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Economic complexity and its influence on the firm's and region's resilience to economic crisis

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Contents

Introduction

The economic crisis is a sharp deterioration of the state of the country's economy, violation of market equilibrium which creates significant difficulties for the firm activity (Grewal and Tansuhaj, 2001; Bao et al., 2011). Distinction of the economic crisis from unfavorable conjuncture in the industry or a group of industries lies in the systemic (global) scale of the consequences of the economic crisis for the country's economy. In other words, the economic crisis affects all companies in a particular country. The systemic impact of the economic crisis on the market position of companies is due to changes in real indicators (exchange rate, interest rates, real wages, etc.), the emergence of free resources due to a decrease in demand, investment, and negative expectations. Changes in price proportions can stimulate large-scale technological transformations, the motivation for which was not enough at a time when commodity markets were growing, and optimism in financial markets made it easy to raise capital (Cincera, 2012; Archibugi, 2013). On the other hand, an economic crisis that has transformed into stagnation may result in decrease in the innovation activity due to a drop in income, investment, research and development expenditures, etc.

During the second half of the 20th century economic crises occurred quite rarely, which was due to the presence of surplus of resources until the 70s (which means that Keynesian recipes for stimulating demand were effective and allowed to avoid huge downturns). In the 90s the transformation of the economies of the socialist countries, the transfer of production to Asian countries very powerfully stimulated consumption in developed countries. However, since the end of the millennium economic crises (the financial crisis of 1997-98, the collapse of the dotcoms in the United States, the financial crisis of 2008, COVID-19 crisis) began to shake the world economy quite regularly. Developing countries such as Russia, whose economies are largely open and dependent on the export of a limited number of products, but which do not have the capacity to saturate their economies with money as an anti-crisis measure, are especially vulnerable. In particular due to the decline in oil prices and the geopolitical confrontation an economic crisis

erupted in Russia in 2014. In the first half of 2014 oil prices were on average 107.5 USD, but in January 2015 oil prices were already below 50 USD. It immediately caused devaluation of Russian currency (RUB) and surge of the interest rate of Russian Central Bank from 7% to 17% in the end of 2014. Such fierce turbulence on financial and commodities markets led to the decline of the industrial production, capital investment, real wages, etc. Although economic crisis was formally overcome in 2017, the rapid recovery growth did not happen. The economy was for a long time in a state of stagnation.

In fact, the economic crisis has become an integral component of the modern world economy, which requires an analysis of the possibility of countering it, primarily at the level of companies. In case of changing demand structure the company's ability to react on it may be an important factor. One of the possible strategical alternatives for the company is to react proactively, to envisage possible transformations and implement innovation projects so that to keep its market leadership position (Covin and Lumpkin, 2011). Company with experience in innovative activities has the skills to identify (create) the needs of consumers, the ability to manage knowledge, has necessary resources, staff motivation tools, etc. However effective implementation of truly large-scale, breakthrough innovative projects is impossible within the framework of one company, even a large one. Possession (acquisition) of all the necessary resources (capabilities) is usually ineffective; the company depends on the availability of suppliers, customers, personnel with the necessary qualifications, tax rules, institutions to support innovation, market accessibility opportunities, etc. Each firm is part of a regional system of division of labor, each region, in turn, is part of the system of country division of labor, which is based on technological capabilities, possessed by local enterprises. To characterize the degree of technological development of the regional economy quite new indicator - level of complexity of the economy is used. Its main idea: if a country is one of the few countries which are capable of exporting a product, then the more such products a country can export, the more complex is its economy. The opposite is true: if a country could export only products which many countries could also export then its economy has low level of complexity

(Hausmann et al., 2011). Since for the production of any product companies must have a unique set of technological capabilities, the more rare products are produced by companies in the region, the more sophisticated competencies are possessed by local firms and the more competitive the region is as a production system. The level of complexity of the economy characterizes not only its structure and innovative potential; it determines the vector of long-term development and its pace. Based on the foregoing, the global research question of the thesis can be formulated as follows: how the regional economic complexity affects the development and sustainability of companies and regions during the economic crisis.

The thesis consists of three chapters. The structure of the dissertation research assumes the characterization of the essence of a key and relatively new category of research in the scientific field - the level of complexity of the economy; an empirical analysis revealing the influence of the regional economic complexity on the sustainability of the regional economy and its development, the firm's efficiency the probability of company's bankruptcy during the economic crisis. A key feature of this study is the emphasis on the role of the fundamental variable characterizing the level of complexity of the regional economy, its technological capabilities. This is justified, since any firm is part of the territorial system of the division of labor and strategically depends on it.

The first chapter **"Economic complexity and regional resilience"** contains a detailed description of the concept of the economic complexity of the regional economy, analyzes the methods for calculating the index of the economic complexity, substantiates the application of the approach developed by Tacchella et al. (2012), which is adapted for the analysis at the regional level. On the basis of spatial autoregression models (namely the Spatial Durbin Model), hypotheses about the influence of the economic complexity on innovation activity, economic growth and income inequality are tested. In the chapter the nonlinear, parabolical nature of the influence of the regional economic complexity on the dependent variables is justified and analyzed. Also the influence of other regions is taken into account.

The second chapter "**Regional economic complexity and its impact on the firm's development during economic crisis"** reveals the influence of the regional economic complexity on firm's profitability and efficiency of capital exploitation. The idea is that in a technologically degrading economy the influence of the regional economic complexity could influence negatively on the firm's development. It should be assumed that innovative companies produce more technologically sophisticated products. The economic crisis leads to a decrease in income and investment, respectively, the demand for more technologically sophisticated products is reduced to a greater extent. More broadly, this also applies to the regions with more complex economies.

The third chapter "**Regional economic complexity and its prevention of firm's bankruptcy in turbulent economic reality"** examines the influence of the regional economic complexity on the likelihood of the firm bankruptcy during the economic crisis. The idea of the study is to test the nonlinearity of the influence of the regional economic complexity. Also, as in Chapter 2, the influence of the moderator variable is considered, which takes into account the level of the economic complexity of a group of regions, primarily neighboring ones.

The contribution of the thesis to the scientific knowledge is made in the following areas. In the field of regional studies it is shown that it is necessary to use spatial autoregression models, because indirect effects i.e. influence of other regions on a focal region are significant. It is confirmed that the influence of the economic complexity is non-linear. The explanation of the nonlinearity based on the idea of the region as a part of the country's production system is proposed. It is shown that the influence of the complexity of the economy during the economic crisis persists and even increases.

The regional economic complexity affects firm's development, but only on the efficiency of capital utilization. At the same time, the state of the economic crisis enhances this relationship. The idea that the growth of the firm depends on the regional capacity is being confirmed. The complexity of the region's economy is also a significant parameter in the model for predicting the bankruptcy of a company. This conclusion is consistent with the results of a number of authors who

consider not only financial indicators as predictors, but, for example, variables characterizing management practices in a company, i.e. its fundamental parameters (Hamerle et al., 2004; Carling et al., 2007; Bonfim, 2007; Jacobson et al., 2011). The results obtained lead to the conclusion that it is reasonable to use variables that characterize the technological capacity of the regional economy in research at the micro level.

Chapter 1

Economic complexity and regional resilience

1. Introduction

The development of the regional economy is determined not only by the quantity of material and financial resources. The region is a territorial economic unit, intensively interacting with other regions, integrated into the system of division of labor (interregional, country, world). Accordingly, the strategic development of the regional economy is determined also by its structure. The structure of the regional economy could be characterized via two dimensions: the diversity of goods and services and its relatedness. The concept of relatedness implies that the ability of the region to enter in a new economic activity depends on a set of already existing activities (Hidalgo, 2021). Since the production of any product requires mastering the necessary set of technological capabilities, the structure of the regional economy reflects the set of capabilities that local companies are able to apply in the manufacture of products and services. The trajectory of the development of the regional economy in a long period and its resistance to economic shocks depend mostly on fundamental factors, for example on the diversity and technological level of the production capacity, i.e. on knowledge absorbed by local economic agents. As a region is a part of a more broad system of labor division, just the quantity of goods and services, which are manufactured by local companies, could not properly reflect product sophistication and technological role of the region in the system of labor development. So that to characterize the competitive position of the region it is necessary to evaluate technological level of each product and properly compare them with each other.

One of the most advanced metrics of economic structure is economic complexity index (Hidalgo et al., 2009). Despite constantly growing number of publications the problem of analyzing the influence of the complexity of the regional economy on its social and economic development, its resilience to economic shocks has not yet been sufficiently studied. It has been shown that at the regional level there is a positive and significant relationship with GRP and GRP per capita, if oil

production from GRP is excluded from GRP (Chávez et al., 2017). The example of China shows that the index remains stable for a number of years; it is positively associated with economic growth and negatively with income inequality (Poncet and Waldemar, 2013; Gao and Zhou, 2018). Analysis for the prefectures of Japan also shows a positive relationship between the economic complexity index and macroeconomic indicators of income (Chakraborty et al., 2020). But conducted studies have some shortages. The list of countries whose regions are the object of the study is limited mostly by industrially developed economies. In particular there are no countries whose GDP largely depends on the extraction of raw materials and their primary processing, like Russian for example. The analysis of the impact of economic complexity in conditions of economic instability is not conducted yet. The influence of economic complexity on regional indicators could be of nonlinear type, but most studies use only linear relationships. The impact of economic complexity could be indirect, i.e. economic complexity of other regions could influence on economic and social development of a focal region. Last but not least, the impact of economic complexity on the regional level could depend on the technological capacity of the country as a whole, its place in the world system of labor division.

So, the aim of this paper is to conduct in-depth analysis of economic complexity influence on regional development and resilience to economic crisis. We explore case of Russia. Its economy is technologically lagging. Due to great size and multinationality Russian regions are different and situated far from each other, which makes them separate economic entities.

The assessment of the technological complexity of the regional economy is non-trivial task, since it requires quantitative expressing the level of technological complexity for each product group, without direct evaluation of its technical nature (it would be very difficult and lengthy work). The method of calculation of the economic complexity index proposed by Hidalgo C. and Hausmann R. (Hausmann et al., 2011), which is called “method of reflections” is based on data on exports and the objects of analysis are the countries of the world. The authors propose to compare products based on the number of countries that can export the product and the product capacity of

these countries. Basic principle: if a country is one of the few countries which are capable of exporting a product, then the more such products a country can export, the more complex is its economy. The opposite is true: if a country could export only products which many countries could also export then its economy has low level of complexity. As shown in Tacchella et al. (2012) this approach has certain computational drawbacks and in some cases gives distorting results. The analysis proposed by Tacchella et al. (2012) is based on the same approach but gives more stable results. Since data on exports and interregional trade flows are usually not available, using classical approaches is impossible without adaptation. It is necessary to develop a methodology that allows obtaining stable and consistent results from the available data. Stability of results means that the leading regions should consistently receive high marks for the level of complexity and the lagging regions should consistently receive low evaluations. There should be no sharp fluctuations in the positions of the regions, since, as mentioned above, the complexity of the economy is an inertial indicator.

It is reasonable to conceive regions as complex adaptive systems. Regional environment consists of other systems and they all co-evolve, adapting to changing conditions (Martin and Sunley 2006; Bristow and Healy, 2018). So simple cause-effect relationships do not properly reflect relationships among parameters of regional development and among the region and its environment (Boschma, 2015). Solving the problem of forecasting and stimulating economic growth, developing and implementing investment projects, analyzing the behavior of firms and the influence of regional factors on the results of their activities require assessing the structure of the economy not only in the region of presence, but also in adjacent territories. This is due to the fact that the region is part of the country's labor division system, which, in turn, is integrated into the world labor division system. So development of regions is interdependent. The need to include variables that characterize spatial effect is indicated in Basile et al. (2019), Pintar and Scherngell (2018). For example the growth of GRP in adjacent regions can have both positive and negative effects on the economy of the region, influencing migration, incomes, investments, etc. So that to take into

consideration interregional relationships it is necessary to use models of spatial autoregression. In this study the analysis is carried out based on the SDM (Spatial Durbin Model) model of spatial autoregression, and the calculation of the main spatial autocorrelation indices (Moran's and Geary's indices) is also performed.

The research structure is as follows. Section 2 provides an overview of studies in the field of analysis of the complexity of the economy, in particular it shows the relationship of complexity indices research with previous studies. Section 3 contains description of the methodology of the regional economic complexity index calculation. Section 4 presents brief description of Russian economy, in particular evaluation of its technological capacity. Section 5 provides justification of the research hypotheses. Section 6 characterizes the parameters of the study, i.e. model, data, and variables. Section 7 presents the calculation results and analyzes the robustness of the results. Section 8 summarizes the research results.

2. The nature of economic complexity: literature review, methodology of evaluation

Regional development issues cannot be considered in isolation from the analysis of the structure of the economy, its innovation capacity and consistent patterns of its transformation. The problem of combining the ideas of regional development and the creative destruction of Schumpeter was posed in the scientific literature for a long time ago (Schumpeter, 1939; Norton, 1979; Markusen, 1985). Innovation capacity is important factor of regional long-term economic renewal and restructuring (Cooke et al. 2012; Wolfe 2014), but research question about influence of regional innovation capacity on regional resilience during economic crisis still lacks empirical investigation (Sunley, 2013). Innovation capacity depends, among other things, on the accumulated technological capabilities possessed by companies in the region. The creation and development of new industries depends on the presence of related, supporting industries, which affects both the size of production cost and the possibility of transforming the economy. The influence of the sectoral structure on the possibility of transforming the regional economy (i.e., the development of new industries),

adaptation of regions dominated by industries of previous technological generation to the requirements of the development of new industries, has not yet received an unambiguous solution.

The influence of the structure of the economy on the vector of its development is determined by a number of parameters. One of them is diversity. The main idea is that not only stock of inputs affects growth, but also composition of the economy, technological complementarities among sectors, recombination of knowledge from different sectors (Jacobs, 1969; Frenken et al., 2007). The analysis of the influence of the territorial economic diversity on its development was carried out in studies of Glaiser (1992), which, thus, supplemented the effects of agglomeration, rethinking studies of Jacobs J. Later it was shown that the emergence of high-tech industries is directly related to the effects of diversity, while specialization of regions is the important factor for the industrial sectors of previous technological generations (Henderson et al., 1995; Neffke et al., 2009). The diversity effect is based on the possibility of a deeper division of labor. As a result, favorable opportunities for innovation are created as a combination of accumulated knowledge, subject to the necessary technological and cognitive proximity of agents, which has been confirmed in a number of empirical studies (Ahuja and Katika's, 2001; Neffke et al., 2009; Frenken et al., 2007; Essletzbichler , 2007; Bishop and Gripaios, 2009). Interaction with other regions, namely the inflow of new knowledge from technologically similar industries, has a positive effect on reducing unemployment (Boschma and Iammarino, 2009).

The concept that technological capabilities possess little specificity or could be easily acquired is very abstract (Hidalgo et al., 2007). In reality product manufacturing technologies could be very specific and not only because they are knowledge-intensive. For example, the production of wheat and the sewing of textiles are not technologically complex, but they require different knowledge, skills, equipment, etc. So another parameter that characterizes the structure of the regional economy is the relatedness of the products produced, i.e. technological possibility of their joint production. The idea that the vector of development is largely technologically dependent on the available industries has been confirmed in a number of studies (Bathelt and Boggs, 2003;

Glaeser, 2005; Hausmann and Klinger, 2007; Hausmann et al., 2011). Countries tend to develop their production basket adding products which are technologically proximate to the produced ones (Kogler et al., 2013; Boschma et al., 2015; Zhu et al., 2017). In fact, the existing knowledge is capitalized during economic growth. More technologically advanced product groups are denser, i.e. more knowledge-intensive and suitable for knowledge capitalization (Hidalgo et al., 2007). Developed countries specialize in more technologically advanced and interconnected groups of products than developing countries, although they also produce simpler products (Cristelli et al., 2015). It complicates the task of maintaining sustainable growth for developing countries, since it is much easier for developed countries (apart from other advantages, of course) to use the knowledge necessary to produce one group of products in the manufacture of products that are technologically close. Accordingly, the acquisition of additional capabilities makes it possible to create a greater number of combinations for the production of goods that are new for a country (region) than in the case when the country (region) has initially fewer capabilities (Hausmann et al., 2011). It actually represents an infinitely increasing return to scale.

In recent years it was argued in a number of studies that diversification based on an unrelated variety can be more productive, because it represents a radical innovation for firms, sectors, territories. This increases resilience to economic downturns due to the unconnectedness of industries (Parrilli and Zabala-Iturriagagoitia, 2014; Castaldi et al., 2015; Cainelli et al., 2019). Also a number of researchers pointed out (Saviotti and Frenken, 2008; Cainelli and Ganau, 2019) that in the short term strategies based on a related variety are more effective, since they are based on capitalizing existing knowledge, on incremental innovations, while strategies based on unrelated variety are more effective in the long run.

Diversification based on the technological proximity of industries is carried out through company-level diversification, spin-off creation, staff mobility, social networking (Boschma and Frenken, 2009). Several studies have shown a positive relationship between one of the mechanisms of industry diversification and geographic proximity (Rodriguez-Pose and Zademach, 2003; Breschi

and Lissoni, 2003; Boschma and Wenting, 2007; Ter Wal, 2009; Balland et al., 2020). This transforms the problem of technological relatedness into the task of regional economic development support and industrial policy to stimulate innovation. The level of diversification and the degree of relatedness of industries do not by itself guarantee the sustainability of economic growth and the ability of the economy to withstand external shocks. It is important to have the knowledge, capabilities necessary for the production of technologically complex products and possess the ability to transfer knowledge to related sectors (Basile et al., 2019). For successful economic policy purposes it is necessary to elaborate an indicator that would properly reflect the level of diversification and complexity of the economy.

Research on economic complexity differs in the way it measures key indicators (Fan and Lang, 2000; Hausmann et al., 2011). For example, Frenken et al. (2007) use the entropy index to measure unrelated variety:

$$UV = \sum_{g=1}^{G} P_g \times \log_2\left(\frac{1}{P_g}\right) \quad (1.1)$$

where:

UV – unrelated variety

G – number of sectors

P_g – share of the sector g.

The disadvantage of entropy index is that only the composition of products is taken into account, and there is no data on the technological complexity of products. As a result resource-based economies and industrialized countries with an equal degree of economic diversification will have equal values of these indicators (Basile et al., 2019). More sophisticated approach based on estimating the number of countries with a comparative advantage in the production of a product is the calculation of indicators of economic complexity (Hidalgo et al., 2009). The criterion for the competitiveness of a product is the fact of its export. Product export, i.e. the ability to compete in the international market reflects that the country's firms possess advanced technologies.

Accordingly the more products the country exports (satisfying the criterion of comparative advantage), the larger its basket of technological and production capabilities (Hidalgo et al., 2009). The complexity of a product depends on the number of countries that have a comparative advantage in exporting it. The more such countries there are, the more affordable, simple, well-known technologies are used in the production process. Mathematical description of the "method of reflections" is presented below (for more detailed description see Hausmann et al. (2011)).

First step of the method is to construct matrix of export flows, where countries are arranged by rows and products are arranged by columns. There are n countries and m products. X_{cp} represents value of export of product p by country c (see Table 1.1).

Table 1.1

Matrix of export flows

	Product 1 (high-tech)	Product 2(mid-tech)	…	Product m(low-tech)
Country 1	X_{11}	X_{12}	…	X_{1m}
Country 2	X_{21}	X_{22}	…	X_{2m}
…	…	…	…	…
Country n	X_{n1}	X_{n2}	…	X_{nm}

Then RCA (Revealed Comparative Advantage) is calculated so that to make export of countries of different size comparable:

$$RCA_{cp} = \frac{\frac{X_{cp}}{\sum_p X_{cp}}}{\frac{\sum_p X_{cp}}{\sum_{cp} X_{cp}}} \quad (1.2)$$

Then matrix M is constructed. Its elements look like is shown in (1.3):

$$M_{cp} = \begin{cases} 1, if\ RCA \geq 1 \\ 0, if\ RCA < 1 \end{cases} \quad (1.3)$$

On the next step two definitions are introduced. First one is diversity, which characterizes number of products, produced by country c with RCA>=1 (this is simply sum over the row in matrix M). And ubiquity, which characterizes number of countries able to produce product p with RCA >=1 (this is simply sum over the column in matrix M).

$$Diversity = k_{c,0} = \sum_p M_{cp} \tag{1.4}$$

$$Ubiquity = k_{p,0} = \sum_c M_{cp} \tag{1.5}$$

"To generate a more accurate measure of the number of capabilities available in a country, or required by a product, we need to correct the information that diversity and ubiquity carry by using each one to correct the other" (Hausmann et al., 2011). It means that diversity and ubiquity indicators are weighted iteratively by each other:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{c,p} \times k_{p,N-1} \tag{1.6}$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_c M_{c,p} \times k_{c,N-1} \tag{1.7}$$

Note: second index in $k_{c,N}$ and $k_{p,N}$ is the number of iteration.

After inserting (7) into (6) we obtain:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{c,p} \times \frac{1}{k_{p,0}} \sum_{c'} M_{c',p} \times k_{c',N-2} \tag{1.8}$$

and mathematical transformation we receive the following expression:

$$k_{c,N} = \sum_{c'} k_{c',N-2} \sum_{p,c'} \frac{M_{c,p}}{k_{p,0}} \frac{M_{c',p}}{k_{c,0}} \tag{1.9}$$

Note: index c' means transposing.

Denote $\sum_{p,c'} \frac{M_{c,p}}{k_{p,0}} \frac{M_{c',p}}{k_{c,0}}$ as $\widetilde{M_{cc'}}$, which is matrix

So we obtain:

$$k_{c,N} = \sum_{c'} \widetilde{M_{cc'}} \times k_{c,N-2} \tag{1.10}$$

And (1.9) is satisfied for $k_{c,N} = k_{c,N-2}$, which are eigenvalues for matrix $M_{cc'}$. First eigenvalue is 1, which is not informative. Eigenvector associated with the second largest eigenvalue (K) captures the largest amount of variance in the system and is our measure of economic complexity. Economic complexity index (ECI) is calculated as follows:

$$ECI = \frac{K - \overline{K}}{stdev} \tag{1.11}$$

where $\overline{K}$ is mean of the elements of the second largest eigenvector, stdev – standard deviation.

The level of complexity of the economy is determined by the number of technological capabilities possessed by the country's companies, i.e. which are used by them in the manufacture of products. The idea of technological capability is not limited to scientific knowledge. It also includes experiential skills, learning by doing, using and interacting (Jensen et al., 2007). Thus, the complexity of the economy is the accumulated stock of technological and practical knowledge, on the one hand, and the result of accumulated implementation and dissemination of innovations, on the other. The technological complexity changes in leaps and bounds, nonlinearly. The effect of increasing the number of capabilities available in a country is exponential (Hausmann and Hidalgo, 2010). Therefore, it is necessary to overcome a certain threshold before the effect of acquiring additional capabilities becomes significant.

The same product could be produced using different technologies (in poor countries less skilled labor is used, less automation), which allows variability for assessing technological capabilities. Accordingly, it is necessary to analyze the production capabilities of the least developed territories as a criterion for product complexity (Caldarelli et al., 2012). Tacchella et al. (2012) give two examples of the clearly incorrect work of the “method of reflections” (Hausmann et al., 2011), on the basis of which the USA and Nigeria were assigned the same level of economic complexity. In a study by Tacchella et al., (2012) China's economy was ranked second in the world in 2010, and as a result of the “method of reflections” China was ranked 29th, next to Panama. Due to the existence of a number of reasons indicating the incorrect results of the “method of

reflections" another indicator of the complexity and competitiveness of the economy was proposed (Cristelli et al., 2013; Tacchella et al., 2012). The mathematical description of the correcting approach is presented below.

Data and data manipulation are the same as in "Method of reflections". Authors also use data on export and calculate RCA and matrix M. They propose two variables analogous to Diversity and Ubiquity in Method of reflections:

Q_p – complexity of the product p, which is similar to its ubiquity. It measures its quality in terms of capabilities. High complexity of the product p means that its production requires more capabilities than for simple product.

F_c – fitness of the country c, which characterizes its capacity to produce complex products. Fitness (F) represents itself as intermediate variable $\widetilde{F_c^{(0)}}$ normalized by dividing by mean. It is within the meaning of ECI. The iterative algorithm for calculating asymptotic fixed point (F_c, Q_p) is presented in (1.12).

$$\begin{cases} \tilde{F}_c^{(n)} = \sum_p M_{cp} Q_p^{(n-1)} \\ \tilde{Q}_p^{(n)} = \dfrac{1}{\sum_c M_{cp} \dfrac{1}{F_c^{(n-1)}}} \end{cases} \rightarrow \begin{cases} F_c^{(n)} = \dfrac{\tilde{F}_c^{(n)}}{\left\langle \tilde{F}_c^{(n)} \right\rangle_c} \\ Q_p^{(n)} = \dfrac{\tilde{Q}_p^{(n)}}{\left\langle \tilde{Q}_p^{(n)} \right\rangle_p} \end{cases} \quad (1.12)$$

Note: initial conditions $\widetilde{Q_p^{(0)}} = 1 \; for \; \forall \; p, \; \widetilde{F_c^{(0)}} = 1 \; for \; \forall \; c.$

As the authors themselves point out, their approach is very sensitive to errors and omissions and requires careful data correction (Cristelli et al., 2013). The algorithm for calculating the indicators of the economic complexity also allows for mathematical variability, for example, whether to weigh the initial data or not.

Both approaches have a number of common disadvantages. Export data are imperfect, reflecting the total value of the product, not the added value created in the country. As a result, the method can distort, increasing the degree of diversification of economies specializing in the final assembly of products. It also matters to which groups of countries the export is carried out: to developed ones, where the level of competition is usually tougher due to the greater technological

complexity of competitors' products, or developing ones, in which consumers may be less demanding (Lyubimov and Yakubovsky, 2019). It is necessary to take into account the presence of foreign economic restrictions imposed for political reasons. A more detailed review of the calculation of indicators of economic complexity, its mathematical peculiarities and interpretation is considered in (Morrison et al., 2017; Mealy et al., 2019).

The indicators of the economic complexity reflect the non-monetary aspects of the object of measurement (level of education, the level of accumulated technological knowledge, the ability to implement innovations, investment attractiveness, etc.), and show possible directions for the development of the economy (Cristelli et al., 2015). Empirical studies have shown that the complexity of the economy is positively associated with the dynamics of GDP per capita; in case of the same economic complexity levels poorer countries grow faster (Hidalgo et al., 2009; Hausmann et al. 2011). Perhaps this is due to the lower cost of factors of production, especially labor. So catch-up development is possible, provided that a country possesses proper technologies. It reflects well the accumulated level of knowledge (Hidalgo, 2015). One possible explanation for the positive impact of economic complexity is that it contributes to the creation of non-tradable competitive advantages, which, in turn, increase the attractiveness of the economy for large-scale, high-tech investment projects. Indicators of the economic complexity are used to develop forecasts of economic growth (for more details see Cristelli et al., 2017). The complexity approach is used in related fields of scientific knowledge, for example, to analyze the technological knowledge accumulated at the regional level in the categories of ubiquity and diversity (Pintar and Scherngell, 2018).

