseline period (Table 3-5), an increase in autumn temperatures should positively influence productivity of winter grains. With a total precipitation in autumn varying between 55.7 and 205.8 mm across regions and years in the baseline period (Table 3-3), winter wheat seems to not entirely exploit fully its biological potential in practically all Russian oblasts. Although a reduced specification of the model for winter wheat excluding average daily temperatures and total precipitation in the winter months, and their squares was rejected, the majority of corresponding parameter estimates did not receive statistically significant estimates.

We find a positive response of grain yields to summer precipitation. The coefficient estimates for spring grains suggest that barley requires considerably

Table 3-5 Model estimation results, 1955-2012.

Variable	Winter wheat	Spring wheat	Spring barley
GDD	0.123***	0.098***	0.113***
	(0.012)	(0.009)	(0.009)
HDD	-0.791***	-1.285***	-0.918***
	(0.181)	(0.199)	(0.178)
T^{autumn}	7.891***	-	-
	(1.812)		
T^{autumn^2}	-0.312**	-	-
	(0.130)		
T^{winter}	-1.952*	-	-
	(1.076)		
T^{winter^2}	-0.057	-	-
	(0.061)		
P^{summer}	0.274***	1.134***	1.013***
	(0.077)	(0.085)	(0.079)
P^{summer^2}	0.0001	-0.003***	-0.002***
	(0.000)	(0.000)	(0.000)
P^{autumn}	0.523***	-	-
	(0.069)		
P^{autumn^2}	-0.001***	-	-
	(0.000)		
P^{winter}	-0.037	-	-
	(0.110)		
P^{winter^2}	-0.001	-	-
	(0.001)		
$HDD \cdot P^{summer}$	-	0.003***	0.001
		(0.001)	(0.001)
R^2	0.985	0.972	0.972
Observations	2790	3218	3422

Note: Standard errors are presented in parentheses; *, ** and *** denote statistical significance at the 10%, 5%, and 1% significance level, respectively. Coefficients and corresponding standard errors are multiplied by 100.

Source: own calculations.

more precipitation from May to July to exploit fully its biological potential than spring wheat: the optimum amount of rainfall is estimated to be 253 mm for barley and to 189 mm for spring wheat. This outcome can be explained by production practices used on Russian farms: traditionally wheat is placed directly after the fallow in the rotation to make it maximally benefit from the moisture accumulated in the soil during the fallowing. This practice makes spring wheat less sensitive to shortages in summer precipitation. Finally, the coefficient estimates of the interaction terms ($HDD\ P^{summer}$) were found to be statistically not significant for winter wheat and spring barley. However, our results suggest that a similar phenomenon as found by Schlenker and Roberts (2009) in the context of US agriculture is observed for spring wheat in Russia: the interaction term of and the summer precipitation is positive and statistically significant indicating that summer precipitation helps to reduce heat stress on spring wheat.

3.4.2 Projected yield changes under Hadley climate change scenarios

Climate change impacts on the productivity of the three studied grain crops under Hadley models for each of four RCPs are presented in Table 3-6. Our estimates go in line with the assessments of earlier studies on the impact of climate change on Russian agriculture (Sirotenko, Abashina, and Pavlova 1997; Alcamo et al. 2007) and project the overall country-wide effect of climate change on grain yields to be negative. In case of the least harmful representative concentration pathway–RCP2.6, crop area-weighted average yield of three studied grains is predicted to reduce by 1.6% in the medium term. However, this estimate is not statistically significant. The value of the long term aggregate impact on productivity of three studied drains is statistically significant and project an increase by 7.7% compared to the 1971-2000 period. An increase in productivity in the long term can be explained by decreases in emissions concentrations projected to take place according to this RCP in the middle of the century. This is expected to slow down upwards shifts in temperatures and soften the effect of global warming on agriculture in the long term. For RCP4.5, which assumes the stabilisation of emissions in the atmosphere only by the end of the century, the estimates are significant for both projected periods and predict the production of three grains to decrease by 14.5% and by 27.7% in the medium and long terms, respectively. According to RCP6.0, which just as well assumes the stabilisation of emissions concentrations by the end of the century, the impact of CC on the aggregate productivity of three studied grains was found to be statistically not significant in the medium term. However, with a statically significant estimate projecting a 22.3% decrease, the long term effect of global warming is expected to be close to that of RCP4.5. The difference between the two medium RCPs expresses itself in relatively low number of heat waves that are projected in the medium term in RCP6.0. Less heat waves results in a lower number of heat degree days thus creating more favourable conditions for crop production. However, in the long run RCP6.0 aligns with similar in terms of emissions RCP4.5, resulting in a significant productivity decline. In the business-as-usual pathway, RCP8.5, which assumes complete absence of measures to mitigate climate change and consequently growing surface temperatures, grain productivities are projected to show a significant decrease, by 21.2% and 52.2% in the medium and long terms, respectively.

Our estimation results suggest that winter wheat is likely to benefit from increasing temperatures in the autumn and winter months as well as from increasing growing degree days, our analysis indicates that by causing a rise in the number of days with extreme temperatures and substantially reducing precipitation levels in the most important winter-wheat producing regions in South Russia, CC should be expected to have a mainly damaging effect on winter wheat yields. Only a considerable reduction in GHG concentrations that could take place in the long term under RCP2.6 could result in a slight increase in winter wheat productivity. For all other projections, which were found to be statically significant, production of winter wheat is projected to reduce in both the medium and long terms: from 12.5% (RCP4.5) to 19.6% (RCP8.5) in the medium term and from 15.5% (RCP6.0) to 44.3% (RCP8.5) in the long term compared to the baseline period.

Spring wheat productivity is expected to increase under RCP2.6 from 12.4% in the medium term to 23.7% in the long term. Its increase is also possible in the case of RCP6.0 in the medium run. This positive impact of CC on spring wheat is mainly a result of the spatial distribution of production in Russia: spring wheat is predominantly concentrated in those European regions of the country, where CC is projected to result in a GDD increase and a limited rise in HDD. Currently major spring wheat producing regions have not yet reached their full production potential because the growing season is not sufficiently long for development of the plant. Therefore, a moderate increase in summer temperatures can improve conditions for spring wheat production in these regions. However, the warmer the climate is projected to be, the more damaging is its potential impact on farming. Our results for RCP4.5 indicate that spring wheat productivity might decline significantly (by 20.1%) in the long term, while, according to the business-as-usual RCP, it could fall down by 11.3% in the medium term and by 52.2% in the long run compared to the 1971-2000 period.

Table 3-6 Predicted climate change impact under HadGEM2-ES for four selected representative concentration pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

Pathway	Period	Total	Winter wheat	Spring wheat	Spring barley
RCP2.6	2046-2065	-0.0156	-0.0427	0.1242***	-0.1440***
		(0.0279)	(0.0394)	(0.0190)	(0.0205)
	2081-2100	0.0771**	0.0217	0.2373***	-0.0228
		(0.0347)	(0.0349)	(0.0406)	(0.0305)
RCP4.5	2046-2065	-0.1447***	-0.1245**	-0.0630	-0.2900***
		(0.0468)	(0.0552)	(0.0431)	(0.0374)
	2081-2100	-0.2768***	-0.2416***	-0.2014***	-0.4429***
		(0.0586)	(0.0723)	(0.0513)	(0.0433)
RCP6.0	2046-2065	-0.0311	-0.0503	0.0939**	-0.1561***
		(0.0418)	(0.0483)	(0.0365)	(0.0391)
	2081-2100	-0.2225***	-0.1551**	-0.2057***	-0.3750***
		(0.0565)	(0.0647)	(0.0585)	(0.0388)
RCP8.5	2046-2065	-0.2122***	-0.1955***	-0.1131**	-0.3730***
		(0.0539)	(0.0603)	(0.0570)	(0.0040)
	2081-2100	-0.5218***	-0.4431***	-0.5215***	-0.6750***
		(0.0804)	(0.1038)	(0.0679)	(0.0511)

Note: Standard errors are presented in parentheses; *, ** and *** denote statistical significance at the 10%, 5%, and 1% significance level, respectively.

Source: own calculations.

Contrary to our expectations, spring barley, unlike spring wheat, is not expected to benefit from climate change in any projection. For all RCPs and time horizons productivity of spring barley is projected to decline substantially. Our study identifies a statically significant reduction by 14.4% in the medium term for RCP2.6. For RCP4.5, we predict a statistically significant fall in barley productivity due to CC–by 29.0% and 44.3% in the medium and long terms, respectively. Given a climate development according to RCP6.0, the barley production can potentially decrease by 15.6% in the medium term and 37.5% in the long term. The impact under RCP8.5 would be most damaging: barley yields can reduce by 37.3% and 67.5% in the medium and long terms, respectively. This drastic fall in barley yields is associated in a joint effect of an increased number of heat degree days and lower level of precipitation, projected for main barley producing regions located predominantly in the southern regions of the country which under current climate already have a relatively high probability of heat waves and dry weather periods. Spring barley traditionally was planted in these regions because it has a more developed root system and thus can better resist long periods of dry weather. This explains why the aggregate impact of climate change might be more damaging in case of barley than spring wheat.

