The Size of Innovation Space as a Factor of Innovation Activity in Regions

Sergey Ayvazyan [1], and Mikhail Afanasyev [2]

[1] Professor, Deputy Director of CEMI RAS, Moscow, e-mail: aivazian@cemi.rssi.ru
[2] Professor of Department of Mathematical Economics of SAUHS, Head of the Laboratory of CEMI RAS, e-mail: miafan@cemi.rssi.ru

ARTICLE INFO

ABSTRACT

The research objective is to obtain and ground the quantitative characteristics of the impact of science and business on the results of innovation activity of the Russian Federation subjects. Under such results the number of patents issued and new production technologies developed are considered. Hypotheses testing is conducted enabling to establish the relationship between the innovation activity of a region and the number of potential links between the organizations creating new knowledge and innovation active businesses. The totality of these relations is characterized as an innovation space of a region. The results obtained through econometric modelling using the official data from the Rosstat and U. S. Census Bureau, Patent and Trademark Office, National Center for Education Statistics for the period 2009-2013 allow to justify some properties of estimates of the regional innovation space technical efficiency and the estimates of innovation activity results elasticity by the innovation space size for the subjects of the Russian Federation and the states of the USA. An emphasis is made on the role of public authorities in creating a favourable environment for innovation activity enhancement for the Russian Federation subjects through facilitating new research organizations emergence and higher education institutions start-ups.

1. INTRODUCTION

The current understanding of the innovation system functioning at the national and regional levels is related to the overall efforts of government, business and academia, aimed at creation, dissemination and use of new ideas, knowledge, technologies and products (Itskovits, 2010). In international practice, an important criterion of effectiveness of the innovation system is the R&D (Research and Development) performance. However, the process of emergence of an innovative idea and its further transformation into innovation has been little explored through computer simulation methods and, partly for that reason, we do not have convincing explanations for the effectiveness or failure of a particular innovation system as a whole. The result of the innovation process is largely determined by the ability of regional innovation system subjects to communicate and interact (Butler and Gibson, 2013; Golinchenko and Balycheva,

2012; Ivanov et al., 2012; Larina, 2012; Makoveyeva, 2012; Rumyantsev, 2013; Simachev, 2012). Apart from the direct outcomes, created by such interaction, we might gain positive externalities and synergistic effects (Polterovich, 2010). Obtaining quantitative characteristics of such relationships and interactions is one of the most difficult tasks in the analysis of innovation processes. The key objective of this paper is to obtain and substantiate the quantitative characteristics of the influence of science and business on the results of innovation activity of the Russian Federation subjects. Under such results the number of patents issued and new production technologies are considered, viewed by K. Freeman as the primary outcome of the innovative development of the economy (Freeman, 1987). The research grounds the expediency of estimating the number of potential relationships between the subjects of the Russian regional innovation systems, i.e. organizations, creating new knowledge and innovative ideas, and innovation active businesses using this knowledge to produce innovations. A hypothesis that these relationships is the core driver of production technologies and patents development has been tested.

The paper consists of four sections. The first section presents the hypothesis testing, which confirms the determining impact of a region's scientific and production potential on its innovation activity enhancement. The second section grounds the relationship between the results of innovation activity in the region and the number of potential links between knowledge creating organizations and innovation active enterprises. The totality of these relations is characterized further as innovation space of the region. The third section demonstrates that the parameters of the relationship between the number of patents issued and the size of the innovation space for the Russian Federation subjects are negligibly different from the ones present in the United States federal structure. The fourth, concluding section, describes the elasticity properties of the result of innovation activity in the region by the size of its innovation space and proves the possibility of estimating the region's share in the innovation space used. The role of the state and regional governments in the development of innovation space to support sustainable innovative performance is emphasized.

2. THE IMPACT OF SCIENCE AND BUSINESS DEVELOPMENT ON INNOVTION ACTIVITY IN REGIONS

Hypothesis 1. The number of organizations, creating new knowledge, and the number of innovation active businesses are the factors determining the result of innovation activity of the Russian Federation subjects.

Testing of the hypothesis is conducted using the methods of econometric modelling based on the official statistics data that characterize the potential of science and business at the regional level.

In (Makarov et al., 2014) the three-factor models of production potential of the Russian Federation regions have been constructed, defining the dependence of GRP on the main production factors: labour, physical and intellectual capitals for the period of 2009-2013. As the characteristics of intellectual capital such indicators as "*the number of personnel engaged in research and development*" and "*the number of higher education institutions*" were considered. "*The number of personnel engaged in research and development*" as the intellectual capital indicator proved to be significant in the models based on the data of 2009 and 2010. In models constructed for 2011-2013 its impact on GRP is being lost, while the importance of "the number of higher education institutions" indicator increases. The research findings allow us to consider the above indicators as **characteristics of the scientific potential of regions** in assessing the results of their innovation activity.