There are significantly fewer studies in which the index is calculated at the regional level than at the country level. It has been shown that at the regional level there is also a positive and significant relationship with the indicators of GRP and GRP per capita, provided that oil production is deducted from GRP (Chávez et al., 2017). The example of China shows that the index remains stable for a number of years. It is positively associated with economic growth and negatively with

income inequality (Gao and Zhou, 2018). Analysis for the prefectures of Japan also shows a positive relationship between the economic complexity index and macroeconomic indicators of income (Chakraborty et al., 2020). On the example of Italy it is shown that it is not so much the diversity of products for further growth is important, but the technological proximity of industries (Buccellato, 2016). Moreover the complexity index is positively related to the dynamics of labor productivity. However, initial differences in the level of complexity of the region's economy lead to higher inequality in the level of labor productivity later on (Basile et al., 2019). Consequently, the generation of added value is positively associated with the presence of several regions that are the key drivers of economic development. Based on export data, studies have also been carried out for Russia and Russian regions (Farra et al., 2013; Kadochnokov and Fedyunina, 2013; Lyubimov et al., 2017; Lyubimov et al., 2018; Lyubimov, 2019; Lyubimov and Ospanova, 2019; Lyubimov and Yakubovsky, 2020). The authors of studies on Russia use the classical approach (Hausmann et al., 2011); however, they themselves point out on methodological shortcomings caused by incomplete data.

Research strand on the economic complexity has only been carried out for the second decade. This science direction is just being formed. Methodological aspects are sufficiently well developed. But utilization of complexity indicators for understanding the patterns of economic and social development of territories is not enough yet. Researchers devote more attention to the relationship between the complexity of the economy and the rate of economic growth, the level of poverty. Meanwhile, the relationship with other economic and social indicators like innovation activity, capital investment; the impact of the economic complexity on the sustainability of the development of the territory during economic crisis, the impact of the economic complexity of territories adjacent to a focal region have not been sufficiently explored yet. Lack of possibility of developing countries to converge to the complexity level of developed ones, described in Hidalgo et al., 2007, allows suggesting nonlinearity influence of economic complexity with economic and social indicators. But such more complicated link hasn’t explored yet, as we know.

3. Construction of the economic complexity index

At the regional level there is a certain specificity of calculating the indicators of the economic complexity due to the lack of data on interregional trade flows. For measurements at the regional level in addition to export flows company data can also be used, in particular on the number of companies in different subsectors, their revenues (Teece et al., 1994; Bryce and Winter, 2006; Neffke and Svensson Henning, 2008; Buccellato, 2016; Chakraborty et al., 2020), the number of employed by sub-sectors (Chávez et al., 2017). The study Gao and Zhou (2018) used data on 2,690 large companies in China as an indicator of the sectoral structure of the country's provinces. In our opinion this is a controversial approach, since there are very few companies, the existence of a company does not indicate the degree of specialization of the province, a company can be reorganized, the profile of its activities could be changed, etc. Chakraborty et al. (2020) use data on sales of firms for a sample of companies (just over 1 million), which seems more reasonable and allows to extract data on sales of specific products. In this case computational algorithms can also be adjusted taking into account regional specificity. Also when calculating the complexity index of the economy, a combined approach can be used. The study by Operti et al., (2018) suggests using country survey data as indicators of product complexity, because the great share of Brazil's industry is concentrated in a few states. This can lead to a bias in the index of product complexity (ubiquity in the terminology of Hausmann et al., 2011).

In this study we will rely on data on value of production by sub-industries. This is the most reliable and consistent available metric of economic complexity on the regional level comparing to the export data. If we would use export data, then only the regions producing the final (from the point of view of the world market) products were considered. Export data at the regional level cannot be applied without analyzing interregional commodity flows, since the added value of an export product is usually formed by several regions. But the collection of data on interregional trade flows may not be carried out in principle. Employment figures cannot be reasonably distributed

across individual products as large companies tend to be diversified conglomerates. Firm-level data are undoubtedly of interest, but they are notoriously incomplete.

As it was indicated above, different approaches are used to analyze the degree of economic diversity. The first complex, multi-parameter method was the method of reflections, developed, more precisely, adapted from the field of physics in relation to economics, by Hausmann R. and Hidalgo C. Description of their approach is presented in the study of Hausmann et al., (2011). Along with the indicator of economic complexity according to the Hausmann and Hidalgo's method a slightly different fitness-complexity method is proposed. The important advantage of it is the substantiation of the need for nonlinearity of the method for assessing indicators of the economic complexity and mathematical realization. Description of the second approach, as well as a criticism of the method of reflections are presented in Tacchella et al., (2012), Cristelli et al., (2013). Both approaches are robust to the amendment in the threshold for the key indicator RCA (Chávez et al., 2017).

In this study we use the fitness-complexity approach, since the preliminary calculations under the "method of reflections" gave volatile results (fitness-complexity approach gives stable, reliable results, see Table 1.2). Preliminary calculations for Russia show that for example Moscow city was ranked 21st in 2005, 1st in 2008-2013 and 47 in 2014. Such changes in the short term cannot be reasonable. To improve the position, it is necessary to master additional technological capabilities, which cannot be implemented in a short time.

The calculation methodology is applied unchanged, however, to calculate RCA, we use the indicator "value of product p in the region r / number of employees in the manufacturing sector of the region r" (VE_r) and compare regional indicator with Russian value on product p (VE_p). The formula is presented below.

$$RCA_{pr} = \frac{VE_{pr}}{VE_p} \tag{1.13}$$

If we carry out the calculation in the classical way, comparing the structure of exports (for the regional economy – value of production), then each region will have an advantage in at least one product simply by virtue of mathematics. The choice of the indicator is due to the desire not only to assess the structure of the region's economy, but to assign 1 only to those products that the region is able to produce with greater productivity compared to the average Russian level, i.e. in the production of which significant investments have been made, innovations have been implemented, and technological capabilities have been accumulated. In theory even a relatively small region can have many 1s in the "products-regions" matrix if it has achieved a high level of competitiveness.

The study of Cristelli et al., (2013) reports about very high estimates of the competitiveness of some developing countries according to the method of reflections, in which the oil sector dominates (in the study of Tacchella et al., (2012) it is about raw products in general). Since Russia is a country in which primary sector is a significant part of the economy, it is advisable to consider only manufactured products. Primary processing of resources, as a rule, is carried out at the place of their extraction in order to reduce transport costs. Respectively the mining regions get an advantage in terms of the level of economic diversification. Weighing indicators in the fitness-complexity method should also not be used, since in this case larger regions gain a tangible advantage, the economic complexity index would be reflecting the size of the economy and the correlation with size indicators (for example, GRP, the number of inhabitants, number of employees, etc.) becomes very high, which will lead to distortions of the regression models.

The inclusion of individual services in the calculation does not make economic sense or is difficult due to distortion / absence of statistical data. When providing services, new knowledge as a rule is not created; innovations developed in industry are used. For example, banks use advances in electronics by purchasing ATMs; a rail transport operator purchases wagons, locomotives, etc. It is difficult to include non-market services (education, health care) in the calculation, since these sectors are financed from the state budget and their size largely correlates with the size of the region's population (certain population groups). Due to the intangible nature of many types of

services statistics are not accurate. An example is the creation of software. There is an imbalance in the location, legal registration of companies providing services in the capital city of the country and nearby territories. This applies to entertainment, education, construction, the financial sector, etc. Certain sectors of the service sector, such as television broadcasting, are presented, in fact, only in the capital city. Accordingly, including all of these sectors would lead to a significant bias in the results (Chakraborty et al., 2020).

4. Brief description of Russian economy

When analyzing the impact of economic complexity it is necessary to take into account the key characteristics of the economies of the studied countries. It affects the list of control variables as well as the content of the research hypotheses. Reasons why Russia is chosen as the object of analysis are as follows. It is a big country with multinational population. Russia possesses developed knowledge assets and is able to produce competitive technological goods in some sectors. At the same time Russian economy is highly dependent on extractive sector (oil, gas, coal, metals, etc). In 2005 its share in GDP was 11.5%, in 2018 it slightly increased to 13%. Of course export keeps depending on non-manufactured sector too. Share of raw materials is much higher: 60-70% and not because rise of prices, but also due to increase of physical quantities. So the development of Russian economy is inertial, role of innovation is still low. As Russian economy depends a lot on raw material rent there is high level of centralization of intergovernmental fiscal relations. Otherwise differences among regions on social parameters would be ten times higher. On average federal budget transfers are in charge of 19% of total income of regional budgets. Moreover the most stable taxes like VAT, excises, etc. are sources of central budget income. So regions don’t have plenty of resources and powerful motivation for the development and support of economic projects.

Another feature of Russia as a country is high role of its capital city. Only share of Moscow in GDP exceeds 20% and trend on concentration of population and manufacturing industry, R&D, investment is upward. For other regions especially peripheral it means constant outflow of

inhabitants, including youth. The knowledge-intensive industry sector inherited from the USSR is closely related to the defense industry. Accordingly, the key achievements of high-tech industries are associated with military and paramilitary products. A decrease in the number of researchers and a low level of funding are the main features of the scientific sector in Russia.

Russia's industrial policy is not focused on supporting innovation in the economy as a whole, but rather on implementing large-scale defense-related projects (for example, military aircraft and civil aircraft). Therefore, the innovative activity of Russian companies is low: only every tenth enterprise innovates. At the same time, the purchase of equipment, mainly foreign, dominates. This, coupled with the raw material dependence of the economy, makes modernization projects dependent on external conditions. Under such conditions, there is reason to believe that the level of complexity of the economy does not have a dominant influence on the regional development. Furthermore according to the study of Operti et al. (2018) Russian economy could be characterized as technologically degrading (see Fig.1.1). The authors compared the volume of exports by the level of complexity of products for 2005 (dotted lines) and 2015 (fitted colors). It is noticeable that the volume of exports of complex products by Russian companies as a whole declined, while the volume of simpler products, on the contrary, increased. This indicates a downward trend in competitiveness in the global market for Russian goods with a high level of complexity.

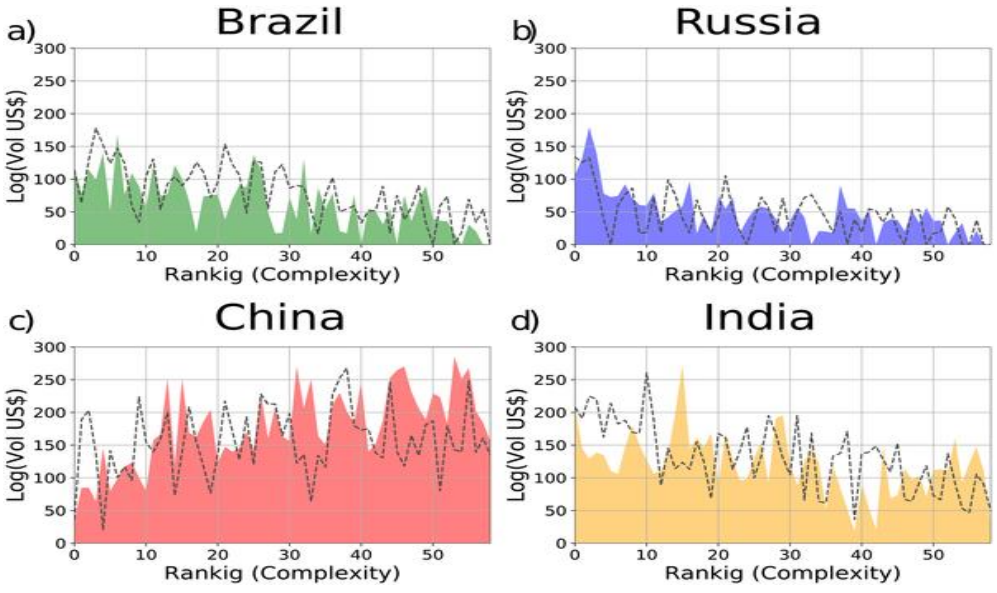

Fig 1.1. Products spectroscopy of the years 2005 (dotted lines) and 2015 (filled colors) of the countries: a) Brazil, b) Russia, c) China, and d) India.

Source: Operti et al. (2018).

5. Research hypotheses

I assume that the complexity of the economy is positively related to innovation, since the accumulated technological capabilities, the ability to generate / acquire additional capabilities, the availability of budgetary funding, concentration of economic activities in big cities have a positive effect on the ability of companies to improve technologies and products. Relationship between complexity and innovation activity could be non-linear. High level of complexity could stimulate synergetic effect, i.e. knowledge from different spheres could bring about new industries. By the way, level of economic complexity could be too high for technologically degrading economy. For example consumers including ones in other regions may simply be technologically unprepared for the purchase of innovative products, i.e. the demand could be too small. So enterprises capable of production of complex products could even be closed because of demand instability. Accordingly, the dependence between economic complexity and innovation activity should have inverted U-shaped form, as shown in Figure 1.2.

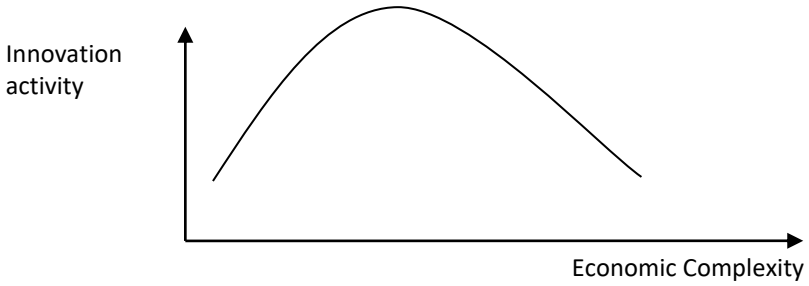

Figure 1.2. Hypothesized relationship between economic complexity and innovation activity

However, the relationship between the complexity of the economy and innovation activity must be analyzed taking into account the complexity of the economy of other regions, since the economies of most regions of Russia are too small to maintain the necessary infrastructure of the innovation process. The total effect may be ambiguous, depending on which effect prevails: cooperation or competition. With regard to innovation, one should expect the prevalence of the

effect of cooperation for high values of the complexity of the economy and competition - for low values. So the relationship between economic complexity of other regions and innovation activity of local firms could be quadratic and positive (see Figure 1.3). If the region is surrounded by regions with relatively high economic complexity, they could be agents of development for the firms of the focal region, engaging them in innovation activity or creating new enterprises. If the region is surrounded by regions with relatively simple economies innovation activity could be also high due to the domination of local firms and absence of severe competition. When the level of complexity of the regional economy is quite close to the neighboring regions, competition could become tougher. As innovation activity requires investment and is associated with risk, some local firms could amend their strategies from innovation-driven to cost-oriented, market penetration, etc.

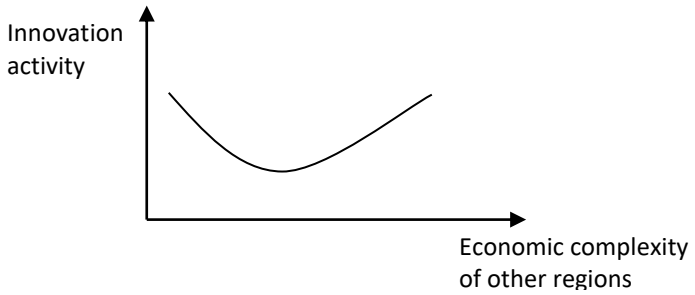

Figure 1.3. Hypothesized relationship between economic complexity of neighboring regions and innovation activity of local companies

I assume that the relationship between the complexity of the economy and the parameters of economic growth (GRP growth, GRP per capita growth) has inverted U-shaped form. The same applies to the impact of economic complexity on income inequality and poverty, since in Russia social differentiation is positively associated with economic growth. For the region with low level of economic complexity its increase could have huge positive results as the region becomes more and more entangled in the country system of labor division. But when the regional economic complexity hugely outperforms the level of the whole country, the pace of growth will be low or could become even negative. In the economy focused on the export of raw materials and simple products of its processing, due to the “Dutch disease”, the profitability of technologically intensive manufacturing enterprises may be low. If economic complexity of the region is high, its firms like

machinery, electronics, etc. have negative perspectives (they could still exist but their pace of growth, profitability are lower than before, products became simpler, employment decreases, etc.). Significant unemployment means decreasing market demand, which also negatively affects economic growth and investment in the long run (Passinetti, 1993).

Economic and social indicators should also be nonlinearly related to the complexity of the economy of neighboring regions, the relationship should have inverted U-shaped form. If the region is surrounded with regions with relatively simple economies then the drivers of local growth are poor. If the region is surrounded with the regions with relatively complex economies, growth rate of GRP could slow down because of increased competition for shrinking demand on products with high added value in technologically degrading economy. The best condition for persistent and stable regional development, when its economic complexity suits to the level of majority regions, which opens up greater number of market opportunities for interregional cooperation and realization of the economy of scale on local enterprises (see Figure 1.4).

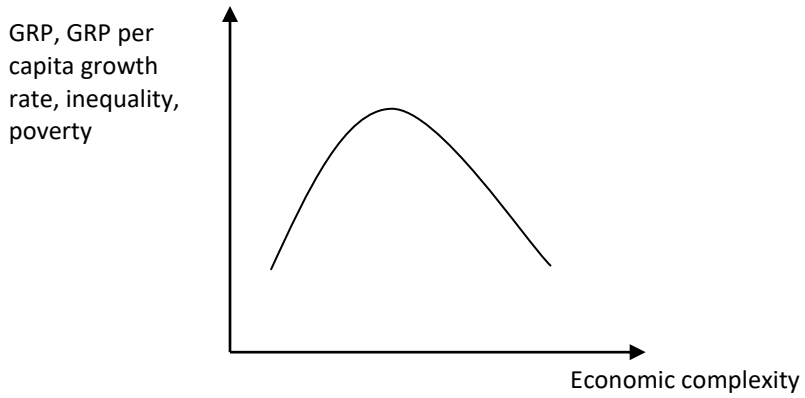

Figure 1.4. Hypothesized relationship between economic complexity of neighboring regions and economic growth of the region

It is necessary to point out that for technologically developing economy the relationship between complexity and other economic variables should be nonlinear and strictly positive due to the general trend on technological development. But as we study the economy of only one country, we leave this proposition for the future research.

The relationship between investment and economic complexity at the regional level may not be significant. There are two reasons for this. On the one hand, a more complex economy requires more investment. On the other hand, projects in extractive industries require significant investments. Accordingly, investments can simultaneously be significant in regions with high and low levels of economic complexity. A similar logic can be applied to the analysis of the impact of the complexity of the economy of other regions.

Economic complexity influence on inequality also could have more complex nature, than just linear form. On the one hand, the relationship between complexity and inequality should be negative, because higher level of economic complexity is the result of long-term economic growth and competitiveness. As it is shown in Lee and Vu (2019) for low- and middle-income countries higher level of education moderates economic complexity negatively, i.e. it reduces inequality. Meanwhile, according to Kuznets curve during the catch-up development economic growth could be accompanied by increase of inequality (Kuznets, 1955). When economy reaches the stage of maturity, i.e. becomes more complex, the income is distributed more evenly because production of complex products requires greater numbers of skilled workers, related industries, supportive institutions, etc., than for resource exploiting economies (Hartmann et al., 2017). At the sub-national level the relationship is also non-linear; it has inverted U-shaped form with small, but significant quadratic coefficient (Bandeira et al., 2018).

The relationship between the economic crisis and the complexity of the economy does not seem to be unambiguously defined. On the one hand, the diversity of the structure of the region's economy can be viewed by analogy with portfolio theory. A properly diversified investment portfolio allows achieving the balance between risk and return. The diversified structure of the regional economy makes it possible to reduce the influence of external shocks on the level of demand, respectively, the value of production and income, and prevent the emergence of structural unemployment (Frenken et al., 2007). On the other hand, during economic downturns commodity prices also fall. Therefore, in the raw materials economy like the Russian one, the recession may

affect all regions and some raw materials dependent ones even harder. In addition, the complexity of the economy is a variable that determines the medium-term trend in the development of an economy. Therefore one should not assume a pronounced dependence on short intervals of time. Based on the foregoing, the following hypotheses are tested:

Hypothesis 1a. The complexity of the economy of the region has inverted U-shaped correlation with the innovation activity indicators.

Hypothesis 1b. The investment growth rate does not depend on the level of complexity of the regional economy.

Hypothesis 1c. The complexity of the economy of the region has inverted U-shaped dependence with indicators of economic growth, income and inequality.

Hypothesis 2a. The level of the economic complexity of neighboring regions has U-shaped correlation with innovation activity indicators.

Hypothesis 2b. The level of complexity of the economy of neighboring regions does not affect investment in the focal region.

Hypothesis 2c. The level of complexity of the economy of neighboring regions has positive effect on indicators of economic growth, income and inequality. This relationship is quadratically negative (inverted U-shaped).

Hypothesis 3. The economic crisis does not change the type of dependence between economic complexity and dependent variables.

6. Data, variables and model

In the study we use data on the manufacturing industry by regions of Russia at the four-digit level. More detailed classification of industries is impossible due to the lack of such detailed data. Sectors producing raw materials, including agricultural products, are excluded from consideration. First, their presence is accidental, due to the action of the forces of nature. Second, the fluctuations in commodity prices are significant (example: the decline in the price of oil and other commodities in March 2020), which could lead to significant fluctuations in RCA. We excluded 17 regions from

85 of total sample. In some cases the reason is a large number of data gaps, in others the reason is the small size of the region, which by definition excludes the very possibility of significant diversification of the economy due to the technical impossibility of achieving economies of scale in a large number of products. Morrison et al. (2017) indicate that this approach is controversial; however, we believe that it is incorrect to compare the regions whose resource endowments differ by tens of times. We do not use the complexity of the product from the study of countries of the world, as it is done in Operti et al., (2018). First, due to the political factors of external economic restrictions, the number of countries producing a certain product may be distorted. Secondly, the fact that the quality of assessing the complexity of a product depends on the regional concentration of its production requires justification. Third, the same technological laws operate within a single country as in the world. As a result 68 regions constitute a panel.

The set of dependent variables consists of ten units, which can be divided into three groups. The first group includes three variables characterizing innovative activity at the regional level. The second group of variables characterizes the dynamics of disposable income, investment, and growth of GRP. Finally, the remaining three variables characterize changes in social indicators (poverty and income inequality). Macroeconomic indicators calculated in accordance with international methodology (for example, GRP, the share of innovative companies, etc.) are selected as dependent variables, which significantly reduces the risk of distortion of the research results due to the use of incorrect methodology of their calculation by state statistician agency. In this study, we assume that the level of complexity of the region's economy has a non-linear impact and a spatial effect. There are very few studies that analyze the nonlinear influence of the complexity of the economy (Morais et al., 2018) and at the moment we are not aware of the studies in which spatial effects of the influence of the complexity of the economy are explored. Therefore the analysis of a large number of dependent variables allows us to draw conclusions about the degree of significance of nonlinear relationships and spatial effects in relation to the regional economy as a whole, and not only in separate direction only. A large number of dependent variables is an additional guarantee of

robustness of the results. For example, if the independent variable significantly and in the same way affects all the variables of the group (for example, the dependent variables characterizing innovative activity), this gives additional grounds to assert that the influence of the independent variable is stable and non-random.

Dependent variables used in this study include the following:

IA is the share of manufacturing enterprises engaged in innovative activities.

IE is the ratio of the expenditures on innovative activities of industrial enterprises to the value of produced goods.

IP is the ratio of the value of innovative products of industrial enterprises to the produced goods.

INV is the growth rate of investments in physical capital for three years.

GRP_GR - GRP growth rate for three years.

GRP_CAP - growth rate of GRP per capita for three years.

INCM is the growth rate of real disposable income of the population for three years.

IND is the increment of the ratio of the upper bound value of the ninth decile (i.e. the 10% of people with highest income) to that of the first decile (OECD, 2021).

GINI – increment of Gini coefficient for three years.

PVRT – increment of the share of inhabitants with income below poverty level.

The independent variables are presented as follows:

ECI – ranking of the region by indicator Fitness, calculated according to approach of Tacchella et al. (2012).

ECISQ – ranking of the region by indicator Fitness in degree 2.

W_ECI – weighted Fitness of other regions.

W_ECISQ – weighted Fitness of other regions in degree 2.

We add a number of parameters characterizing regional resource endowment and institutional environment. The logarithm of real median wages (LN_MSALARY) shows the level

of average labor costs in the region. In contrast to the average salary the median is closer to the real salary of an ordinary worker, not a top manager. The logarithm of the population size (LN_POP) characterizes the size of the region, indirectly the size of the regional market. Since the level of complexity of the economy also depends on the amount of available resources (the larger the market, the more profitable it is to strive for a deeper division of labor and product diversification), taking this factor into account allows to clarify the influence of the economic complexity on the socio-economic development of the region. The logarithm of the number of employees (LN_EMP) is an alternative measure of the size of the region. The share of urban population (CITY) shows the share of the region's population living in cities.

Innovations are more intensively created in places where there is a concentration of specialists, a diversity of knowledge is achieved, there is an infrastructure for the implementation of ideas, etc. The concentration of people allows and ensures the concentration of industrial firms, service companies, which leads to the provision of economies of scale, a deeper division of labor, as a result, a decrease in average costs (Balland et al., 2020). Higher level of urbanization facilitates trade, fosters competition and accelerates economic growth (Di Clemente et al., 2021). Also variable characterizing the status of the capital city - CAPL is included (in Russia, in addition to the official capital city, Moscow, St. Petersburg is considered as informal capital city too). In any case, it is a large, industrially and economically developed city that plays a very important role in Russian economy). Also there is variable which characterizes existence of the common border with the capital cities (CAPLBORDER).

The share of extractive industries in GRP (PRMRGRP), the share of non-fuel resources in GRP (NONFUELGRP), the share of fuel natural resources in GRP (FUELGRP) allows to reveal the influence of the resource sector on the dependent variable (Chávez et al., 2017), which may be negative due to the Dutch disease. Also it allows assessing the resource provision of the regional economy. The share of employees with higher education (HE), the share of employees with vocational education (PE) characterize the comparative provision of the regions with personnel of

the required qualification level, show the ability of the region to adopt knowledge. The ratio of R&D expenditures to GRP (RDGRP) characterizes regional companies and research organizations endeavor to develop / adapt new knowledge. Alternative indicators measuring the regional ability to generate knowledge are two coefficients of inventive activity: PATMA (the ratio of patents issued to the number of inhabitants) and APPMA (the ratio of patent applications to the number of inhabitants). The variable RISK is an integral estimate of the regional investment risk. The investment risk rating is annually formed by one of the leading rating agencies in Russia "Expert RA" (www.raexpert.ru). Since economic development implies the implementation of investment projects, the positive dynamics of the dependent variables like GRP, income, etc. should be associated with a lower level of investment risk. In the absence of this variable endogeneity is very likely to occur. Also instead of RISK we use Index of economic freedom (EFINDEX), the indicator which is proposed by Coates and Mirkina (2021).

In 2017 and 2018 methodologies of calculation of some dependent variables (IA, IP, IE, GRP, GRP_CAP) were amended by Russian Statistics Agency without possibility of matching with previous years. It forced us to correct calculation of abovementioned variables. Instead of calculation growth rate for three years we calculate increment of the following ratio: regional value to the total Russian one. For example GRP_CAP for the region i in the year t looks as follows (1.14):

$$GRP\_CAP_{i,t} = {grp\ per\ capita_{i,t}}\Big/{gpr\ per\ capita_{RU,t}} - {grp\ per\ capita_{i,t-3}}\Big/{gpr\ per\ capita_{RU,t-3}} \quad (1.14)$$

where grp per capita i,t is the value of grp per capita for the region i in year t; grp per capita ru, t is grp per capita for Russia in year t. Additional variables, respectively, are IA_RU, IE_RU, IP_RU, GRP_RU, GRPCAP_RU. GRP_RU for the region i is calculated as difference of shares of the regional grp in sum of grp of 68 Russian regions for years t and t-3. So analysis is performed for two time periods with different sets of dependent variables: 2005-2016 and 2005-2019. And the separate econometric modeling is provided for crisis period.