Our study predicts serious differences in the CC impact across single oblasts. Figures 3-5, 3-6, and 3-7 show the spatial distribution of the projected CC impacts for two selected RCPs at the oblast level in the medium and long terms for three examined crops.[33] Although the magnitude of productivity changes varies across RCPs, trends in productivity for single oblasts indicate similar developments in both RCPs (the only exception is RCP2.6, which projects predominantly positive impact of CC in the long term). At the first glance, it seems that the effect on winter wheat (Figure 3-5) is rather positive than negative. In fact, winters in the northern and Siberian parts become warmer, thus creating better conditions for the germination and tillering. However, the share of these regions in the country's wheat production is very small. As mentioned above, most important winter wheat producing regions are located in the South of the country. In these regions, the production is projected to suffer from rising temperatures in summer and spring.

The CC impact on spring wheat, presented in Figure 3-6, is assessed to be negative for most regions in the South of the European part of the country. Spring wheat productivity is expected to decline partly due to a higher number of HDD and partly due to lack of precipitation in the summer period. According to RCP8.5 most regions in the South Siberia are expected to experience an increase in spring wheat productivity, while the same regions under RCP2.6 are projected to show a significant reduction in productivity of this crop. This difference in our assessment results is due to the fact that RCP2.6 projects higher than any other RCP levels of precipitation and an only modest increase in temperatures. This change should worsen conditions for growing spring grains in these regions: given high levels of precipitation a significantly higher increase in growing degree days is necessary to improve spring grain productivity. The latter, however, is expected to happen under RCP8.5 and thus positively affect spring wheat yields in a number of grain-producing regions in Siberia. Northern regions of Russia mainly benefit from the global warming in both RCPs in the

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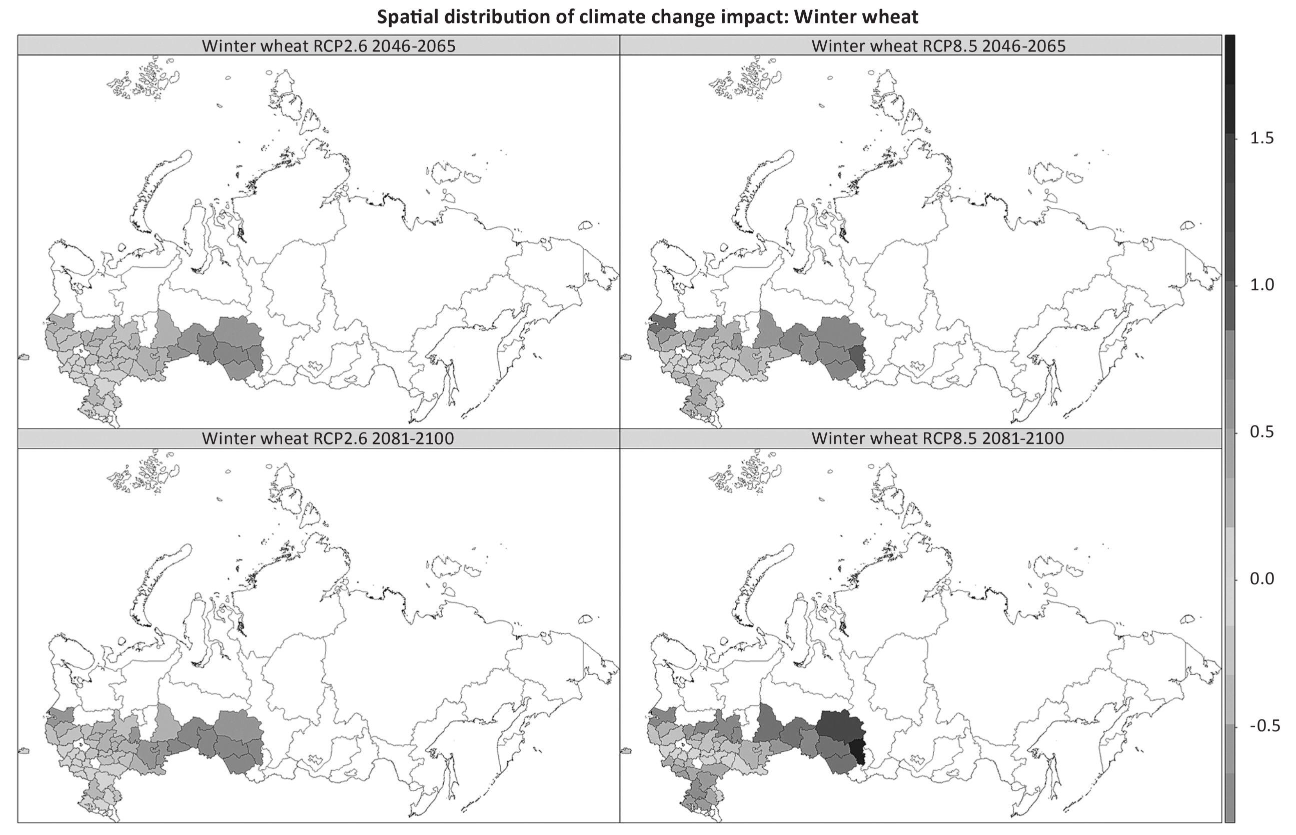
[33] Figures D.1, D.2, and D.3 in Appendix D show spatial distribution of projected climate change for other two scenarios (RCP4.5 and RCP6.0).

Figure 3-5 Predicted climate change impact under HadGEM2-ES for winter wheat at the oblast level for two selected representative concentration pathways (RCP2.6 and RCP8.5).



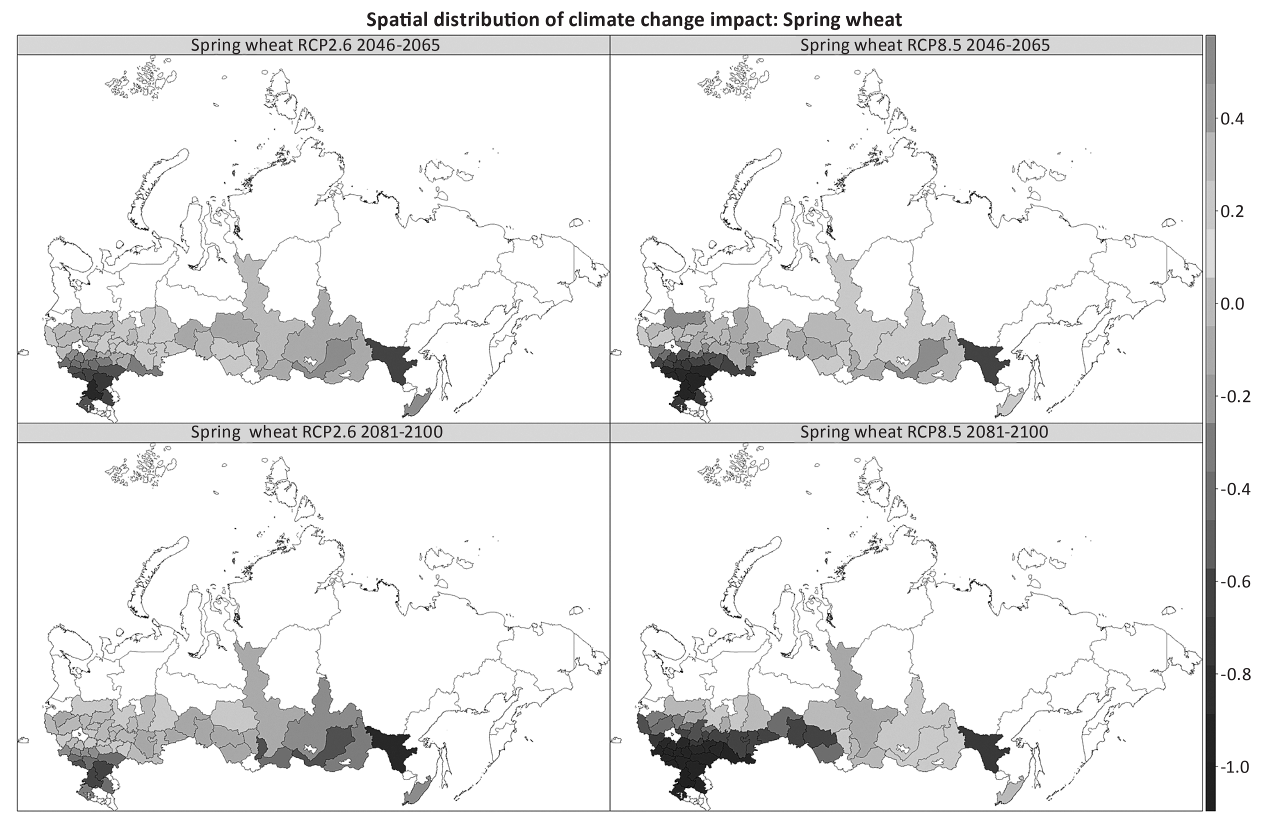
Source: own calculations.

medium term, but might be negatively affected in the long term. A prolonged growing period as indicated by a higher number of GDD and higher levels of precipitation projected for the summer period under RCP2.6 are expected to considerably increase productivity of spring wheat in both medium and long terms. Given a high share of these regions in the national production of spring wheat, this is expected to increase the aggregate yield of spring wheat under RCP2.6. However, higher rises in temperatures projected by RCP8.5 would lead to a considerable increase in heat degree days which would damage spring wheat yields also in these regions. This explains a negative effect of CC on the aggregate spring yield in RCP8.5 (Table 3-6).