As an alternative to characterize the number of higher education institutions the indicator of the number of organizations engaged in R&D is applied. The latter to a greater extent takes into account the specific features of scientific research arrangement in the Russian Federation, since it includes the Russian Academy of Sciences institutes, project institutes and design bureaus. The number of higher education institutions is a characteristic of intellectual capital in most developed countries, thus making it convenient for comparative analysis. However, the estimates obtained for the subjects of the Russian Federation on the basis of this indicator, currently can be classified as hypothetical, being valid under the condition that only universities are involved in innovation activities as organizations that create new knowledge, ignoring the participation of other research organizations. Hence, hereinafter the indicator of "*the number of organizations engaged in R&D*" will be employed as the fundamental characteristics of the scientific potential of the Russian Federation subjects. As a conditional estimate, for comparison purposes, the indicator of "the number of higher education institutions" will be considered.

In (Makarov et al., 2014) it is argued that the significant factor of efficiency in regions production potential models based on 2009-2013 statistical data is the number of innovation active businesses. Further, this indicator is used as the **characteristics of business potential** at the regional level. For the same purpose fixed assets value is considered.

To test Hypothesis 1 the production functions that determine the dependence of the result of innovation activity in the region on the totality of the above characteristics of science and business for each year in the period 2009-2012 are constructed. Further, we explore power-law production functions[1], in logarithmic form presented as

$$\ln Q_i = \beta_0 + \beta_K \ln K_i + \beta_L \ln L_i + \beta_S \ln S_i + \beta_B \ln B_i + v_i - u_i . \quad (1)$$

Here Q_i is the result of innovation activity in the region i (two indicators are considered: $Q_i = pat_i$ - the number of patents issued in the region i , $Q_i = tech_i$ - the number of new production technologies developed in the region i in a year t); K_i - the fixed assets value; L_i - the number of personnel engaged in R&D; S_i - the number of organizations creating new knowledge (two indicators are considered: $S_i = hei_i$ - the number of higher education institutions, $S_i = ror_i$ - the number of organizations engaged in R&D); B_i - the number of businesses (two indicators are considered: $B_i = bus_i$ - the total number of businesses in a region, $B_i = inn_i$ - the number of innovation active businesses); $\beta_0, \beta_K, \beta_L, \beta_S, \beta_B$ - parameters. The random component $v_i - u_i$ reflects the impact of uncertainty and efficiency factors on the process of innovation activity in the region. To simulate effects of uncertainty a normally distributed random variable v_i with zero mathematical expectation $v_i \in N(0, \sigma_v^2)$ is used. For the simulation of the effects of efficiency factors a non-dependent on v_i non-negative random variable u_i , having zero-truncated normal distribution with zero mathematical expectation $u_i \in N^+(0, \sigma_u^2)$ is applied. This approach to the modelling of residues is consistent with the concept of stochastic frontier (Kumbhakar and Lovell, 2004) and allows to obtain the correct estimates of technical efficiency of production factors.

---

[1] The rationale for this specification of the production function is given in (Aivazyan and Afanasyev, 2014)

Table 1. Given data for testing Hypothesis 1

Notation	Indicator Title	Time period	Source
pat_i	the number of patents issued	2008-2013	(Inflow…, 2013)
$tech_i$	the number of new production technologies developed in a region	2008-2013	(new technologies developed, 2013)
K_i	fixed assets cost	2009-2012	(fixed assets cost …, 2012)
L_i	the number of personnel engaged in R&D	2009-2012	(the number of personnel …, 2013)
hei_i	the number of higher education institutions in a region	2008-2013	(higher education institutions, 2013)
ror_i	the number of organizations engaged in R&D	2008-2013	(organizations …, 2013)
bus_i	the number of businesses	2008-2013	(the number of businesses in a region, 2013)
I_i	the share of innovation active businesses in total number of enterprises in a region	2008-2013	(organizations' innovation activity…, 2013)

In the adopted notations the number of innovation active businesses in the region is expressed by the value $inn_i = I_i \times bus_i$. To test Hypothesis 1 production functions that determine the dependence of the number new production technologies developed (patents issued) on the set of science and business potential characteristics at the regional level are constructed. The factor of results of innovation activity is estimated by the science or business characteristic significant in production functions models constructed for the given period of time. The method of testing Hypothesis 1 $H_0^1 : \beta_S \neq 0; \beta_B \neq 0$ is being reduced to the verification of statistical hypothesis. The Hypothesis 1 is accepted if the statistical hypothesis H_0^1 is not rejected for 90% of the total number of estimated models of the form (1), built for different characteristics Q_i and S_i for the period 2009-2012. If the hypothesis H_0^1 is rejected for more than 10% of the constructed models, the Hypothesis 1 is rejected.

