International Journal of Economics and Financial Issues

ISSN: 2146-4138

available at http: www.econjournals.com

International Journal of Economics and Financial Issues, 2015, 5(4), 910-921.

Modeling Response to Innovations in Industrialized Regions: The Russian Experience

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ABSTRACT

The objective of the paper is to provide a rationale for mathematical models that describe a response to innovations (response to innovations) across industrialized regions of Russia. The paper gives an advanced analysis of trends in a development of industrialized regions. Based on the mentioned analysis, the authors have put forward and tested a number of hypotheses. There are the hypothesis for an unbalanced economic development in industrialized regions of various types, the hypothesis for development distinction, inherent to industrialized regions of certain types, the hypothesis for a catalytic role of the government in the innovation dynamics and the hypothesis for the available response to innovations in the economic system. The authors have proposed a methodology for the response to innovations, proved conditions, under which the response appears in the economic system, grounded types of the response to innovations. The authors have also presented mathematical formalization for mechanism for the response to innovations in the regional production system. In an action-oriented section of this paper, the authors have explored the response to innovations in industrialized regions of Russia. The findings given in the paper can be used to justify mechanisms of the regional industrial policy, as well as evaluate a regulatory impact of valid regulatory legal acts.

Keywords: Response to Innovations, Industrialized Regions, Functional Industrial Policy, Government Support Measures
JEL Classifications: C13, C33, C51

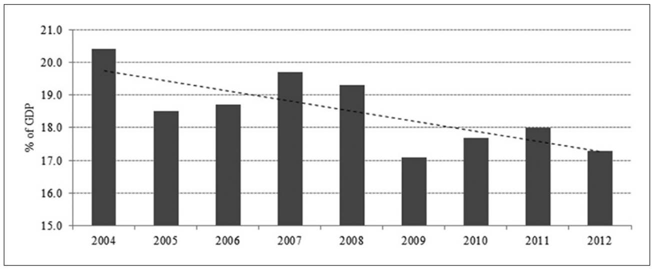
1. INTRODUCTION

Trends in the global economic development say that there are no alternatives to reindustrialization (Rodionova, 2009), a determinant vector of which is a development of high-tech manufacturing plants in national economies (Inozemtsev, 2011; Aiginger, 2007; Naude, 2010; Rodrik, 2006), and certain, first of all, industrialized, regions (Akberdina and Grebenkin, 2009; Romanova and Akberdina, 2013; Makarova and Korovin, 2014; Romanova et al., 2011; Steinmeier, 2012; Tregenna, 2011). Industrialized regions are a basis for a development of any national economy. It is in industrialized areas, where a transformation of the economy's technological structure, a change to paradigms, upgrades to manufacturing plants and consumption take place. The industrialized areas were among the first to enter a stage of an industrial development. Therefore, so far, many of them have had their poorly diversified business structures and specific internal territorial structures. Not all the industrialized regions are able and should become engines for the technological development. Some industrialized regions have experienced an objective process of de-industrialization associated with a significant decrease in a share of industry in gross regional product (GRP), turning into the economics of the consumer type. For other industrialized regions, the re-industrialization situation is typical. It relates to a change to a share of traditional industrial sectors with the simultaneous formation of the high-tech manufacturing sector.

Russia is one of the largest industrialized countries. In general, Russia has obviously faced a process of de-industrialization. It refers to a decrease in a share of manufacturing plants from 20.4% in 2004 to 17.3% in 2012 (Figure 1).

This process could be for sure considered in a theoretical context of the post-industrial economics (Galbraith, Bell, Toffler, etc.) or the Klark and Furaste's tartarisation concept (fr. – development

Figure 1: De-industrialization in Russian economics: Decline in share of manufacturing plants in gross domestic product



of the tertiary sector) apart from an extremely low production rate in the Russian production sector. Gurova and Ivanter say that there is a significant gap between Russia and (but not limited to) the leading industrial powers by output per capita. This index for Russia is $504, while for the USA it is 11 times as much, for Singapore and Japan it is 16 times as much, and it is also higher in China, Brazil, Greece, Thailand, Uruguay and other countries that have not been traditionally considered industrialized (Gurova and Ivanter, 2012). For a wide range of manufacturing activities, the Russian indices are also low, except for production of precious and non-ferrous metals. For the most of the other items, there is also a significant lag: Lagging in electric motor, generator and power convertor production is 2.6 times behind the USA, 5.2 times behind Germany, and 14.6 times behind Finland. Lagging in clothing sector is 5.9 times behind the USA, 4.4 times behind Germany, 16.4 times behind the South Korea and 2 times behind Brazil. As for reduction of goods in general engineering, lagging is 10.4 times behind the United States, 17.8 times behind Germany and 8.8 times behind the South Korea. As for pharmaceutical products and substances, lagging is 66 times behind the USA, 31.5 times behind Germany and 18 times behind the South Korea (Ibidem).

In this regard and applied to the local specifics, we consider an advanced analysis of de-industrialization and re-industrialization of particularly importance.

2. INFORMATION AND ANALYTIC FRAMEWORK

To identify specifics of de-industrialization and re-industrialization in the Russian regions, we have explored the regions, where a share of the manufacturing sector in the GRP was over 25%. A usage of the one-criterion method to determine whether a region is industrialized or not had been sufficiently substantiated in papers by the Council for Studies of Productive Forces (Granberg and Zaitseva, 2003), regulations issued by the RF Ministry of Regional Development, analytic and scientific sources (Golubitskaya, 2003; Industrial Frame of Russia, 2012).

In this research, as a criterion to include a region into industrialized areas, we have intentionally denied a share of all the industry in the GRP, as in this case, a number of industrialized regions would by default include raw-material-producing regions with the high share of extractive industries (the Russian north and northeast). Using the more rigid criteria to include regions into a group of the industrialized regions allows us choosing only those, where it is possible to open high-tech plants with the significant added value.