Spring barley (Figure 3-7) is traditionally considered as a crop that is least vulnerable to heat waves or sudden frosts, and therefore, it is planted country-wide, including southern regions, which are often exposed to temperature extremes during the summer months. In these regions, barley productivity is expected to decline greatly due to high exposure to HDD in the summer period. In regions where conditions are expected to become more favourable (predominantly in the North of the country and some regions in Siberia) the share of cropland allocated to spring barley is relatively low presently to have any significant impact on the aggregate productivity of this crop. Therefore, the impact of CC on aggregate productivity of barley is assessed to be negative.

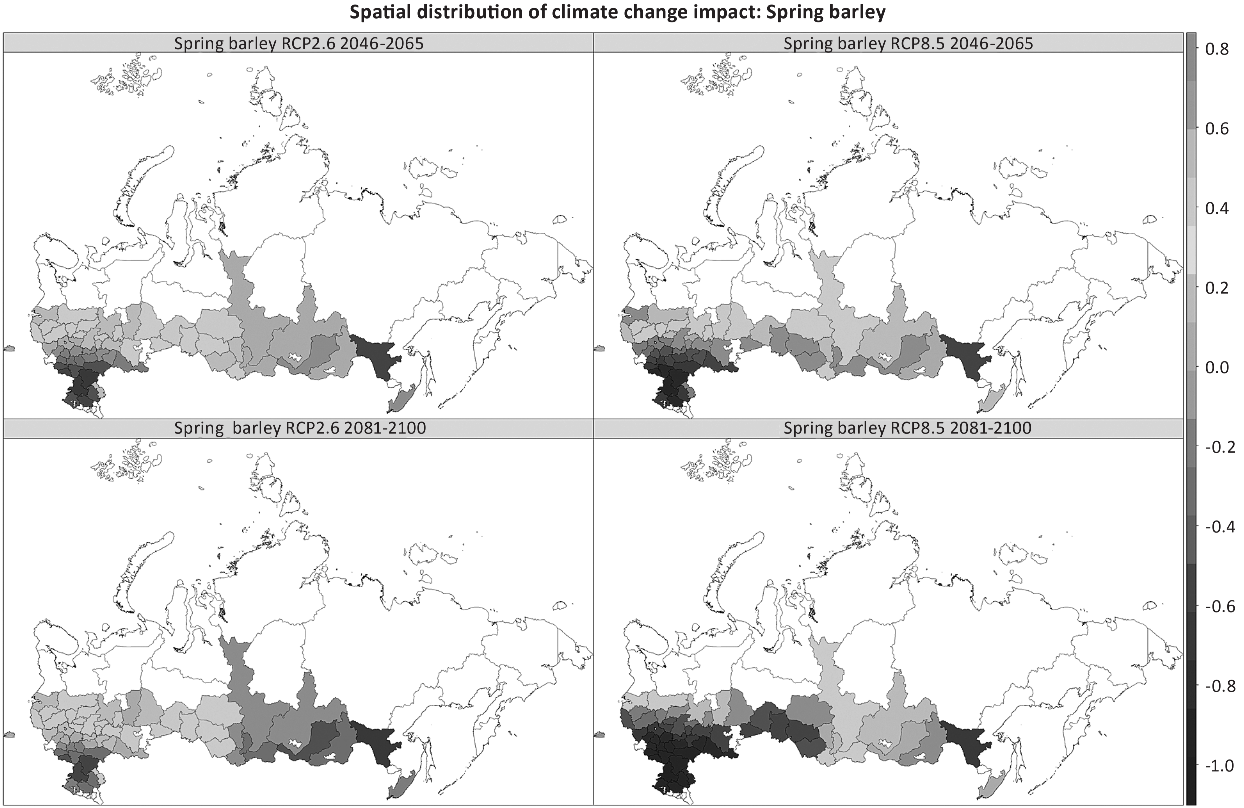
A more detailed examination of the oblasts level CC effects on grain yields shows that in the absence of new adaptation measures agricultural productivity in Russia might result in a dramatic decline. Winter grain productivity is expected to show a decline of up to 50% in the most productive and important grain-producing regions of the country with highly fertile black soils–Krasnodar, Rostov and Stavropol. An option to mitigate negative impact of CC on agricultural production in Russia would be a shift of grain production to the northern and Siberian parts of the country. Warmer and milder climate in autumn and early springs in the central and northern Russia, and Siberia, might have a beneficial effect for the development of winter wheat, while warmer summers will create favourable conditions for spring grains. However, several recent studies (Prishchepov et al., 2013; Schierhorn et al., 2013) draw attention to the process of land abandonment, which took place in Russia during the 1990s and resulted in a substantial shrinkage in agricultural land in these regions. Therefore, extensive investments would be required to restore agricultural production in such areas. Moreover, given a relatively low soil fertility in the majority of regions in the Northern and Siberian parts of the country, this option would not offset production losses caused by climate change in most productive regions in South Russia.

Figure 3-6 Predicted climate change impact under HadGEM2-ES for spring wheat at the oblast level for two selected representative concentration pathways (RCP2.6 and RCP8.5).



Source: own calculations.

Figure 3-7 Predicted climate change impact under HadGEM2-ES for spring barley at the oblast level for two selected representative concentration pathways (RCP2.6 and RCP8.5).



Source: own calculations.

3.5 CONCLUDING REMARKS

Using recent advances in statistical crop yield modelling, this part of the research investigates the potential impact of climate change on productivity of the three most important grains in Russia. Our study results indicate that CC might have a positive effect on winter wheat, spring wheat and spring barley productivity in a number of regions in the northern and the Siberian part of Russia. In contrast, most productive southern regions are projected to experience considerable decreases in productivity of all three crops.

Holding current grain growing areas fixed, the aggregate productivity of three grains is projected not to change significantly in the medium term and to increase by 7.7% in the long term under the most optimistic RCP2.6. This positive impact is mainly due to an increased productivity of spring wheat in the majority of northern grain-producing regions of the country where conditions for grain production are expected to improve due to an extended and warmer vegetation period. Based on the projections of the other three representative emission concentration pathways, the aggregate productivity of three studied crops is assessed to decrease from 14.5% (RCP4.5) to 21.2% (RCP8.5) in the medium term and from 22.2% (RCP6.0) to 52.2% (RCP8.5) by the end of the century. However, considering that our historical climate-yield relationship is identified from a year-to-year variation in weather about a smooth time trend capturing the effect of technological adjustments, our estimates control only for short-run adaptations of the kind that were present in the historical period and do not take into account any serious changes in production practices and adaptation strategies. Therefore, more research is required to evaluate the effect of different adaptation measures and their effectiveness in reducing negative impact of climate change on Russian agriculture. Our research suggests that in the medium and long terms, an effective option to mitigate the negative impact of CC on Russian grain production could be an extension of grain production to North Russia. Milder autumns and earlier springs due to global warming can considerable improve growing conditions for winter and spring grains in these regions. However, the lack of infrastructure and low soil productivity make these regions not attractive for private investments. Moreover, given relatively low soil fertility in the majority of regions in the northern Russia, this option would not help to offset production losses caused by climate change in the South. Therefore, more efforts are required to adapt agricultural production in currently most productive regions of the country to climate change. Water scarcity in combination with increased spring and summer temperatures might considerably affect productivity of both winter and spring grain crops in these regions. Accordingly, adaptation measures should focus on breeding new–more drought-resistant–grain varieties and adopting soil moisture accumulating and preserving technologies.