Table 2. Parameter estimates of model (1) for patents issued

	2009	2009	2010	2010	2011	2011	2012	2012
K	.130	.139	.086	.127	.273	.313	.192	.148
L	.208	-.078	.137	-.112	.124	-.051	-.016	-.038
Ror		.823***		.759***		.697***		.851***
inn	.540***	.481***	.798***	.657***	.540***	.427***	.448***	.430***
hei	.425**		.343*		.406**		.868***	
cons	-2.151	-1.954	-3.279	-3.050	-3.829*	-3.964*	-2.201	-2.191
log likeli	-99.16	-97.64	-94.61	-92.85	-98.01	-96.76	-90.12	-96.84
sigma v	.442	.444	.447	.471	.441	.482	.508	.460
sigma u	1.243	1.204	1.127	1.049	1.212	1.122	.930	1.160

* 10% significance level; ** 5% significance level; *** 1% significance level

For each year within the period from 2009 to 2012 stochastic production functions (1) are constructed. Their parameters are estimated by maximum likelihood on the basis of information data on 80 subjects of the Russian Federation. The list of regions is presented in column 2 of Table A1 of the Annex. Overall, for this period 16 models (8 for the patents and 8 for production technologies) have been built. Parameter estimates of these models are presented in Tables 2 and 3. The results obtained do not contradict the Hypothesis 1. In all models the characteristics of a region's scientific potential – "the number of organizations engaged in R&D" (the alternative is "the number of higher education institutions") and business capacity – "the number of innovation active businesses" significantly influence both the number of patents granted (Table 2) and the number of production technologies developed (Table 3).

Table 3. Parameter estimates of model (1) for production technologies

	2009	*2009*	*2010*	*2010*	*2011*	*2011*	*2012*	*2012*
K	.115	.019	-.086	-.146	-.041	-.094	.168	.071
L	.297	-.007	-.039	.091	.286	.158	.249	-.054
ror		.813***		.363*		.623***		.452***
inn	.236***	.150*	.314***	.544***	.469***	.299**	.538**	.538***
hei	.224***		.261*		.242*		.357**	
cons	-4.261	-2.697	-4.062	-1.665	-2.736	-1.675	-2.031	-3.031
log likeli	-100.08	-96.16	-99.59	-98.62	-106.77	-104.85	-111.15	-113.57
sigma v	.845	.804	.751	.408	.482	.623	.299	.494
sigma u	.357	.211	.722	1.261	1.359	1.093	1.730	1.520

The number of organizations creating new knowledge as a characteristic of the scientific potential in a region and *the number of innovation active businesses* as a characteristic of business affect the result of innovation activity of the Russian Federation subjects. Through testing results for the period 2009-2012 the Hypothesis 1 is accepted. The characteristics of the scientific potential – the number of personnel engaged in R&D" and of business capacity – "the fixed assets value" are insignificant in all models. Model (1) can be transformed to the form

$$\ln Q_i = \beta_0 + \beta_S \ln S_i + \beta_B \ln B_i + v_i - u_i . \tag{2}$$

3. THE SIZE OF INNOVATION SPACE AS A FACTOR OF INNOVATION ACTIVITY OUTCOME

Hypothesis 2. The outcomes of innovation activity in the Russian Federation regions depend on the size of innovation space, which is determined by the number of potential pairwise relationships between organizations, creating new knowledge, and innovation active businesses.

The results of this hypothesis validation allows to prove the possibility of using quantitative estimates of potential pairwise relationships between organizations engaged in R&D (the alternative is higher education institutions) and businesses that use new knowledge for creating innovations, as a factor determining the results of innovation activity at the regional level. The totality of potential links between such organizations and businesses will be referred to as innovation space, and their number as the size of innovation space.

Introduce the notations $\beta_S = \beta_1, \beta_B = \beta_1 + \eta$, where $\beta_1 \geq 0$, η can be both positive and negative. Then after the transformation of function (2) we get:

$$\ln Q_i = \beta_0 + \beta_1 \ln(S_i * B_i) + \eta B_i + v_i - u_i . \qquad (3)$$

Under the notations $\beta_B = \beta_1, \beta_S = \beta_1 + \eta$, after the transformation we obtain:

$$\ln Q_i = \beta_0 + \beta_1 \ln(S_i * B_i) + \eta S_i + v_i - u_i . \qquad (4)$$

Testing of Hypothesis 2 is being reduced to the verification of statistical hypothesis $H_0^2 : \beta_1 \neq 0, \eta = 0$ for each estimated model of the form (3) or (4). The Hypothesis 2 is accepted for the period in question, when a statistical hypothesis is not rejected for 90% of the total number of the estimated models. If the hypothesis H_0^2 is rejected for more than 10% of the models, the Hypothesis 2 is rejected for the period in question.