A research across the Russian regions covered the period of 2004-2012. To make an analysis for the time before 2004 is difficult as statisticians only began to identify the share of the manufacture in statistics after Russia's move to the European system of statistic records in 2004.

In a spatial aspect, the de-industrialization in Russia in 2004/2012 was unbalanced. Thus, if in 2004, there had been 18 industrialized regions, then by 2012, there were already 20. Today, we can build the following rating of the Russian industrialized regions (Figure 2). The following regions have the highest share of manufactures in GRP: The Kaluga Oblast (40.2%), the Omsk Oblast (38.6%) and the Republic of Bashkortostan (37.2%). The Chuvash Republic has the lowest value of this index among the industrialized regions (26.3%), so do the Kirov Oblast (25.5%) and the Samara Oblast (25.0%).

At the same time, there have been significant changes to a composition of the industrialized regions.

In the reporting period, four regions traditionally considered industrialiser, lost their industrialiser status. There are the Moscow Oblast (decrease in a share of manufactures in GRP from 27.4% in 2004 to 17.8% in 2012), the Ivanovo Oblast (decrease from 28.1% to 19.6%), the Leningrad Oblast (decrease from 31.9% to 22.8%) and the Ulyanovsk Oblast (decrease from 25.7% to 22.1%). The de-industrialization across these regions was accompanied with a significant increase in the service sector with a simultaneous economic growth, improved quality of life and investment revitalization. That is, the de-industrialization may be called optimization of the manufacture share. The experience of these regions evidences that the de-industrialization may occur against a background of the increased productivity, on the one hand, and measures to make an extensive infrastructure of services in field of logistics, product promotion, innovative service and brand-making, on the other hand.

Another four regions traditionally considered industrialiser, in the reporting period reinforced their standing as manufactures in the regional gross value added. There are the Kaluga Oblast (share growth from 28.4% to 40.2%), the Republic of Bashkortostan (share growth from 29.6% to 37.2%), the Novgorod Oblast (share growth from 33.2% to 35.8%) and the Tula Oblast (share growth from 33.9% to 34.1%). Large-scale investment projects to upgrade traditional sectors, as well as open new enterprises became a reason to say of the new industrialization in these subjects of the Federation.

In 2004/2012, six new industrialized regions appeared as the share of manufacture plants in GRP had increased. They are the Perm Territory (increase from 24.8% to 31.4%), the Republic of Mari El (increase from 20.8% to 29.8%), the Volgograd Oblast (increase from 20.6% to 26.6%), the Kirov Oblast (increase from 22.2% to 25.5%), the Chuvash Republic (increase from 23.4% to 26.3%) and the Ryazan Oblast (increase from 23.6% to 26.6%). The

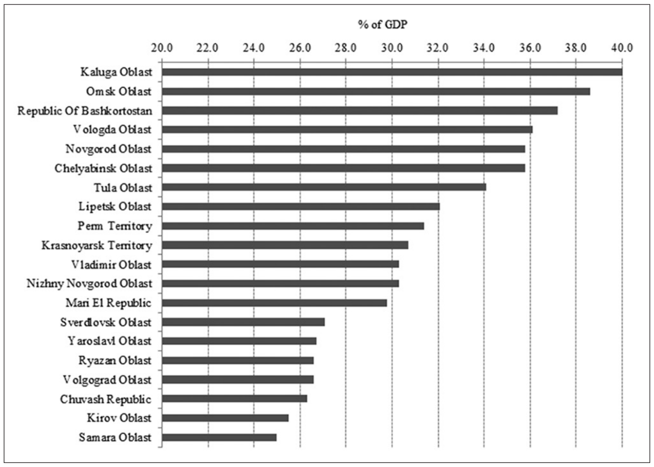


Figure 2: Rating of industrialized Russian regions by manufacture plants' share in GDP 2012

increasing importance of the manufacturing sector in economics of those regions has been mainly due to an implementation of large-scale investment projects.

Finally, the development of the most of the regions traditionally considered industrialized is accompanied with the negative de-industrialization. There are the Lipetsk Oblast (decline from 63.2% to 32.1%), the Krasnoyarsk Territory (decline from 47.8% to 30.7%), the Omsk Oblast (decline from 53.1% to 38.6%), the Yaroslavl Oblast (decline from 36.6% to 26.7%), the Chelyabinsk Oblast (decline from 45.2% to 35.8%), the Vologda Oblast (decline from 45.4% to 36.1%), the Sverdlovsk Oblast (decline from 35.1% to 27.1%), the Samara Oblast (decline from 32.3% to 25.0%), the Vladimir Oblast (decline in a share of manufactures in GRP from 33.2% to 30.3%) and the Nizhny Novgorod Oblast (decline from 31.8% to 30.3%). So far, these early-industrialized regions have faced serious constraints for their further development, caused by abnormal multistructurality, understood as the simultaneous reproduction of multiple techno-economic paradigms, starting from the third and finishing with the fifth (Mezentseva et al., 2008).

To the most extent, structural and technological shifts in the economics of the early-industrialized regions took place spontaneously and were influenced by ongoing conjuncture changes. This led to an emergency with the plant-equipment ratio. A result was an imbalance, where low-tech and medium-tech energy-intensive and environmentally risky industries prevailed. Moreover, the simultaneous expanded reproduction of multiple techno-economic paradigms due to overall resource constraints has led to lower growth rates for each of them, including the fifth and the sixth one, and retardation in structural shifts.

Thus, the differentiation of the industrialized regions allows hypothesizing that not all the industrialized regions are able in the long term to be a driving force of an economic growth: Each industrialized region has its own development path in terms of its resource, structural and institutional capacity. Simulation of such individual development path may be based on models of the response to innovations.