CONCLUSIONS

In the last decade Russia transformed from the net importer to the net exporter of grain, thus occupying important position on the world grain market. Among the main drivers behind this rapid growth researchers traditionally name changes in legislative system that allowed non-agricultural companies to invest in agricultural sector, transforming soviet type cooperative farms into large, vertically integrated, organisations that are now widely known as agroholdings. Agroholdings in turn, due to their size and investments in technology, minimised transaction costs and increased productivity, establishing the practice of large-scale agricultural production. In addition to investments brought to the sector, favourable weather that persisted in the last decade played an important role in boosting productivity, increasing grain harvests to an amount that enabled to fulfil the needs of domestic market and to enter and actively participate in the world grain trade. This research therefore intends to provide a comprehensive analysis of Russian grain production and determine the possibilities for Russia in the future to keep its position as one of the largest suppliers of grain on the world market of agricultural goods. The main contribution of the study is that it recognises the importance of climate conditions for the successful and beneficial grain production. We state that climate determines the efficient production on a regional level, take into account and analyse climatic conditions in relation to the historical dataset of grain yields, and employ projections of climate change to determine grain productivity in the medium and long runs. We base our analysis on the assumption that future productivity almost entirely depends on forthcoming changes in temperatures and precipitation, given the current level of existing production technologies. Thus, adequate policy measures and efficient management of agricultural production should not neglect the influence of changing climate and concentrate the medium- and long-term development of agriculture on mitigating the impact of global warming on strategically important grain sector.

The study is twofold. We first use the productivity analysis framework to analyse the efficiency of grain production in Russia, and set the main determinants of productivity on a regional level. The main argument that underlies our decision to first conduct the efficiency analysis lies in the fact that efficiency and production technologies in the past decade have significantly improved, bringing grain production on a higher level and signalling that some external factors might determine production volumes. We aimed to update existing studies and contribute to the knowledge of technical progress impact on grain production. In addition, by applying a modified approach to the Stochastic Frontier Analysis we manage to separate the impact of factors that usually remain outside the boundaries of farmers' control and therefore often remain unaccounted for in theoretical research. We develop several indicators that aim to capture the effect of social and infrastructural development, transportation system and climate conditions on the production efficiency of each regional unit in Russia. The empirical results from the productivity analysis indicate that grain production became almost completely efficient from the point of view of input application. Given its current condition, it entirely depends on production technology and factors beyond the control of agricultural producers. We find evidence that climatic conditions in combination with the level of human and institutional development and infrastructure have a significant impact on production structure on a regional level and cannot be neglected while assessing production potential of the country. Moreover, the exploitation of production possibilities can have a positive effect on transition process and lead to successful economic development of grain producing regions. Overall, despite the large diversity of conditions in regions and regional potential, the largest problem that regions face right now is the creation of their own growth trajectory that would compensate negative trends in agriculture. It is important to keep in mind that each territorial unit should be treated in a unique way, applying different approaches to the agricultural development, given the diversity and various conditions which regions are facing.

Having established that climate plays an important part in Russian agricultural production and determines production efficiency on a regional level, we then analyse its impact on grain production in more details. We study three most important grains planted in Russia, i.e. winter wheat, spring wheat and spring barley, in their relation to past temperatures and precipitation levels during their vegetation period and use future climate conditions as projected by the latest available assessment report on climate change made by IPCC (2014) to calculate estimates of the future productivity of three named crops in the medium (2046-2065) and long (2081-2100) runs. We find that climate change is expected to have a positive impact on winter wheat, given milder winters and warmer springs. Similarly, spring wheat and spring barley, planted in northern and some south Siberian parts of the country, are projected to experience increases in productivity, as a result of warmer summers caused by changing climate. However, Russia's most productive and rich of black soil regions, located in the South, are expected to face heat waves and droughts that could damage harvests of all three examined crops. Accordingly, adequate measures should be taken to mitigate the negative impact of climate change on Russian grain production. One possibility, suggested by obtained results, can be the extension of grain producing areas to the North of the country. Given milder autumns and winters and warmer springs and summers in the medium and long terms, productivity of all three grain types can potentially achieve higher levels. Nevertheless, considering lower levels of infrastructure development and soil fertility, higher production in the North is not likely to compensate losses of other, currently more productive, southern regions. In view of this, adaptation measures should be taken to soften the negative effect of global warming. The problem that grain producing regions are face at the moment or might encounter in the future are water scarcity and increasing temperatures in springs and summers, and, therefore, the main challenge is not only to develop grain varieties that resist to droughts and heat waves and maintain high yields, but also to adopt technologies that allow for the accumulation and preservation of moisture in soils.

The analysis conducted in this study faced a number of difficulties and, therefore, suffers from some limitations. Although regional data allows us to conduct an extensive overview of agricultural production within the country, it provides only limited characteristics of regions, where production conditions beyond the farmer's scope, such as climate, soil quality, vicinity to the closest distribution centre, can significantly vary within each territorial unit, distorting the estimation of agricultural production and projections of climate change impact on productivity. Thus, it should always be kept in mind that obtained results characterise average conditions in each region. Unfortunately, the absence of comprehensive data on municipal or farm level limits a more detailed and profound analysis. The second limitation resided in uncertainty of estimates of future climate, both temperatures and precipitation. Although the latest IPCC report provides estimates with 95% confidence level, the uncertainty remains and the possibility that projections do not precisely coincide with future weather conditions, especially weather anomalies, still remains elevated. Finally, historical data obtained from the USSR statistical agency raises some doubts about its validity. Nevertheless, the methodology employed in chapter 3 requires the most extensive dataset in order to obtain accurate projections, and therefore, even approximate estimates of yields as those provided by the state statistical agency can serve as a useful instrument to establish the connection between agriculture and climate conditions.

Given these limitations, the issues related to climate change impact on agriculture require further investigation. Thus, future research might employ a more precise dataset on the farm or municipal level to obtain better estimates of global warming on agriculture in specific locations. In addition, it is of policy interest, in view of current economic and political situation and instability on the market, to analyse the potential impact of changing climate on crops, other than grains, to justify considerable investments made in agriculture. Future research may also include all sectors of agriculture, including animal production, to estimate the overall effect of changing climate on farming in Russia. Current research identifies climate and productivity relationship from a year-to-year variations in weather and employed smooth time trend control only for short-term adaptations to changing climate, not accounting for any considerable changes in production practices and adaptation technologies. Therefore, another direction for theoretical and empirical analysis is to evaluate the impact of adaptation strategies on productivity, as well as their effectiveness in softening the negative impact of climate change on grain production.

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APPENDICES

APPENDIX A - MAIN CHARACTERISTICS OF FEDERAL SUBJECTS OF THE RUSSIAN FEDERATION

Table A.1 Main characteristics of federal subjects of the Russian Federation, 2014.

Region	GRP in 2013, mln.roubles	Territory (thousand km²)	Population (as of 1.01.2015)	Agricultural production, mln.roubles	Share of crop production	Share of animal production	Grain harvest	Area sown under grains	Share of winter wheat sown area	Share of spring wheat sown area	Share of spring barley sown area
					Central						
Belgorod oblast	569414.1	27.1	1547.9	188217	0.28	0.72	35248.4	794.1	0.37	0.00	0.30
Bryansk oblast	223324.3	34.9	1233.0	56323	0.41	0.59	8938.4	317.9	0.33	0.06	0.08
Vladimir oblast	307486.0	29.1	1405.6	32793	0.49	0.51	1884.8	82.0	0.15	0.27	0.33
Voronezh oblast	606667.7	52.2	2331.1	158945	0.63	0.37	44726.9	1425.0	0.36	0.02	0.30
Ivanovo oblast	157735.1	21.4	1036.9	15721	0.53	0.47	1310.6	62.1	0.19	0.21	0.19
Kaluga oblast	293433.8	29.8	1010.5	31327	0.50	0.50	1404.6	67.9	0.17	0.11	0.21
Kostroma oblast	143108.2	60.2	654.4	19449	0.50	0.50	653.9	41.1	0.01	0.25	0.13
Kursk oblast	272238.0	30.0	1117.4	98311	0.59	0.41	42118.3	980.9	0.41	0.04	0.30
Lipetsk oblast	314790.4	24.0	1157.9	81964	0.61	0.39	25275.0	760.9	0.37	0.06	0.39
Moscow oblast	2551284.2	44.3	7231.1	89980	0.58	0.42	2840.5	102.3	0.28	0.07	0.51
Oryol oblast	164525.8	24.7	765.2	52317	0.68	0.32	31368.8	791.1	0.47	0.03	0.26
Ryazan oblast	278731.8	39.6	1135.4	46061	0.59	0.41	13979.1	476.4	0.30	0.07	0.46
Smolensk oblast	225594.8	49.8	964.8	21927	0.41	0.59	2281.7	108.5	0.18	0.14	0.08
Tambov oblast	235859.7	34.5	1062.4	93528	0.57	0.43	31201.8	992.5	0.32	0.11	0.37
Tver oblast	291408.1	84.2	1315.1	24450	0.37	0.63	1083.0	66.6	0.06	0.13	0.02
Tula oblast	347060.2	25.7	1513.6	45852	0.60	0.40	14645.2	474.7	0.35	0.12	0.35
Yaroslavl oblast	360731.5	36.2	1271.6	30059	0.35	0.65	970.5	46.8	0.06	0.23	0.27
City of Moscow	11632506.4	2.6	12197.6	9434	0.72	0.28	40.6	2.0	0.26	0.15	0.32