To analyze the data and test hypotheses we will use spatial regression methods (SDM - Spatial Durbin Model). The spatial regression model SDM looks as follows:

$$Y = \alpha + \delta WY + X\beta + WX\theta + \varepsilon \quad (1.15)$$

where:

α – constant

δ – coefficient characterizing the spatial lag of the dependent variable.

β – coefficients characterizing the influence of Xi on Yi.

θ – coefficients characterizing the spatial lag of independent variables.

The need to include variables that characterize the spatial effect is indicated in Basile et al. (2019), Pintar and Scherngell (2018). Spatial autoregression modeling requires choice of matrix of weights. As Russia is a big country, road network is not as dense as in small countries. Therefore to be closer to reality it is better use matrix of inverted distance by car between capital cities of regions. To avoid the problem of endogeneity we use lagged dependent variables. IA, IP, IE are calculated as average for three consecutive years in relation to independent and control variables. For example for year t IA is calculated as $(IA_{t+1} + IA_{t+2} + IA_{t+3})/3$. For GRP_GR, GRP_CAP, INV, INCM calculation of growth rate for three consecutive years are made as multiplication of annual growth rates, i.e. t+1, t+2, t+3. For GINI, IND, PVRT calculation is made as difference between values for t and t+3 years. The size of the lag is three years, which is quite enough to neutralize accidental annual fluctuations of indicators. To make some independent variables (PATMA, APPMA) less volatile they are calculated as moving averages.

7. Research results

7.1. Descriptive analysis

The calculation of the ECI indicator shows that this indicator intuitively correctly reflects the state of economic complexity of Russian regions. Industrialized, large regions consistently occupy leading positions in the ranking. At the same time, peripheral regions located mainly on the outskirts of Russia (Arctic, Far East, North Caucasus) are characterized by a low level of economic

complexity. The absolute values of the indicator of the economic complexity over the years are not fully comparable due to some differences in the matrix of product groups, the need for correction, industry fluctuations, etc[1]. Table 1.2 shows results of calculations of absolute values of ECI and ranks of regions on ECI for some regions.

Table 1.2

ECI for the leading and peripheral regions of Russia, rating values (absolute value - in parenthesis)

Region	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Moscow	68 (18.70)	68 (14.80)	68 (58.16)	68 (57.80)	68 (33.93)	68 (36.61)	67 (7.64)	67 (6.64)	67 (6.63)	67 (7.93)	66 (4.6)	66 (4.44)
Saint Petersburg	67 (12.08)	67 (6.80)	67 (4.77)	67 (5.13)	67 (16.39)	67 (14.29)	68 (13.36)	68 (29.89)	68 (29.89)	68 (28.68)	68 (11.72)	68 (11.47)
Chelyabinsk	64 (1.84)	59 (1.15)	64 (0.12)	62 (0.17)	62 (0.60)	61 (0.52)	61 (1.45)	54 (0.76)	52 (0.74)	55 (0.71)	53 (1.09)	51 (1.03)
Ekaterinburg	65 (2.82)	65 (5.82)	66 (1.21)	64 (0.19)	65 (1.06)	64 (0.85)	65 (2.16)	61 (1.10)	61 (1.11)	63 (1.46)	62 (2.04)	62 (1.96)
Kazan	62 (1.18)	58 (1.11)	56 (0.09)	58 (0.12)	60 (0.53)	57 (0.46)	62 (1.60)	65 (1.40)	65 (1.41)	64 (1.53)	65 (2.64)	65 (2.64)
Novosibirsk	58 (0.94)	60 (1.30)	59 (.10)	48 (0.09)	57 (0.43)	58 (0.47)	58 (1.33)	56 (0.78)	56 (0.80)	62 (1.4)	52 (1.08)	50 (1.03)
Primor'e	15 (0.21)	16 (0.19)	10 (0.01)	9 (0.01)	13 (0.07)	14 (0.07)	13 (0.22)	14 (0.13)	13 (0.13)	11 (0.06)	11 (0.15)	11 (0.15)
North Osetiya	3 (0.1)	7 (0.1)	4 (0.007)	2 (0.005)	3 (0.02)	3 (0.02)	1 (0.05)	1 (0.02)	1 (0.02)	7 (0.02)	5 (0.05)	6 (0.05)
Murmansk	8 (0.12)	9 (0.11)	7 (0.007)	7 (0.009)	6 (0.04)	7 (0.03)	10 (0.14)	10 (0.09)	10 (0.09)	14 (0.07)	13 (0.17)	13 (0.17)
Adygey	11 (0.15)	14 (0.15)	15 (0.01)	10 (0.01)	14 (0.07)	15 (0.07)	17 (0.29)	16 (0.16)	17 (0.16)	23 (0.2)	30 (0.46)	28 (0.47)
Tyumen'	23 (0.33)	19 (0.25)	20 (0.02)	31 (0.05)	25 (0.13)	26 (0.13)	31 (0.44)	26 (0.23)	27 (0.23)	28 (0.22)	26 (0.4)	24 (0.39)

It can be noticed from Table 1.2 that fluctuations in the absolute values of ECI are accompanied by the stability of the region's place among other regions of the sample. This confirms

[1] For calculations of economic complexity indicators it is necessary to construct matrices "regions-value of production". These matrices could differ because price and volume fluctuations could impact on matrix M, which contains RCA ratios.

the relevance of the methodology proposed by Tacchella et al. (2012). The calculation of the economic complexity indicator using the method of reflections doubts its reliability. There are significant fluctuations in the positions of the regions. Therefore, fitness is used as the only indicator of economic complexity.

The global Moran and Geary indices are used to determine the presence of spatial autocorrelation. In the case of the positive autocorrelation regions with more complex economies are also closer to regions with more complex economies, and vice versa. With negative autocorrelation regions with more complex economies are surrounded by peripheral regions, and vice versa. A positive global Moran's index indicates a positive spatial autocorrelation. For the Geary index autocorrelation is positive if its value is in the range (0;1). It is negative if its value lies in the range (1;2). The results of calculations for ECI are presented in Table 1.3.

Table 1.3

Global Moran and Geary indices (p-value = 0.95 in parenthesis)

Year	Moran		Geary	
	ECI (absolute values)	ECI (rank)	ECI (absolute values)	ECI (rank)
2005	-0.017 (0.883)	0.066 (0.000)	1.133 (0.239)	0.886 (0.000)
2006	-0.024 (0.545)	0.095 (0.000)	1.154 (0.129)	0.846 (0.000)
2007	-0.022 (0.199)	0.105 (0.000)	1.212 (0.164)	0.833 (0.000)
2008	-0.021 (0.253)	0.118 (0.000)	1.212 (0.166)	0.825 (0.000)
2009	-0.018 (0.761)	0.107 (0.000)	1.164 (0.195)	0.839 (0.000)
2010	-0.019 (0.685)	0.113 (0.000)	1.179 (0.182)	0.834 (0.000)
2011	-0.008 (0.642)	0.109 (0.000)	1.027 (0.783)	0.842 (0.000)
2012	-0.012 (0.718)	0.113 (0.000)	0.974 (0.855)	0.839 (0.000)
2013	-0.012 (0.732)	0.113 (0.000)	0.974 (0.856)	0.839 (0.000)
2014	-0.011 (0.708)	0.096 (0.000)	0.981 (0.891)	0.849 (0.000)
2015	0.007 (0.158)	0.112 (0.000)	1.000 (0.998)	0.831 (0.000)

2016	0.007 (0.163)	0.107 (0.000)	1.001 (0.992)	0.834 (0.000)

Spatial autocorrelation is positive and significant, but only if the results are presented as ranks. Perhaps this is due to the fact that the transition to ranks increases the distance between regions. Below descriptive statistics is presented (see Table 1.4).

Table 1.4

Descriptive statistics of variables

Variable	N	Min	Max	Mean	St.dev.
CAPL	68	0	1	0.3	0.17
CAP	68	0	1	0.19	0.40
HE (%)	816	14.3	50	26.62	5.64
PE (%)	816	15.9	58.2	31.64	9.54
RISK	816	1	68	35.38	20.63
PRMRGRP	816	0	0.95	0.12	0.20
FUELGRP	816	0	0.95	0.09	0.19
GRP_CAP	612	0.84	1.45	1.09	0.10
INCM	816	0.77	1.94	1.09	0.17
GRP	612	0.87	1.52	1.09	0.10
LN_POP	816	12.99	16.33	14.25	0.67
LN_EMP	816	5.16	8.87	6.63	0.68
NONFUELGRP	816	0	0.58	0.03	0.07
RDGRP	816	0.000001	0.057	0.008	0.009
GINI	816	-0.057	0.047	-0.002	0.016
IA	612	2.83	25.23	9.28	3.52
IP	612	0.066	58.43	6.06	6.16
IE	612	0.07	11.36	1.90	1.53

LNMSALARY	816	8.44	10.70	9.48	0.36
ECI	816	1	68	34.5	19.64
W_ECI	816	0.26	4.29	2.23	1.16
EFINDEX	816	3.8	7.26	4.98	0.39
GRPSHARE	816	-0.024	0.014	-0.000004	0.0022
IND	816	-10	4.6	-0.28	1.62
GRPCAP_RU	816	-2.16	2.44	0.011	0.23
IA_RU	816	0.19	2.80	0.96	0.39
IP_RU	816	0.004	7.34	0.90	0.86
IE_RU	816	0.044	6.06	0.88	0.695
PATMA	816	0.0045	0.94	0.151	0.125
APPMA	816	0.009	1.32	0.185	0.155
CITY	816	43.4	100	71.66	10.72
INV	816	0.40	3.17	1.15	0.38

Correlation matrix is presented in Appendix 1. Correlation matrix contains only values significant on p=0.05. Its analysis allows drawing conclusions about degree of interdependence among variables and justified compounding of sets of independent and control variables. As ECI and W_ECI are variables of interest, modeling of their undistorted influence requires accurate choice of control variables, which are less correlated with ECI, W_ECI and other control variables and at the same time not correlated with most of dependent variables. In our opinion it would be better to refuse from RDGRP, CAPL, CAPLBORDER, PE, CITY. Some other variables like PRMRGRP, EFINDEX, LNEMP are also correlated with ECI, but they are significant almost in all models (see Tables 1.5, 1.6, 1.8-1.10). So their exclusion could cause serious distortions with coefficients.

To test the hypotheses of the study, the data were conditionally divided into three parts (more precisely, data samples) taking into account the chronology of the onset of economic crises in the Russian economy. The Russian economy was affected by the 2008-09 global financial crisis, which was a short-term recession. As a result of quantitative easing programs in the leading developed countries of the world, Russian economy was able to recover quickly. The second crisis for Russia came in 2014 as a result of geopolitical confrontation and a decline in oil prices, although a number of Russian economists argued that the economic slowdown had been accruing since 2012. We can conditionally interpret the second crisis as a medium-term one. On the one hand, for example, investments recovered to the pre-crisis level in 2016 in real prices. On the other hand, there was no further sustained growth in indicators. In 2017-19 the Russian economy was in a state of stagnation. Thus, for two economic crises, the impact of the level of the economic complexity on sustainability will be assessed. We perform the analysis for two crises simultaneously, because in other case sample size would be too small for an appropriate assessment. For simplicity of results presentment models without independent variables ECI and ECISQ and its spatial effects are presented in Appendix 2 (see Tables A2.1-2.3).

7.2. Econometric models for the time period 2005-2016

Dependent variables are considered with a lag of three years. Explanatory variables are taken from 2005 to 2013 inclusively. The calculation results are shown in Table 1.5.

Table 1.5

Spatial Regression Models for 2005-2016

	Dependent variable									
	IA	IP	IE	INV	GRP_GR	GRP_CAP	INCM	GINI	IND	PVRT
ECI	.0142 (.044)	.0004 (.083)	-.0290 (.0243)	.003 (.007)	.0018 (.001)	.0018 (.001)	.004** (.002)	.0003 (.0002)	.026 (.02)	-.109** (.047)
ECISQ	.0002 (.005)	-.0002 (.001)	.0003 (.003)	-.00005 (.001)	-.00004*** (.000)	-.00002 (.000)	-.00007*** (.0000)	.0002924* (.0000)	-.0004 (.0003)	.002*** (.0006)
W_ECI	-.965** (.382)	-2.129*** (.728)	-.357* (.212)	-.002 (.065)	-.006 (.012)	-.013 (.012)	-.0222 (.016)	.0007 (.001)	.0034 (.2)	.058 (.417)
W_ECISQ	.0150**	.0354**	.007**	.0000	.00008	.0003*	.00017	-.00002	-.00075	-.0015

	* (.005)	* (.010)	(.003)	8 (.001)	(.000)	(.0001)	(.0002)	(.0000)	(.003)	(.006)
HE	-.0353 (.038)	-.032 (.072)	-.026 (.021)	-.009 (.006)	.00009 (.001)	.0011 (.001)	-.006*** (.0016)	-.0005*** (.002)	-.0601*** (.02)	.108** (.041)
PRMRGRP	-1.338 (.799)	30.47*** (3.389)	2.70*** (.992)	.673** (.31)	-.257*** (.001)	-.212*** (.057)	.0304 (.075)	-.007 (.009)	-1.327 (.94)	-.641 (1.958)
LNEMP	6.521*** (.309)	.961 (4.375)	6.082*** (1.285)	-.633[2] (.399)	-.392*** (.057)	-.130* (.074)	-.158* (.097)	.018* (.01)	.855 (1.217)	3.291 (2.523)
PATMA	5.306** (.153)	1.647 (4.084)	1.06 (1.196)	.377 (.372)	-.0876 (.073)	.0435 (.069)	-.020 (.09)	.0105 (.01)	3.254*** (1.139)	9.271*** (2.362)
LNMSALARY	5.260*** (.315)	4.421* (2.49)	.604 (.729)	-.515** (.227)	-.151*** (.068)	.0355 (.042)	-.086[3] (.055)	.007 (.006)	.800 (.693)	2.122 (1.438)
EFINDEX	5.260 (.338)	-1.463** (.641)	-.279[1] (.188)	-.151** (.058)	.0056728 (.010)	-.0289*** (.010)	-.0392*** (.014)	-.004** (.001)	-.229 (.178)	1.441*** (.370)
N	612	612	612	612	612	612	612	612	612	612
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	Yes
Spatial (Rho=0)	.282** (.132)	-.541** (.258)	.585** (.281)	.216 (.243)	.418*** (.156)	-.075 (.065)	.087 (.92)	.092 (.143)	.066 (.054)	-.627*** (.156)
R^2 (within)	.092	.21	.16	.43	.627	.643	.795	.685	.617	0.603
Hausman test	14.03	54.6***	28.12*	27.7*	57.4***	20.53	38.1***	32.7**	28.6*	66.3***

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses.

The quality of econometric models with the exception of ones, which use indicators of innovation activity as dependent variables, is very good if we consider R^2 (within). Spatial variables (W_ECI and Rho) are often significant, which confirms the correctness of the selected model type (SDM). The Hausman test is also almost always significant. Consequently, the specification of models with fixed effects rather than with random effects is justified.

The regions of Russia differ significantly in the accumulated intellectual capital, location, institutional characteristics, environment, etc., which leads to differences in the impact of independent and control variables. Similar effects are seen in regional studies in other countries (Vickerman et al., 1999; Fornahl et al., 2009). The results of econometric modeling very brightly characterize the essence of the Russian economy. Negative values of the LNMSALARY variable for the dependent variables INV, GRP_GR (for GRP_CAP, INCM the variable is insignificant) mean that the growth of the quantitative parameters of the Russian economy is determined by the level of costs, in particular for labor. The role of external demand is very significant, since a

decrease in wages with an increase in GRP automatically means a relative decrease in the role of domestic demand in favor of external demand. However, a low cost strategy, i.e. the growth of the exploitation of workers, comes into conflict with the task of increasing innovative activity. This is confirmed by the positive and significant value of the LNMSALARY in relation to IA, IP. Skilled engineers, developers and workers do not work for a pittance and would rather emigrate. This contradiction is also confirmed by the signs at the variable PRMRGRP: they are positive for the parameters of innovation and investment (investments are directed mainly to regions provided with resources, and hence domestic demand) and negative for the dynamics of GRP and GRP per capita (extraction and primary processing of natural resources has limited impact on generating new technological capabilities and increasing value added). Consequently, in Russian economy there is a contradiction between the sectors of the economy, which hinders the accumulation of technological capabilities and an increase in the level of complexity.

This contradiction could be also illustrated by models with social indicators as dependent variables (GINI, IND, PVRT). Social inequality decreases with the growth of employees who have higher education, but share of poor inhabitants increases. The same is true for number of patents (PATMA). Higher scientific activity leads to higher increment of poor people, but do not influence on economic development. It is also confirmed by indicator of economic freedom (EFINDEX). Development of knowledge-intensive activities requires intensive interactions among economic agents, predictability of economic policy, high level of property rights protection, etc. It means democratic government in the country and free and independent elections, which allow controlling of bureaucracy by society. But the impact of EFINDEX points out that in Russian regions autocratic type of government is more effective which is suitable for economy with standardized, not knowledge-intensive products. It could be seen from Table 1.5 that EFINDEX *negatively* correlates with innovation activity, economic growth and *positively* with increment of poverty.

According to Table 1.5, the complexity of the economy affects the dependent variables, but this effect is not significant in all cases. With regard to indicators of innovation activity (IA, IP, IE),

the level of complexity of the region's economy does not have a significant impact. Perhaps this is due to the relative autonomy of the activities of innovatively active companies from other local firms, their focus on cooperation with companies from other regions and on external demand. This is confirmed by the significance of the W_ECI variable. The dependence *formally* has inverted U-shaped form (see section 5.5 for more details): a decrease in the level of complexity of the economies of other regions leads to a decrease in innovation activity in this region, however, when a certain threshold level is passed, the type of dependence changes (there are too few worthy competitors around, market niches are not occupied).

The quantitative parameters of GRP and income growth also depend on the level of complexity of the economy, but only in a focal region. In case of investment there is no dependence and this is understandable: investment depend on the availability of resource endowment (PRMRGRP is positive), the level of wages (LNMSALARY is negative) and the number of local limited skilled workers and their ability to change their professional field of activity (the fewer employees with higher education, the better for investors; HE is negative but not significant). The growth of GRP depends on the complexity of the economy, but the orientation of the country's economy towards relatively simple products and a low share of medium- and high-tech industries lead to the fact that the influence of the complexity of the economy of other regions is insignificant. Economic growth depends on the level of complexity of the economy of the region, but this dependence is, in fact, the opposite: a decrease in the level of complexity leads to economic growth due to a greater match of demand from other regions (if the level of complexity is too high, the economy of this region will simply not structurally match the rest regions of the country).

7.3. Econometric models for time period 2005-2019

Extended time period (2005-2019) includes three years, which could be characterized as crisis ones. But greater sample size with three years of economic turbulence allows checking results described in the Table 1.5 on stability. Results are presented in Table 1.6.

Table 1.6

Spatial Regression Models for 2005-2019

	Dependent variable									
	IA_RU	IP_RU	IE_RU	INV	GRP_RU	GRP_CAPAV	INCM	GINI	IND	PVRT
ECI	-.003 (.004)	.0164* (.019)	-.0182** (.009)	.004 (.006)	.00007** (.000)	.0136*** (.003)	.002* (.001)	.00016 (.0002)	.0168 (.0193)	-.0382 (.0371)
ECISQ	.00005 (.000)	-.0003** (.0001)	.0003*** (.0001)	-.00006 (.0000)	-8.94e-07* (.000)	-.00018*** (.000)	-.0003* (.000)	-2.65e-06 (.000)	-.00026 (.002)	.0008* (.0004)
W_ECI	-.140*** (.03)	-.050 (.083)	-.119 (.075)	-.1008** (.052)	-.0004 (.003)	.0385 (.034)	-.024** (.015)	.0006 (.001)	-.0703 (.1604)	.136 (.3101)
W_ECISQ	.002*** (.0004)	.0008 (.001)	.0025** (.001)	.0014** (.0007)	4.43e-06 (.000)	-.00068** (.000)	.0003* (.0001)	-1.38e-06 (.000)	.0017 (.0022)	-.0036 (.0042)
HE	-.0006 (.004)	-.0109 (.009)	-.0148* (.008)	-.005 (.006)	-.00004 (.000)	.0119*** (.003)	-.006*** (.001)	-.0005** (.0002)	-.059*** (.0187)	.108*** (.0361)
PRMRGRP	-.0661 (.154)	1.378*** (.373)	.602* (.338)	.260 (.224)	-.0022* (.001)	-.822*** (.135)	.120** (.056)	-.0017 (.007)	.0338 (.7270)	-1.291 (1.402)
LNEMP	.980*** (.226)	.405 (.546)	2.852*** (.482)	-.327 (.228)	.0047** (.001)	1.045*** (.198)	-.0529 (.078)	.0084 (.013)	1.014 (1.054)	2.135 (2.043)
PATMA	.513** (.228)	.539 (.556)	1.119** (.494)	.139 (.327)	-.0025 (.001)	-.0262 (.193)	-.0212 (.082)	.0083 (.015)	2.001* (1.066)	5.842*** (2.061)
LNMSALARY	.542*** (.122)	.542* (.312)	-.0528 (.287)	-.693*** (.182)	-.011*** (.001)	-1.087*** (.113)	-.120*** (.043)	-.005 (.0058)	-.565 (.6072)	4.646*** (1.182)
EFINDEX	-.0326 (.033)	-.108 (.097)	-.140* (0.088)	-.0856[1] (.055)	-.0006** (.0003)	-.3225*** (.034)	-.045*** (.012)	-.004** (.0017)	-.2114 (.1774)	1.636*** (.3375)
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	Yes	yes
N	816	816	816	816	816	816	816	816	816	816
Spatial (Rho=0)	.301** (.141)	-.277 (.198)	-.699** (.220)	.102 (.157)	-.105 (.169)	.090 (.182)	.206 (.146)	.218 (.148)	.082 (.161)	-.347* (.183)
R^2 (within)	.0801	.05	.12	.393	.137	.308	.82	.6044	.535	.584
Hausman test	19.81	37.2**	36.5**	37.3**	45.4***	52.86***	39.3**	27.02	53.7***	63.7***

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses

According to R^2 quality of almost all models became worse despite bigger sample size. The choice of models with fixed effects is still justified due to Hausman statistics. For indicators of innovation capacity the lists of significant variables mostly coincide. ECI became significant for the

share of innovation products and innovation expenditures, but as signs are different it is not possible to infer about existence of steady influence. But economic complexity of neighboring regions still have pronounced and steady influence. Economic complexity of a region became significant variable for economic growth (INV, GRP_RU, GRP_CAPAV), but its influence is weaker in case of social indicators. Control variables keep their signs and significance levels. For example LNMSALARY and EFINDEX influence negatively on economic growth. It confirms speculations about dominating of standardized products in GDP and low cost as one of important competitive advantages.

7.4. Economic crises (2008-2009 and 2014-2016)

As each of the economic crises did not last long and the dependent variables are taken with a lag of three years, the number of observations for each of the economic crises is too small to conduct separate econometric analysis. The calculation results are presented in Table 1.7.

Table 1.7

Spatial Regression Models for economic crises periods

	Dependent variable									
	IA	IP	IE	INV	GRP_GRP	GRP_CAP	INCM	GINI	IND	PVRT
ECI	.109* (.060)	.0348 (.0118)	.0062 (.030)	.0129 (.009)	.005*** (.0017)	.0027 (.002)	.006*** (.0021)	.00047* (.0002)	.0151 (.0297)	.0472 (.063)
ECISQ	-.0007 (.000)	-.001 (.0015)	- .00005 (.000)	- .00025** (.0001)	- .00009*** (.000)	-.00003 (.000)	- .00008*** (.000)	-7.53e- 06* (.000)	-.0003 (.0003)	-.0004 (.0008)
W_ECI	-1.149** (.584)	-2.268** (1.147)	-.155 (.289)	.0577 (.090)	.0022 (.017)	-.0422** (.017)	.0103 (.021)	.0027 (.002)	-.176 (.286)	.545 (.615)
W_ECISQ	.0206*** (.073)	.0433*** (.143)	.0054 (.003)	-.0007 (.001)	.00007 (.0002)	.0004** (.0002)	-.0002 (.000)	- .00006* (.000)	.0033 (.003)	-.0092 (.007)
HE	-.0124 (.0582)	.092 (.114)	-.0228 (.029)	-.008 (.009)	.0018 (.001)	.00216 (.0017)	-.0045** (.0021)	- .00054* (.0002)	.0185 (.0288)	.04 (.061)
EFINDEX	-.113 (.505)	.334 (.990)	.0613 (.253)	-.191** (.078)	.0071 (.0014)	-.0267* (.0153)	. -.0267 (.0184)	-.0044* (.0025)	- .849** (.25)	1.05* (.534)
PRMRGRP	-.282 (2.588)	31.88*** (5.055)	-.141 (1.28)	.639* (.404)	-.309*** (.076)	-.226*** (.078)	.0388 (.094)	-.0063 (.0125)	1.431 (1.277)	-2.125 (2.371)
LNEMP	10.1*** (3.339)	3.625 (6.526)	6.8*** (1.66)	-1.209** (.519)	-.532*** (.097)	-.0293 (.101)	-.289** (.122)	.0033 (.0160)	-1.966 (1.644)	1.542 (3.547)
PATMA	7.346* (3.902)	6.078 (7.650)	-.936 (1.945)	1.021* (.608)	.0245 (.114)	.0224 (.117)	-.130 (.143)	-.0063 (.0189)	-2.059 (1.932)	-3.38 (4.157)
LNMSALARY	7.345*** (1.967)	1.748 (3.807)	1.643* (.972)	-.135 (.302)	-.074 (.057)	.116** (.058)	-.166** (.071)	.0059 (.0094)	-1.264 (.960)	4.145*** (2.060)
N	340	340	340	340	340	340	340	340	340	340
Year fixed	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

effects										
Spatial (Rho=0)	.164 (.245)	-0.469 (.334)	-.762** (.355)	.269 (.218)	.429** (.185)	.0503 (.265)	.201 (.272)	.504 (.253)	.219 (.268)	.389*** (.302)
R^2 (within)	.151	.217	.170	.332	.328	.264	.766	.689	.36	.557
Hausman test	21.29	34.62***	15.85	13.48	43.55***	14.2	20.15	25.81**	11.65	27.62*

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses.

The models do not demonstrate stable results for the variables of innovation activity (IA, IE, IP). So, R^2 (within) has low values. The results are quite stable for the variables characterizing the complexity of the economy of the neighboring regions. Economic crises do not change the pattern of variable influence. The same can be inferred for some other variables like LNMSALARY and LNEMP. The level of complexity of the economy becomes consistently significant more often than for longer time period (2005-2016) sample for the variables of economic growth and income inequality.

7.5. Detailed analysis of nonlinear influence of the economic complexity

Formally the dependence between economic complexity variables and dependent ones is quadratic. But as ECI and W_ECI could be calculated on intervals only ([1;68] and [0.26;4.29] see Table 1.4) true correlation could be unidirectional. To illustrate this proposition for variables IA, IP, IE three curves describing dependence for W_ECI and W_ECISQ are depicted on the graph (see Figure 1.5). We use the following formula for each dependent variable:

$$a*W\_ECI + b*W\_ECISQ \quad (1.16)$$

Data for variables W_ECI and W_ECISQ are taken for 2010. For other years results are almost the same, because values of economic complexity index are quite steady and matrix of weights is the same.