3. MATERIALS AND METHODS

3.1. Methodology for Response to Innovations

To overcome the abnormal multistructurality and establish the high-tech sector in the industrialized regions, the authors have proposed the methodology for response to innovations, which refers to a phenomenon of an accelerated economic development within the economic system subject to the wave dynamics, caused by from-time-to-time changes to innovation-technology parameters at the expense of a catalytic mechanism built into the triad synergistic system of relations "science-government-business."

Formation of fundamental technologies for the new paradigm is a nonlinear process to restructure production chains from the previous stages (Yablonsky, 1986). At the same time, the economic growth is only understood as a consequence from the response to innovations, while a reason is a congruence between the influence intensity from certain actions by economic agents in a field of technological development and with the economic dynamics intensity.

Certain researchers have grounded the feasibility to apply the cross-functional logistic approach based on *S*-shaped curves to simulate the techno-economic dynamics. Yablonsky (1986) presented an opportunity to use *S*-shaped curves and equations of the Lotka-Volterra type to simulate processes of technological development. Experimental studies by Polterovich and Henkin (1988) showed that a diffusion process, presented with a share of output at a certain technological level, or a share of companies that have won the market of new products, is also described with the logistic curve or its modifications. Majewski (1997) offered to use the positive properties of the logistic curve to describe a life cycle of macro generations (product innovations in the USA economics that determine the GDP dynamics).

The technological dynamics may be described with the equation (1), where $Y(t)$ is a function that describes a result (an effect) of the innovative development; r is a value that describes a speed of the innovative development and is in charge of a slope of the *S*-shaped curve, P is a positive value that makes a top limit for the innovative development effect (the highest value for the $Y(t)$ function, potential) and C is a value that determines a shift of the *S*-shaped curve with respect to the horizontal axis.

$$Y(t) = \frac{P}{1 + Ce^{-rt}} \tag{1}$$

Figures 3 and 4 show plots of two functions and their derivatives before and after their bringing into the resonance. To identify the resonance conditions, we obviously need to define the t parameter, with which function derivatives achieve their peak at the same point and which is presented with C and r parameters (2).

$$\frac{-\ln \frac{1}{C_1}}{r_1} = \frac{-\ln \frac{1}{C_2}}{r_2} = t^* \tag{2}$$

Figure 3: Plots of functions $Y_1(t)$ and $Y_2(t)$ and their derivatives prior to functions' bringing into resonance

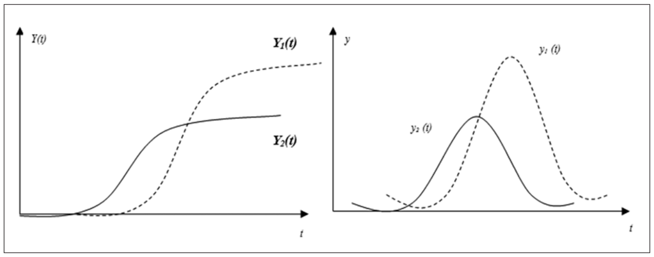
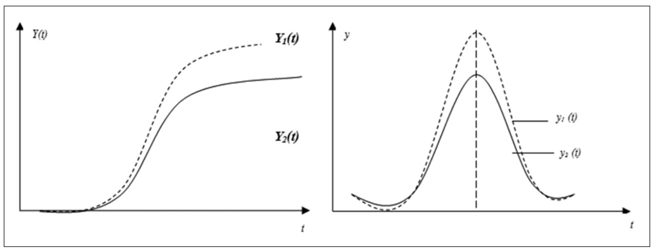


Figure 4: Plots of functions $Y_1(t)$ and $Y_2(t)$ and their derivatives after functions' bringing into resonance



It becomes clear that adjustments to the slope of the *S*-shaped curve (*r* parameter) and its shift with respect to the x-axis (*C* parameter) may lead to the resonance of functions (Skiba and Garkavy, 2011).

If a control over *r* parameter, in charge of a respond of the market demand for technological innovations, is rather difficult due to a lot of subjectivism demonstrated by the consumers, then *C* parameter, which describes the performance of public institutions in activities to create conditions for the distribution of innovations, may be referred to as a basic adjustable parameter to achieve the response to innovations (Romanova et al., 2010).

In the context of the response to innovations, the authors have explored the functional industrial policy (*C* parameter), a revival of which has been mentioned by numerous experts (Advances that Will Transform Life, Business, and the Global Economy, 2013; Toward knowledge-driven, 2013). In 2013, two key reports on the industrial policy were published. The first one is the OECD report "Revival of Proactive Industrial Policy: Pressing Challenges and New Trends." The second one is the report by the EU Commission "Towards knowledge-driven reindustrialization." They suggest a surge of interest in the industrial policy. The reason is that the new techno-economical paradigm, according to the experts, will not have become valid by 2030 (even in the developed countries), so there is a need in a further usage of the existing paradigm, which is in its turn only possible with the usage of efficient tools of the industrial policy.

Having explored a phenomenon of the response to innovations in terms of the above-mentioned definition, we have put forward additional hypotheses for conditions, under which the resonant response of the economic system to changes in technology appears: (1) The resonant response is manifested when the third element - a catalyst - appears in a triadic structure of relationships within the innovation system. As the catalyst, a support institute may act in a form of a special-purpose motivational mechanism made by business in a competitive environment or by the government; (2) the resonant response has a nature of a positive feedback of the innovation self-development up to saturation points (applied capacity) of the certain techno-economic system.

The theoretical research has proved that the response to innovations is parametric. Understanding the response as a phenomenon, which only appears when there is a rhythmic external influence upon an oscillating system and when frequencies of an external effect are the same with regard to the frequency of a system itself, was excluded. The reason is that under conditions of an open economic system, it is difficult to achieve a periodic external influence with a necessary rhythm, if not impossible, as the mentioned external influence relates to the economic policy pursued by entities that are beyond the system under consideration.