Region	GRP in 2013, mln.roubles	Territory (thousand km²)	Population (as of 1.01.2015)	Agricultural production, mln.roubles	Share of crop production	Share of animal production	Grain harvest	Area sown under grains	Share of winter wheat sown area	Share of spring wheat sown area	Share of spring barley sown area
Northwestern											
Rep. Karelia	175975.0	180.5	632.5	5449	0.51	0.49	0.7	0.1	-	-	-
Rep. Komi	490741.1	416.8	864.5	9763	0.36	0.64	0.1	0.0	-	-	-
Arkhangelsk oblast	512393.6	589.9	1183.3	13706	0.50	0.50	56.1	3.0	-	0.22	0.50
Vologda oblast	341137.6	144.5	1191.0	25588	0.34	0.66	2317.7	105.7	0.01	0.17	0.65
Kaliningrad oblast	277362.6	15.1	969.0	25296	0.53	0.47	4291.8	112.5	0.38	0.23	0.15
Leningrad obalst	692798.6	83.9	1775.5	86359	0.30	0.70	1274.2	38.6	0.04	0.11	0.54
Murmansk oblast	307459.3	144.9	766.3	2639	0.25	0.75	-	-	-	-	-
Novgorod oblast	177930.1	54.5	618.7	21418	0.42	0.58	388.3	14.5	0.34	0.22	0.24
Pskov oblast	114246.5	55.4	651.1	20700	0.28	0.72	1119.4	38.6	0.35	0.09	0.19
City of Saint-Petersburg	2496549.0	1.4	5191.7	-	-	-	-	-	-	-	-
Southern											
Rep. Adygea	72011.6	7.8	449.2	16335	0.58	0.42	5416.4	134.7	0.58	0.00	0.00
Rep.Kalmykia	41136.8	74.7	280.5	20023	0.12	0.88	2973.3	191.1	0.70	0.00	0.22
Krasnodar krai	1617875.9	75.5	5453.3	286519	0.72	0.28	128708.5	2410.6	0.58	0.00	0.02
Astrakhan oblast	267511.5	49.0	1021.3	31024	0.57	0.43	287.6	13.1	0.06	0.06	0.37
Volgograd obalst	606122.6	112.9	2557.4	107805	0.70	0.30	39137.6	1950.9	0.53	0.04	0.18
Rostov oblast				923531.7	101.0	4242.1	191316	0.67	0.33	93453.5	3212.4
Northcaucasian											
Rep.Dagestan	429510.6	50.3	2990.4	87915	0.45	0.55	3117.1	128.1	0.45	0.01	0.10

Region	GRP in 2013, mln.roubles	Territory (thousand km^2)	Population (as of 1.01.2015)	Agricultural production, mln.roubles	Share of crop production	Share of animal production	Grain harvest	Area sown under grains	Share of winter wheat sown area	Share of spring wheat sown area	Share of spring barley sown area
Rep. Ingushetia	45171.0	3.6	463.9	5464	0.38	0.62	977.1	46.8	0.35	0.01	0.02
Rep. Kabardino-Balkaria	113229.8	12.5	860.7	34330	0.53	0.47	9382.1	207.7	0.24	0.00	0.03
Rep. Karachaevo-Cherkessia	62704.4	14.3	469.0	23838	0.41	0.59	2990.4	83.3	0.28	0.01	0.16
Rep. North Ossetia - Alania	112138.5	8.0	705.2	25719	0.31	0.69	6504.2	127.2	0.20	-	0.01
Rep. Chechnya	118150.7	15.6	1370.3	15250	0.23	0.77	1594.7	138.1	0.56	-	0.04
Stavropol krai	478368.0	66.2	2799.5	149001	0.68	0.32	85557.8	2293.0	0.74	0.00	0.03
Volga											
Rep. Bashkotorstan	1266983.0	142.9	4072.0	136920	0.43	0.57	24209.2	1750.9	0.05	0.33	0.23
Rep. Mari El				124400.2	23.4	687.4	38514	0.38	0.62	2258.4	143.7
Rep. Mordovia	149331.7	26.1	808.9	46280	0.41	0.59	9468.6	432.5	0.15	0.13	0.52
Rep. Tatarstan	1547151.7	67.8	3855.0	185974	0.48	0.52	33659.8	1572.3	0.16	0.31	0.26
Rep. Udmurtia	404833.7	42.1	1517.5	60293	0.42	0.58	6097.9	359.2	0.01	0.22	0.38
Rep. Chuvashia	224447.6	18.3	1238.1	37054	0.53	0.47	5541.7	264.7	0.17	0.32	0.39
Perm krai				893409.8	160.2	2637.0	41669	0.41	0.59	3646.9	243.8
Kirov oblast	224726.5	120.4	1304.4	34198	0.40	0.60	6712.3	319.7	0.03	0.25	0.30
Nizhny Novgorod oblast	925832.9	76.6	3270.2	67100	0.51	0.49	11334.2	529.0	0.18	0.28	0.30
Orenburg oblast	709523.7	123.7	2001.1	90370	0.43	0.57	25437.0	2964.0	0.10	0.47	0.20

Region	GRP in 2013, mln.roubles	Territory (thousand km²)	Population (as of 1.01.2015)	Agricultural production, mln.roubles	Share of crop production	Share of animal production	Grain harvest	Area sown under grains	Share of winter wheat sown area	Share of spring wheat sown area	Share of spring barley sown area
Penza oblast	270854.1	43.4	1355.6	58218	0.54	0.46	12653.9	549.4	0.25	0.21	0.29
Samara oblast	1040713.5	53.6	3212.7	75793	0.61	0.39	20700.8	1103.7	0.28	0.11	0.29
Saratov oblast	528676.4	101.2	2493.0	109571	0.66	0.34	36825.6	2136.2	0.38	0.11	0.19
Ulyanovsk oblast	260340.6	37.2	1262.6	29369	0.57	0.43	10642.7	548.2	0.31	0.25	0.23
Ural											
Kurgan oblast	165150.3	71.5	869.8	31792	0.50	0.50	12672.0	1157.3	0.00	0.80	0.12
Sverdlovsk oblast	1586228.7	194.3	4327.4	65686	0.37	0.63	6605.9	347.2	0.01	0.41	0.42
Tyumen oblast				5017946.8	1464.2	3581.3	72253	0.49	0.51	14819.2	694.9
Chelyabinsk oblast	879274.0	88.5	3497.3	97265	0.35	0.65	11395.4	1381.2	0.00	0.69	0.22
Siberian											
Rep. Altai	33089.9	92.9	213.7	9582	0.21	0.79	90.6	6.9	-	0.14	0.06
Rep. Buryatia	177692.0	351.3	978.5	16731	0.35	0.65	813.6	89.3	-	0.54	0.09
Rep. Tyva	41749.2	168.6	313.8	5827	0.19	0.81	75.1	10.3	-	0.67	0.20
Rep. Khakassia	143534.2	61.6	535.8	12777	0.30	0.70	1629.4	107.3	-	0.47	0.11
Altai krai	410824.6	168.0	2384.8	113938	0.47	0.53	32949.2	3717.0	0.01	0.60	0.10
Zabaikalsky krai	229782.0	431.9	1087.5	18673	0.25	0.75	2111.8	143.5	-	0.53	0.04
Krasnoyarsk krai	1256674.5	2366.8	2858.8	79205	0.46	0.54	22082.2	1039.9	0.00	0.65	0.14
Irkutsk oblast	796587.0	774.8	2414.9	56417	0.45	0.55	8575.6	407.1	0.00	0.55	0.21
Kemerovo oblast	668311.9	95.7	2725.0	49652	0.49	0.51	9675.8	596.5	0.01	0.48	0.22
Novosibirsk oblast	821415.4	177.8	2746.8	71408	0.40	0.60	17845.9	1547.5	0.01	0.66	0.14

Region	GRP in 2013, mln.roubles	Territory (thousand km^2)	Population (as of 1.01.2015)	Agricultural production, mln.roubles	Share of crop production	Share of animal production	Grain harvest	Area sown under grains	Share of winter wheat sown area	Share of spring wheat sown area	Share of spring barley sown area
Omsk oblast	553242.7	141.1	1978.2	83590	0.51	0.49	31369.1	2147.1	0.00	0.76	0.15
Tomsk oblast	402546.1	314.4	1074.4	26092	0.38	0.62	2964.8	213.7	0.01	0.57	0.05
					Far Eastern						
Rep. Sakha	569131.6	3083.5	956.9	21847	0.34	0.66	122.4	10.9	-	0.09	0.29
Kamchatka krai	131560.6	464.3	317.2	8106	2.94	1.71	1.7	0.1	-		0.60
Primorsky krai	575615.4	164.7	1933.3	37734	0.30	0.25	3073.0	113.2	0.00	0.18	0.05
Khabarovsk krai	473695.2	787.6	1338.3	20758	1.30	0.60	192.6	9.5	-	0.10	0.24
Amur oblast	211224.4	361.9	809.9	39515	0.12	0.09	4176.6	194.4	-	0.49	0.14
Magadan oblast	88490.1	462.5	148.1	1948	0.53	0.47	-	-	-	-	-
Sakhalin oblast	673775.4	87.1	488.4	9961	0.71	0.29	-	-	-	-	-
Jewish autonomous oblast	37885.4	36.3	168.4	5169	0.83	0.17	167.1	9.9	-	-	0.18
Chukotka autonomous krai	46989.7	721.5	50.5	1054	0.03	0.97	-	-	-	-	-

Source: own representation based on Rosstat (2015a, 2016).