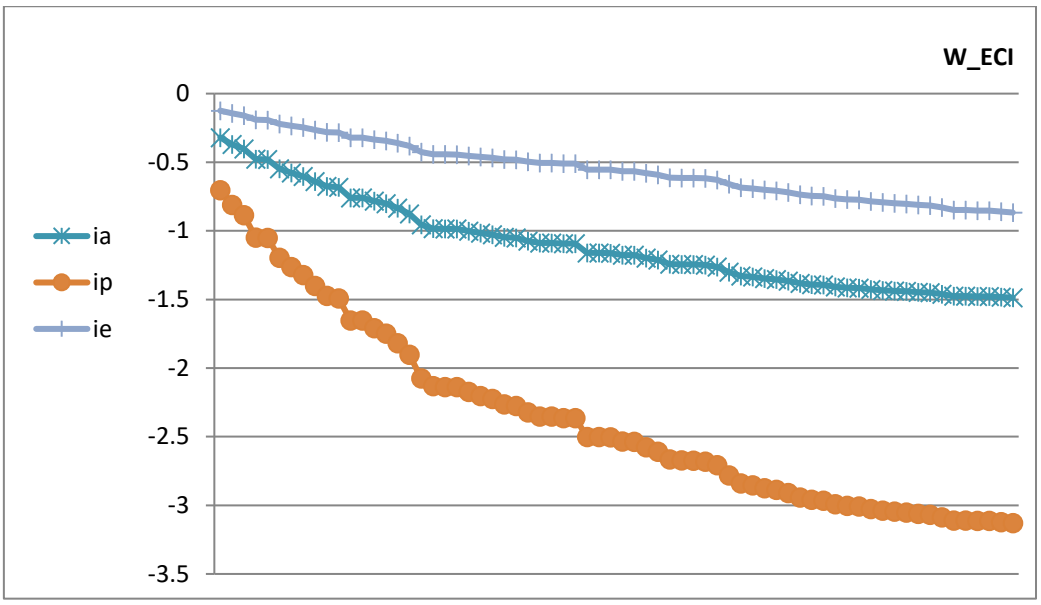

Figure 1.5. Influence of economic complexity of neighboring regions on innovation activity in a focal region

There is well-known formula of calculation the apex of parabola:

$$X = -b/2a \quad (1.17)$$

It could be inferred for all cases in which variables W_ECI and W_ECISQ are significant that apex of a parabola lies further than maximum value of W_ECI. In fact, economic complexity of neighboring regions influences on dependent variables non-linearly, but not quadratically. This is true for all cases, in which these variables are significant. In case of economic complexity of a focal region the type of dependence on the contrary is quadratic. The value of ECI, representing apex of parabola for the models with significant ECI and ECISQ could be seen in Table 1.8.

Table 1.8

Apex of parabola for ECI

Time period	IA_RU or IA	IP_RU or IP	IE_RU or IE	INV	GRP_RU or GRP_GR	GRP_CAPAV or GRP_CAP	INCM	GINI	IND	PVRT
2005-2016	n.a	n.a	n.a	n.a	n.a	n.a	29	n.a	n.a	28
2005-	n.a	28	31	n.a	39	38	n.a	n.a	n.a	n.a

2019										
Economic crises time period	n.a	n.a	n.a	n.a	28	n.a	38	32	n.a	n.a

So the most pronounced influence of economic complexity is observed approximately for a region, whose economic complexity is in the middle of the sample. For example regions with ranks around 28th place experienced less acute economic slowdown during economic crisis than regions with higher or lower economic complexity.

7.6. Robustness check

To conduct robustness check we use different variants of control variables as the test for robustness. For example, instead of PRMRGRP (the share of the extractive sector in GRP), a more focused analog is used - FUELGRP (the share of fuel production in GRP) or NONFUELGRP (the share of non-fuel resources in GRP). The variable PATMA (coefficient of inventive activity) has been replaced by APPMA (the number of patent applications per 1000 people). In general, varying control variables and time lags (i.e., using shorter variants of the dependent variable), adding spatial components for other variables did not improve the quality of estimates. Hausman's test shows that fixed-effects SDMs should be preferred over random-effects models almost in every case. List of significant variables in every model is almost the same, despite variable substitution. Signs of LNMSALARY and FUELGRP confirm conclusions about low cost competitive advantage of Russian economy and bounded influence of resource endowment on growth pace and sustainability of the regional economy. Kind of surprise is significant impact of RDGRP on investment and GRP growth. May be partially this is due to positive correlation of the size of a regional economy and its endeavor to use knowledge. Other possible explanation could be impact of sanctions and currency

devaluation which make local innovation more competitive. Modeling is performed for the "long" period (2005-2019). Results are presented in Table 1.9.

Table 1.9

Spatial Regression Models for 2005-2019 with alternative set of control variables

	Dependent variable									
	IA_RU	IP_RU	IE_RU	INV	GRP_RU	GRP_CAPAV	INCM	GINI	IND	PVRT
ECI	-.004 (.005)	.0125 (.0235)	-.025*** (.009)	.002 (.003)	.00005 (.0006)	.0132*** (.043)	.0022 (.0013)	.0001 (.0005)	.008 (.007)	-.06 (.033)
ECISQ	.00006 (.0007)	- .0003** (.014)	.0004*** (.0002)	-.00003 (.0004)	-5.55e- 07 (.000)	-.00017*** (.0004)	-.00003 (.0004)	-1.97e- 06 (.000)	-.00016 (.0004)	.0011** (.054)
W_ECI	-.160*** (.043)	-.071 (.0578)	-.156** (.075)	-.105** (.048)	-.0005* (.0003)	.0228 (.045)	- .0282* * (.0138)	- .00022 (.0003)	-.153 (.239)	.135 (.287)
W_ECISQ	.002*** (.0003)	.0012 (.043)	.003*** (.001)	.0016** (.0075)	6.02e-06 (.000)	-.00045 (.0005)	.0004* * (.0002)	9.11e- 06 (.000)	.0028 (.005)	-.0034 (.005)
PE	-.005* (0.0027)	.006 (.005)	-.007 (.0056)	.006* (.003)	-.00003 (.0003)	-.0078*** (.0023)	.0014 (.003)	-.0002 (.0001)	-.0161 (.024)	-.0265 (.047)
FUELGRP	-.203 (.367)	1.77*** (.369)	.465 (.561)	.229 (.289)	-.003** (.0014)	-1.129*** (.238)	.181** * (.031)	-.0044 (.007)	-.262 (.458)	-2.474 (1.45)
LNPOP	1.032*** (0.321)	2.26** (1.081)	3.213*** (1.002)	1.122 (.989)	.0075** (.0037)	1.527*** (.422)	.297** (.137)	.0333* (.0173)	2.403 (1.89)	-6.91* (3.98)
APPMA	.495** (.251)	.767* (.415)	1.957*** (.549)	.229 (.403)	-.0023* (.0012)	.0752 (.065)	.075 (.089)	.009 (.008)	1.115 (1.56)	-4.78*** (1.56)
LNMSALARY	.576*** (.123)	.598** (.302)	.161 (.143)	-.663*** (.128)	- .0108*** (.0032)	-1.269*** (.398)	-.21*** (.004)	-.0053 (.007)	-.333 (.679)	5.677*** (2.01)
RISK	-.0004 (.0006)	-.003** (.0015)	-.0008 (.0007)	.0011 (.002)	-2.40e- 06 (.000)	.00078 (.00075)	.00024 (.0006)	.00003 (.0006)	.0025 (.004)	-.00347 (.0067)
RDGRP	-6.89* (3.63)	4.74 (3.89)	20.99** (10.256)	18.85*** (5.86)	.113*** (.033)	5.8 (3.1)	-2.13 (1.18)	.103 (.148)	10.21 (7.56)	27.794
N	816	816	816	816	816	816	816	816	816	816
Year fixed effects	yes	yes	yes	Yes	yes	yes	yes	yes	yes	yes
Spatial (Rho=0)	.324** (.168)	-.223 (.245)	-.708*** (.0287)	.148 (.211)	-.074 (.0899)	.078 (.095)	.231 (.376)	.201 (.189)	.092 (.138)	-.321* (.169)
R^2 (within)	.0902	.079	.145	.403	.15	.233	.816	.6044	.532	.573
Hausman test	27.00	30.55**	34.4*	62.04***	49.57***	20.46	40.71* *	24.62	24.05***	39.98**

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses.

The next step of robustness check consist of screening sample, so that to make it more homogeneous. First, the role of the capital of Russia – Moscow in the national economy is increasing year by year. Now it accounts approximately for 20% of total GRP, 15% of investment

in fixed capital, more than one third part of innovation expenditures, etc. Growth of variables for Moscow could substantially influence results of econometric modeling. This problem is mitigated by calculation of relative indicators and rankings, but nevertheless it exists, because there are several absolute variables (LNPOP, LNEMP).

As Russian economy is based on extracting resources, the role of regions specializing on primary sector is outstanding. At the onset of the research the smallest and poorest regions with undeveloped economy were excluded from the sample. Now six regions, in which primary sector prevails, i.e. PRMRGRP is higher than 50% (Kemerovo, Komi, Khanty-Mansiysk, Yamal-Nenets, Orenburg and Sakhalin) are also excluded from the sample. Such regions depend a lot on conjuncture of the world market of oil, gas, coal, so fluctuations of resource prices could heavily influence economic and social indicators of these regions. Results of calculation are presented in Table 1.10.

Table 1.10

Spatial Regression Models for 2005-2019, truncated sample

	Dependent variable									
	IA_RU	IP_RU	IE_RU	INV	GRP_RU	GRP_CAPAV	INCM	GINI	IND	PVRT
ECI	-.006	.0004	-.0137	.0046	1.01e-06	.0016	.00008	.000018	-.0021	.00181
	(.007)	(.001)	(.0185)	(.007)	(.000)	(.004)	(.0014)	(.0000)	(.003)	(.0029)
ECISQ	.00008	-.00013	.00025**	-.00007	7.28e-08	-.000024	-5.97e-06	-6.26e-07	1.71e-06	.0003
	(.0012)	(.0002)	(.0001)	(.0009)	(.000)	(.000)	(.000)	(.0000)	(.000)	(.0005)
W_ECI	-.158***	-.0263	-.094	-.0295	-.00044***	-.0098	-.0319***	.00077	-.0447	.470
	(.029)	(.004)	(.076)	(.032)	(.0001)	(.018)	(.012)	(.00194)	(.0433)	(.279)
W_ECISQ	.002***	.0006	.00227**	.0005	5.09e-06**	.00007	.00036**	-8.66e-06	.0005	-.0069*
	(.0005)	(.0009)	(.001)	(.0009)	(.000)	(.00012)	(.00017)	(.000)	(.0005)	(.0038)
HE	.00125		-.0165*	.0015	-9.50e-06	.0006	-.0073	-	-	.1406***
	(.0028)	.0026	(.0097)	(.003)	(.000)	(.0012)	(.0089)	.0006***	.0597***	(.533)
		(.008)						(.0002)	(.0237)	
PRMRGRP	-.132	.695**	.799**	.183	.00182**	.160***	.0762	-.0086	-.600	-1.730
	(.189)	(.340)	(.392)	(.254)	(.0087)	(.048)	(.138)	(.0237)	(1.402)	(2.83)
LNEMP	.933***	.626	2.822***	-.702**	-.00556***	-.2315***	-.184**	-.0134	-1.67	5.459**
	(.302)	(.549)	(.843)	(.345)	(.0022)	(.093)	(.0879)	(.0212)	(1.001)	(2.700)
PATMA	.376	.157	.999**	-.142	-.0009	-.122*	-.128	-.005	-.203	7.799***
	(.221)	(.178)	(.478)	(.268)	(.0007)	(.075)	(.077)	(.004)	(.401)	(2.65)
LNMSALARY	.730***	.425	-.191	-	-	-.3182***	-.124**	.0035	.488	2.56*
	(.185)	(.25)	(.325)	.768***	.0055***	(.05)	(.061)	(.0032)	(.399)	(1.422)
				(.187)	(.0012)					
EFINDEX	-.044	-.202**	-.106	-.08	.00154**	.0775***	-.0336*	.00059	.193	1.65***

	(.069)	(.099)	(.155)	(.074)	* (.0005)	(.022)	(.0195)	(.0004)	(.322)	(.0422)
N	732	732	732	732	732	732	732	732	732	732
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Spatial (Rho=0)	.178 (.328)	-.535 (.761)	-.576*** (.128)	.257* (.157)	.026	.169 (.163)	.074 (.145)	.305** (.098)	.261* (.152)	-.465** (.223)
R^2 (within)	.097	.11	.13	.413	.192	.199	.846	.629	.584	.611
Hausman test	31.66*	40.3**	22.4	68.24***	69.17***	55.37***	27.6	15.77	33.58*	59.08***

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses.

According to R^2 quality of models in Tables 1.6 and 1.10 is approximately the same. Hausman test is also significant almost for all models, which confirms that choice of SDM model with fixed effects is correct. Analysis for groups of dependent variables draws conclusions on similarity of models describing impact on innovation activity. Influence of ECI doesn't have clear direction in any model, but impact of W_ECI is quite stable (quadratic, but in fact negative). For other dependent variables influence of ECI isn't confirmed unlike W_ECI, which becomes significant for GRP_RU and PVRT and keeps significance in case of INCM. Impact of control variables is quite similar. For example number of patents strengthens innovation capacity, but enhances level of poverty. The same is true for HE. One of possible explanation is low demand for employees with higher education and local capacity to create knowledge assets. Level of regional economic freedom (EFINDEX) changes direction for truncated sample. In full sample set of models its impact is negative, which is justifiable by necessity of high autocracy to extract rent and distribute it among privileged people. But for industrially developed regions only its impact becomes positive. Of course, development of manufacturing industry needs free entrepreneurship.

8. Conclusions

The conducted econometric analysis allows characterizing Russian economy as cost-oriented, the competitiveness of which largely depends on the magnitude of costs. This is justified by the significance of the LNMSALARY variable and the negative sign of the coefficient. There is a direct correlation between income growth and change in GINI (INCM vs. GINI = 0.82). Given the growth in the number of billionaires in Russia with a simultaneous sharp increase in the number of people whose income is below the subsistence level, this relationship should be assessed negatively

in terms of its impact on the growth of the complexity of the economy. That is, in these conditions, investment in more technologically advanced sectors are difficult for reasons such as emigration of highly qualified employees, negative selection of university students for relevant specialties, stagnating demand for expensive products, lack of capital among potential technology entrepreneurs, etc.

The variables characterizing the resource endowment are by no means often significant. Of course, the Russian economy remains dependent on the export of raw materials, but economic growth is not solely driven by the resource availability. Perhaps this is due to intergovernmental equalization.

Group 1 hypotheses are partially confirmed. Hypothesis 1a is not confirmed: the complexity of the region's economy does not affect its innovative activity. Perhaps this is due to the relative autonomy of innovation activities of companies, the dominance of equipment procurement among the types of innovation activities. In some models ECI and ECISQ are significant, but without clear pattern in signs of the coefficients. Therefore unambiguous conclusions about their impact could not be made. Hypothesis 1c is conditionally confirmed: the dependence is significant and quadratically negative, except for variables of inequality and poverty. An excessive level of complexity impedes economic growth: the domestic market may not be ready for significant volumes of high-quality (and therefore expensive) products, and foreign markets are not always available. However, starting from a certain point (see Table 1.8), the simplification of the structure of the economy leads to a damping of economic development. But for truncated sample (see Table 1.10) these variables are not significant. Hypothesis 1b is also confirmed: investments do not depend on the complexity of the economy. Key investment factors: resource prices and its availability. Investment is directed to the production of relatively simple products, since the sign of the variable he (the share of employed with a higher education) is negative.

Group 2 hypotheses are partially confirmed. Thus, hypothesis 2b is confirmed: investment does not depend on the complexity of the economy of neighboring regions. This is easily explained

for projects in the field of mining. For simple, technologically standard products that do not require extensive cooperation, the complexity of the economy is also not a significant factor. Hypothesis 2a is confirmed: all innovation indicators depend on the complexity of economies in other regions and formally this dependence has U-shaped form. Perhaps this is due to the fact that the market in a particular region is too small, so companies export most of their products outside the region. But in reality (see section 7.5) correlation is non-linear, but strongly negative. If the neighboring regions have high innovative activity, then the companies of the focal region can act as junior partners in production chains and their innovation activity decreases. Effect of cooperation among companies from different regions is absent. Companies from the region with lower economic complexity lose their competitive position. Hypothesis 2c is not confirmed: the clear pattern of influence of W_ECI and W_ECISQ is absent. For example their influence for GRP_RU is significant only for truncated model (see Table 1.10), but it is opposite to the predicted inverted U-shaped form. Effect of competition prevails, as in case of innovation activity: increased economic complexity of neighboring regions persistently diminishes economic growth of a focal region.

Hypothesis 3 is confirmed. Economic crisis does not change pattern of influence of economic complexity. For example its influence on investment is absent. Innovation activity still fits U-shaped form for the influence of neighboring regions. Economic complexity of a focal region influences on economic growth in accordance with hypothesis 1c. So may be regions with economic complexity of medium level are more sustainable in economic crisis than leading and lagging regions.

The research results contribute to the development of the concept of economic complexity in three directions. The methodology for calculating the economic complexity index at the country level is quite well developed. However, at the regional level, researchers use data on the number of firms, their revenues, and the number of employees by sub-sectors (Buccellato, 2016; Chávez et al., 2017 Chakraborty et al., 2020). Also, data from only large firms can be used (Gao and Zhou, 2018). This selectivity can lead to significant distortion of the results. The approach proposed in the study

is almost entirely based on the methodology of Tacchella et al., (2012), and the calculation results correspond to the observed structure of the Russian economy. That is, large regions with a developed industry occupy leading positions in the ranking of the complexity of the economy, regions with a mono-specialization of the economy, with the dominance of the mining industry, occupy the last places.

The second direction in the development of the concept of the complexity of the economy is the empirical findings, which confirm the non-linear nature of its influence on the development of the economy of the territory (Morais et al., 2018; Bandeira et al., 2018). For example, when approaching the state of full employment of the economy, the more fully the resources of the region are used, the lower the growth rates of the economy is with the further build-up of technological competencies. Income inequality can be positively associated with economic growth. However, with an increase of the diversification of the economy, a more complete use of resources, income is distributed more evenly (Hartmann et al., 2017). So income inequality could also be correlated with economic complexity non-linearly.

Since the region is part of the country, the dynamics of its economic and social indicators significantly depends on the complexity of the economies of other regions. This is due to both the technological dependence of companies from different regions and the influence of macroeconomic parameters. The need to include variables that characterize spatial effect is indicated in Basile et al. (2019), Pintar and Scherngell (2018). The impact of the complexity of the economies of other regions is significant and negative. I.e. in the context of Russia, regional rivalry dominates, rather than technological cooperation. This result can be used in the macroeconomic theory of economic growth.

There are two main limitations of the research. First one is limited number of years, for which it is possible to calculate ECI. Data are presented by Russian Statistical Agency only from 2005. So sample includes only 12 years. The second limitation lies in the absence of a country to compare results. It would be interesting to perform calculation of ECI according the same approach

and compare results for Russian economy with a country, which intensively develops its economic complexity and outperforms its main competitors, for example China or India.

This research can be continued in various directions. The most interesting is a comparative analysis with one of the world's fastest growing economies in the technological dimension, for example, China. Hypotheses H1a-H2c assume a quadratic relationship, but negative due to the technological regression of Russian manufacturing enterprises. It should be assumed that for countries whose economies are growing in complexity, this relationship could be positive and still nonlinear. It would also be interesting from a scientific point of view to confirm the conclusions of this research in comparison with another large economy, similar to Russian one in terms of its role in the system of the world division of labor, for example, Brazil.

This research is fundamental in nature, but it allows drawing a number of conclusions that are useful for economic policy. Level of cooperation among Russian regions is not enough to produce positive effect. “Strong” regions dig in lagging regions instead of acting as dragging power for them. If a region is surrounded by regions with higher economic complexity, its pace of growth and innovation activity become slower. It is necessary to pursue a policy to align the complexity of the economy, especially in neighboring regions. Since innovations are a key driver of increasing the complexity of the economy, more attention should be paid to the implementation of institutions for the diffusion of innovations, the creation of macro-regions, and the formation of a denser network of interaction between enterprises from adjacent regions. Stimulating innovation is impossible without raising the level of wages in the economy as a whole, and not only for individual, highly qualified categories of workers. Otherwise, a critical mass of people is not created, capable of ensuring the creation of firms in technologically related fields. The high level of complexity of the economy, as well as the high share of the raw materials sector do not guarantee a higher resilience of the region's economy to external shocks. Therefore, it is necessary to continue to focus on the instruments of interregional equalization through transfers from the federal budget.

Chapter 2

Regional economic complexity and its impact on the firm's development during economic crisis

1. Introduction

The economic crisis is a sharp deterioration of the state of the country's economy, violation of market equilibrium which creates significant difficulties for firm activity (Grewal and Tansuhaj, 2001; Bao et al., 2011). Distinction of the economic crisis from unfavorable conjuncture in the industry or a group of industries lies in the systemic (global) scale of the consequences of the economic crisis for the country's economy. In other words, the economic crisis affects all companies in a particular country. Decrease in price level and change in relative prices, reduction of resource demand due to decline of aggregate product demand, increase in the level of risks, reduction of available financial resources, and etc. influence on the strategy of companies, their investment plans and business models. The impact of the economic crisis is manifested not only in the deterioration of financial indicators, decreasing R&D expenditures or surge in the number of bankruptcies. The economic crisis could also stimulate changes in the structure of the country's economy (Geroski and Walters, 1995; Cincera, 2012; Archibugi, 2013). It could be positive, pro-innovation. Or structural changes may be negative, namely, aimed at simplifying the structure of the economy, increasing the role of industries with low added value. The longer the crisis, the greater the impact and the deeper the structural transformation of the whole economy and separate companies. Some industrial companies could flourish and realize active strategies even during economic crisis while others are forced to with-draw from the market (Archibugi, 2013).

The concept of creative destruction by J. Schumpeter assumes that significantly changed parameters of the market make it possible to implement projects, the implementation of which was postponed in the past because of the lack of incentives for change. The concept of creative accumulation complements the previous one. Innovative

projects are implemented in conditions of uncertainty and their regular implementation requires the creation of the necessary infrastructure within the firm (Malerba and Orsenigo, 1995). The presence of the company in innovation-intensive market segments facilitates the implementation of subsequent innovations due to market power and a wider range of technological opportunities (Duguet and Monjon, 2004). As the growth of economic activity gradually leads to excess supply over demand, it increases competition, forces companies to seek new markets. Therefore competitors that do not have the expertise and resources to develop and implement innovations will find it more difficult to develop and perform innovation projects. Consequently, the degree of competition for firms more experienced in innovation is reduced, and their ability to use resources, on the contrary, grows.

The company's competitive advantage can be reliably verified in acute conditions of economic recession. Crisis compels firms to make forced strategic decisions so that to fit with external environment (Kunc and Bhandari, 2011).The inability to finance profitably all desired directions and projects enforces to select them. Reducing market prices makes it necessary to reduce costs, etc. The decreased availability of financial resources stimulates the introduction of financial management technologies, cost management, etc. Under these conditions, companies that previously managed reasonably, in a balanced manner, can gain a competitive advantage.

The effectiveness of the company's strategy also could be influenced by strategies of other firms co-located with the company in the same region or in neighboring regions. Also regional product structure, economic policy, resource endowment, R&D capacity, institutional environment and other regional parameters, which influence on its ability to manage technological knowledge, could stimulate firm adaptation to crisis shock. This is due to the number of reasons. Firstly, the specialization of companies in the region on more knowledge-intensive activities leads to increased efficiency through the effect of learning,

the creation of related institutions, and the effect of agglomeration. Secondly, the economy of the region with a higher level of innovation activity can be more diversified, which gives added resilience to exogenous shocks. Thirdly, achieved level of product variety means higher level of regional economic complexity, which influences on possible increase in total regional productivity due to acquiring additional technological competence. All in all, it allows reaching deeper labor division and better opportunities for knowledge creation and recombination, which in brings more chances for economic restructuring during a crisis (Ahuja and Katila, 2001; Neffke et al., 2009).

Economic crisis is a good occasion to check validity of a firm strategy and regional economic capacity. Region with diversified, knowledge-intensive economy should be less vulnerable to the economic activity fluctuations. It should have more resources to support firm innovation projects and provide anti-crisis stimulating packages. Thus, the research question can be formulated as follows: whether regional economic complexity influences positively on the firm sustainability during economic crisis.

To shed light on the issue, we collect data on 639 Russian industrial firms from technology-intensive industries, which span six years, including 2014-2016. In these three years Russian economy underwent through severe economic shock, caused by drop in oil price, currency devaluation and political tensions. We use two dependent variables. The first one – asset turnover ratio- characterizes firm's ability to manage effectively its capital, to realize aggressive competitive strategies. The second dependent variable – return on assets – reflects firm's efficiency, i.e. its capacity to receive profit. Among independent variables we use not only index of economic complexity of a focal region, where a firm is registered, but also weighted economic complexity of other regions. It allows including in the analysis spatial component, measuring broader environment of a firm. It is reasonable because in reality a firm interacts with economic agents of different regions and its development depends on economic policy and resource capacity in other regions of the country too.

Results are mixed. Firm innovation capacity influences negatively on its growth. Resources invested in R&D are deadweight losses for a firm, aspiring to become the biggest company on the market during the short period of time. But profitability depends positively on firm's investment in R&D. It also could be justified: when there is constant threaten of an appearance of a new product on the market, firms able to envisage it (or even initiate) have greater chance to survive and continue to grow. Only impact of the economic complexity of other regions is significant (linear and negative), but exceptionally for asset turnover ratio. Its influence on profitability is neutral. This result is opposite to hypothesized one and could be explained by low innovation activity in Russian economy, which means low growth rate of knowledge-intensive markets.

The paper is structured as follows. Literature review and research hypotheses propositions are made in section two. In section three data and methodology of the research are described. In section four research results are analyzed and discussed. In the last part conclusions, limitations and practical implications of the research are described.

2. Literature review and research hypotheses

2.1. Economic crisis and firm's strategy

As indicated above, the economic crisis has a significant and multidirectional impact on the national economy and the activities of individual companies. Researchers identify various strategies that firms adhere to in a crisis: reactive, characterized by a passive reaction of the firm to external circumstances, and proactive, aspiring to the leadership and effectiveness (Alonso- Almeida et al., 2015). The reactive strategy is defensive. It is focused on financial results andcost reduction. A proactive strategy is aggressive, involves expanding the firm's activities on new markets or product categories. Also there is a third kind of strategy - inertial. In this case companies do not take actions either to preserve their position or to take advantage of the economic crisis. For example about a quarter of financially sustainable companies have not developed a strategy for using excess stock of financial

resources by December 2008 (Banerji et al., 2009a). Also the short-term and long-term consequences of the economic shock should be distinguished. In a short-term period most firms choose a strategy to reduce costs and investments (reactive strategy). However, if the crisis is long-term, then there is a need to adjust the strategy due to a possible significant change in economic parameters after the crisis (Archibugi et al., 2013).