Parameter estimates for the eight models of the forms (3) and (4) based on the data of 80 regions of the Russian Federation within the period 2009-2012 for the patents issued are presented in Table 3. For all models the hypothesis H_0^2 is not rejected. Parameter estimates for the eight models of the forms (3) and (4) for production technologies are presented in Table 4. For 7 out of the 8 models the hypothesis H_0^2 is not rejected. For one of the models built on 2009 data the hypothesis H_0^2 is rejected. Thus, the hypothesis H_0^2 is not rejected for 15 out of the 16 constructed models that allows for accepting the Hypothesis 2.

Table 4. Parameter estimates of models (3) and (4) for the patents issued

	2009	2009	2010	2010	2011	2011	2012	2012
ror*inn		.532***		.559***		.788***		.692***
hei*inn	.624***		.645***		.874***		.794***	
ror		.162		.172		-.268		
inn	.127		.007		-.364		-.337	-.235
cons	-.252	-.740	-.880	-1.057	-.266	-1.006	-.163	-.019
log likeli	-102.21	-94.36	-82.60	-90.80	-91.57	-98.03	-93.04	-99.62
sigma v	.4250	.437	.378	.409	.471	.450	.539	.460
sigma u	1.338	.746	.982	1.100	1.024	1.200	.944	1.229

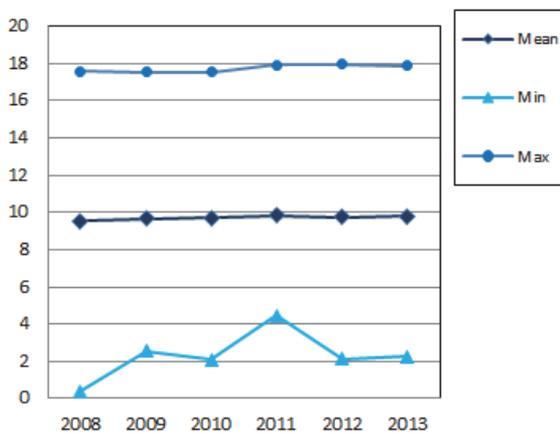**Table 5.** Parameter estimates of models (3) and (4) for production technologies

	2009	2009	2010	2010	2011	2011	2012	2012
ror*inn		.813***		.492***		.795***		.239**
hei*inn	.496***		.283***		.346***		.432	
ror				.109				
inn	-.173	-.658**				-.545		.375
hei			.342		.379		-.070	
cons	-2.266	-2.524*	-1.975	-2.087	-1.83	-2.212*	-1.453	-2.657***
log likely	-105.01	-96.17	-108.63	-102.60	-112.06	-105.61	-121.97	-115.61
sigma v	.898	.804	.931	.807	.737	.653	.830	.484
sigma u	.027	.025	.217	.549	1.091	1.061	1.243	1.587

The production function of the form (2) can be transformed to the form (5):

$$\text{M1:} \quad \ln Q_i = c + \delta \ln V_i + v_i - u_i \quad, \tag{5}$$

where $V_i = S_i * B_i$ - is the number of potential pairwise relationships between organizations engaged in R&D (the alternative is higher education institutions) and innovation active businesses. Further value V_i will be called the size of innovation space in the region. Thus, model (5) describes the dependence of the result of innovation activity in the region on the size of innovation space. Thereafter, as one of the characteristics of the innovation system of the Russian Federation at the regional level, the δ parameter estimate is considered, characterizing the elasticity of innovation activity in the region by the size of innovation space.