APPENDIX B - INDICES OF REGIONAL DIVERSITY DETERMINANTS

Table B.1 Indices of determinants of regional diversity.

Region	Climate index	Human development index	Transportation and infrastructure index
		Central Federal District	
Belgorod oblast	0.577	0.350	0.443
Bryansk oblast	0.586	0.340	0.498
Vladimir oblast	0.570	0.349	0.544
Voronezh oblast	0.538	0.414	0.380
Ivanovo oblast	0.562	0.321	0.269
Kaluga oblast	0.599	0.314	0.495
Kostroma oblast	0.535	0.281	0.182
Kursk oblast	0.605	0.341	0.609
Lipetsk oblast	0.563	0.341	0.537
Moscow oblast	0.599	0.600	0.987
Oryol oblast	0.604	0.303	0.410
Ryazan oblast	0.551	0.338	0.421
Smolensk oblast	0.599	0.323	0.405
Tambov oblast	0.532	0.337	0.370
Tver oblast	0.568	0.356	0.365
Tula oblast	0.593	0.357	0.683
Yaroslavl oblast	0.539	0.341	0.310
		Northwestern Federal District	
Kaliningrad oblast	0.742	0.285	0.714
Leningrad oblast	0.585	0.353	0.569
Novgorod oblast	0.576	0.268	0.356
Pskov oblast	0.588	0.275	0.337
		Southern Federal District*	
Rep. Adygea	1.000	0.230	0.345
Rep. Dagestan	0.538	0.492	0.172
Rep. Ingushetia	0.868	0.243	0.254
Rep. Kabardino-Balkaria	0.778	0.311	0.183
Rep. Kalmykia	0.363	0.219	0.036
Rep. Karachayevo-Cherkessia	0.801	0.240	0.064

Region	Climate index	Human development index	Transportation and infrastructure index
Rep. Severnaya Ossetia - Alania	0.874	0.279	0.308
Krasnodar krai	0.877	0.532	0.478
Stavropol krai	0.566	0.432	0.239
Astrakhan oblast	0.295	0.311	0.216
Volgograd oblast	0.439	0.421	0.243
Rostov oblast	0.549	0.503	0.317
Volga Federal District			
Rep. Bashkotorstan	0.441	0.522	0.176
Rep. Mari El	0.516	0.284	0.133
Rep. Mordovia	0.514	0.287	0.355
Rep. Tatarstan	0.500	0.497	0.221
Rep. Udmurtia	0.493	0.370	0.319
Rep. Chuvashia	0.501	0.340	0.372
Kirov oblast	0.514	0.340	0.155
Orenburg oblast	0.369	0.405	0.221
Samara oblast	0.487	0.443	0.439
Saratov oblast	0.459	0.418	0.390
Ulyanovsk oblast	0.506	0.339	0.327
Ural Federal District			
Kurgan oblast	0.355	0.305	0.178
Sverdlovsk oblast	0.430	0.487	0.312
Tyumen oblast	0.371	0.484	0.029
Chelyabinsk oblast	0.407	0.468	0.348
Siberian Federal District			
Rep. Altai	0.291	0.187	0.000
Rep. Tyva	0.246	0.236	0.000
Rep. Khakassia	0.346	0.253	0.180
Altai krai	0.389	0.419	0.167
Krasnoyarsk krai	0.308	0.439	0.015
Kemerovo oblast	0.414	0.419	0.307
Novosibirsk oblast	0.338	0.421	0.146
Omsk oblast	0.349	0.402	0.095
Tomsk oblast	0.368	0.298	0.019

Region	Climate index	Human development index	Transportation and infrastructure index
Rep. Chita	0.296	0.339	0.096
Far Eastern Federal District			
Rep. Sakha	0.078	0.333	0.001
Amur autonomous oblast	0.395	0.289	0.139
Jewish autonomous okrug	0.595	0.166	0.197

Note: *After 2010 Southern Federal District was divided into Southern and Northcaucasian Federal Districts. For simplicity, in this research we maintain the previous division of regions, accounting for the now Northcaucasian Federal District as Southern Federal District.

Source: own calculations based on Rosstat (2014).

APPENDIX C - CALCULATION OF DEGREE DAYS

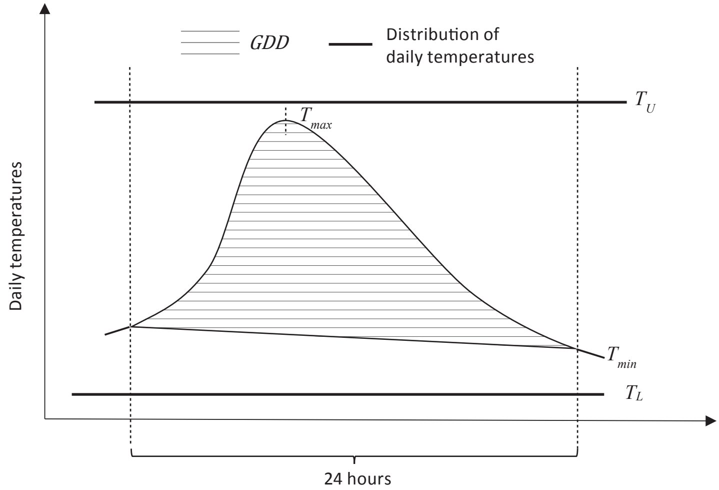
Following Burke and Emerick (2013), we employ the agronomic concept of growing and heat degree days (GDD and HDD, respectively), defined in equations *(3-5)* and (3-6) in section 3.3. The measurement of degree days estimates the amount of time the crop has been exposed to a predefined segment of temperatures (GDD), and when temperatures are higher than the upper bound of the defined segment (HDD). Using the procedure, described in Snyder (1985), we calculate measures of degree days with the steps described below.

Case 1. Threshold below the minimum temperature and above the maximum temperature

In case the minimum daily temperature (T_{min}) exceeds the lower temperature threshold (T_L) and the maximum daily temperature (GDD) is less than the upper threshold (T_{max}), the growing degree days (T_U) presents the area integrated under the curve of daily temperatures, as demonstrated on Figure C.1. The value of GDD is then calculated as the difference between maximum and minimum daily temperatures, as presented by equation C. 1, while HDD is set equal to 0.

$$GDD = \frac{(T_{max} - T_{min})}{2} \tag{C. 1}$$

Figure C.1 **Calculation of *GDD* with the threshold below the minimum temperature and above the maximum temperature.**



Source: own representation based on Snyder (1985).

Case 2. Threshold above the minimum temperature and above the maximum temperature

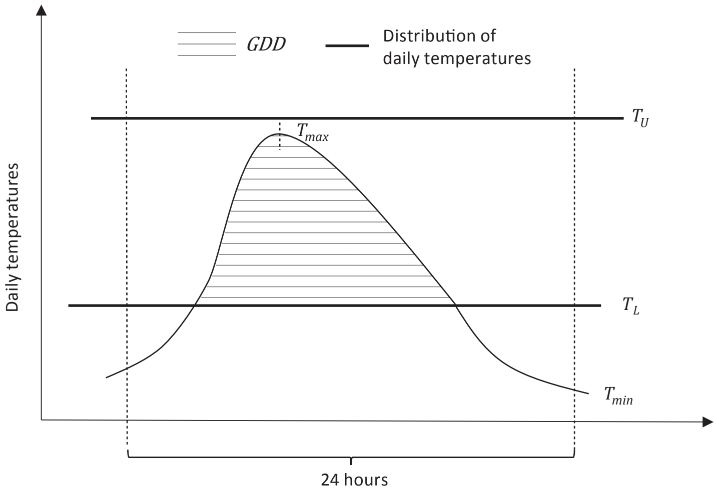
In the event that the minimum daily temperature is below the lower threshold and the maximum temperature is above the upper temperature limit, the GDD is an integrated area under the sine temperature curve, bound by the lower temperature bound, as presented on Figure C.2. In this case the measure of is GDD calculated as demonstrated below by the equation C. 2, while HDD, as in example 1 above, is equal to 0.

$$GDD = \frac{\left(\frac{T_{max} + T_{min}}{2} - T_L\right)\left(\frac{\pi}{2} - \theta_L\right) + \left(\frac{T_{max} - T_{min}}{2}\right)\cos(\theta_L)}{\pi} \qquad \text{(C. 2)}$$

where θ_L represents the time when the temperature sine curve intersects the lower temperature bound (T_L) and is calculated as follows:

$$\theta_L = \text{acrsin}\left[T_L - \frac{\frac{T_{max} + T_{min}}{2}}{\frac{T_{max} - T_{min}}{2}}\right] \qquad \text{(C. 3)}$$

Figure C.2 Calculation of *GDD* with the threshold above the minimum temperature and above the maximum temperature.