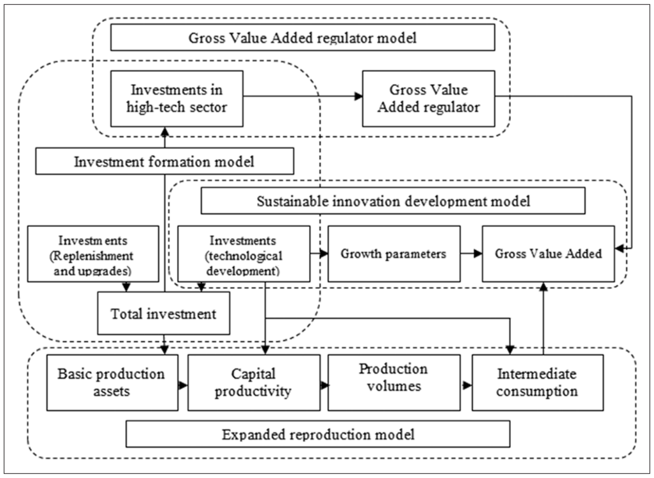
Besides, there is an objective understanding that any modulation to the *C* parameter (in this case, usage of functional industrial policy tools) is unable to "overbalance" the economic system that is at rest and in its equilibrium. To excite parametric response to innovations, the economic system should take its own fluctuations associated with conjuncture cycles, medium-term business cycles, and Kondratieff long waves. Thus, the response to innovations phenomenon, where a growth in the dynamics does not depend on an external influence, but parameters of the system itself, was proposed to be described with differential equations of the parametric respond within linear and nonlinear systems.

In case of the parametric respond, the system's equilibrium becomes unstable and a shift away from it has a nature of oscillations with a progressively increasing amplitude. In this regard, an important point is an analysis of thresholds and acceptable ranges, as well as conditions to absorb vibrations and damp down dynamically the negative economic dynamics, which might bring the system into a recession.

A design of a comprehensive mathematical model for high-quality resonant responses of the economic system to control influences was based on the innovation cycle "science-technology-market." In this regard, we may state that significant resonant responses appear at points of a transition from one field to another. In this regard, there are three types of resonant responses including scientific and technological, market and technology, and integrated.

A mechanism of the response to innovations within the regional industrial system is based on a combination and interaction of the government regulation, innovation business and its infrastructure, as well as fundamental and applied research in high technology. A main difficulty to design such a mechanism is to identify ways and tools to ensure the efficient implementation of scientific and technological programs to develop and master knowledge-driven and resource-saving technologies that make possible for industrial companies to carry out an economic production cycle in a mode of the advanced reproduction. In this regard, the response to innovations mechanism for the regional industrial system should include the following elements (Figure 5).

Figure 5: Math complex of economic system's mechanism of response to innovations



3.1.1. Model to configure investments by industries and replenishment sectors

Investment resources have two directions in their application: (1) Replenishment and upgrades to the fixed capital in the framework of existing technology to produce traditional products (*M*); (2) technological development in a form of R&D costs and related expenses to get fixed assets and technology (*R*). Thus, a volume of investments in the fixed capital is described with a sum of investment directions.

Consequently, two groups of investors appear including the conservatives and the innovators. At the same time, a change to a size of each sub-group may be either one-time, related to changes to output or a manufacturing process concerning one investor only, or repeated.

A parameter that describes investor's preferences should play an essential role in this model. Positive values of the parameter say that investors prefer a move to *M-type* investments, while negative values say of a transition to *R-type* investments. This parameter depends on time and is essential in making a cyclic behavior for the scientific and technological development mechanism. As an output variable, we will use an index value equal to a ratio of a difference of M-type and R-type investment volumes to their sum. It will be shown below that if certain reasonable assumptions come true, the dynamics of the investor's preferences coefficient and the index itself are exactly described with the system of two differential equations of the first order.

An outcome from the model includes defined volumes of investments by industries and reproductive sectors in the economy. Besides, an important result from the model will include the allocation of investment resources by directions, i.e. to maintain existing facilities and for the innovative development. Growth rates and R&D investment volumes define two essential parameters for the long-term innovative development, i.e. the return on assets ratio and the share of value added in the gross output.

3.1.2. Dynamic diversified (multi-sector) reproduction model

This model describes relationships that determine output and value added volumes by industry and reproductive sector. All calculations in the models are made within a chosen system of fixed prices (usually in prices of a year, in which planning takes place). The model includes two groups of relationships: Macroeconomic relationship to make scripts based on an analysis of the most common proportions, limitations and elasticities. The system of interbranch and balance relationships that provide consistent quantitative assessments for the dynamics and the production profile for a long term by industry as well as by reproductive sector.

3.1.3. Model of innovation self-development adaptive control within the regional industrial system

As any dynamic system, the regional industrial system is a structure with a feedback. In technical terms, it means that besides its executive core (innovative self-development process itself) and its management structure, there is a feedback mechanism. A purpose of this element includes worked out advice for the basic management layout based on estimated results and their comparison with expected figures.

Within the regional economy, the information got in such a way, mostly relates to strategic and tactical decisions in a field of investments into the high-tech industrial sector, costs for events to encourage scientific and technological progress, particularly the development and introduction of new technology and resource saving campaigns. Moreover, the feedback device makes it possible to receive regularly the data on the efficiency of made decisions and assess possible changes to them. If in this process there are only changes to values of the system parameters, then it is called a self-turning. At the same time, if new elements appear inside it or the old ones disappear, it is called self-organizing. With regard to the innovative development, we may point out that characteristics of an external environment and an object (region) are always not quite precisely predictable, and the uncertainty situation appears. In terms of the control theory, this means that the object and the environment parameters will face changes throughout the control process, therefore the device to control over the innovative self-development should be able to achieve three objectives: (1) Monitor an object to identify (find) changes to its parameters; (2) make a synthesis for the regulator's performance algorithm under certain values for the parameters to ensure a required system performance; (3) design the regulator that implements the synthesized algorithm (Bagrinovsky, 1999).