Figure 1a. Statistical characteristics   **Figure 1b.** Statistical characteristics
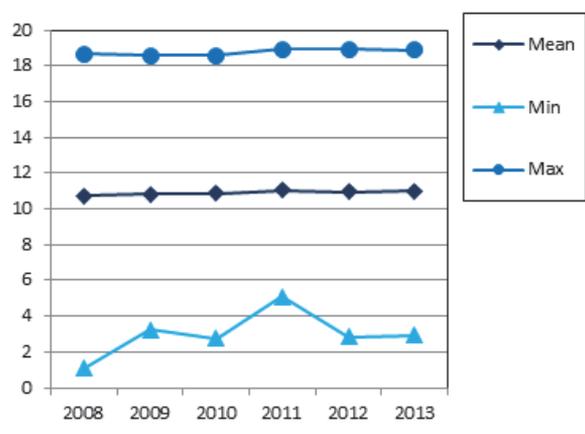
$V_i = hei_i * inn_i$, logarithmic scale $V_i = ror_i * inn_i$, logarithmic scale

Figure 1a shows the dynamics of statistical characteristics of the size of innovation space $V_i = hei_i * inn_i$ for 80 regions of the Russian Federation, being estimated by the number of higher education institutions and innovation active businesses in logarithmic form for each year of the period from 2008 to 2013. Figure 1b presents the statistical characteristics of innovation space size $V_i = ror_i * inn_i$, estimated by the number of organizations engaged in R&D and innovation active businesses. The mean values demonstrate their stability over time for each evaluation method. The maximum values corresponding to the region of Moscow are also stable for the given period of time. It should be noted that the size of innovation space, calculated by the number of higher education institutions indicator, is significantly below the level estimated on the basis of more relevant to the research objectives indicator of the number of organizations engaged in R&D. Accordingly, the use of characteristics $V_i = hei * inn_i$ when evaluating the impact of science and business on the results of innovation activity of the Russian Federation subjects may lead to inflated estimates of the technical efficiency of innovation space. Table 6 presents the parameter estimates of the six models of the form (5) for the patents issued with the size of innovation space estimated by the number of

organizations engaged in R&D and innovation active businesses for each year of the period from 2008 to 2013.

Table 6. Parameter estimates of models (5) with $V_i = ror_i * inn_i$ for the patents issued

	2008	2009	2010	2011	2012	2013
δ	0.615***	0.586***	0.618***	0.630***	0.581***	0.571***
C	-1.105***	-0.805***	-1.151***	-1.374***	-0.699***	-0.591***
log likely	-102.598	-94.715	-91.131	-98.484	-99.941	-98.281
sigma v	0.569	0.428	0.398	0.448	0.499	0.484
sigma u	1.134	0.762	1.122	1.213	1.179	1.162
W	0.165	0.253	0.155	0.112	0.301	0.355

Table 7 provides parameter estimates of the 6 models of the form (5) for the patents issued with the size of innovation space, estimated by the number of higher education institutions and innovation active businesses for each year between 2008 and 2013.

Table 7. Parameter estimates of models (5) c $V_i = hei_i * inn_i$ for the patents issues

	2008	2009	2010	2011	2012	2013
δ	0.626***	0.620***	0.649***	0.661***	0.623***	0.599***
C	-0.535***	-0.344***	-0.853***	-0.994***	-0.581***	-0.275***
log likely	-96.202	-91.601	-82.606	-92.729	-94.105	-92.921
sigma v	0.520	0.400	0.378	0.453	0.550	0.500
sigma u	1.053	1.133	0.982	1.078	0.950	1.011

Table 8 offers the parameter estimates of five models of the form (5) for new production technologies with the size of innovation space, estimated by the number of organizations engaged in R&D and innovation active enterprises for each year of the period 2008-2012.

Table 8. Parameter estimates of models (5) c $V_i = ror_i * inn_i$ for production technologies

	2008	*2009*	*2010*	*2011*	*2012*
δ	0.513***	0.587***	0.565***	0.655***	0.572***
c	-2.859***	-4.139***	-3.684***	-4.558***	-3.156***
log likely	-126.410	-135.704	-138.374	-136.169	-141.695
sigma v	1.39E-07	0.3682	0.330	0.362	0.377
sigma u	2.349	2.330	2.454	2.350	2.532

Table 9 demonstrates parameter estimates of five models of the form (5) for the production technologies with the innovation space size, estimated by the number of higher education institutions and innovation active businesses for each year of the period 2008-2012.

Table 9. Parameters estimates of models (5) с $V_i = hei_i * inn_i$ for production technologies

	2008	*2009*	*2010*	*2011*	*2012*
δ	0.494***	0.568***	0.544***	0.585***	0.519***
C	-2.194***	-3.237***	-2.778***	-2.965***	-1.913***
Log likely	-136.319	-143.577	-146.084	-145.531	-149.159
sigma v	0.471	0.587	0.545	0.583	0.597
sigma u	2.252	2.374	2.515	2.456	2.586

Parameter estimates are significant in all 22 models of the form (5). The size of innovation space can be considered as a factor of the patents issued and production technologies at the regional level.