The effectiveness of an anti-crisis strategy depends on many factors in itself. For example, the company's readiness for an economic crisis. If anti-crisis measures are carried out ad hoc, without a preliminary comprehensive analysis of the possible consequences, the actual results are much worse than expected (Heckman et al., 2009; Banerji et al., 2009a). The development of an effective anti-crisis strategy is closely related to the company's ability to correctly predict changes in the external environment. To a large extent this ability is peculiar to firms with entrepreneurial orientation, since the orientation towards innovation implies functioning under conditions of uncertainty (Keh et al., 2007).

Company’s effectiveness and survival during economic crisis depend on fundamental factors. To survive, the company needs a stable supply of resources, which, in turn, depends on the firm's ability to generate added value under any market conditions. Entrepreneurial orientation should be one of the components of the company's strategy. It is an active strategic position of the company and is aimed at the continuous development of innovative activities, proactive behavior, willingness to consider investments in projects with a high degree of uncertainty (Covin and Slevin, 1989). Proactivity manifests itself in the identification and use of new opportunities to strengthen competitive positions, willingness to set trends in the market, shaping the external environment, which may be a key factor of the competitiveness of a firm (Lumpkin and Dess, 1996). This dependence can be positive (Rauch et al., 2009), negative (Arbaugh et al., 2009), nonlinear (Wales et al., 2013). The reasons for these differences in the results can be subjective, related to the imperfection of the research instruments, or objective, that is, due to the peculiarities of the external

environment of companies. A number of studies have shown that in a hostile environment (reduction of product markets, tightening of access to resources, government intervention, etc.), entrepreneurial firms achieve better results (Covin, Slevin, 1989; Kreiser, Davis, 2010; McGee et al., 2012; Soininen et al., 2012; Osiyevskyy et al., 2015). Companies which follow proactive strategies are more likely to carry out bold, large-scale steps that will enable them to benefit from implementation of new opportunities that have emerged in the crisis (Alonso-Almeida et al., 2015).

The company's strategy may not be related to innovations at all. The company can focus on cost control, well-known goods and creation the highest value for consumers (Narver and Slater, 1990), diversification of activities, market penetration so that to become the dominating player. The last strategy envisages large investment, using of financial leverage. If the share of debt in firm’s capital becomes too high, indebtedness could plunge it into losses and cause even decrease of the market share during economic crisis.

The firm's strategy can also be based on the search for rent, i.e. redistribution of public welfare to its own advantage (Krueger, 1974). Rent-seeking allows the company to concentrate on maximizing the income of owners to the detriment of investment in development. The search for rent can be carried out in various ways: obtaining contracts for the supply of products for state needs, obtaining of preferences for product tariffs or other provisions for the supply of goods (if the company's goods are included in the list of products which are due to state regulation), the provision of public resources on non-market conditions, the reduction of competition, the receipt of government subsidies, etc. This requires the implementation of both explicit, as well as hidden (corrupt) investments. Corruption investments involve investing in creating relationships with individual officials, promoting affiliated persons to government bodies, bribes and the like. Explicit investments consist in maintaining social initiatives of the authorities. First of all, this is sponsorship, creation of social infrastructure facilities, etc. The company can also seek to gain a

monopoly position on the market. Accordingly, it invests in expanding the scale of the business to the detriment of the quality level. However market competition may imply informal support of officials.

The economic crisis makes the problem of limited resources for the company more acute. Accordingly, strategic miscalculations are manifested precisely in the years of economic recession, when demand decreases, the struggle for a client intensifies, and the lack of financial resources does not allow a company to wait out difficult times. Therefore, we propose that for the crisis years the level of significance of many variables should be higher than for the period of economic growth.

Based on these arguments, we test the following hypotheses:

H1a. When the economy is booming, innovation-active companies have lower efficiency of capital utilization.

H1b. When the economy is booming, innovation-active and non-innovation-active companies don't differ significantly in profitability.

H1c. When the economy is in depression, capital efficiency of innovation-active companies is still lower but their profitability becomes higher.

H1d. When the economy is in depression, profitability of innovation-active companies is higher.

2.2. Regional innovation capacity

The structure of the regional economy characterizes the technological, industrial capital possessed by companies of the region. This is the achieved level of development of the regional economy, which shows the potential for diversification and resilience to external shocks (economic, technological, social), and determines the vector of development (Bathelt and Boggs, 2003; Glaeser, 2005). Industrial diversity is an important structural parameter. The effect of diversity implies more complete use of resources and the possibility of a deeper division of labor. When analyzing the structure, it is not only the variety of products

that matters, but also their relatedness. The level of relatedness shows the degree to which the production of different products is interrelated, i.e. can be produced jointly in the case of an end product, or must be done together due to production relationships. The interconnectedness of products is based on technological competence. Accordingly, the higher the level of diversity and relatedness of products, the more opportunities for innovation due to the recombination of technological knowledge, adaptation of existing knowledge for the production of new products.

Index of economic complexity has been developed for an integral assessment of the degree of diversity and relatedness (Hidalgo et al., 2009; Tacchella et al., 2012). The idea of economic complexity is as follows: if a country (region) can export a product that only few countries can export, that product is considered complex. Moreover, the more complex products a country (region) can export, the more complex its economy is considered. The variant of the algorithm for calculating the complexity of the economy, proposed by Tacchella et al. (2012) implies that a product is considered more complex if it is not exported by countries with simpler economies. That is, the higher level of economic complexity of countries which export a product, the more complex this product is considered. Higher level of economic complexity creates a concentration of firms, scientific organizations, and infrastructure facilities, which provides significant non-tradable competitive advantages.

Territorial concentration of companies, universities, research organizations, etc. could be the source of competitive advantage influencing positively on firm innovation activity. This economic and social phenomenon received a lot of names: innovation system, learning region, local buzz, innovative milieu, and cluster. The causes of territorial competitiveness are not only of technological nature like economy of scale, but also of institutional one, i.e. the system of interconnected institutions for creation, preservation and transfer of knowledge, skills and artifacts that define the technological opportunities (Freeman, 1987; Carlsson and Stankiewitz, 1991). The system of institutions provides not

only interaction of area residents among themselves but also with external agents whose competences are necessary for the development of sectors of the local economy (Lundvall, 2010). Effective institutions reduce the uncertainty and costs of exchange of information, thereby facilitating the transfer of technology (Rodriguez- Pose, 2013).

Analysis of the influence of territorial factor on innovation activity multiplied by economic crisis usually concentrates on state level impact. The first reason is that a lot of parameters are under the central government regulation. And the more inter-budget relations are centralized the less role is played by regional institutions. The second explanation is that the innovative activity of firms during a crisis is significantly influenced by the characteristics of the national innovation system. This is due to the fact that a completely innovative project is not implemented by any company, even a very large one. And the larger, more complex the project, the wider the scope of the invention, the more complex commercialization strategies need to be developed, including cooperative partnership strategies. And these cooperation agreements couldinclude companies from different regions especially in small countries.

Above we pointed to the significant role of financial security as a factor in counteracting the crisis (especially financial!). In study (Alvarez et al., 2010) on the basis of data analysis for 2008-09 crisis this is confirmed: the better the financial sector of the national economy is developed, the more countercyclically the firms behave, increasing the costs of innovation during the crisis. An important factor of the dampening of the decline in innovation activity is the expanded access of firms to public financial resources, especially for small and newly established companies. If a firm received public financial support in time of crisis the probabilitythat it interrupts innovation activity after crisis is lower (Cruz-Castro et al., 2017). On the country level the impact of the knowledge stock expressed as the volume of R&D to GDP does not affect the policy of firms in the field of innovation. This may be due to the inertia of knowledge: the level accumulated before the crisis can

exceed the ability of firms to commercialize them, so reducing investments in R&D does not affect the intensity of the implementation of innovative projects in the medium term (Alvarez et al., 2010). On regional level it depends positively on R&D intensity of the region before crisis. If a region already has strong knowledge exploitation system, there is negative dependence between changes in the intensity of regional R&D policies during the crisis and probability of ceasing of the innovation activity by companies (Cruz-Castro et al., 2017). Regional specialization on knowledge-intensive industries complements R&D expenditures as factor of local innovation persistence (Tavassoli and Karlsson, 2016). Also researchers noticed significance of latent variables which were attributed to regional innovation system when some regions are more innovation-persistent then others, for example Basque Country in Spain (Holl and Rama, 2016). Some regional innovation systems could be exploration in nature, i.e. based on knowledge-generation organizations and others are exploitative ones (Cooke, 2009). So regional resilience could be due to different reasons including both current stimulation policies and path-dependence (Crespo et al., 2014).

Regional parameters also affect the performance of firms directly. The size of the region's economy reflects the size of the regional market, which can be a significant factor for firms producing consumer goods. Regional investment risk influences investment decisions, respectively, on the performance of construction, engineering and other companies operating in the B2B market. The regional level of poverty indirectly characterizes, on the one hand, the purchasing power of local residents, on the other hand, the level of wages in the region. Regional ability to exploit knowledge could be more valuable in crisis period than exploration because it allows local enterprises to correct operatively market strategy. But before economic crisis this difference could be insignificant if the role of innovations in economic growth is low.

The complexity of the region's economy makes it possible to more effectively withstand economic shocks due to extensive opportunities for companies to create

innovation and diversify their businesses. On the other hand, a simpler economy can be more resilient. At first, firms in such a region produce less complex products, and demand for them during a crisis replaces more complex products. Secondly, the regions with a simpler economy, by definition, have a higher share of the raw materials sector, and the demand for raw materials and productsof its primary processing is less elastic. The influence of the neighboring regions is similar: the presence of regions with a simpler economy makes it possible to maintain the demand for the products of the manufacturing industry of firms located in the $_{ith}$ region with a more complex economy and to provide them with cheaper raw materials. It is especially correct for the economy, which specializes on extraction of primary resources, like Russian one.

It is necessary to take into account that as a region is part of the state labor division system, production systems of different regions should match each other according to the level of economic complexity. If it isn't so, the country production system is unbalanced which causes problems with technological cooperation. Firms, which are situated in lagging and leading regions, could have the same problems in cooperation with the rest of the country. It urges to check the possible nonlinearity relationship between economic complexity and firm's development.

Accordingly, we test the following hypotheses:

H2a. The higher is the level of the economic complexity of the focal or neighboring regions, the lower the profitability and efficiency of a firm during the economic crisis.

H2b. The higher is the level of the economic complexity of the focal or neighboring regions, the lower the efficiency of a firm during the economic crisis.

H2c. During economic boom firm's development indicators are not under influence of the economic complexity.

H2d. Moderating effect of the economic complexity is negative during economic crisis and neutral during economic boom.

3. Data and variables

3.1. Data

All data on firms' indicators are obtained from the database of enterprises and organizations FIRA-PRO. The observation period is 2010-2016 since current economic crisis in Russia started from the end of 2013. So the period of study is divided in two parts: before crisis (2010-2013) and during crisis (2014-2016). Firms of the sample are small and medium enterprises. They are related to several innovation-active industries like engineering, chemical, production of plastic, metal and non-metal mineral products. This choice of industries is due to the fact that these industries are middle-high-technology or middle-low-technology (Technology…, 2011). As the hypotheses of this study are concerned to innovation activity the sample is divided in two groups: innovation-active companies and non-innovation-active ones. To make the analysis as correct as possible firms are pair-wised approximately of the same size, industry, i.e. to each knowledge-based company at least one analogical company of approximately the same size and industry is selected. The total sample size is 639 companies. We take companies with turnover no less than 50 mln. RUB. and no more than 2 bln. RUB. So the smallest microenterprises are excluded because their indicators could be too volatile. Some companies that could be outliers are also excluded from the sample. For example we exclude several companies with too high or too low levels of asset turnover ratio. If a company constantly has very high asset turnover ratio, it means that with high probability it is trade division in the group of interconnected companies. If asset turnover ratio is constantly very low it means that a firm could be used for tax avoidance purposes or it is a bankrupt in reality. The final dataset is the balanced panel. Approximately 60% represents innovation-active firms. There is no dominance of any industry but production of machinery equipment has the greatest share (39%). Companies represent 56 region of Russian Federation. This is more than half of its total quantity and more than 86% of total GRP.

Data on patents are collected from website of Rospanent (Federal Institute of Patent Property). It is Russian state agency which is in charge of IPR regulation. This web-source is free and allows search on such parameters as name of a patent owner, address, authors, etc. Such multicriteria search allows receiving valid results.

To collect the data on regional indicators datasets of Rosstat (official Russian statistical body) are used. There are doubts about reliability of some statistical indicators like average wage or level of poverty which could be manipulated because of their "publicity". So we focus on variables which are not so prone for manipulations like number of employees, expenditures on R&D, innovation activity.

3.2. Variables

Firm performance could be calculated in different ways. Absolute dependent variable would correlate with others through latent variable firm size. It is most reasonable to use asset turnover ratio (ATR) as dependent variable. It measures efficiency of exploitation of firm resources. During the economic crisis indicators of company activity could change drastically up to firm bankruptcy. On the contrary, the size of the company's assets may not change much if the company reduces the level of business activity, and may also grow during a crisis, for example, thanks to investments. Due to the relational rigidity of the denominator in the formula ATR is preferred than other variants of the dependent variable: the revenue growth rate (depending on the size of the company, so there may be bias of the dependent variable), the profitability of sales and cost (the crisis reduces turnover, and the numerator and denominator simultaneously decrease).

But ATR doesn't immanently mean that a firm receives profit. The firm could follow very aggressive strategy of market penetration, rely more on credit financing that on its own sources of capital. Such aggressive strategy could generate losses because of credit payments and great commercial expenditures. Therefore we use another dependent variable – ROA (return on assets), which characterizes firm's profitability.

Independent variables of the study which are used to test hypotheses are variables measuring firm innovation activity and regional economic complexity. Innovation activity of a firm could be characterized by such indicators as R&D expenditures, patent statistics, and survey results on innovation activity. Data which are available do not allow direct quantitative evaluation of innovation activity, so we have to use dummy variable "Firm innovation activity" (FIA), which takes 1 if a firm conducted some activities to perform innovation projects and 0 otherwise. Patents possessed by a firm characterize its intention to perform innovation projects. The more patents belong to a firm, the greater probability that it is a persistent innovator. But in some cases firm could protect its knowledge through know-how or firm owners could be patent owners. So we also use data contained in balance sheet, i.e. results of unfinished R&D.

The complexity of the region's economy is characterized by the variable ECI, which is calculated based on the algorithm proposed by Tacchella et al. (2012). Since data on regional exports and interregional commodity flows are not presented in the statistics of Russia, we use data on production volumes on the 4-digit level. To more accurately express the level of competitiveness by product, we use data on the value of production of a product per employee. This allows making the result of calculating the complexity index of the economy dependent not only on the size of the economy, but also on labor productivity, on the competitiveness of the product, which better corresponds to the meaning of the competitiveness index. The variable ECI is expressed not in absolute values, since it changes from year to year due to the impact of external factors influencing the production volumes of individual products, but as a rating of a region, its place among other regions. The rating is a very stable indicator, as shown in Table 2.1. Stability confirms the correct calculation procedure of the economic complexity, since the complexity of the economy is inert per se as technological knowledge stock possessed by regional companies changes quite slowly. Alternatively we also calculate economic complexity index according to the "method of

reflections" derived by Hidalgo et al. (2009). It is presented in Table 2.2. It is important to emphasize that the rating of the regions is built in ascending order, i.e. the region with the lowest level of economic complexity is ranked first, and so on.

Table 2.1

Calculation of the ECI for the leading and peripheral regions of Russia, rank

Region	2005	2006	2007	2008	2009	2010	2011	2012	2013
Moscow	1	1	1	1	1	1	2	2	2
Saint Petersburg	2	2	2	2	2	2	1	1	1
Chelyabinsk	5	10	5	7	7	8	8	15	17
Sverdlovsk	4	4	3	5	4	5	4	8	8
North Osetiya	66	62	65	67	66	66	68	68	68
Murmansk	61	60	62	62	63	62	59	59	59
Adygey	58	55	54	59	55	54	52	53	52
Tyumen'	46	50	49	38	44	43	38	43	42

Table 2.2

Calculation of economic complexity index according to the "method of reflections", rank

Region	2005	2006	2007	2008	2009	2010	2011	2012	2013
Moscow	31	13	68	1	1	1	1	1	1
Saint Petersburg	21	36	66	4	3	3	3	2	5
Chelyabinsk	66	6	65	59	55	43	14	57	10
Sverdlovsk	65	1	67	24	42	4	4	63	9
North Osetiya	27	49	8	43	27	53	55	20	57
Murmansk	4	67	7	21	19	14	13	48	41
Adygey	8	58	6	8	44	63	66	15	68
Tyumen'	20	52	20	38	34	44	38	21	42

Table 2.2 shows that the ranks of the regions change chaotically, outside of any regularity. At the same time, the places of the same regions in Table 2.1 are constant and correspond to the economic logic (industrialized regions occupy leading positions, etc.). This

excludes the error in the data for individual years as possible explanation of deviations and makes us assume the imperfections of the “method of reflections”. Therefore, in regression analysis we rely on the calculations obtained according to the method of Tacchella et al. (2012).

Since a firm and a region operate as a part of the system of country division of labor, it would be more reliable to take into account the impact of the level of economic complexity of other regions (Basile et al., 2019; Pintar and Scherngell, 2018). For this purpose the variable W_ECI is calculated, which is the weighted ECI value for the rest of the regions of Russia, except for the $_{ith}$ region. The calculation is performed by multiplying the weighting matrix W by the vector of values of the ECI variable. The sample of regions includes 68 territories, because the least developed regions are excluded from consideration, in some regions there is a large number of data gaps. Matrix W (68x68) is a matrix of inverted distance between the administrative centers of regions by road transport. For example the distance between Moscow and St. Petersburg by car is 706 km. Accordingly, element ij in matrix W will be 1/706. To test the possible non-linear nature of the influence of the level of complexity of the economy, the models also contain the squares of the variables ECI and W_ECI. Also effect of interaction of the internal economic complexity (ECI) and external one (W_ECI) is captured via variable ECI*W_ECI.

Control variables include the following ones. Regional innovation activity is characterized by two variables. The first one is share of innovators in total sample of industrial enterprises (IA) and the second is share of innovation expenditures in total turnover of industrial enterprises (IE). The first indicator depicts the prevalence of innovation behavior in regional economy; the second one characterizes the volume of innovation activity. To characterize knowledge-generation capacity we use R&D to GRP ratio (RDGRP). Dummy variable CAPL takes 1 if the region belongs to one of two biggest agglomerations of Russia – Moscow city or Saint-Petersburg city. The economic system in

these cities (which are separate Russian regions) differs from other Russian regions; their resource endowment, market size outperforms the other regions. These two agglomerations affect their neighboring regions. To catch up this effect we use dummy variable CAPLBORDER, which takes 1 if a region has common border with Moscow oblast or Leningrad oblast (these regions surround two biggest Russian cities). The other control variables are regional size measured as natural logarithm of number of employees (LNEMP) and level of labor cost in the region, measured as natural logarithm of median salary (LNMSALARY).

Quality of firm operational and financial management influence firm performance. We characterize sustainability of financial provision by analyzing the ER – equity ratio. The greater the role of owners' sources the less firm activity is vulnerable to contract clauses with financial institutions on amendments of interest rates, early repayment of loans, etc. I.e. firm is less dependent on financial market conjuncture. Variable ER is calculated as total equity value to total assets. Alternative variable to characterize firm's provision with own working capital is WCCA (working capital to current assets). The next two variables reflect firm relations with its partners: accounts payable turnover ratio (APR) and accounts receivable turnover ratio (ARR). APR characterizes the ability of a company to get access to financial resources, because delay of payment is the same as loan. ARR evaluates level of risk the company is ready to accept in its sales activity, ability to manage risk, to select clients, etc. The reasons of high value of coefficients could be multiple: qualified financial management, greater power of the firm, flexibility of firm operations, marketing activity, diversification of firm commodity assortment, etc. The other control variables are firm size measured as natural logarithm of revenue (LNTR), industry and year dummies. Descriptive statistics of variables is shown in Table 2.3.

Table 2.3

Summary statistics of variables

Variable name	Variable description	Min	Max	Mean	Std.dev.
ROA - return on assets (%)	Continuous variable. It measures profitability of exploitation of firm resources (assets).	-110.7	142.5	9.82	14.29
ATR - asset turnover ratio	Continuous variable. It characterizes the overall efficiency of resource exploitation.	.045	5.56	1.58	.82
FIA - firm innovation activity	Dummy variable. It takes 1 ifa firm has intention to perform innovation projects, 0 - otherwise.	0	1	.59	.49
ECI – economic complexity index	Continuous variable. It measures regional level of economic complexity (68-the highest)	5	68	53.17	15.02
W_ECI – weighted economic complexity index	Continuous variable. It measures weighted regional level of economic complexity of other regions.	.41	2.59	1.93	.50
IA - share of innovators in total sampleof industrial enterprises (%)	Continuous variable. It evaluates prevalence of innovation behavior among regional companies.	3.87	24.43	11.19	4.07
IE - share of innovation expenditures in total turnover of industrial enterprises (%)	Continuous variable. It characterizes the volume of innovation activity and indirectly its persistence and radicalness.	.1	9.14	2.81	1.56
RDGRP - R&D toGRP ratio	Continuous variable. It characterizes knowledge-exploration component of the regional innovation system.	0.00026	.051	.017	.013
CAPL	Dummy variable. 1 – if a region is Moscow city or Saint-Petersburg city. 0 – otherwise.	0	1	0.16	0.37

CAPLBORDER	Dummy variable. 1 – if a region has common border with Moscow oblast or Leningrad oblast. 0 – otherwise.	0	1	0.26	0.44
LNEMP - natural logarithm of number of employees in the region	Continuous variable. It characterizes size of the regional economy.				
LNMSALARY – natural logarithm of median salary	Continuous variable. It characterizes	9.09	10.36	10.65	0.29
ER - equity ratio – total equity to total assets ratio (%)	Continuous variable. It characterizes degree of firm independence from external financial institutions and rules.	-93.4	99.9	42.62	29.9
APR - accountspayable turnover ratio	Continuous variable. It evaluates the ability of a company to access financial resources.	0	3259	112.26	142.25
ARR - accounts receivable turnover ratio	Continuous variable. It evaluates level of risk the company is ready to accept in its sales activity.	0	1574	69.18	72.65
SIZE - firm size	Continuous variable. It is calculated as ln of revenue.	9.93	16.09	13.29	.76
WCCA – working capital to current assets	Continuous variable. It measures firm's financial sustainability	-444.8	99.89	32.79	48.34
MASHINERY	Dummy variable. It takes 1 if a firm belongs to engineering,0 - otherwise.	0	1	.39	.49
CHEMICAL	Dummy variable. It takes 1 ifa firm belongs to chemical industry, 0 - otherwise.	0	1	.15	.35
PLASTIC	Dummy variable. It takes 1 ifa firm belongs to production of plastic goods, 0 - otherwise.	0	1	.15	.35
METALL	Dummy variable. It takes 1 if a firm belongs to production of metal products, 0 - otherwise.	0	1	.17	.37
NMMINERAL	Dummy variable. It takes 1 ifa firm belongs to production of non-metal mineral products, 0 - otherwise.	0	1	.15	.36

n=639.

Correlation matrix is presented in Appendix 3. For the most part firm-level variables do not have high correlation, except for WCCA and ER. These two variables characterize firm's ability to finance its activity by equity, so it is better not to use them in the same model so that to avoid multicollinearity. For the bundle of regional variables LNEMP and LNMSALARY are correlated very strongly (.075). ECI is positively correlated with the regional size (LNEMP), investment in knowledge generation (RDGRP), innovation activity (IA and IE). So it is necessary to conduct econometric analysis with and without regional controls.

To test hypotheses we use OLS. But there could be latent variables which influence performance of each company. Often these variables couldn't be expressed quantitatively or even reliable data are absent. For example conflicts in board of directors or top-management could impede a firm from developing productive anti-crisis strategy. Some firms could pursue policy of pure market relationships in organization while other companies could focus on providing intra-organizational rules and institutions. It makes working in such firm much more comfortable and attractive so allows keeping valuable staff during economic crisis. Data about real owners of a firm could be absent because it is registered in offshore jurisdiction. So in reality firms function in different environment and models with random-effects are also tested. To compare pooled regression with RE-model we use Breusch and Pagan test. Unfortunately, the FE model cannot be used, since its application involves the elimination of dummy variables like FIA.

Models are susceptible to endogeneity. For example low ARR means that firm's clients serve their obligations on time, which reduces necessity to go to court, take loans to overcome cash gaps, etc. So negative influence on the profit before taxes is absent. But more profitable company could reduce risk by avoiding unreliable clients or acquire its clients, etc. To reduce endogeneity problem dependent variables are taken with one-year lag; models for crisis period are constructed with regional variables taken with three year lag.

4. Results and findings

The economic crisis in Russia lasted from 2014 to 2016. Therefore, to identify differences in the influence of independent variables, we divided the sample into two periods: 2011-2013 and 2014-2016. The test shows that models with random effects are preferable to pooled regression; therefore, only models with random effects are presented below. Indeed, firms of the same industry differ in the history of creation, management practices, resource availability, etc., so the sample should be considered a priori heterogeneous. The results of econometric modeling for the pre-crisis period (2011-2013) and for crisis period are presented in Tables 2.4 and 2.5 respectively.

Table 2.4

Regression results for pre-crisis time period

Time period	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Dependent variable	ATR	ATR	ATR	ATR	ATR	ATR
Cons	2.95*** (.458)	2.79*** (.583)	2.72*** (.525)	2.55*** (.558)	2.57*** (.765)	3.17*** (.739)
FIA	-.174*** (.062)	-.190*** (.063)	-.189*** (.062)	-.192*** (.0062)	-.193*** (.063)	-.194*** (.062)
SIZE	-.071** (.033)	-.073*** (.0336)	-.074** (.033)	-.0754** (.0033)	-.0758** (.033)	-.074** (.033)
ARR	-.001*** (.0002)	-.001*** (.0002)	-.001*** (.0002)	-.001*** (.0002)	-.001*** (.0002)	-.001*** (.0002)
APR	-.00016 (.0002)	-.00017 (.0001)	-.00016 (.0001)	-.00017 (.0001)	-.00016 (.0001)	-.00017 (.0001)
ER	-.0039*** (.0008)	-.004*** (.0008)	-.004*** (.0008)	-.004*** (.0008)	-.004*** (.0008)	-.004*** (.0008)
LNEMP		.0399 (.051)			-.0091 (.065)	-.011 (.065)
RDGRP		2.423 (2.96)			1.83 (3.06)	1.875 (3.04)

IA		.0041			.0022	.0031
		(.007)			(0.007)	(.007)
CAPL		.00849			-.0268	.0057
		(.103)			(.108)	(.104)
CAPLBORDER		.00943			-.0725	-.0793
		(.052)			(.097)	(.097)
ECI			-.00578	-.018	-.0182	-.0072
			(.005)	(.0114)	(.011)	(.005)
ECISQ				.00015	.00014	
				(.0001)	(.0001)	
W_ECI			-.162*	-.399	-.391	-.197*
			(.083)	(.6721)	(.680)	(.102)
W_ECISQ				-.065	-.0529	
				(.1633)	(.165)	
ECI*W_ECI			-.0046*	-.0035	-.0043	-.005
			(.0023)	(.0047)	(.005)	(.003)
Industry fixed effects	yes	yes	yes	yes	yes	Yes
Year fixed effects	yes	yes	yes	yes	yes	yes
N	1917	1917	1917	1917	1917	1917
R^2	.074	.080	.083	.084	.088	.084
Wald	156.4***	160.2***	165.6***	167.2***	168.6***	164.7***

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

Analysis in pre-crisis period demonstrates very stable and reasonable results, which do not depend on the bundle of variables. If a firm is engaged in knowledge acquisition activity, i.e. devotes a part of its capital on R&D and patenting, its ATR decreases, because the company builds up additional assets and has less capital to seize market. Accordingly, firm turnover increases faster if it receives back its debt faster (ARR is negative) and uses financial leverage more intensively (ER is negative). Regional variables are not important if the economy grows. The size of a region, its proximity to capital cities, and level of innovation activity do not determine its asset turnover. One possible explanation is ability to redistribute capital among regions by creating branches. But economic complexity matters.