In terms of technology, these tasks should be automatically solved, without human's intervention. In other words, if parameters of an object did not become known in advance, but are stable, then the tasks are performed as early as at a design stage. At the same time, if its characteristics vary in time, tasks should be solved in conditions and with a performance rhythm natural for an object. This means that the regulator's algorithm has quickly to transform itself in time of the system functioning with adjustments (self-setting, adaptation) to the changing environment and object parameters so, that the performance of the latter remained unchanged (Adaptive Systems and their Applications, 1978).

3.1.4. Model of sustainable innovation dynamics of extended reproduction

The model of sustainable innovation dynamics and extended reproduction is intended to assess the sustainability of the innovative development in the economic system. It is known that a stable equilibrium is impossible for economic systems and their standard condition refers to a dynamic balance. A move from one equilibrium condition to another never occurs instantly. Any exogenous shock generates a chain of events that ultimately and exclusively leads to an established new dynamic equilibrium. Research in a course of their development may alone help to understand a scenario for future events.

Such is the methodological approach logic in the mathematical complex for the mechanism of response to innovations in the economic system.

3.2. Mathematical Formalization for Model of Response to Innovations

3.2.1. Model to make investment volumes by industries

As we have already mentioned, investment resources have two directions of their application: (i) Replenishment and upgrades to the fixed assets in the framework of existing technology to produce traditional output (*Mt*), (ii) technological development in a form of R&D costs and related expenses to have fixed assets and technologies (*Rt*). The volume of investments into the fixed capital is thus described as a sum of investment patterns:

$$I_t = M_t + R_t \tag{3}$$

A source of investments into the fixed assets is net incomes of economic agents for a previous period. At the macro level, they make the gross value added (*Yt*). Let us introduce the parameter that describes a share of investments in the gross value added – γ_i and get an equation for investments:

$$I_t = M_t + R_t = \gamma_1 Y_{t-1} + \gamma_2 Y_{t-1} \tag{4}$$

It is clear that proportions of such an allocation influence values of investments allocated for various purposes, which ultimately affects a value of gross outputs ($V_{i,t}$) and the gross value added (Y_t).

It is profitable for manufacturers to increase their production capacities for consumer goods or manufacturing facilities depending on market prices, which say them of patterns for future investments (γ_1 and γ_2), thereby raising their profit. As an indicator of the investor's preferred activities there may be a ratio of a difference between amounts of M-type and R-type investments to their sum.

$$\begin{cases} I_t = M_t + R_t, \\ k = \dfrac{M_t - R_t}{M_t + R_t} \end{cases} \tag{5}$$

Having solved this system of equations, we get:

$$M_t = \frac{(1+k)\cdot I_t}{2}; R_t = \frac{(1-k)\cdot I_t}{2} \tag{6}$$

3.2.2. Multi-sector dynamic reproduction model

The dynamics of changes to principal production assets for each time period is calculated in terms of their retirement and investments from various sources allocated for their replenishment and upgrades. The embodiment of these investments takes place in view of a time lag as follows:

$$F_{j,t} = (1-\alpha)\cdot F_{j,t-1} + l\cdot(M_{ij,t} + R_{ij,t}) + (1-l)\cdot(M_{ij,t} + R_{ij,t}); j = (1,\ldots,n) \tag{7}$$

where α – is the asset retirement rate; l – is the time lag factor.

The calculation involves either activities or four reproductive sectors (consumer, high-tech, traditional and infrastructure sectors).

To find volumes of gross outputs produced per activity and reproduction sector, we will use the return on assets ratio, which is, in turn, influenced by R_t in each sector:

$$V_{j,t} = f_{j,t} F_{j,t} \tag{8}$$

where f_j – is the return on assets ratio in each industry or reproduction sector.

The return on assets ratios are found in terms of aging equipment and investments allocated for plant's technological development:

$$f_{j,t} = f_{j,t-1}\cdot(1-\mu)\cdot(1+\frac{\beta\cdot R_t}{M_t + R_t}) \tag{9}$$

where μ – is the equipment aging rate, β – is the coefficient that describes an impact of an innovation component in investments upon the return on assets.

Volumes of the gross added value will be found based on the intermediate consumption, also influenced by R_t:

$$Y_{j,t} = (1-s)_{j,t}\cdot V_{j,t}, \tag{10}$$

where s_j – is a share of the intermediate consumption in an output in each industry or reproduction sector.

In such a way, the GRP will be found in compliance with the formula as follows:

$$Y_t = \sum_{j=1}^{n}(1-s)_{j,t}\times\left[f_{j,t-1}(1-\mu)(1+\frac{\beta\cdot\gamma_2 Y_{t-1}}{\gamma_1 Y_{t-1}+\gamma_2 Y_{t-1}})\right]\cdot \left[(1-\alpha)F_{j,t-1} + l(\gamma_1 Y_{t-1}+\gamma_2 Y_{t-1}) + (1-l)(\gamma_1 Y_{t-1}+\gamma_2 Y_{t-1})\right] \tag{11}$$

Key indices of the techno-economic development include the growth rates for the GDP (GRP) and industrial production indices:

$$g_j = \frac{V_t}{V_{t-1}}, \tag{12}$$

$$G = \frac{Y_t}{Y_{t-1}} \quad (13)$$

The formula (11) says that the growth rate of GDP (GRP) essentially depends on the following parameters: the growth rate of investment by industry (reproductive sector); targets for investments, first of all, investments for innovations; fixed assets retirement rates; return on assets ratios; a share of the intermediate consumption in the output; investment time lag.