4. COMPARATIVE ANALYSIS OF INNOVATION SPACE IMPACT ON THE NUMBER OF PATENTS ISSUED TO THE SUBJECTS OF THE RUSSIAN FEDERATION AND THE USA

Hypothesis 3: The parameters of the function (5) describing the dependence of the number of patents issued on the size of innovation space of the Russian Federation subjects, estimated by the number of organizations engaged in R&D and innovation active businesses do not differ significantly from the parameters of the function (5) representing the dependence of the number of patents issued on the size of innovation space across the US states, estimated by the number of higher education institutions and high-tech companies.

While testing Hypothesis 3 for the subjects of the Russian Federation, the data presented in Table 1 were used, for the US states - the data described in Table 10, respectively.

Table 10. Given data for testing Hypothesis 3 by US states

Notation	Indicator Title	Time period	Source
pat_i	the number of patents issued	*2006-2013*	(Number of Patents, 2014)
hei_i	the number of higher education institutions in a region	*2006-2010*	(Number of institutions, 2010)
com_i	total number of companies	*2006-2012*	(All business establishments, 2014)
$htcom_i$	the number of high-tech companies	*2006-2010*	(High-technology establishments, 2014)

Table 11 provides the parameters estimates for five models of form (5) for the patents is-
sued with the size of innovation space, estimated for the US states as
$V_i = hei_i * htcom_i$ for each year in the period 2006-2010.

Table 11. Parameter estimates of models (5) c $V_i = hei_i * htcom_i$ for the patents issued

	2006	2007	2008	2009	2010
δ	0.663***	0.662***	0.679***	0.668***	0.679***
c	-1.939***	-2.027***	-2.293***	-2.108	-2.011***
log likely	-53.607	-53.859	-54.120	-53.463	-52.528
sigma_v	0.692	0.695	0.699	0.690	0.677
sigma_u	0.008	0.010	0.009	0.015	0.014
w	0.053	0.046	0.034	0.042	0.051

Fig. 2 (series 1) shows the dynamics of estimates of the elasticity of the number of patents
issued by the size of innovation space across the US states, calculated with consideration of the
number of higher education institutions and high-tech companies according to 2006-2010 data
(see the δ parameter estimates in Table 11). Series 2 in Fig. 2 reflects the dynamics of the
elasticity values by the size of innovation space of the Russian Federation subjects, calculated
subject to the number of organizations engaged in R&D and innovation active businesses (see
the δ parameter estimates in Table 6). The difference in values of the elasticity coefficient es-
timates for the subjects of the Russian Federation and of US states for the period 2008-2010
does not exceed 0.08.

Figure 2. Estimates of the elasticity of the number of patents issued by the size of innovation
space for the US states (Series 1) and the Russian Federation subjects (Series 2).
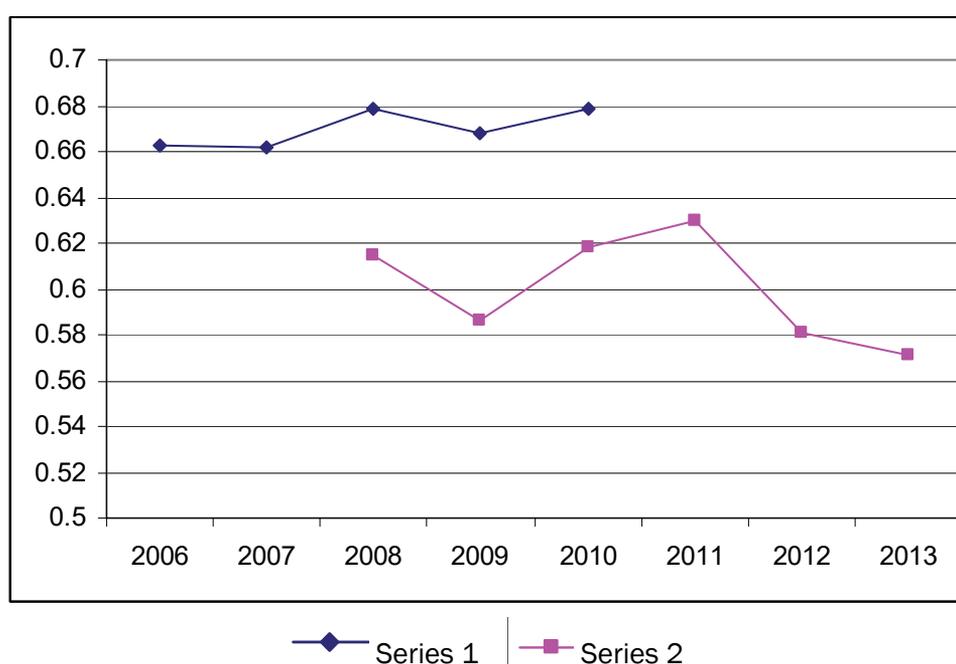
Figure 3a demonstrates the dependence of the number of patents issued on the size of innovation space, in logarithmic scale, for the Russian Federation subjects based on 2010 data; Figure 3b - for the US states and Figure 3c – for the totality of the Russian Federation subjects and the states of the USA.