Source: own representation based on Snyder (1985).

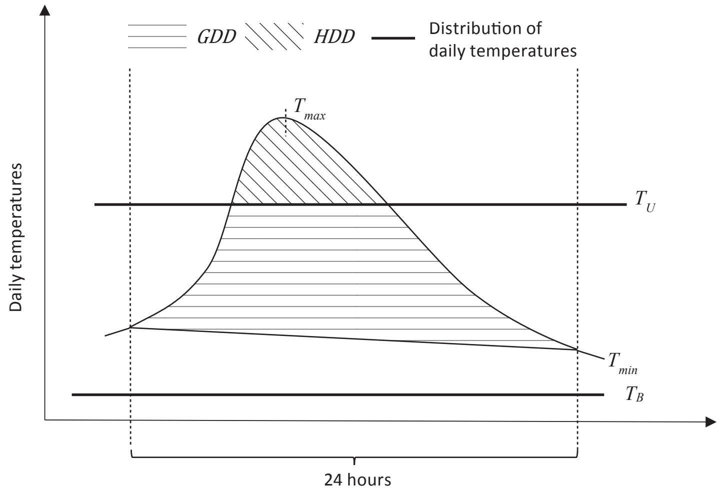
Case 3. Threshold below the minimum temperature and below the maximum temperature

Figure C.3 demonstrates the case when the minimum daily temperature is above the lower temperature threshold and the maximum daily temperature is above the upper temperature threshold. This way the value of GDD is represented by the integrated area under the sine curve, bound by upper and lower temperature bounds. The value of HDD is show by the area under the sine curve, bound from bottom by the upper temperature limit. In this case GDD and HDD are calculated as presented by equations C. 4 and C. 6, respectively.

$$GDD = \frac{T_{max} + T_{min}}{2} - \frac{\left(\frac{T_{max} + T_{min}}{2} - T_u\right)\left(\frac{\pi}{2} - \theta_u\right) + \left(\frac{T_{max} - T_{min}}{2}\right)\cos(\theta_u)}{\pi} \quad \text{(C. 4)}$$

where θ_u represents the time when the temperature sine curve intersects the upper temperature bound (T_u) and is calculated as follows:

Figure C.3 **Calculation of *GDD* and *HDD* with the threshold below the minimum temperature and below the maximum temperature.**



Source: own representation based on Snyder (1985).

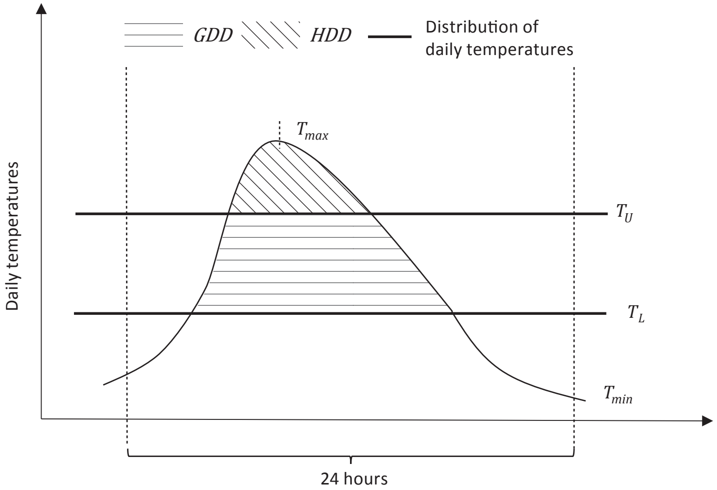
$$\theta_u = \arcsin\left[T_u - \frac{\frac{T_{max} + T_{min}}{2}}{\frac{T_{max} - T_{min}}{2}}\right] \tag{C. 5}$$

$$HDD = \frac{\left(\frac{T_{max} + T_{min}}{2} - T_u\right)\left(\frac{\pi}{2} - \theta_u\right) + \left(\frac{T_{max} - T_{min}}{2}\right)\cos(\theta_u)}{\pi} \tag{C. 6}$$

Case 4. Threshold above the minimum temperature and below the maximum temperature

The fourth possible situation is when the lower threshold is above the daily minimum temperature and the upper threshold is below the daily maximum temperature (Figure C.4). In this case GDD is an integrated area under the sine curve, bound from the top and the bottom, as demonstrated by equation C. 7, while the measurement of HDD, similar to previous case, is an area, integrated under the temperature curve, bound from the bottom by upper temperature threshold, shown by formula C. 6.

Figure C.4 Calculation of *GDD* and *HDD* with the threshold above the minimum temperature and below the maximum temperature.



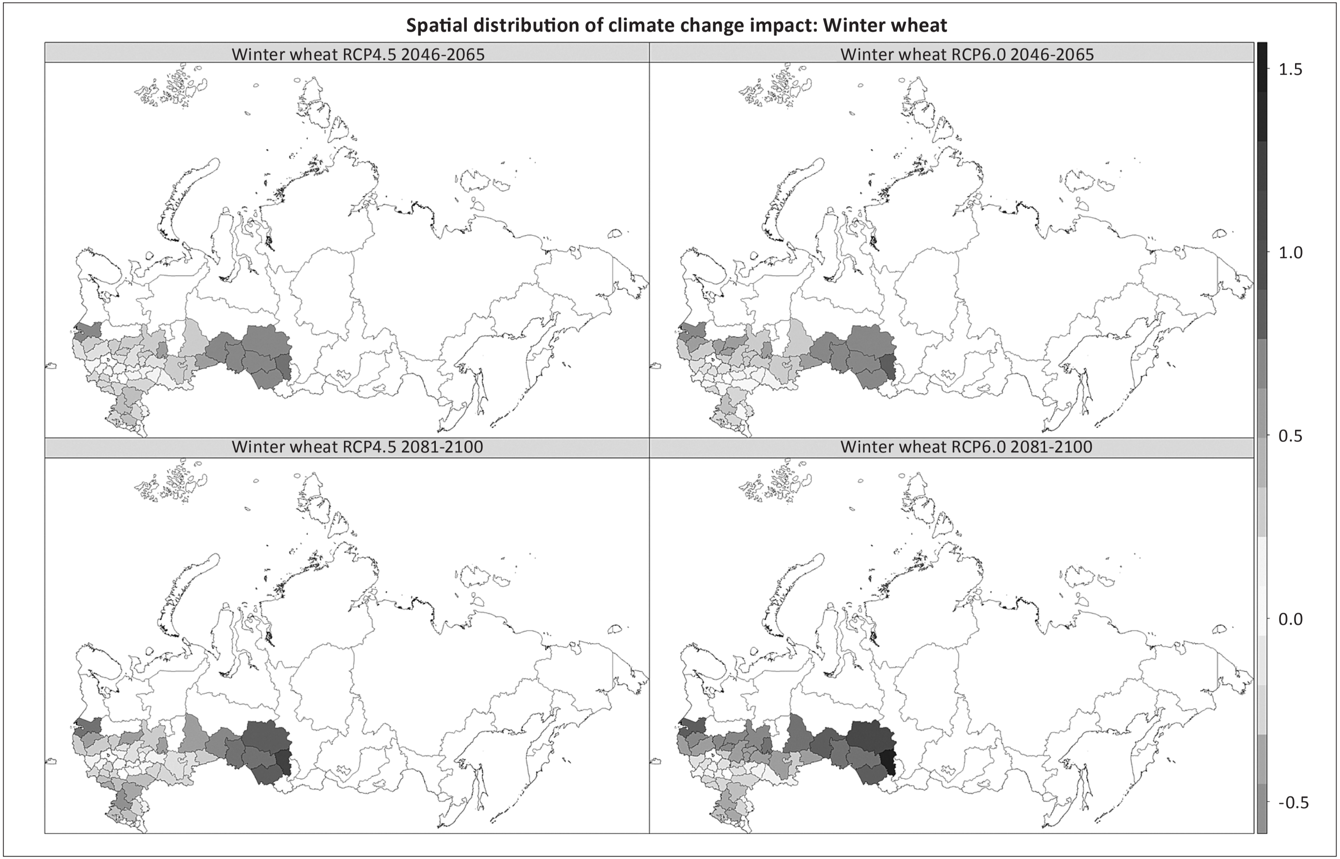
Source: own representation based on Snyder (1985).

$$GDD = \left[\frac{\left(\frac{T_{max}+T_{min}}{2} - T_L\right)\left(\frac{\pi}{2} - \theta_L\right) + \left(\frac{T_{max}-T_{min}}{2}\right)\cos(\theta_L)}{\pi}\right] - \left[\frac{\left(\frac{T_{max}+T_{min}}{2} - T_u\right)\left(\frac{\pi}{2} - \theta_u\right) + \left(\frac{T_{max}-T_{min}}{2}\right)\cos(\theta_u)}{\pi}\right], \qquad (C.\ 7)$$

where θ_L and θ_u are calculated as in equations C. 3 and C. 5.