3.2.3. Innovation self-turning adaptive control model

Let us refer a purpose of the adaptive control in innovation development to ensuring that the economic system is able to function efficiently in ever-emerging new conditions caused by the response to innovations. A feedback device is usually called a regulator, a set of a controlled object, a direct feedback control device and a regulator make a principal control circuit and the control process supported by the feedback is called a regulator's performance algorithm (Saradis, 1980). The most common way to use the information in the feedback circuit is a scheme of inflexible control, in which each piece of advice to change decisions directly depends on deviations of actual results from the expected results using fixed coefficients (feedback parameters). The usage of this scheme is quite useful if conditions of the environment and an object itself remain stable or have predictable small changes when a situation is quite known.

Let us build the adaptive control model for the innovation development of the economic system. Let us assume that at any time *t*, the regional system has the following features: F_t is a value of principal fixed assets; Y_t is the gross domestic product (a sum of values added by reproductive sector) and I_t is investments into the fixed assets.

Let us assume the following as principal ratios for the system's dynamics:

$$Y_t = f \cdot F_t, \quad (14)$$

$$F_t = (1-\alpha) \cdot F_{t-1} + I_t, \quad (15)$$

where *f* – is the return on assets coefficient per value added, while *α* – is the retirement rate for assets.

Here, I_t is a control action that influences a course of a process, that is a regulator's algorithm. Assume that a purpose of control is an achieved reference value for GDP (GRP) at *C* level. Then, under conditions of the comprehensive certainty, the regulator's performance algorithm is as follows:

$$I_t = f^{-1} \cdot (C - f \cdot (1-\alpha) \cdot F_{t-1}) \quad (16)$$

In the business practice, many factors that influence parameters *f* and *α* are either unavailable for a direct measurement, or unalterably vary in time (like the return on assets may change with a transition to the new equipment). In this regard, let us take the following definition: the control process is called self-organizing, if a decrease in a priori uncertainties, leading to the efficient control, is achieved owing to the information obtained in the control process from successive observations of available input and output signals (Bagrinovsky, 1999). The self-organization is achieved with: (a) a decrease in a degree of the uncertainty in the described dynamics of an object (parameter adaptation self-organizing process); (b) decreased uncertainty directly associated with the improved system quality (functional-adaptive self-organizing process). At the same time, to evaluate the performance, a control unit and a corresponding unit directly use the information from an object of control. Next, let us take that values *Y*, *F* and *I* are always available for measurements and parameters are defined from measured input and output variables.

In such a way, the principal control unit performs the following functions: A preliminary assessment of the economic efficiency of investments into high-tech; the assessment of a high-tech sector contribution into GDP (GRP); the updated assessment of the economic efficiency in terms of local incentive methods; the system (synergistic) assessment of the high-tech sector performance.

Thus, the adaptive regulator always appears when you need to maintain strictly a figure of an output value in terms of the unpredictable environment. In this case, the feedback circuit usually has time lags, which technical devices simulate with inertial units. The process itself to achieve an expected signal has a nature of the asymptotic approximation and is extended in time.

As there are mainly qualitative changes to the economic dynamics, while the information comes in quite an aggregated form, it is advisable to use built-in controls according to Bagrinovsky (1999). There are a lower interest rate on bank loans in a need in additional investments increase; lower VAT rate in case of a need in additional supplies of raw materials; higher VAT rate for goods in high demand; lower payments on shares, etc.

However, in economic processes, especially those of an innovative character, a response to a deviation (if any) is usually slow and stretched for long. Here natural market processes should have an important role: the profitable production or an investment direction attracts investors; the competition reduces the profitability making us look for new directions for profitable investment.

3.2.4. Model of the innovation dynamics sustainability and extended reproduction

It has been already mentioned that an impetus for the economic system development is the innovative dynamics, which quantitative characteristics include the R&D costs, their structure and sources of funding, as well as a ratio to the gross value added.

Let us building a model of the innovation dynamics sustainability and extended reproduction, a starting assumption for which there is a continuum of financial flows and flows of innovative products. The flowchart design is based on an initial flow of R&D costs making new or improving an existing production process, as a result, this generates a material flow of the innovative products. At the same time, this generates a cash flow from innovative activities, i.e. the innovation profit, defined as a difference between the innovative revenue and costs for production of innovative products. Taking into account a calculation of the gross value added by primary income, among which the profit is a leader, we may say of a contribution of the innovation process in the expanded reproduction. At the same time, this very profit is a source to fund new R&D.

Thus, a closed algorithm of a mutual influence between the R&D costs and a growth in the gross value added, when the gross value added is decreased by an amount of R&D costs, and they, in turn, serve as a source of a profit growth and thus the value added. In this process, the innovation development takes place, as well as a change to techno-economic paradigms.

To get a quantitative description of the process, let us specify the notations used above and introduce a number of new designators:

R_n – costs for research and development in the *n*-th year, R_{n+1} – costs for research and development in the *n+1*-th year, R_{max} – the highest possible value of costs for research and development within the economic system and dependant on market constraints.

Y_n – gross value added (GDP or GRP) in the *n*-th year, Y_{n+1} – gross value added in the *n + 1*-th year, Y_{max} – the highest possible value of the gross value added in the economic system, dependant on market constraints.

d_n – share of profit from the innovative products in the gross value added in the *n*-th year, d_{n+1} – share of profit from the innovative products in the gross value added in the *n + 1*-th year, where (dY_n) is the innovative profit.