At first, corresponding linear coefficients are significant or close to p=0.1 level of significance. Secondly, economic complexity influences negatively. For the influence of the neighboring regions it is expected, because higher level of economic complexity of the neighboring regions could match with higher level of their competitiveness. So the effect of tougher competition could manifest itself. But the fact that ECI influences negatively (coefficient significance is on p=0.12) is a bit of surprise at a first glance. One of the possible explanations is stabilization of growth rates of corresponding markets in a focal region. So when regional market is saturated supporting of high ATR becomes a challenge for management. Second explanation could lie in market structure: increase of number and complexity of products could be accompanied by necessity of enlargement of a firm size due to economy of scale effect. As a result small and medium enterprises are squeezed from the market by corporations.

Table 2.5

Regression results for crisis time period

Time period	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Dependent variable	ATR	ATR	ATR	ATR	ATR	ATR
Cons	1.33***	1.45***	1.38***	1.50***	2.65***	1.76***
	(.336)	(.459)	(.408)	(.0442)	(.677)	(.654)
FIA	-.168***	-.1767***	-.189***	-.189***	-.181***	-.182***
	(.0530)	(.053)	(.053)	(.05)	(.053)	(.053)
SIZE	.0438*	.0412*	.0469*	.0466*	.0468*	.466*
	(.0243)	(.024)	(.024)	(.02)	(.024)	(.024)
ARR	-.0011***	-.0011***	-.0011***	-.001***	-.0011***	-.001***
	(.0002)	(.0002)	(.0002)	(.0002)	(.0002)	(.0002)
APR	-.0002**	-.00022**	-.00022**	-.00022**	-.00022**	-.0002**
	(.0001)	(.0001)	(.0001)	(.0001)	(.0001)	(.0001)
ER	-.0025***	-.0026***	-.0027***	-.0027***	-.0027***	-.003***
	(.0006)	(.0007)	(.0006)	(.0007)	(.0007)	(.0006)
LNEMP		-.0236			-.138**	-.14**
		(.040)			(.062)	(.061)

LNMSALARY						
RDGRP		7.655***			5.45**	5.68**
		(2.18)			(2.35)	(2.303)
IA		-.00008			-.0008	-.0075
		(.0064)			(.007)	(.006)
IE						
CAPL		-.0785			-.0331	-.0216
		(.094)			(.098)	(.095)
CAPLBORDER		-.0924			-.276***	-.270***
		(.065)			(.082)	(.082)
ECI			-.00746	-.006	-.0107	-.0113**
			(.0048)	(.0118)	(.012)	(.005)
ECISQ				.00004	.00005	
				(.0001)	(.0001)	
W_ECI			-.224***	.1837	-.0128	-.364***
			(.0741)	(.6711)	(.6833)	(.095)
W_ECISQ				.0957	.0883	
				(.1604)	(.1676)	
ECI*W_ECI			-.0047*	-.0017	-.0063	-.009***
			(.0026)	(.005)	(.005)	(.0035)
Industry fixed effects	yes	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes	yes
N	1917	1917	1917	1917	1917	1917
R^2	.129	.126	.134	.134	.134	.134
Wald	100.2***	113.8***	113.6***	113.4***	130.1***	130.4***

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

According to Table 2.5 economic crisis doesn't change radically the pattern of a firm development. As economic crisis brings shortages of available resources and lack of trust, firm size becomes positively significant, because bigger firms with diversified product structure are more sustainable. Negative influence of APR confirms that ability of a firm to perform its obligations supports its presence on the market.

Some regional variables become significant. For example RDGRP points out that if local companies and state invest in R&D, regional economy is more sustainable. Increased R&D expenditures stimulate patenting and patenting, in turn, stimulates cooperation between firms and research organizations. As it was already mentioned, economic crisis shakes markets and could open "windows of opportunities" due to the effect of creative destruction, but not for all regions. If a region has common border with the capital city, it worsens state of a company because migration of local employees. Crisis strengthens the impact of economic complexity, but it continues to be negative. The main reason could be in low level of innovation activity. As innovations in one sector stimulate innovations in adjacent ones, low level of innovation activity in the whole economy destroys this positive feedback, because company, which develops innovation product couldn't find demand of necessary volume inside the country, reach competitive level of cost and supersede competitors. By the way, it is in line with negative influence of FIA on asset turnover.

The same analysis is conducted for another dependent variable – ROA. In this case we wish to evaluate the influence of independent variables on a firm's profitability. Results are presented in Tables 2.6 and 2.7.

Table 2.6

Regression results for pre-crisis time period

Time period	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Dependent variable	ROA	ROA	ROA	ROA	ROA	ROA
Cons	14.11* (7.90)	12.34 (9.715)	16.24** (8.76)	24.00* (9.37)	11.18 (12.94)	8.80 (12.603)
FIA	1.347 (.965)	1.287 (.974)	1.300 (.972)	1.264 (.973)	1.260 (.977)	1.294 (.977)
SIZE	-.755 (.731)	-.782 (.582)	-.749 (.582)	-.779 (.582)	-.790 (.583)	-.784 (.582)
ARR	-.0026 (.004)	-.003 (0.004)	-.003 (.004)	-.0029 (.0045)	-.0030 (.0045)	-.0029 (.0045)
APR	.0024 (.003)	.002 (.003)	.0023 (.003)	.0020 (.0031)	.0018 (.0031)	.00199 (.0032)

ER	.100***	.097***	.1001***	.0989***	.0976***	.0974***
	(.014)	(.014)	(.014)	(.0146)	(.0147)	(.0145)
LNEMP		.764			1.237	1.062
		(.797)			(1.10)	(1.08)
RDGRP		-4.460			-3.514	-.174
		(46.74)			(48.45)	(48.24)
IA		-.208*			-.189	-.198
		(.124)			(.127)	(.127)
CAPL		1.779			1.506	1.820
		(1.61)			(1.705)	(1.628)
CAPLBORDER		-1.147			-.5776	-.708
		(1.29)			(1.578)	(1.572)
ECI			.00117	-.240	-.1802	.0192
			(.084)	(.199)	(.212)	(.088)
ECISQ				.00248	.0012	
				(.002)	(.002)	
W_ECI			-.420	-6.722	-7.951	-.7707
			(1.33)	(11.31)	(11.49)	(1.692)
W_ECISQ				1.409	1.642	
				(2.73)	(2.761)	
ECI*W_ECI			-.0162	.0535	.0795	.0199
			(.046)	(.081)	(.0893)	(.058)
Industry fixed effects	yes	yes	Yes	yes	yes	yes
Year fixed effects	yes	yes	Yes	yes	yes	yes
N	1917	1917	1917	1917	1917	1917
R^2	.127	.13	.13	.129	.131	.13
Wald	75.3***	78.1***	72.41***	74.2***	79.6***	78.3***

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

Table 2.7

Regression results for crisis time period

Time period	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Dependent variable	ROA	ROA	ROA	ROA	ROA	ROA
Cons	-18.86***	-15.32*	-17.06**	-8.77	-16.73	-17.95
	(6.90)	(9.20)	(8.12)	(8.76)	(13.26)	(12.78)
FIA	2.137**	1.995**	2.111**	2.097**	2.003**	1.999**
	(.973)	(.983)	(.982)	(.984)	(.988)	(.987)

SIZE	1.630***	1.550***	1.630***	1.616***	1.538***	1.539***
	(.501)	(.503)	(.502)	(.503)	(.506)	(.505)
ARR	-.009*	-.0095*	-.009*	-.0091*	-.0095*	-.0095*
	(.005)	(.0050)	(.005)	(.005)	(.005)	(.005)
APR	.0047**	.00455*	.0047**	.0046*	.0045*	.00458*
	(.002)	(.0023)	(.002)	(.002)	(.002)	(.002)
ER	.077***	.0754***	.077***	.0760***	.0746***	.075***
	(.014)	(.0145)	(.014)	(.014)	(.014)	(.014)
LNEMP		-.115			.204	.0924
		(.774)			(1.19)	(1.172)
RDGRP		29.760			31.345	32.196
		(42.98)			(46.76)	(45.671)
IA		-.198			-.2003	-.191
		(.134)			(.152)	(.147)
CAPL		3.369*			3.273*	3.306*
		(1.78)			(1.874)	(1.872)
CAPLBORDER		-.494			-.3919	-.319
		(1.21)			(1.60)	(1.573)
ECI			-.0263	-.209	-.1226	.0245
			(.091)	(.233)	(.242)	(.095)
ECISQ				.0014	-.00008	
				(.002)	(.002)	
W_ECI			-.445	-8.428	-9.747	-.390
			(1.40)	(13.50)	(12.83)	(1.85)
W_ECISQ				1.848	2.263	
				(3.00)	(3.06)	
ECI*W_ECI			.0007	.0658	.0762	.0205
			(.50)	(.094)	(.106)	(.067)
Industry fixed effects	yes	yes	Yes	yes	yes	Yes
Year fixed effects	yes	yes	yes	yes	yes	yes
N	1917	1917	1917	1917	1917	1917
R^2	.124	.127	.125	.125	.128	.128
Wald	89.6***	95.5***	89.7***	90.04***	94.88***	94.90***

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

According to the Table 2.6 ROA of different firms during economic prosperity is not influenced by its financial indicators or regional parameters. Only ER (share of firm's own capital in total capital) has significant positive influence. It is reasonable to lean on the own sources of the capital because interest rates in Russia are quite high.

Insignificance of the majority of variables confirms statement that in times of economic growth there is room almost for all companies in the market. Economic crisis is real challenge for the firm's strategy. According to the Table 2.7 bigger, innovation-active firms, less dependent on external sources of financial resources and interacting with clients, which are able to pay their obligations on time, have higher ROA during economic crisis, i.e. such firms are more sustainable. Regional parameters do not influence on ROA, except for CAPL. Its significance means that in capital city ROA decreases less than in provincial regions.

We also conducted industry-level analysis (see Tables 2.8-2.11). The same six models as in Tables 2.4-2.7 are calculated. As significance/insignificance of variables is persistent, only model with set of variables as in Model 6 is demonstrated.

Table 2.8

Regression results for pre-crisis time period: industry-level analysis for ATR

Industry	**Machinery**	**Chemical**	**Metal**	**Non-metal mineral products**	**Plastic products**
Dependent variable	ATR	ATR	ATR	ATR	ATR
Cons	3.094**	4.23**	2.64	1.62	2.33
	(1.29)	(1.90)	(1.876)	(1.612)	(2.08)
FIA	-.22**	-.618***	-.006	.0116	-.2333
	(.109)	(.152)	(.158)	(.165)	(.168)
SIZE	-.125**	-.049	-.0614	.0286	-.0186
	(.057)	(.074)	(.083)	(.0809)	(.0104)
ARR	-.002***	-.0013**	.00003	-.0005*	-.0017*
	(.0006)	(.0005)	(.0007)	(.0002)	(.0010)
APR	.0002	-.0005**	-.0006	-.00026	.00086
	(.0002)	(.0002)	(.0005)	(.0002)	(.0007)
ER	-.007***	-.00367*	-.0041*	.001	-.0016
	(.0014)	(.0019)	(.0024)	(.0018)	(.0024)
LNEMP	.046	-.089	.0298	-.0105	-.0210
	(.109)	(.154)	(.188)	(.153)	(.177)
RDGRP	-1.158	11.823*	3.487	-5.267	11.62
	(5.112)	(7.31)	(7.401)	(7.37)	(9.49)
IA	.0026	.0126	.001	.0036	-.0289
	(.013)	(.016)	(.016)	(.018)	(.02)
CAPL	-.2036	.2312	-.0484	.2115	.2614
	(.163)	(.236)	(.310)	(.303)	(.308)

CAPLBORDER	-.337**	-.012	.279	.174	-.172
	(.160)	(.228)	(.247)	(.240)	(.282)
ECI	.0066	-.0318*	-.0101	-.0159	.0007
	(.009)	(.017)	(.0132)	(.012)	(.014)
W_ECI	-.0669	-.5173**	-.146	-.3837	.0180
	(.163)	(.236)	(.277)	(.266)	(.294)
ECI*W_ECI	.00011	-.0136	-.0055	-.01	.00426
	(.0056)	(.009)	(.009)	(.007)	(.008)
Industry fixed effects	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes
N	741	279	318	297	282
R^2	.148	.274	.061	.122	.095
Wald	102.7***	44.9***	35.3***	26.5**	25.3**

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

Table 2.9

Regression results for pre-crisis time period: industry-level analysis for ROA

Industry	**Machinery**	**Chemical**	**Metal**	**Non-metal mineral products**	**Plastic products**
Dependent variable	ROA	ROA	ROA	ROA	ROA
Cons	24.71	55.3	-12.5	-30.57	38.36
	(20.98)	(42.65)	(29.39)	(29.61)	(34.79)
FIA	2.400	.3122	.630	-.383	1.028
	(1.632)	(3.071)	(2.36)	(2.551)	(2.561)
SIZE	-1.428	-1.272	-.3887	1.382	-2.52
	(.954)	(1.69)	(1.348)	(1.511)	(1.743)
ARR	-.0266**	-.0107	.0416***	-.0029	-.0297
	(.010)	(.0144)	(.013)	(.006)	(.019)
APR	.0083	-.0073	.00383	-.0051	.022
	(.005)	(.006)	(.009)	(.007)	(.013)
ER	.0744***	.0723*	.1314***	.105***	.165***
	(.023)	(.042)	(.043)	(.032)	(.041)
LNEMP	-.532	1.539	2.064	2.174	.679
	(1.743)	(3.35)	(2.934)	(2.74)	(2.862)
RDGRP	66.94	-91.89	85.201	-99.26	-36.419
	(77.82)	(149.57)	(112.41)	(119.347)	(148.65)
IA	-.192	-.0647	-.1258	-.299	-.225
	(.214)	(.374)	(.262)	(.337)	(.338)

CAPL	.0303	5.222	8.844*	-3.454	3.639
	(2.452)	(4.741)	(4.63)	(4.752)	(4.731)
CAPLBORDER	-1.9	-1.147	2.283	.0317	3.498
	(2.484)	(4.805)	(3.772)	(4.031)	(4.456)
ECI	.1596	.7616**	.0831	.2439	-.0239
	(.146)	(.365)	(.204)	(.203)	(.238)
W_ECI	2.222	-5.431	-2.252	3.950	2.821
	(2.617)	(5.04)	(4.317)	(4.689)	(4.759)
ECI*W_ECI	.0702	-.3357	.0528	.0824	-.0233
	(.093)	(.222)	(.149)	(.142)	(.148)
Industry fixed effects	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes
N	741	279	318	297	282
R^2	.102	.274	.225	.197	.205
Wald	32.3***	44.9***	46.5***	24.2**	25.6**

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

For pre-crisis period size of a firm matters almost for every case. If ATR is the dependent variable, FIA influences negatively but only for the most knowledge-intensive sectors of the sample (machinery equipment and chemical production). Its low significance for the profit generation is confirmed in the models with ROA as the dependent variable. Regional variables, including economic complexity, still are not significant, except for chemical production. It could be supposed that such relationship for chemical production may be due to dependence on local sources of raw materials and personnel and high interconnections among its subsectors.

Table 2.10

Regression results for crisis time period: industry-level analysis for ATR

Industry	**Machinery**	**Chemical**	**Metal**	**Non-metal mineral products**	**Plastic products**
Dependent variable	ATR	ATR	ATR	ATR	ATR
Cons	2.45**	3.09	2.55*	1.06	0.91
	(1.132)	(1.953)	(1.593)	(1.55)	(1.723)

FIA	-.257***	-.641***	.1435	.0948	-.1718
	(.088)	(.139)	(.134)	(.163)	(.133)
SIZE	-.0153	.127**	.0214	.176**	.1744**
	(.0402)	(.0622)	(.053)	(.0704)	(.0693)
ARR	-.0013***	-.0013*	-.0008	-.0005	-.0015**
	(.0004)	(.0007)	(.0004)	(.0003)	(.0007)
APR	-.0002*	-.00026	-.00018	.00009	-.0007
	(.0001)	(.0003)	(.0002)	(.0002)	(.0005)
ER	-.0046***	-.0004	-.004**	9.53e-06	-.00005
	(.0011)	(.0018)	(.0018)	(.0017)	(.0018)
LNEMP	-.065	-.2568*	-.165	-.2505*	-.1247
	(.104)	(.154)	(.169)	(.142)	(.160)
RDGRP	5.447	10.68*	3.119	.0701	12.6**
	(3.864)	(5.772)	(5.141)	(6.618)	(6.443)
IA	-.0105	.0107	-.0034	.0033	-.0438**
	(.011)	(.018)	(.016)	(.0168)	(.0180)
CAPL	-.1176	-.0527	-.041	.2178	.3832
	(.146)	(.223)	(.277)	(.304)	(.269)
CAPLBORDER	-.460***	-.154	-.118	-.2265	-.227
	(.132)	(.203)	(.202)	(.223)	(.225)
ECI	-.00295	-.0367**	-.0019	-.0168	-.0103
	(.008)	(.018)	(.0125)	(.12)	(.012)
W_ECI	-.3123**	-.734***	.1054	-.548**	.2558
	(.157)	(.241)	(.2472)	(.232)	(.269)
ECI*W_ECI	-.0056	-.022**	-.0057	-.0130	-.0013
	(.005)	(.0111)	(.0088)	(.0085)	(.009)
Industry fixed effects	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes
N	741	279	318	297	282
R^2	.151	.356	.073	.074	.243
Wald	64.2***	58.8***	14.3	35.6***	55.5***

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

Table 2.11

Regression results for post-crisis time period: industry-level analysis for ROA

Industry	**Machinery**	**Chemical**	**Metal**	**Non-metal mineral products**	**Plastic products**
Dependent variable	ROA	ROA	ROA	ROA	ROA

Cons	18.79	-27.39	-65.4*	-5.197	-38.32
	(21.49)	(41.851)	(37.04)	(25.24)	(35.78)
FIA	2.939*	.965	4.99*	1.012	2.867
	(1.634)	(2.93)	(3.077)	(2.25)	(2.37)
SIZE	.4662	3.46**	1.864	1.849	1.838
	(.798)	(1.38)	(1.263)	(1.19)	(1.58)
ARR	-.024***	-.039**	-.0055	.00539	-.0227
	(.0087)	(.017)	(.012)	(.008)	(.237)
APR	-.0029	.0122	.0256***	-.00262	.0164
	(.0032)	(.007)	(.005)	(.005)	(.0158)
ER	.0282	.201***	.0548	.0600*	.0718*
	(.0220)	(.040)	(.043)	(.032)	(.0424)
LNEMP	-1.682	-1.75	2.861	-2.627	3.894
	(1.954)	(3.292)	(3.91)	(2.41)	(2.991)
RDGRP	137.33*	-46.41	174.07	-141.61	-267.64**
	(73.61)	(125.85)	(120.9)	(110.238)	(132.569)
IA	-.709***	.0391	.372	.0552	-.2568
	(.222)	(.424)	(.386)	(.0315)	(.459)
CAPL	6.446**	3.252	-4.784	2.576	7.565
	(2.756)	(4.802)	(6.417)	(4.37)	(5.204)
CAPLBORDER	-3.789	-2.932	6.888	-5.366	7.149*
	(2.481)	(4.392)	(4.683)	(3.556)	(4.312)
ECI	.0286	-.188	.3089	.05889	-.0758
	(.163)	(.391)	(.287)	(.190)	(.237)
W_ECI	-.5913	-7.506	7.758	1.408	2.135
	(2.936)	(5.146)	(5.723)	(4.239)	(4.862)
ECI*W_ECI	.0114	-.155	.292	-.0820	.0362
	(.110)	(.236)	(.203)	(.138)	(.164)
Industry fixed effects	yes	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes	yes
N	741	279	318	297	282
R^2	.115	.319	.094	.109	.119
Wald	52.9***	57.2***	36.2***	25.9**	22.9*

*, **, *** - variable is significant for 0.1, 0.05, 0.01 p-level respectively. Standard errors are in parentheses.

Economic crisis makes impact of the economic complexity more pronounced. For example W_ECI becomes significant for machinery equipment and non-metal mineral products production (ATR is dependent variable) and it is negative. It is possible to make interim conclusion that growth of small and medium industrial enterprises during economic

crisis depends negatively on the regional economic complexity. This statement should be checked on the bigger sample. By the way, contradiction between growth and profitability is manifested itself on sector-level analysis. For example the firm with higher profitability should be bigger and innovative while fast growing company should be smaller and innovation-passive.

To conduct robustness check different sets of control variables are used. Instead of LNEMP we use LNMSALARY and instead of ER WCCA respectively. Also we use innovation expenditures to total turnover of industrial enterprises ratio (IE) instead of share of innovation-active companies (IA). It does not change results significantly and conclusions about hypotheses are still valid.

5. Conclusion

This paper is devoted to the problem of firm sustainability during economic crisis. The aim of it is to analyze could economic complexity of the region, where a company is situated, sustain its performance. We hypothesize that if a firm is innovation- active it influences negatively efficiency of its capital utilization, which is measured as asset turnover ratio (ATR). There is no difference, if it is period of economic depression or boom. For the firm's asset profitability (ROA) the proposed relationship is as follows: no correlation during economic growth period and positive relationship during economic crisis. These hypotheses are supported, despite strong positive correlation coefficient between ATR and ROA (.32), which presumes that higher capital efficiency brings higher profitability. Econometric models witness that these development indicators have different patterns of relationship with independent variables. For ATR investment in R&D is a burden, which diverts resources from financing expansion. Opposite is true for profitability: R&D is not significant for growth but positively influences on firm's sustainability during economic crisis. This is true in particular for several sectors, like machinery equipment and chemical production (except crisis period for ROA), which means that these hypothesized

relationships are not accidental and need additional in-depth research on bigger sectoral datasets.

Regional variables do not have persistent relationships with the dependent variables. So regional size, level of innovation activity or R&D investment capacity do not influence on a company development. But the level of economic complexity has limited, but steady impact. The level of complexity of the region's economy affects the company's return on assets, but the corresponding hypotheses have not been fully confirmed. It is predicted, that the economic complexity doesn't influence on firm's development during economic prosperity. But for a firm's growth it is better to locate in the region with lower level of the economic complexity of surrounding regions. Possible explanation could be the support of new enterprises by local authorities of neighboring regions, which prevents access on market of other regions by the company of a focal region. The other explanation is limited opportunities for cooperation of companies from different regions. So when new enterprises are created, they are more prone to cooperate with foreign companies, than domestic firms. But on the sectoral level the relationship is significant only for chemical production, which makes it reasonable to conduct in-depth research on the sectoral level.

The results of the study contribute to the development of theoretical ideas about the growth of the firm. The study adds empirical findings on the influence of regional factors on firm growth, namely the role of factors related to innovation and technological capacity (Raspe and Oort, 2011; Audretsch and Dohse, 2017; Ipinnaiye, 2017). Audretsch and Dohse (2017) show that knowledge assets availability in a region has a positive effect on a company's employment growth. According to the study by Raspe and Oort, (2011), correlation is also positive, but they noted on a number of moderating factors that influence the level of significance of independent variables. This study also highlighted the moderating factor - the economic crisis, the occurrence of which increases the importance of variables associated with innovation and knowledge. At the same time, the analysis of spatial effects is

carried out, which allows to speak about the negative influence of the technological level of neighboring regions on the efficiency of utilization of the company's assets.

The present study can be continued in the following directions. It is reasonable to add other variables. For example if a firm has crisis plan, its loss in terms of revenues or lay-offs are less than for firms which are not prepared (Penn, Schoen and Berland Associates, 2009). The company de-facto can consist of several parts. In case that the division of the organization is based on the motives others, than improving the quality of management (for example, tax optimization, asset protection, etc.) or the firm is affiliated with big business or if it has state as one of the owners, real size and resource power of the firm could be skewed. State owner could be the source of subsidies or public procurement contracts which could really support a company.

The analysis presented here is limited by the data and the statistical models. At first, the company's innovative activity is evaluated on the basis of such an indicator as the presence of patents in the company's assets. This approach has some advantages, the most important of which are the objectivity and ease of obtaining information. However, patenting is characterized by industry specificity. Protection of intellectual property rights may be exercised through know- how. The expenditures on innovative projects are an integral, accordingly more reliable indicator. Secondly, the findings of the study depend on the state of the investment climate in the region, on the quality of institutions, on the relationships between local and federal authorities, and on many other factors that are difficult to quantify. The same applies to the activities of firms. For example, it is difficult to reflect such parameters as the competitiveness of the firm's products, the quality of corporate governance, dynamics of the company's product market, and so on. Thirdly, the study concerns only Russia. The current crisis has economic reasons (as it follows from the discussion in the community of Russian economists), but it is strengthened by the actions of other geopolitical opponents. This prevents the normal recovery of the economy due to an

artificial disruption of production and financial ties. The study could be broadened on current Covid-19 crisis, so capture more countries. Finally, not all variables are totally satisfactory. For example, ROA is calculated using earnings before taxes (EBIT). This kind of profit could be underestimated so that to reduce tax. So it would be reasonable to try gross profit.

Chapter 3

Regional economic complexity and its prevention of firm's bankruptcy in turbulent economic reality

1. Introduction

There are two directions in economics for the analysis of the problem of liquidation of companies. Within the framework of the industrial economy the decisive role of external parameters is emphasized. Followers of behaviorism, organizational psychology, emphasize the role of management personnel (Kristóf and Virág, 2020). There is no doubt that financial imbalance is more often the result of an intra-organizational crisis, and not its cause. It is the inability of the company to meet the requirements of the market and the external environment that leads to the loss of competitiveness and financial difficulties. Due to the increasing role of knowledge, acceleration of scientific and technological progress, innovation processes have become more intensive. The need to make large-scale capital investments with a view to the world market forces entrepreneurs to turn to financial institutions, which makes them dependent on financial markets and conjuncture. Accordingly, the process of "creative destruction" (Schumpeter, 1934) becomes more common. The regulation of financial markets and the supply of money play a much larger role now. Thus, in modern conditions, the role of external factors has increased significantly and the analysis of only the company's resources is not enough.

Probability of bankruptcy increases drastically during economic crisis. Since the economic crisis implies the risk of large-scale bankruptcies, it is necessary to take into account the expanded capabilities of national states to stop crisis phenomena. It leads to the conclusion that information about the financial condition of the company is not enough to predict its bankruptcy. It is advisable to integrate data on the innovative activities of the company, which allows characterizing the availability of resources for transforming the activities of the company in response to a change in the external environment, possessing not only technological competencies, but also tools for managing changes in the company. However, firms are not

atomized economic units. A large company is part of the system of international division of labor; regional partners and markets are less important for it. For medium-sized companies, which are the object of this study, the market of the region of presence and neighboring regions, the regional system of division of labor are of much greater importance.