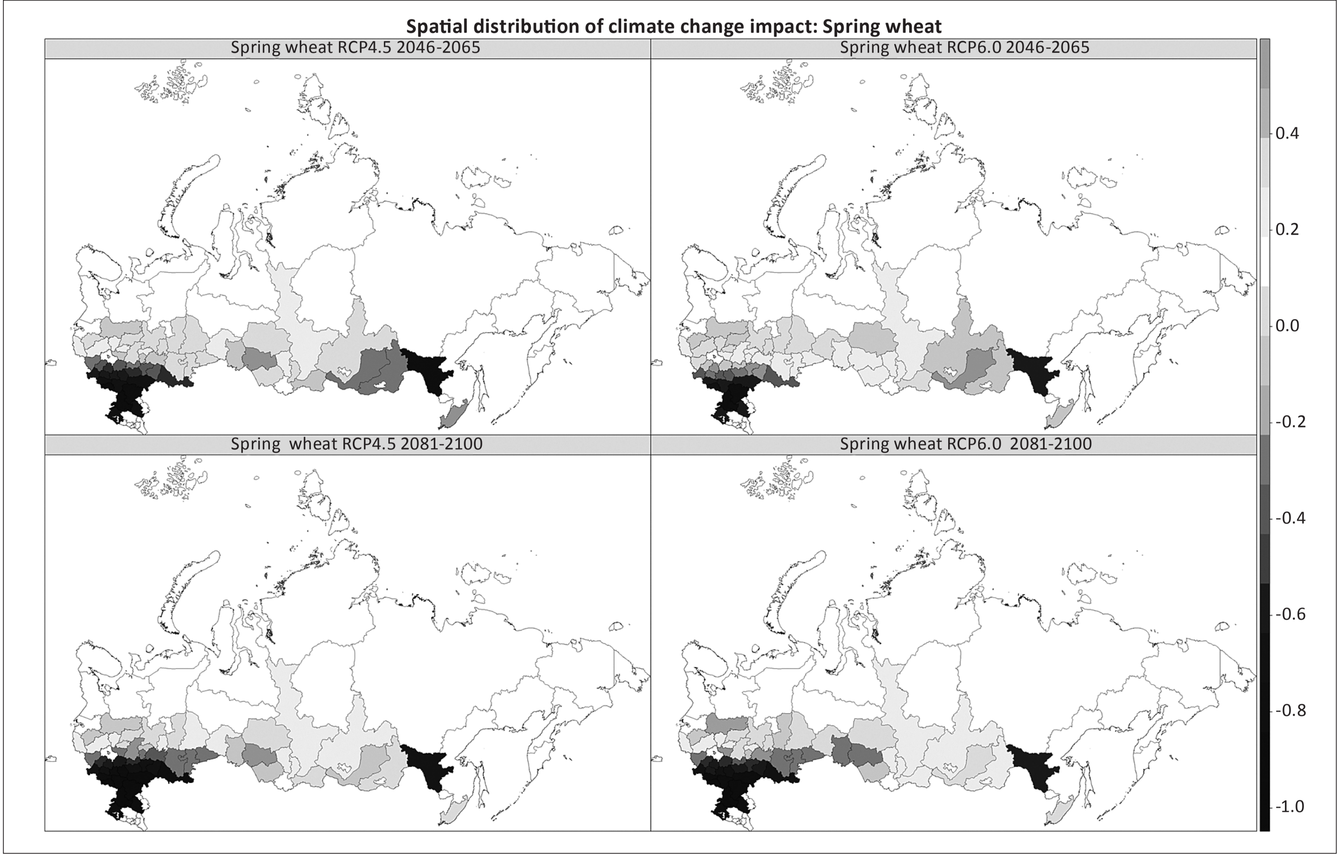
APPENDIX D - SPATIAL DISTRIBUTION OF CLIMATE CHANGE IMPACT (RCP4.5 AND RCP6.0)

Figure D.1 Projected climate change impact under HadGEM2-ES for winter wheat at the oblast level for two selected representative concentration pathways (RCP4.5 and RCP6.0).



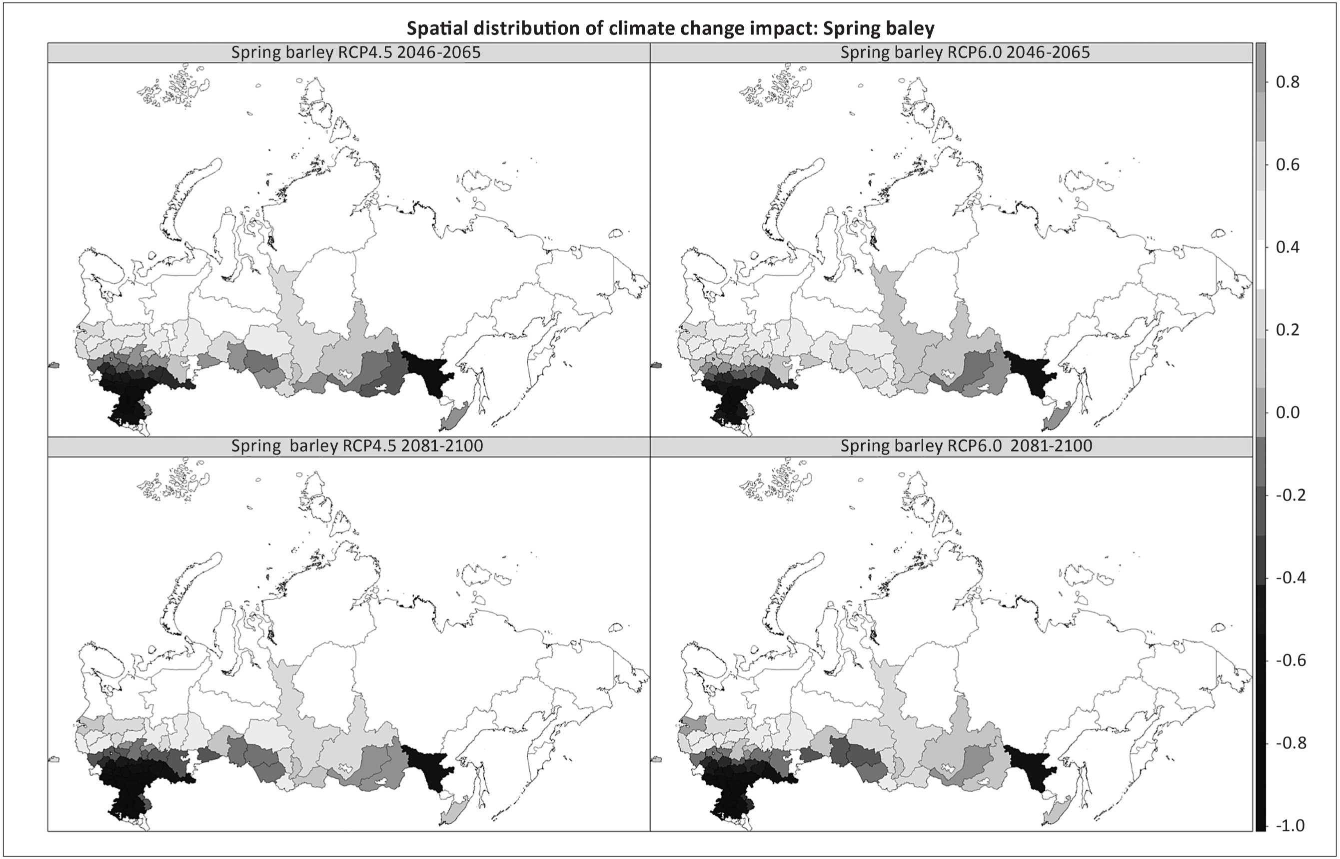
Source: own illustration.

Figure D.2 Projected climate change impact under HadGEM2-ES for spring wheat at the oblast level for two selected representative concentration pathways (RCP4.5 and RCP6.0).



Source: own illustration.

Figure D.3 Projected climate change impact under HadGEM2-ES for spring barley at the oblast level for two selected representative concentration pathways (RCP4.5 and RCP6.0).



Source: own illustration.

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