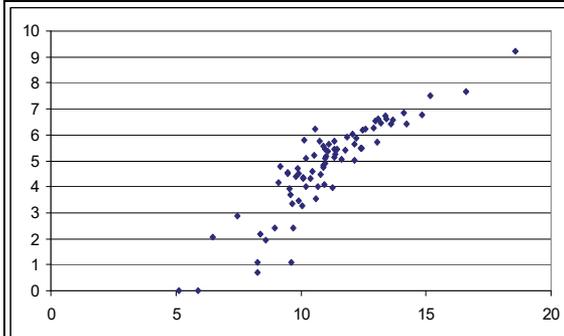**Figure 3a.** Subjects of the Russian Federation   **Figure 3b.** USA states

Figure 3a. Subjects of the RF,

$$V_i = ror_i * inn_i$$
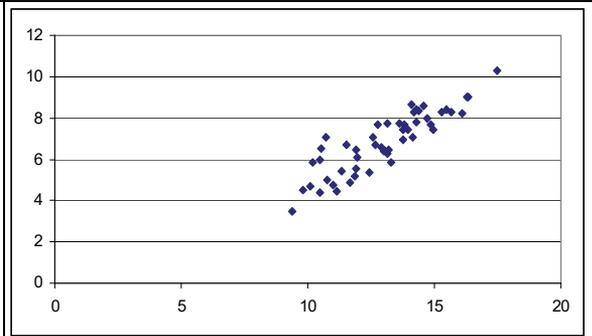
Figure 3b. USA states,

$$V_i = hei_i * htcom_i$$

Figure 3c. Regions of the Russian Federation and the US states
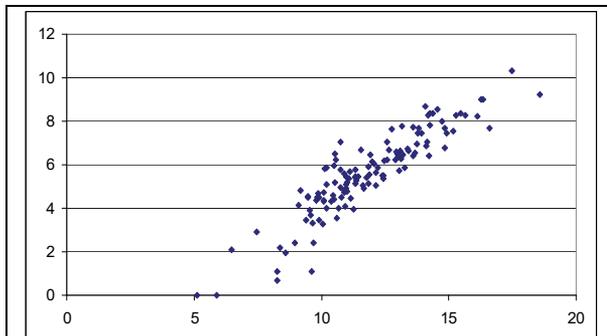
Figure 3c. Regions of the RF and the US states

To test Hypothesis 3 models have been built in the form

$$\text{M2: } \ln Q_i = c + c_d d_i + (\delta + \delta_d dv_i) \ln V_i + v_i - u_i, \tag{6}$$

where $d_i = dv_i = 0$, if the index i refers to the subject of the Russian Federation and $d_i = dv_i = 1$, if the index i refers to a US state. For the subjects of the Russian Federation the innovation space size is calculated on the basis of the number of organizations engaged in R&D and the number of innovation active businesses $V_i = ror_i * inn_i$. For the US states – with respect to the number of higher education institutions and high-tech companies $V_i = hei_i * htcom_i$.

Test of Hypothesis 3 is reduced to verification of the statistical hypothesis $H_0^3 : c_d = \delta_d = 0$ for models of the form (6) constructed for 2008-2010. The Hypothesis 3 is accepted if the statistical hypothesis H_0^3 is not rejected for each of the three models.

Estimation of parameters of model M2 by maximum likelihood is performed for each year of the period 2008-2010 within the data on 131 regions: 80 subjects of the Russian Federation and 51 state of the USA. Parameter estimates of model M2 given in Table 12 under the control variables d_i and dv_i proved insignificant. The hypothesis H_0^3 is not rejected for each of the three models. Hypothesis 3 is accepted. Thus, to describe the dependence of the number of patents issued on the size of innovation space across the subjects of the Russian Federation and the US states a generic model of the form M1 can be constructed. Parameter estimates of this model for 2008-2010 period are given in Table 12.

Table 12. Parameter estimates of models M1 and M2 for the totality of 131 regions.