The category of economic complexity is derived from the system of regional division of labor. The idea of the complexity of the economy is that a country (region) is able to export products that are quite unique. Uniqueness implies that only a small number of countries (regions) export similar products. And the more such goods a country (region) exports, the higher the complexity of the economy. In fact, the complexity of the economy shows what technological competencies and production capacity a country (region) possesses. Each product requires its own set of technological competencies. A more complex economy is a priori more stable, since, firstly, the local system of division of labor is based on a larger number of competencies, and secondly, each additionally mastered technological competence by local companies can be adapted in a larger number of products to develop incremental innovations. In other words, in a more complex economy, economies of scale apply to knowledge: it can be capitalized in a larger number of products. The relationship between the complexity of the economy and the bankruptcy of companies is not limited only to the region of the firm's presence. Consumers and competitors can be based in other regions of the country, including remote ones. Interaction with partners from other regions means that the firm is included in the system of division of labor in another region. Knowledge flows between regions and the adaptability of local agents also affect a company's sustainability. Accordingly, when assessing the likelihood of bankruptcy, it is necessary to expand the range of parameters at the expense of regional ones, as having strategic, long-term significance.

To diagnose and predict bankruptcy, financial reporting data (dynamics of reserves, assets, liquidity assessment, accounts receivable and payable, etc.) are traditionally used, on the basis of which bankruptcy forecasting models have been developed (H. Altman, Taffler, Biver,

etc.) It should be noted that financial indicators used in the models for diagnosing and forecasting bankruptcy may incorrectly reflect its real financial condition. For example, retained earnings represent the results of previous years do not provide reliable data on the real and estimated future profitability of the company. A number of models for predicting bankruptcy are based on indicators of profitability (ROE, ROA), which can be manipulated by the company's management. It is necessary to adapt bankruptcy models to the industry characteristics of firms. Thus, despite the abundance of methods, a universal model for predicting bankruptcy has not been developed. The effectiveness of a certain model may depend on the country, moment in time, economic situation, stage of the company's financial distress (Kristóf and Virág, 2020; Laitinen, 1993). Given these gaps in knowledge, the overall purpose of this paper is to evaluate the impact of the regional economic complexity on firm’s probability to go bankrupt during economic crisis. This allows supplementing the bankruptcy prediction models with more objective parameters that are not subject to manipulation by the company and at the same time assess not only the current, but the future state of the economy.

To test the hypotheses of the study, a sample of 449 Russian small and medium industrial companies is constructed. Some of these firms did not survive the strong economic decline that occurred in Russia in 2014 under the influence of geopolitical tensions, the decline in world prices of fuel resources, and the devaluation of the national currency. Logit and probit models are used as tools.

Econometric analysis confirms the significant influence of the regional economic complexity of the region, where a firm is situated. It has an inverted U-shaped form. Accordingly, the most resilient to the bankruptcy during the crisis are companies located in regions with the simplest and most complex economies. The impact of economic complexity of other regions is not statistically significant.

The structure of the research is determined by its tasks and looks as follows. Section 2 analyzes the main research on the problem of diagnosing and predicting bankruptcy. It also

presents an analysis of the literature on the theory of the complexity of economics and applied research in this area. Section 3 describes the data and methodological aspects of the study. Section 4 presents an analysis of the research results, including checking for robustness. At the end the conclusions of the study are presented.

2. Literature review and research hypotheses

2.1. Firm bankruptcy models

The bankruptcy of a company means its inability to perform its obligations in time. Various criteria are used here: a decrease in the value of net assets below zero, the duration of the delay in payment in days, etc. The conceptual approach to predicting bankruptcy is based on comparing the performance of the firm of interest with bankrupt companies. Since bankruptcy is initially interpreted as a financial crisis of a company, the source of data is financial statements, on the basis of which the selected indicators are formed. The key task is to find the variables that best distinguish between solvent firms and bankruptcies using discriminant analysis, logistic regression, machine learning, neural networks, etc. More than 50 methods in total were elaborated (Du Jardin, 2010). The first models were based on discriminant analysis. So, Altman's model is as follows:

$$Z = 1.2X_1 + 1.4X_2 + 3.3X_3 + 0.6X_4 + X_5 \quad (3.1)$$

where:

X_1 is the ratio of working capital to asset value

X_2 - the ratio of retained earnings to assets

X_3 is the ratio of operating income to assets

X_4 is the ratio of the market value of shares to the amount of debt

X_5 is the ratio of revenue to asset value.

Empirical calculations have shown that if Z <1.81, then the firm is financially unstable, while if Z> 2.99, the opposite is true. The interval [1.81-2.99] is a zone of uncertainty. In 1983,

he also proposed a modification of the formula for companies that are not listed on the stock exchange.

$$Z = 0.717X_1 + 0.847X_2 + 3.107X_3 + 0.42X_4 + 0.995X_5 \quad (3.2)$$

In this formula the market value of the shares is replaced by the book value. It is noteworthy that in this way an external, independent assessment of other, non-financial factors is excluded from the model. A similar model was proposed by Tuffler in 1977. His model includes four financial ratios: the ratio of profit before tax to current liabilities, the ratio of current assets to total liabilities, current liabilities to total assets, and the ratio of revenue to total assets. Taffler's model is a modified Altman model based on the selection of financial coefficients from 80 considered. If the Tuffler model total is less than 0.2, then the firm is in a pre-bankruptcy state. If more than 0.3, then the financial position is stable. It was also proposed to transform the Z-factor into a PAS-factor, i.e. consider company's z-ratios (i.e., bottom lines) relative to each other in order to mitigate the problem of margins. It is reasonable to assume that firms which are the worst performers are more likely to go bankrupt.

The Beaver model focuses on assessing the share of equity in financing the company's activities. It includes five coefficients that are evaluated separately from each other. The Beaver ratio is the ratio of the cash flow to the amount of the company's liabilities. It shows the ability of the firm to meet its obligations at the expense of its activities. Return on assets shows the efficiency of the company, the current liquidity ratio characterizes the balance of liabilities and assets in the short term. Leverage measures the ratio of borrowed funds to assets. Of course, a higher leverage allows a firm to develop faster, but creates significant risks, which, however, depend on the share of long-term funds in liabilities. The share of own working capital also characterizes the degree of attraction of external resources.

Since the late 70s, the development of computational technologies and statistical methods has made it possible to use the methods of logit and probit models. A pioneering work in this direction was the study by Ohlson (1980). The use of neural networks began in the 90s (Odom

and Sharda, 1990). Combinations of various methods, methods of machine learning, clustering, artificial intelligence, etc. are currently widely used (Kristóf and Virág, 2020). The inadequacy of purely financial indicators is obvious if the bankruptcy of the company is viewed not as a financial crisis, but as a significant violation of the optimal management of the company. This is reflected in a number of quantitative indicators of governance that are discussed in the Argenti indicator. For example, these are lawsuits, scandals, resignations, decline in market share, etc. Thus, the financial indicators of a company's bankruptcy are often the result of deep internal crisis in the company. A company can lose the ability to track, predict and manage technological changes, make mistakes in market positioning, invest too much in one project, lose key employees due to bureaucratization of activities, etc. A number of studies have shown that the use of macro-level variables improves the quality of the forecast (Hamerle et al., 2004; Carling et al., 2007; Bonfim, 2007; Jacobson et al., 2011).

2.2. Regional economic complexity

Economic development refers to the ability of local companies to develop new products and technologies. Thus, economic development is based on innovation, while economic growth is an integral indicator and can be based on an increase in the volume of used production factors without changing production technologies. Knowledge management, namely the ability to generate, transfer, store knowledge, determine the need for knowledge, is a prerequisite for the implementation of innovative projects. Knowledge can be explicit (codified, for example, expressed in patents, scientific articles) and tacit, which means the skills acquired as a result of accumulated experience (example: the ability to drive a car at a speed of 300 km / h). Tacit knowledge is inseparable from the owner and can be transmitted only as a result of interaction, learning.

Knowledge cannot be quantified, but any product is a set of technological competencies for production, storage, transportation, etc. Therefore, the structure of the economy indirectly reflects the stock of knowledge available to local organizations and the quality of management,

in particular, the ability of agents to cooperate, transfer knowledge and transform it into new technological capabilities (Hausmann et al., 2011). The structure of the economy determines its competitiveness, technological development trajectory and growth rates in the long run (Bathelt and Boggs, 2003; Glaeser, 2005; Hausmann and Klinger, 2007; Hausmann et al., 2011). The influence of the structure of the economy on the vector of its development is determined by a number of parameters. The analysis of the influence of the territorial economic diversity (urban diversity) on its development was carried out in studies of Glaiser (1992), which, thus, supplemented the effects of agglomeration, rethinking studies of Jacobs J. The diversity effect is based on the possibility of a deeper division of labor. As a result, favorable opportunities for innovation are created as a combination of accumulated knowledge, subject to the necessary technological and cognitive proximity of agents (Ahuja and Katika's, 2001; Neffke et al., 2009; Frenken et al., 2007; Essletzbichler , 2007; Bishop and Gripaios, 2009). Interaction with other regions, namely the inflow of new knowledge from technologically similar industries, has also positive effect (Boschma and Iammarino, 2009). Another parameter that characterizes the structure of the regional economy is the relatedness of the products, i.e. technological possibility of their joint production. It means that the existing knowledge is capitalized. Accordingly, the acquisition of additional competencies makes it possible to create a greater number of combinations for the production of goods that are new for a country (region) than in the case when the country (region) has initially fewer competencies (Hausmann et al., 2011).

So economic structure, its diversity and relatedness should influence on firm development because each firm is part of regional labor division system. To quantitatively express this impact it is necessary to calculate economic complexity index. The most sophisticated approach of the evaluation of the regional economic structure is the calculation of indicators of economic complexity (Hidalgo et al., 2009). The criterion for the competitiveness of a product is the fact of its export. Product export, i.e. the ability to compete in the international market reflects that the country's firms possess technologies necessary to develop and produce a

given product. Accordingly the more products a country exports (satisfying the criterion of comparative advantage), the larger its basket of technological and production competences (Hidalgo et al., 2009). The complexity of a product depends on the number of countries that have a comparative advantage in exporting it. The more such countries there are, the more affordable, simple, well-known technologies are used in the production process.

The indicators of the economic complexity reflect the non-monetary aspects of the object of measurement (level of education, the level of accumulated technological knowledge, the ability to implement innovations, investment attractiveness, etc.), and show possible directions for the development of the economy (Cristelli et al., 2015). Empirical studies have shown that the complexity of the economy is positively associated with the dynamics of GDP per capita; in case of the same economic complexity levels poorer countries grow faster (Hidalgo et al., 2009; Hausmann et al. 2011). Perhaps this is due to the lower cost of factors of production, especially labor. So catch-up development is possible, provided that a country has the proper technologies. At the country level the index of economic complexity is relevant for income inequality (Hartmann et al., 2017). It reflects well the accumulated level of knowledge (Hidalgo, 2015). One possible explanation for the positive impact of economic complexity is that it contributes to the creation of non-tradable competitive advantages, which, in turn, increase the attractiveness of the economy for large-scale, high-tech investment projects. Indicators of the economic complexity are used to develop forecasts of economic growth (for more details see Cristelli et al., 2017). The complexity approach is used in related fields of scientific knowledge, for example, to analyze the technological knowledge accumulated at the regional level in the categories of ubiquity and diversity (Pintar and Scherngell, 2018).

Research strand on the economic complexity has only been carried out for the second decade. This science direction is just being formed. Methodological aspects are sufficiently well developed, the model for forecasting economic growth based on the indicator of the economic complexity has been developed too (Cristelli et al., 2017). But utilization of complexity

indicators for understanding the patterns of economic and social development of territories is not enough yet. There is also a significant gap in research on the impact of economic complexity on the position of firms. Meanwhile, it should be assumed that if a company is located in a region with a higher level of economic complexity, this reduces the likelihood of bankruptcy for the following reasons. The company exists in a more competitive environment, which implies the ability to proactively respond to fluctuations in the external environment. In other words, such companies operate under conditions of stricter natural selection. A higher level of diversification of the local economy allows the company to adjust its market positioning, assortment, etc. The level of complexity of the economy and the stock of knowledge available to local organizations are positively related. Consequently, the firm is less dependent on companies from other regions; the selection of partners from local companies is higher. The availability of budgetary resources and infrastructure to support innovation allows local firms to quickly adapt to changes in the external environment. It should be assumed that the relationship between the complexity of the economy and the probability of bankruptcy is non-linear, namely parabolic with a negative slope (see Figure 3.1).

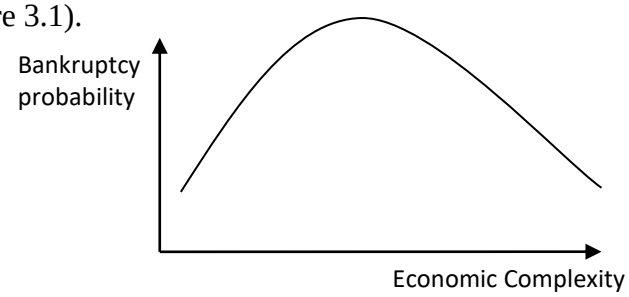

Figure 3.1. Hypothesized relationship between economic complexity and its bankruptcy probability

Accordingly, the hypothesis 1 can be formulated as follows:

H1. The level of complexity of the regional economy has inverted U-shaped relationship with the probability of a company's bankruptcy during the economic crisis.

The low level of complexity of the economy implies the specialization of the region on a few products. Consequently, there is little or no intraregional competition. Low level of

complexity means that the region does not benefit from scale by capitalizing on knowledge (i.e., the ability to apply technological competence to produce more products). Perhaps the region's specialization is based solely on raw material advantages. The high level of complexity of the economy implies the full use of resources, the possession of a wide range of competencies, the ability of local companies to develop and implement new projects. The enterprises of the region possess competitive advantages over companies from other regions. In these extreme cases, the likelihood of local firms going bankrupt during an economic crisis is less likely. In the intermediate area, the probability of bankruptcy is higher, since the region's enterprises do not possess rare, unique competencies for the country. At the same time, the absence of a narrow specialization means that the companies in the region operate in fairly competitive markets. At the same time, we repeat, they do not have dominant competitive advantages.

The influence of the level of complexity of economies in other regions should be parabolically positive (see Figure 3.2).

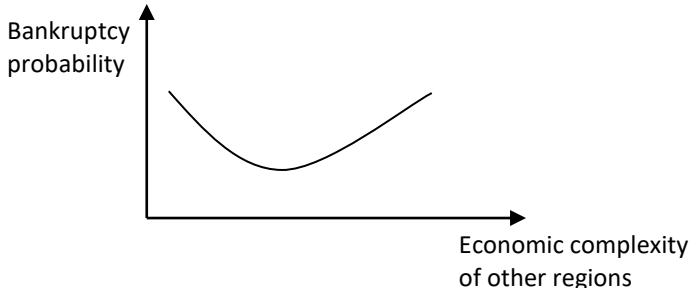

Figure 3.2. Hypothesized relationship between economic complexity of other regions and bankruptcy probability of local companies

Thus, hypothesis 2 can be formulated as follows:

H2. The level of complexity of the economies of other regions has U-shaped relationship with the probability of bankruptcy of companies in the focal region.

The impact of the economic complexity can also be determined by the ratio of the complexity levels of a focal region and other regions. For example, what is the likelihood of bankruptcy for a company from a region with a high level of economic complexity if the level of economic complexity of other regions is also high? Or low? The analysis of the ratio of the level

of economic complexity in this case allows drawing conclusions about the dynamic aspect of the influence of the complexity of the economy, considering the regions in their spatial proximity, as macroregion. Considering that in hypotheses 1 and 2 the relationship between the complexity of the economy and the probability of bankruptcy is assumed to be nonlinear and inverse to each other, this influence should be neutral. Accordingly, hypothesis 3 can be formulated as follows:

H3. The complexity of the economy of a bundle of regions, the center of which is a focal region, does not affect the probability of bankruptcy of a company from a focal region.

3. Data and methodology

The regional economy complexity index was calculated based on the methodology proposed by Tacchella et al. (2012). According to their approach data on the export of countries by commodity groups are used to calculate this index. Unfortunately, Russian statistics do not contain data on interregional trade flows within Russia. In this case, the export data are incomplete because individual parts, components, etc. products may be produced in other regions. Interregional division of labor is very typical for production of complex technical products. Accordingly, the production of the good will be attributed to the region that carried out the final production operation. Therefore, instead of export data, 4-digit level of production data is used. The index of economic complexity, in our opinion, should assess not so much the diversity of the structure but the level of technological competence possessed by the region. Otherwise, there will be a bias of the results towards larger regions. In this regard, the basic indicator for calculating the index is not the ratio of the shares of export of product i in the region and in the country, but the ratio of labor productivity by product, namely, the quotient of the ratio of the volume of production of product i in the region to the total number of employed to similar parameters for the country as a whole. Thus, regions which are not large agglomerations can receive a high economic complexity rating due to effective management, stimulation of scientific research and innovation, etc. Variable which characterizes index of the complexity of an economy is ECI. ECI is presented as a rating for each region (1 is the lowest, 68 is the

highest). To calculate this variable, 68 regions of Russia are used. Some regions are excluded due to the large number of missing data that could not be assessed. Others are removed due to their very small size and very simple structure of the economy, which makes it impossible to correctly compare them with large agglomerations. To assess the impact of the complexity of the economy of other regions on the dependent variable, the W_ECI variable is calculated. It is calculated as follows:

$$W\_ECI = W \times ECI \tag{3.3}$$

W_ECI in (3.3) is a vector of the W_ECI_i variable. ECI is a vector of ECI_i values across all regions, W is a matrix of weights. This study uses a matrix of inverted distances, whose element w_{ij} is the reciprocal of the distance between the administrative centers of regions i and j. Since a lot of goods are delivered by road, it is the distance covered by the car. The main diagonal of the matrix W contains zeros.

To check H3 variables ECI and W_ECI are multiplied (ECIW_ECI). For analysis of U-shaped relationship squares of ECI and W_ECI are calculated (ECISQ and W_ECISQ respectively).

Researchers interpret the very concept of “bankruptcy” in different ways. Some consider bankruptcy as a legal fact, while others adhere to the classical view that bankruptcy is the company's inability to fully fulfill its monetary obligations, i.e. the onset of default. The latter assumes that the net assets of the bankrupt company are negative. In this study we will adhere to the first approach, since in the selection of the sample we encountered firms that had negative net assets for a number of years and, at the same time, were functioning, judging by positive sales proceeds. In addition, a default is a contingent event such as the parameters of a loan agreement. This is a temporary deterioration in solvency and does not necessarily indicate that the company is not competitive. Bankruptcy, on the other hand, implies that the company is consistently generating negative cash flow and has no prospects. We also consider cases of voluntary liquidation of a company without creating a new legal entity in the same industry as

bankruptcies. In a crisis, this is very similar to the recognition by the owners of the obvious fact that the firm is not competitive and does not want to continue to generate losses. Accordingly, the dependent variable BANKRUPTCY is binary: 1- the company has become bankrupt, i.e. finally ceased to exist, in 2014-16, 0 - the company survived the economic crisis and is operating. The data are taken for the period, since it is not known in what year the firm actually first experienced fatal financial difficulties (financial report could be improved due to additional investments of the owners).

Control variables are as follows. First of all it is the parameter characterizing the innovative activity of the company. We suppose that if a company is involved in innovative activities, then it implies a higher quality of management. Innovative activity requires constant study of market demand; search for free market niches, and forecasting demand. Knowledge management requires monitoring the technological environment, predicting trends, i.e. development of strategic management. The implementation of innovative projects requires networking. Thus, the strategy of an innovatively active firm is proactive rather than reactive. Such a firm influences the external environment, and not only adapts to it. The economic crisis presents an opportunity for innovatively active firms to capture and create new market niches. The independent variable reflecting the company's innovative activity (Firm Innovation Activity - FIA) is calculated according to two sources of data. A firm is presumed to be involved in innovation if it owns a valid patent or if the balance sheet indicates that it owns research and development results. The second way to find innovative firms is the simplest and most affordable. However, it reveals only those R&D results that the firm receives by itself, or that are acquired by the firm. However, the company can use the knowledge obtained under licensing terms from the parent or subsidiary company, from the owners. In this case, it is necessary to consider the Russian patent database maintained by the Federal Service for Intellectual Property (Rospatent). The search is carried out in a comprehensive manner for the period 2008-2013 in the following directions. Firstly, companies from the sample, as well as their subsidiaries and

owner firms, are considered as patent holders. Secondly, in the absence of a positive result in the first direction of search, the CEO of the company itself, its subsidiaries, owner firms, as well as individual owners are considered as authors and patent owners. For public joint stock companies in the absence of clear owners, affiliates are considered. Since the Rospatent database does not allow the use of identifiers of firms and individuals, the correspondence of the search results to the sample firms is checked by the content of the patent, the uniqueness of the name of the company, and its location. When in doubt, companies are excluded from the sample.

The onset of bankruptcy of a company depends primarily on its financial position at the time of the onset of the economic crisis. For example, creditors may not agree to an extension of the due date; a loan agreement with a bank may provide that in case of deterioration of the previously agreed performance indicators of the company, the bank has the right to claim early repayment of the debt. Even if the company was financially stable on the eve of the crisis, the significant amount of receivables significantly increases the risk of bankruptcy. If the debtor of the company is unable to repay the debt in full, then a potentially sustainable enterprise may face financial difficulties along the chain. Accordingly, two variables are used to characterize these risks: accounts receivable turnover in days (Accounts Received Ratio - ARR) and accounts payable turnover in days (Accounts Payable Ratio - APR). The likelihood of bankruptcy can also increase when assets and liabilities do not match in terms of liquidity. Ideally, the liquidity of assets should be higher (this allows them to be sold faster and with a lower discount). The higher the share of the founders' funds or long-term liabilities in the capital of the company, the more stable its financial position. Of course, achieving an ideal position is difficult, since in the stage of intensive growth, a company can attract a large amount of borrowed funds. To assess the balance of the company's capital, two ratios are used: the working capital to current assets (WCCA), which shows the company's endowment with its own working capital, and the equity ratio (ER), which is the ratio of the company's equity and assets, i.e. shows the degree of independence of the firm from external agents. The effectiveness of the company allows

assessing the potential of the company to generate added value. A more efficient firm, as a rule, is larger, seizes shares in more profitable market segments, has a more efficient management structure, etc. Greater efficiency implies that the firm is more mobile in terms of changing its market position. Of course, greater efficiency can also be due to the special nature of relations with representatives of the state customer, for example. This variable is represented in the model as the asset turnover ratio (ATR). Company size (TR) is presented as the natural logarithm of revenue. This variable can influence in different ways, depending on how it is measured (Bauer and Endresz, 2016). Also dummy variables are used that characterize the industry affiliation of the company. This is due, firstly, to the need to take into account the sectoral features of financial indicators, and secondly, to the need to take into account sectoral shocks.

The following indicators are used as control variables at the regional level. The size of the region (LNEMP), which is characterized as the natural logarithm of the number of employees (in thousands of people). Median wage (LNMSALARY) is calculated as the natural logarithm of the median wage. LNMSALARY is the indicator of the level of average labor costs in the region's economy. It is indirectly an indicator of the poverty level of the bulk of the region's population. IA shows the level of innovation activity of manufacturing enterprises in the region, namely the share of companies that innovated in a given year. The high level of innovation activity indicates that the economic system of the region is able to flexibly respond to the need for transformation. To reduce volatility, IA is calculated as a three-year moving average. RDGRP is the ratio of R&D expenditures to GRP and indirectly characterizes the resource endowment of the innovation process, the ability of regional companies to create, transfer and adapt knowledge. Finally, two dummy variables are used. CAPL is set to 1 for Moscow and St. Petersburg, two greatest agglomerations. CAPLBORDER takes on the value 1 if the region borders on one of the two metropolitan regions, or rather, on the Moscow or Leningrad region. A description of the variables, including some statistical indicators, is presented in Table 3.1.

Table 3.1

Summary statistics of variables

Variable name	Variable description	No of obsrv.	Min	Max	Mean	Std.dev.
BANCRUPTCY	Dummy variable. It takes 1 if a firm has gone bankrupt in 2014-16, 0 - otherwise.	449	0	1	.396	.489
FIA - Firm innovation activity	Dummy variable. It takes 1 if a firm has intention to perform innovation projects, 0 - otherwise.	449	0	1	.198	.399
ECI	Continuous variable. It measures regional level of economic complexity (68-the lowest)	449	64	1	17.05	16.00831
W_ECI	Continuous variable. It measures weighted regional level of economic complexity of other regions except ith.	449	.353	2.58	1.89	.53
ER - equity ratio – total equity to total assets ratio	Continuous variable. It characterizes overall firm independence from external financial institutions and rules.	449	-593.8	99	22.43	61.66
APR - accounts payable turnover ratio	Continuous variable. It evaluates the ability of a company to access financial resources.	449	0	33232.13	246.41	1901.77
ARR - accounts receivable	Continuous variable. It evaluates level of	449	0	7320.17	103.74	433.08

turnover ratio	risk the company is ready to accept in its sales activity.					
ATR - asset turnover ratio	Continuous variable. It characterizes the overall efficiency of resource exploitation.	449	0	344.41	3.36	21.17
TR - firm size	Continuous variable. It is calculated as ln of total revenue.	449	5.03	15.72	12.28	1.51
WCCA	Continuous variable. This ratio characterizes firm independence from external agents in financing of working capital.	449	-593.8	99	2.223	84.93
IA - share of innovators in total sample of industrial enterprises (%)	Continuous variable. It evaluates prevalence of innovation behavior among regional companies. It characterizes knowledge-exploitation component of the regional innovation system.	449	3.73	21.133	11.57	4.59
RDGRP	Continuous variable. It characterizes knowledge-exploration component of the regional innovation system.	449	.0007	.040	.01537	.0116549
LNEMP - size of the regional economy	Continuous variable. It is measured as ln of employees.	449	193.4	6762.2	2173.85	1812.06
LNMSALARY	Continuous variable. It is measured in RUB	449	13582.24	41633.63	22261.49	7887.85

	in constant prices.					
CAPL	Dummy variable. It takes 1 if a region is Moscow City or Saint-Petersburg, 0 - otherwise.	449	0	1	.172	.378
CAPLBORDER	Dummy variable. It takes 1 if a region has common border with Moscow City or Saint-Petersburg, 0 - otherwise.	449	0	1	.253	.435
ENGINEER	Dummy variable. It takes 1 if a firm belongs to engineering, 0 - otherwise.	449	0	1	.259	.439
CHEMICAL	Dummy variable. It takes 1 if a firm belongs to chemical industry, 0 - otherwise.	449	0	1	.152	.360
PLASTIC	Dummy variable. It takes 1 if a firm belongs to production of plastic goods, 0 - otherwise.	449	0	1	.198	.399
METALL	Dummy variable. It takes 1 if a firm belongs to production of metal products, 0 - otherwise.	449	0	1	.146	.353
NMMINERAL	Dummy variable. It takes 1 if a firm belongs to production of non-metal mineral products, 0 - otherwise.	449	0	1	.243	.429

The sample consists of companies from five manufacturing industries: mechanical engineering and electronics (25.9% of the sample), the chemical industry (15.2), the manufacture of finished metal products (14.6), the manufacture of non-metallic mineral products (24.3), and the manufacture of plastic products (19.8). So the sample is fairly evenly distributed across industries. The choice of industries is due to the fact that not only large, but also small and medium-sized companies can effectively exist in them. The sampling enterprises consist of small and medium-sized companies, whose revenues in 2010 were in the range of 50 million rubles up to 2 billion rubles. The upper bound is also the threshold for classifying a company as a medium-sized firm in Russia. Large companies are not considered due to the fact that the probability of government assistance to them is higher due to their importance for the economy (do not forget about corruption ties). All enterprises are private; state and municipal organizations are not among the owners of any company. The financial indicators of the companies are calculated according to the financial statements presented in the FIRA-PRO database. Logit and probit models are used to assess the effect of parameters on the dependent variable. Independent and control variables are taken for 2013, the last year before economic crisis of 2014-2016. So all independent and control variables are taken with 1-3 year lag (it depends on the year of bankruptcy), which reduces possible endogeneity.