P_n – the innovative profit in *n*-th year, P_{n+1} – the innovative profit in the *n + 1*-th year, P_{max} – the highest possible value of the innovation profit in the economic system dependant on market constraints.

g_Y – growth parameter for the gross value added.

g_R – growth parameter for R&D costs.

k_Y – specific value added per unit of the innovative products.

k_R – costs per unit for R&D per unit of the innovative products.

m – transformation ratio of value added in a new flow of R&D costs.

The increase in gross value added is described as $\frac{Y_{n+1}-Y_n}{Y_n}$ and with a growth in the value added and its value, approached Y_{max}, an increase for each successive period should be reduced. The dynamics of the gross value added then is presented as follows:

$$Y_{n+1} = Y_n + Y_n \cdot g_Y \cdot (1 - \frac{Y_n}{Y_{max}}) \tag{17}$$

However, within the gross value added there is a source of R&D costs, the innovative profit. In this regard, the innovative profit dynamics looks like the following:

$$P_{n+1} = d_{n+1}Y_{n+1} = d_nY_n + d_nY_n \cdot g_Y \cdot (1 - \frac{d_nY_n}{d_nY_{max}}) \tag{18}$$

Obviously, a part of the added value allocated to funding expenditures for R&D will depend on a ratio of specific values $\frac{k_R}{k_Y}$ and the ratio, with which the value added transforms into a new flow of R&D costs *(m)*. Then, the equation to make changes to the gross value added will look like the following:

$$Y_{n+1} = Y_n + Y_n \cdot g_Y \cdot (1 - \frac{Y_n}{Y_{max}}) - m \cdot \frac{k_R}{k_Y} \cdot R_n \tag{19}$$

The equation for a change to R&D costs will derive in the same way, understanding that the highest value of costs R_{max} depends on the volume of the gross value added in the economic system at any given time with due regard to specific values and the transformation ratio:

$$R_{max} = Y_n \cdot \frac{k_Y}{k_R \cdot m} \tag{20}$$

Then, for the R&D costs, we get the following equation:

$$R_{n+1} = R_n + R_n \cdot g_R \cdot \left(\frac{Y_n \cdot \frac{k_Y}{k_R \cdot m} - R_n}{Y_n \cdot \frac{k_Y}{k_R \cdot m}} \right) = R_n + R_n \cdot g_R \cdot \left(1 - \frac{m \cdot \frac{k_R}{k_Y} \cdot R_n}{Y_n} \right) \tag{21}$$

4. PARAMETERS OF THE RESPONSE TO INNOVATIONS IN THE INDUSTRIALIZED REGIONS OF RUSSIA

To understand the economic resonance and the consolidation of competitive advantages for the industrialized regions, an analysis of innovation dynamics patterns is of great interest. Thus, in a research of the plant-equipment ratio of the industrialized regions of Russia, we have identified certain regularities in a change to technology behaviors at a regional level, some of which can be considered impulses of the response to innovations. In particular, the matter is that the change to the techno-economic paradigm and, consequently, the response to innovations, begins in the structure of R&D costs, and only after a change to a direction of innovations, there is a change to the output structure and GRP. The capacity and prospects of the techno-economic paradigm are to the greatest extent presented with a structure of the innovation product output. All this describes inherent natural oscillations within the economic system associated with the *r* parameter in the formula (1). At the same time, as we have mentioned above, the *C* parameter modulation in the formula (1), in charge of government support measures, causes a shift of the curve and the resonance of functions. Under the concept of area self-development (Tatarkin, 2011; Tatarkin, 2013). We have only reviewed regional government support measures and corresponding costs from consolidated budgets of subjects of the Russian Federation.

An analysis of available support measures in the industrialized regions of Russia has showed that a standard unit of measures (tax exemptions, guarantees and warranties, subsidies for loan interest rates and lease payments, subsidies for costs for engineering infrastructure, special-purpose economic zones, technology parks and tech clusters, support to small and medium-sized manufacturing businesses, etc.) was codified by each industrialized region (Annex A). Despite this, some industrialized regions have faced severe de-industrialization challenges, mentioned above, while the others worked on a rapid development and consolidation of positions for the industrial complex in the economics.

We believe that the matter is not so much which regulatory support measures were codified, as how much funds a regional budget allocates to implement these mentioned support measures. The research has showed that the costs of regional budgets in the new industrialized areas and regions, that consolidated their industrial status, are 1.5 times higher than in the industrialized regions, in which the share of industry has been in a rapid fall (Annex B). Thus, if in the new industrialized regions, average regional budget expenditures are $ 1.3 thousand per 1 million of the industrial output, then in the de-industrialized regions, the index is $ 0.9 thousand. This particular factor causes the congruence between the dynamics of economic and innovation development and an occurrence of the response to innovations in the new industrialized regions, as a ratio of investments and R&D expenditures to GRP for all the industrialized regions is about the same (Annex B).

Thus, available codified support measures are not a guarantee for the accelerated industrial development. At the same time, government expenditures for the industry development are not a panacea. The government expenditures are a momentum only that attracts private investments, reduces risks and increases the local competitiveness. Thus, according to the "Expert" rating agents, the investment risks are essentially lower in the new industrialized regions and regions with recently consolidated industrial status.

For the de-industrialized regions, the only index that says of an available actual capacity for new industrialization is the GRP research intensity index (ratio of R&D to GRP, %). Among the de-industrialized regions, there are those clearly identified regions, for which this index is over 1%. There are the Nizhny Novgorod Oblast (4.4%), the Samara Oblast (2.0%), the Yaroslavl Oblast (1.4%), the Chelyabinsk Oblast (1.4 %), the Sverdlovsk Oblast (1.4%) and the Vladimir Oblast (1.3%).