4. Results

Correlation matrix is presented in Appendix 4. Variables of micro-level are not correlated with each other, except for ARR and APR. But regional variables are interconnected with one another. It is especially true for LNEMP, RDGRP, CAPL and IA. So it is better not to use them in the same model so that to reduce multicollinearity. ECI is strongly correlated with LNEMP and RDGRP. They shouldn't be used in the same model either.

The results of logit models are presented in Table 3.2.

Table 3.2

Logit-models

Independent variable	Model 1	Model 2	Model 3	Model 4	Model 5
FIA	-.9466842**	-.9064209**	-.9146759**	-.8989847**	-.8573414**
	(.4033)	(.4072)	(.4045)	(.4044)	(.4063)
ARR	-.0009677	-.0010253	-.0009964	-.0012196	-.0012378
	(.0009)	(.0011)	(.0010)	(.0011)	(.0012)
APR	.0018055*	.001854*	.0018422*	.0024287**	.0023817*
	(.0011)	(.0011)	(.0011)	(.0011)	(.0012)
ATR	.1822227**	.1945759**	.1903152**	.2066352***	.2073461**
	(.0820)	(.0834)	(.0819)	(.0835)	(.0853)
ER	-.0181125***	-.0183078***	-.0184677***	-.018096***	-.018142***
	(.0041)	(.0041)	(.0041)	(.0042)	(.0042)
TR	-.517069***	-.5169282***	-.5287524***	-.516055***	-.509630***
	(.1434)	(.1467)	(.1452)	(.1485)	(.0148)
LNMSALARY		.0000122			5.82e-06
		(.00002)			(.00003)
CAPLBORDER		-.2845728			-.3877517
		(.3846)			(.462)
IA		-.0273385			.0086149
		(.0435)			(.0603)
ECI			-.0043326	.1711013*	.018849*
			(.0242)	(.0912)	(.1092)
ECISQ				-.0020574**	-.0023159**
				(.00009)	(.0011)
W_ECI			-.1045306	.9286219	.8856962
			(.4674)	(4.071)	(4.3612)
W_ECISQ				-.0219324	.0210704

				(.9603)	(1.037)
ECIW_ECI			-.0058843	-.0476277	-.0498498
			(.0139)	(.0341)	(.0395)
Industry dummy	Yes	Yes	Yes	Yes	Yes
Cons	4.735519***	4.786575***	4.750245***	2.326694	1.951855
	(1.785)	(1.816)	(2.063)	(4.532)	(5.041)
N	449	449	449	449	449
LR chi2	93.62***	93.46***	92.91***	98.14***	99.50***
Pseudo R^2	0.2317	0.2344	0.23331	0.2462	0.2496
Correctly classified (%)	83.96	83.96	83.96	83.74	84.63

*** significant at .01, ** significant at .05, * significant at .1. Standard errors are in parentheses.

The presented models correspond to sample data. This is noticeable both by the LR and Pseudo R^2 criteria, and by the importance and stability of the signs of key variables. The Pseudo R^2 value is as high as in similar studies (Bauer and Endresz, 2016). The sign of the variable characterizing the turnover of accounts payable is quite logical: the worse the company manages accounts payable, the less revenue covers the amount of debt to creditors, the higher the risk of bankruptcy. Asset turnover is also positively associated with the risk of bankruptcy. Perhaps this is due to the too rapid growth of the firm and the insufficient size of assets owned by the company. Too fast growth can create risks due to the increase in inventories, receivables. The sign of the TR variable indicates that large firms are more resilient. ER predictably shows that the higher the share of the company's own funds in liabilities, the lower the risk of bankruptcy. The FIA variable is consistently significant and has a negative impact on the likelihood of bankruptcy. Thus, firms whose strategy is active, which are ready for changes in the external environment, are expected to be more resilient.

Regional variables are not significant. It should be assumed that this is due to the flow of resources between regions. For example, the growth of wages outstripping inflation in the focal region can provoke an influx of labor force. Hypothesis 1 is confirmed: the level of complexity of the region's economy affects the likelihood of bankruptcy, and this dependence has inverted U-shape, as predicted. Model 3 includes exclusively linear variables and they are insignificant. Hypothesis 2 is not confirmed, since both parameters characterizing the influence of the level of the economic complexity of other regions turned out to be absolutely insignificant. Hypothesis 3 is formally confirmed: the level of complexity of the economy of other regions does not change the degree of influence of the complexity of the economy of a focal region on the likelihood of firm's bankruptcy. However, the significance level of the moderator variable is 15%. In other words, hypothesis 3 should be tested more thoroughly on a larger sample.

To check the robustness of the estimates, the WCCA variable is added to the model instead of ER and composition of regional variables is changed. The results are presented in Table 3.3.

Table 3.3

Logit-models with modified set of control variables

Independent variable	Model 1	Model 2	Model 3	Model 4	Model 5
FIA	-.8681077**	-.8014824**	-.8548548**	-.9034152**	-.8652547**
	(.3741)	(.3782)	(.0375)	(.3781)	(.383)
ARR	.0008807	.0008227	.0008101	.0001462	.0001967
	(.0017)	(.0017)	(.0017)	(.0017)	(.0017)
APR	.0025665**	.0024791**	.0025974**	.0030834**	.0029107**
	(.0011)	(.0011)	(.0011)	(.0012)	(.0012)
ATR	.1986308**	.1987973**	.2056504**	.2180495**	.2140806**
	(.0857)	(.0860)	(.0865)	(.0888)	(.0883)
TR	-.7564146***	-.7439551***	-.7634022***	-.737037***	-.723521***

	(.1672)	(.1674)	(.1704)	(.1722)	(.0172)
WCCA	-.0024679*	-.0025527*	-.0024913*	-.0022695	-.0023566
	(.0015)	(.0015)	(.0015)	(.0015)	(.0015)
LNEMP		.0000878			.0001416
		(.00009)			(.0002)
RDGRP		-17.95462			-10.16335
		(17.85)			(20.73)
CAPLBORDER		-.0268022			-.0029174
		(.0384)			(.485)
ECI			-.0015052	.1564654*	.1419396
			(.0242)	(.0885)	(.0911)
ECISQ				-.0019384**	-.0020368**
				(.0009)	(.0010)
W_ECI			-.0865726	.9249708	-.2947145
			(.4611)	(3.995)	(4.142)
W_ECISQ				-.0879227	.1481144
				(.9451)	(.9851)
ECIW_ECI			.0000742	-.0397783	-.026062
			(.0139)	(.0332)	(.0368)
Industry dummy	Yes	Yes	Yes	Yes	Yes
Cons	7.145562***	7.051802***	7.396999***	4.820543	5.810821
	(2.032)	(2.05)	(2.334)	(4.432)	(4.561)
N	449	449	449	449	449
LR chi2	76.85***	77.29***	75.96***	80.91***	82.35***
Pseudo R^2	0.1959	0.1996	0.1962	0.2090	0.2127
Correctly classified (%)	84.40	84.21	84.69	84.45	83.73

*** significant at .01, ** significant at .05, * significant at .1. Standard errors are in parentheses.

Replacing the ER variable with WCCA does not affect the significance level of other variables of micro-level. As before, for innovation-active companies with a lower credit burden, able to effectively manage capital, i.e. do not take an excessive risk, the likelihood of bankruptcy during economic crisis is lower. The new regional variables are not significant, but the significance/insignificance of variables characterizing regional economic complexity remains the same. In the truncated model, the research hypotheses are still confirmed/not confirmed as in previous set of models, although the quality of the models according to Pseudo R^2 is a little worse.

The growth of multicollinearity due to the correlation of ECI and LNEMP and RDGRP is almost not reflected in the level of significance of the regional economic complexity. In model 5, the coefficient ECI becomes formally insignificant at the level of p=0.12.

Robustness check is also performed using the lag of independent and control variables. In the basic calculations, the lag is 1. Similar calculations are carried out for two-year lag. The results again confirm that the explanatory variables do not change significance. This means that economic preconditions of bankruptcy appear early enough. Finally, the calculations are repeated using the probit model, which shows approximately similar results.

5. Conclusion

The bankruptcy of a company is determined not only by the quality of financial management. Of course, excessive dependence on external sources of financing or a high level of accounts receivable can provoke the company's inability to fulfill its financial obligations. However, the dependence on partners and market conditions determine the influence of macro-level factors on a focal firm. Of course, industry and global factors affect all companies in the industry in the same way, but some of them are due, for example, to better resource availability, prudent financial policies, etc. able to withstand external threats better. But the firm is part of the system of regional division of labor, therefore, regional support measures in a crisis, the effectiveness of local development institutions, the investment climate, established local business

practices, the size of the region's market, the ability of companies to adapt to changing conditions, the diversity and conjugacy of the structure of the economy, and many other regional factors can influence the development of the company. This paper examines the impact of the complexity of the regional economy on the likelihood of company's bankruptcy during an economic crisis.

The company's innovative activity contributes to its sustainability, since any innovation requires unconventional thinking, information from different areas (market, technology, scientific trends, etc.), integration into social networks, etc. So a firm involved in innovation should be more effective due to the non-standard management tasks being solved. Analysis using the logit and probit models shows that the FIA variable is negatively associated with the probability of bankruptcy and this relationship is significant. Perhaps the dependence would be more pronounced in the case of using a parameter that would characterize the intensity of innovative activity, and not just the very fact of its implementation, or rather, the intention to carry it out. Significant influence of the firm's innovation activity suggests that other non-financial factors of micro-level could also be significant for the firm's sustainability.

Econometric analysis confirms that the level of complexity of the regional economy has a nonlinear influence on the likelihood of bankruptcy in full accordance with hypothesis 1. Companies from leading regions and outsiders are the most stable in a crisis. Share of bankrupt companies is .185 for eight leading regions, 0.24 for the middle part of the sample and 0.19 for the regions with the lowest level of economic complexity. The complexity of the economies of other regions has no effect. Moreover, the verification of the linear dependence is also carried out for both hypotheses with non-significant result. We also calculate a moderator variable to test the hypothesis of how the complexity of the economy of other regions affects the level of complexity of the economy of a focal region. For example, a strong environment could increase the influence of a region with a high level of economic complexity. However, the influence of the moderator variable is absent, which confirms hypothesis 3. Possible explanation: the

nonlinear influence of the ECI, which makes it difficult to identify a clear relationship. However, we also carry out the analysis for two subsamples, namely, for the twenty regions with the highest level of economic complexity and for the rest part of the sample, i.e. for more uniform samples. In each case, ECIW_ECI variable is not significant.

The empirical findings of this study can be used to enrich multivariate models of firm bankruptcy. According to the Altman, Tuffler, Beaver models, firm-level indicators are the only parameters of the models (Du Jardin, 2010; Kristóf and Virág, 2020). But a number of studies have shown that the use of macro-level variables improves the quality of the forecast (Hamerle et al., 2004; Carling et al., 2007; Bonfim, 2007; Jacobson et al., 2011). Since the company is an element of the regional economic system and its development depends both on the technological competitiveness of partner companies and the technological level of competitors and their partners in other regions, the input of the economic complexity index into the bankruptcy model is justified. This study shows that the index of complexity of the economy of a focal region is a significant variable in contrast to other regional variables. However, the impact of economic complexity is limited. First, the complexity of the economies of other regions does not significantly affect the likelihood of bankruptcy. Second, adding this variable does not significantly improve the forecast quality.

Variables characterizing the level of complexity of an economy are often significant at the p=.10 level. This is one of the limitations of this study. Another limitation is the presence of industry specifics. Research should be done for each industry separately. Finally, the COVID-19 epidemic has caused serious difficulties for many industrial enterprises. It is advisable to conduct research on the data of the current economic crisis.

Overall conclusion

One of the key trends in the world economy is the growing importance of knowledge as a factor of production. This leads not only to an increase in the amount of knowledge available. Knowledge is shared among many participants; one firm, even a very large one, is not able to physically master all the knowledge available and necessary to it. This leads to an increase in the need for cooperation between economic agents. Since cooperation largely depends on the territorial proximity of the participants, the role of the region as a place of presence of the owners of the necessary knowledge, the necessary technological capabilities increases many times over. Therefore, even when analyzing economic problems at the firm level, regional parameters must be taken into account.

This dissertation research examines the problem of the influence of the regional economic complexity on sustainability of firms and regions in the context of the economic crisis. The thesis consists of three chapters. Chapter 1 is devoted to the detailed analysis of the economic complexity as scientific concept, approaches to the calculation of the index of economic complexity, reviewing of research and evaluation of the relationship of economic complexity index and development of Russian regions.

There are still a few studies that look at the complexity of the region's economy. Accordingly, a generally accepted approach to calculating the index of the complexity of the economy at the regional level has not yet been developed. The dissertation proposes an adaptation of the approach, described in Tacchella et. al (2012), which allows calculating the index based on publicly available statistics. The calculation results confirm the correctness of the approach: the ranks of the regions are stable and correspond to their economic importance (see Table 1.2). Since the regions are closely interconnected, spatial econometrics is applied for econometric analysis. As a rule, researchers consider only direct links, although the need to take into account the indirect influence of other regions is said in a number of papers (Basile et al., 2019; Pintar and Scherngell, 2018). In particular, it makes it possible to take into account the

influence of the complexity of the economy of neighboring regions on the development of a focal region, and for a number of dependent variables the influence of the complexity of the economy of other regions turns out to be significant. In addition, hypotheses are formulated about the nonlinear influence of the complexity of the economy, a number of which are also confirmed. There are very few scientific papers analyzing the impact of the complexity of the economy in the context of the economic crisis due to the relative rarity of this event (due to the COVID-19 crisis, there will be much more research papers). Our results show that the impact of the complexity of the economy in the context of the economic crisis is more pronounced.

Chapters 2 and 3 examine the impact of economic complexity on firm performance and the likelihood of bankruptcy. The impact of the complexity of the economy at the micro level is limited: the company's profitability does not depend on the complexity of the regional economy, the asset turnover depends negatively. At the same time, during the economic crisis, this relationship increases. The likelihood of bankruptcy of a company also depends on the level of complexity of the economy, but not linearly. Companies from regions with the least and most complex economies are showing the greatest resistance to the crisis.

Firm-level results should be viewed with caution, as economic complexity variables are often significant at the p=0.1. At the same time, the result may vary depending on the sample structure, namely, analysis at the level of a particular industry shows the insignificance of the economy complexity index. This necessitates further research to verify the results at the industry level. It is advisable to conduct an analysis at the regional level of other countries, since country-level factors can have a decisive influence on the significance of the complexity of the economy.

The results of the dissertation research can be used in the development of models for the analysis of the sustainability of small and medium-sized enterprises. The complexity of the economy is a significant factor of the probability of company’s bankruptcy, in contrast to a number of other regional variables, since it reflects the fundamental economic capacity of the

region. Also when choosing a location region, it is necessary to explore the long-term trends of its development, consider impact of adjacent regions through the economic complexity index.

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Appendix 1

Correlation matrix of independent variables

	CAPL	CAPLBORDER	HE	PE	RISK	PRMRGRP	FUELGRP	NONFUELGRP	CITY	RDGRP	LNPOP	LNEMP	PATMA	APPMA	LNMSALARY	ECI	EFINDEX	WECI
CAPL	1.00																	
CAPLBORDER		1.00																
HE	.69		1.00															
PE		.32		1.00														
RISK					1.00													
PRMRGRP						1.00												
FUELGRP						.93	1.00											
NONFUELGRP						.32		1.00										
CITY	.46		.38			.24	.24		1.00									
RDGRP	.36		.41		.29	-.27	-.24		.40	1.00								
LNPOP	.41		.37		.25					.45	1.00							
LNEMP	.43		.40		.26				.30	.48	.99	1.00						
PATMA	.72		.61			-.27			.42	.48	.55	.57	1.00					
APPMA	.70		.60			-.28	-.24		.35	.46	.53	.54	.97	1.00				
LNMSALARY	.31		.35			.59	.53	.25	.68						1.00			
ECI	.29	.31		.29	.43	-.38	-.29	-.28	.28	.57	.57	.59	.53	.50		1.00		
EFINDEX					.39				.38	.35	.43	.47	.24			.57	1.00	
WECI		.43			.54	-.47	-.39	-.28		.32			.37	.37	-.39	.61	.32	1.00

Only coefficients, which are significant on p=.05 are shown.

Appendix 2

Table A2.1

Spatial Regression Models for 2005-2016

	Dependent variable									
	IA	IP	IE	INV	GRP_GR	GRP_CAP	INCM	GINI	IND	PVRT
HE	-.028 (.038)	-.0417 (.072)	-.0306 (.0212)	-.009 (.006)	-.00002 (.001)	.001* (.001)	-.006*** (.001)	-.0004** (.0001)	-.06*** (.022)	.118*** (.042)
PRMRGRP	-1.187 (1.795)	30.33*** (3.39)	2.626*** (.988)	.664** (.306)	-.258*** (.057)	-.191*** (.057)	.048 (.075)	-.005 (.008)	-1.268 (.937)	-.464 (1.966)
LNEMP	6.095*** (2.031)	-.281 (4.401)	5.920*** (1.987)	-.649* (.377)	-.403** (.073)	-1.141*** (.074)	-.172* (.097)	.018* (.011)	.808 (1.212)	3908. (2.545)
PATMA	5.588*** (2.154)	3.132 (4.102)	1.490 (1.194)	.380 (.369)	-.082 (.068)	.040 (.069)	-.032 (.091)	.008 (.011)	3.122*** (1.131)	9.158*** (2.375)
LNMSALARY	5.207*** (1.322)	3.912* (2.467)	.483 (.732)	-.520** (.226)	-.157*** (.042)	.032 (.042)	-.090* (.056)	.007 (.006)	.801 (.693)	2.386* (1.455)
EFINDEX	-.356 (.338)	-1.474** (.645)	-.262 (0.188)	-.0152*** (.058)	.005 (.0122)	-.029*** (.011)	-.040*** (.014)	-.004** (.0012)	-.242 (.178)	1.496*** (.373)
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
N	612	612	612	612	612	612	612	612	612	612
Spatial (Rho=0)	.34** (.151)	-.463* (.246)	-.558** (.254)	.215 (.170)	-.094 (.167)	-.074 (.199)	.103 (.185)	.119 (.184)	.067 (.189)	-.655** (.231)
R^2 (within)	.07	.19	.14	.433	.62	.63	.79	.68	.61	.59
Hausman test	10.95	33.25***	22.16*	18.21	39.72***	16.75	14.27**	17.51	17.1	46.3***

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses.

Table A2.2

Spatial Regression Models for 2005-2019

	Dependent variable									
	IA_RU	IP_RU	IE_RU	INV	GRP_RU	GRP_CAPAV	INCM	GINI	IND	PVRT
HE	-.00013 (.004)	-.011 (.009)	-.0163* (.008)	-.005 (.005)	-.00004 (.000)	.0112*** (.003)	-.006*** (.001)	- .0004** (.0001)	- .059*** (.0186)	.110*** (.036)
PRMRGRP	-.038 (.1553)	1.338*** (.376)	.582* (.338)	.263 (.222)	-.002* (.001)	-.829*** (.135)	.120** (.056)	-.002 (.006)	-.021 (.726)	-1.117 (1.405)
LNEMP	.985*** (.224)	.326 (.547)	2.980*** (.492)	-.349 (.325)	.0042** (.002)	1.008*** (.196)	-.0529 (.078)	.008 (.011)	1.005 (1.051)	2.254 (2.046)
PATMA	.591*** (.225)	.486 (.550)	1.328** (.494)	.165 (.326)	-.0023 (.002)	-.120 (.197)	-.0212 (.082)	.007 (.013)	2.001* (1.060)	5.840*** (2.054)
LNMSALARY	.522*** (.129)	.558* (.315)	-.053 (.283)	-.695*** (.187)	-.011*** (.001)	-1.069*** (.113)	-.120*** (.043)	-.004 (.005)	-.594 (.606)	4.577*** (1.184)
EFINDEX	-.0324 (.037)	-.104 (.090)	-.153* (0.081)	-.086* (.053)	-.0006** (.0003)	-.326*** (.032)	-.045*** (.012)	-.004** (.0014)	-.224 (.174)	1.639*** (.337)
Year fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
N	816	816	816	816	816	816	816	816	816	816
Spatial (Rho=0)	.367*** (.132)	-.299 (.199)	-.586*** (.215)	.102 (.157)	-.094 (.167)	.112 (.179)	.203 (.146)	.223 (.148)	.082 (.161)	-.364** (.183)
R^2 (within)	.06	.039	.106	.393	.129	.294	.818	.603	.535	.583
Hausman test	11.97	34.22**	29.46**	25.13	39.78***	44.14***	39.97**	10.51	21.8	48.8***

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses.

Table A2.3

Spatial Regression Models for economic crises periods

	Dependent variable									
	IA	IP	IE	INV	GRP_GRP	GRP_CAP	INCM	GINI	IND	PVRT
HE	-.002 (.059)	.076 (.116)	-.0262 (.0292)	-.008 (.009)	.0015 (.0017)	.0022 (.0017)	-.0042* (.0021)	-.00054* (.0002)	-.064 (.028)	.0967 (.0622)
EFINDEX	-.387 (.510)	.114 (.1.001)	.008 (.252)	-.191** (.078)	.0038 (.0152)	-.0328** (.0151)	-.0301* (.0184)	-.0044* (.0024)	-.302 (.249)	1.558*** (.534)
PRMRGRP	-.266 (2.599)	29.78*** (5.066)	-.633 (1.263)	.603 (.399)	-.332*** (.077)	-.196** (.077)	.0599 (.093)	-.002 (.012)	-1.190 (1.261)	.435 (2.706)
LNEMP	8.464*** (3.339)	-.157 (6.58)	6.28*** (1.65)	-1.259** (.517)	-.578*** (.100)	-.066 (.102)	-.299** (.122)	.006 (.016)	-0.683 (1.632)	8.001** (3.532)
PATMA	7.808** (3.916)	6.372 (7.666)	-.363 (1.927)	.867 (.602)	-.007 (.116)	.0066 (.117)	-.0210 (.0142)	-.017 (.018)	1.759 (1.908)	7.87 (4.11)
LNMSALARY	7.427*** (1.987)	1.334 (3.767)	1.503 (.976)	-.191 (.303)	-.091 (.0586)	.131 (.059)	-.167** (.072)	.006 (.009)	.454 (.960)	3.503* (2.069)
N	340	340	340	340	340	340	340	340	340	340
Year fixed effects	yes	Yes	yes	yes	yes	yes	Yes	yes	Yes	Yes
Spatial (Rho=0)	.316 (.214)	-0.411 (.325)	-.673* (.348)	.262 (.220)	.377* (.195)	-.105 (.269)	-.177 (.271)	.124 (.244)	-.005 (.265)	-.712** (.302)
R^2 (within)	.107	.187	.157	.319	.283	.243	.766	.680	.631	.57
Hausman test	11.97	24.22***	11.72	10.95	20.55**	11.62	11.73	8.04	8.79	31.25***

*** 0.01 level significance. ** 0.05 level significance. * 0.1 level significance. Standard errors are in parentheses.

Appendix 3

Correlation matrix of independent variables

	FIA	ARR	APR	WCCA	ER	LNEMP	LNMSALARY	RDGRP	IA	IE	ECI	W_ECI	LNTR	CAPL	CAPLBORDER
FIA	1.000														
ARR	0.027	1.000													
APR	0.037	0.479	1.000												
WCCA	0.065	-0.000	-0.39	1.000											
ER	0.078	-0.178	-0.377	0.656	1.000										
LNEMP	0.115	0.051	0.023	0.030	0.027	1.000									
LNMSALARY	0.155	0.082	0.066	0.067	0.059	0.753	1.000								
RDGRP	0.131	0.017	-0.009	0.070	0.037	0.546	0.512	1.0000							
IA	0.082	0.020	-0.008	0.037	0.058	0.319	0.296	0.233	1.000						
IE	-0.089	0.014	0.012	0.040	0.017	0.256	0.207	0.381	0.283	1.000					
ECI	0.092	0.042	-0.025	0.036	0.015	0.700	0.503	0.622	0.313	0.304	1.000				
W_ECI	-0.105	0.023	0.073	-0.072	-0.072	-0.247	-0.142	-0.371	-0.088	-0.319	-0.441	1.000			
LNTR	0.080	-0.085	-0.096	0.076	0.025	0.004	0.040	0.059	0.047	0.055	0.011	-0.044	1.000		
CAPL	0.121	0.027	0.023	0.078	0.097	0.559	0.685	0.348	0.502	0.098	0.411	-0.089	0.062	1.000	
CAPLBORDER	0.062	0.020	-0.012	0.053	-0.005	-0.051	0.099	0.251	-0.392	0.120	-0.239	0.458	-0.004	-0.256	1.000

Appendix 4

Correlation matrix of independent variables

	FIA	ARR	APR	ATR	WCCA	ER	LNTR	LNEMP	LNMSALARY	RDGRP	IA	ECI	W_ECI	CAPL	CAPLBORDER
FIA	1.000														
ARR	-0.030	1.000													
APR	-0.041	0.626	1.000												
ATR	-0.064	-0.028	-0.016	1.0000											
WCCA	0.133	0.002	-0.256	-0.1144	1.0000										
ER	0.126	-0.059	-0.052	-0.1863	0.6866	1.0000									
LNTR	0.294	-0.086	-0.268	-0.0498	0.1134	0.1417	1.0000								
LNEMP	0.054	-0.021	-0.040	0.0291	0.0812	0.0837	0.0031	1.0000							
LNMSALARY	0.048	-0.013	-0.024	0.0092	0.0817	0.0800	0.0322	0.8893	1.0000						
RDGRP	0.138	-0.046	-0.061	0.0531	0.0929	0.0739	0.1010	0.5060	0.4343	1.0000					
IA	0.048	0.004	-0.019	-0.0453	0.0612	0.0692	0.0573	0.5262	0.5376	0.3100	1.000				
ECI	0.044	-0.026	-0.120	0.0342	0.0240	0.0475	0.0680	0.5920	0.3778	0.6523	0.4214	1.000			
W_ECI	0.065	0.0410	-0.049	0.0410	0.0410	0.0292	-0.0316	0.4091	0.2174	0.3807	0.3030	0.5383	1.000		
CAPL	0.047	0.0011	-0.010	-0.0266	0.0719	0.0642	0.0211	0.7565	0.7788	0.4130	0.7597	0.4452	0.2116	1.000	
CAPLBORDER	0.058	0.0663	-0.027	0.0623	-0.0182	-0.0140	-0.0221	-0.0715	-0.0675	0.2395	-0.2361	0.2462	0.4235	-0.2535	1.000