Thus, the hypothesis was confirmed for a catalytic role of the government support for the response to innovations, leading to the congruence between the economic and innovation dynamics. In those regions, where there is a high level of public expenses per 1 million of the industrial output, the annual average industrial production index (IPI) is significantly higher. In such a way, in a group of regions that have consolidated their industrial status, the annual average IPI is 113%; in the new industrialized areas, it is 109%, while in the de-industrialized regions, it is 106%.

5. CONCLUSION

The research has proved that the response to innovations is a quantitative entity in the innovation dynamics. Such the response to innovations is understood in terms of the synergistic approach and presents non-linear relationship between non-equilibrium processes of a capital renewal, changes to technology and a social and economic growth in economic systems. The suggested hypotheses for an existence of this phenomenon have been proven using mathematical models.

In the paper, the industrialized Russian regions have been explored. They are a foundation of the national economy development. So far, one third of the total manufacturing output in Russia has fallen to the share of 20 industrialized regions. It is within the industrialized areas, where a transformation of the economy plant-equipment ratio has taken place, as well as a change to behaviors and upgrades in production and consumption. The research showed that the Russian industrial complex has quite a high potential for innovations, but there is a significant range of indices for the innovation dynamics of the capacity by various regions, hence, the hypothesis for the uneven economic development in the industrialized areas of different types has been empirically proven. An analysis of the development capacity for various industrialized regions has confirmed the hypothesis for a need in a design of an individual development path for regions of certain types.

In terms of the response's capacity and the accumulated economic and innovation dynamics, a part of regions should in their development follow the new industrialization vector, the second part of them will choose update and maintenance strategy for traditional industries, while the third group of the industrialized regions will objectively turn into service and consumption areas. At the same time, it should be emphasized that local initiatives to implement any option or a combination of them are not sufficient to solve challenges that come from areas' restructuring. The most important catalyst for the response to innovations should be the functional industrial policy held by regions, when the approaches to evaluate its performance are grounded on an empirical analysis. This paper starts a series of papers on the response to innovations. In further research, the functioning of the modeling complex will be confirmed with both the historical data, and the simulations.

6. ACKNOWLEDGMENTS

This paper was prepared with the financial support from the RFBR's grant № 15-06-08375a, "Flow Modelling in Business Ecosystem of Centre Subregion."

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ANNEX A

Table A1: Regional measures of government support in some industrialized regions of Russia

Government support measures	Regions that have consolidated their industrialized status			New industrialized regions		Regions that traditionally considered industrialized and that faced negative de-industrialization						
	Kaluga Oblast	Republic of Bashkortostan	Tula Oblast	Mari El Republic	Kirov Oblast	Lipetsk Oblast	Krasnoyarsk Oblast	Chelyabinsk Oblast	Vologda Oblast	Sverdlovsk Oblast	Samara Oblast	Nizhny Novgorod Oblast
Land tax												
Property tax exemptions	+		+	+	+	+	+	+	+	+	+	+
Income tax exemptions	+		+	+	+	+	+		+	+	+	+
Transport tax exemptions				+		+			+	+		
Subsidies for leasing payments	+		+		+	+	+	+	+	+	+	+
Guarantees for leasing							+	+	+		+	
Giving public property on lease											+	
Guarantees for loans	+		+	+	+	+	+	+	+	+	+	+
Subsidies for loan interest rate	+	+	+	+		+	+	+	+	+	+	+
Privileged investment loans										+		
Guarantees			+				+	+		+	+	
Grants to small businesses	+	+	+	+		+	+	+	+	+	+	+
Loans to small businesses	+		+	+	+		+	+	+	+		
Subsidies for connection	+		+			+						
Incubation services			+	+	+			+	+	+		
Giving public property for rent				+	+							+
Industrial parks and tech clusters			+	+	+					+	+	
Energy efficiency						+					+	
Subsidies for localization						+					+	
Subsidies for power consumption						+			+			
Subsidies for professional development			+			+			+		+	
Soc. entrepreneurship			+		+	+			+	+		
Equity participation in authorized capital			+				+				+	
Venture financing	+									+	+	
Subsidies for international standardization						+			+			
Subsidies for innovations	+			+		+		+		+	+	
Grants for promotion	+		+		+	+		+				+

ANNEX B

Table B1: Certain indices that describe industrialized regions of Russia, 2013

Subject of federation	Subsidies from regional budget per $1 million of industrial output, thousand US dollars	Investments into fixed assets, in % of GRP	R&D Volume, in % of GRP	Average industrial production index for 2010/2013, %
Regions that have consolidated their industrialized status				
Kaluga Oblast	0.82	33.3	2.79	119.3
Republic of Bashkortostan	0.75	20.2	0.61	107.5
Novgorod Oblast	1.72	26.1	0.68	110.0
Tula Oblast	1.01	27.2	0.79	114.1
New industrialized regions				
Perm Oblast	0.55	18.1	1.20	111.2
Mari El Republic	1.50	26.9	0.15	110.1
Volgograd Oblast	0.78	23.7	0.80	105.2
Kirov Oblast	2.08	23.8	0.48	107.7
Chuvash Republic	1.59	30.1	0.65	109.9
Ryazan Oblast	1.49	27.0	0.56	108.7
Regions traditionally considered industrialized, that faced negative de-industrialization				
Lipetsk Oblast	0.91	31.7	0.07	108.7
Krasnoyarsk Oblast	0.94	32.0	0.82	102.4
Omsk Oblast	0.74	21.8	0.65	105.6
Yaroslavl Oblast	1.48	25.0	1.36	105.7
Chelyabinsk Oblast	0.72	22.9	1.40	105.4
Vologda Oblast	0.82	42.4	0.10	105.5
Sverdlovsk Oblast	0.77	23.7	1.37	108.7
Samara Oblast	0.91	22.6	1.95	107.3
Vladimir Oblast	1.10	21.4	1.25	108.4
Nizhny Novgorod Oblast	0.88	30.7	4.44	109.7