	2008	2008	2009	2009	2010	2010
	M2	M1	M2	M1	M2	M1
V	.623***	.669***	.616***	.663***	.637***	.723***
dv	.027		-.002		-.0001	
d	.113		.460		.743	
cons	-1.318***	-1.689***	-.995**	-1.426***	-1.467*	-2.335***
log likeli	-159.90	-163.82	-155.68	-159.08	-146.33	-156.96
sigma v	.601	.648	.453	.530	.482	.656
sigma u	.948	.915	1.133	1.064	.958	.771

Control variables are not significant in each of the three models (M2). To compare the technical efficiency of the subjects of the Russian Federation and the US states, models of the form M1, built for the totality of 131 regions, can be used.

5. SOME ESTIMATES PROPERTIES OF INNOVATION ACTIVITY RESULTS ELASTICITY BY THE SIZE AND THE EFFICIENCY OF REGIONAL INNOVATION SPACE

Property 1. A method of estimating the size of innovation space (based on the number of higher education institutions or the number of organizations engaged in R&D for the subjects of the Russian Federation; for the states of the US – considering the number of high-tech companies in the total number of firms) has no significant effect on the estimates of the elasticity of innovation activity results by the size of innovation space and their dynamics.

Figure 4 provides the estimates of the elasticity of the number of patents issued by the innovation space size $V_i = hei_i * inn_i$ calculated for the period 2008-2013 based on the number of higher education institutions (series 1) and the size of innovation space $V_i = ror_i * inn_i$, given the number of organizations engaged in R&D (series 2). The maximum difference in elasticity coefficients obtained under model (5) for the two methods of estimating the size of innovation space does not exceed 0.05. The correlation coefficient of 0.906 indicates the dependence of the estimates of elasticity for different methods of estimating the size of innovation space. The choice of method for estimating the size of innovation space

(based on the number of higher education institutions or organizations engaged in R&D) has no significant effect on the dynamics of the elasticity coefficients of the number of patents issued.

Fig.ure 4. Elasticity estimates on the number of patents issued by the size of innovation space for the subjects of the Russian Federation under model (5) for the period 2008-2013: series 1 $V_i = hei_i * inn_i$ (data from Table 7), Series 2 - for $V_i = ror_i * inn_i$ (data from Table 6)
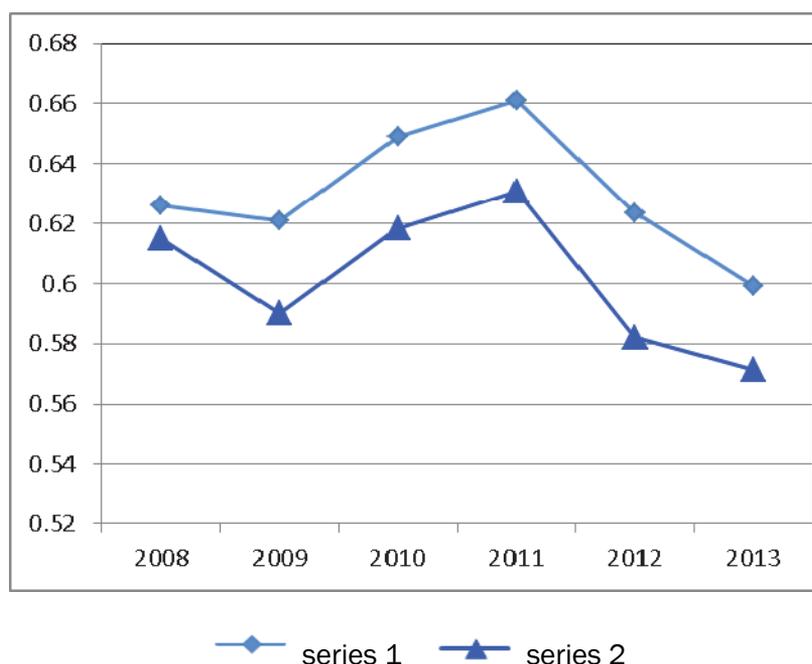

Figure 5 shows the estimates of the elasticity of the number of production technologies developed within the size of innovation space $V_i = ror_i * inn_i$ calculated for the period 2008-2012 taking into account the number of organizations engaged in R&D (series 1) and the size of innovation space $V_i = hei_i * inn_i$, calculated with regard to the number of higher education institutions (series 2). The maximum difference between the elasticity coefficients for each year does not exceed 0.07. A high correlation coefficient of 0.903 indicates the strength of relationship between these estimates. The choice of estimation method to measure the size of innovation space has no significant effect on the dynamics of the elasticity coefficients of the number of production technologies.

Figure 5. The estimates of elasticity of production technologies developed within the size of the Russian Federation subjects innovation space according to model (5) for the period 2008-2012: series 1 for $V_i = ror_i * inn_i$ (data from Table 8), series 2 - for $V_i = hei_i * inn_i$ (data from Table 9)
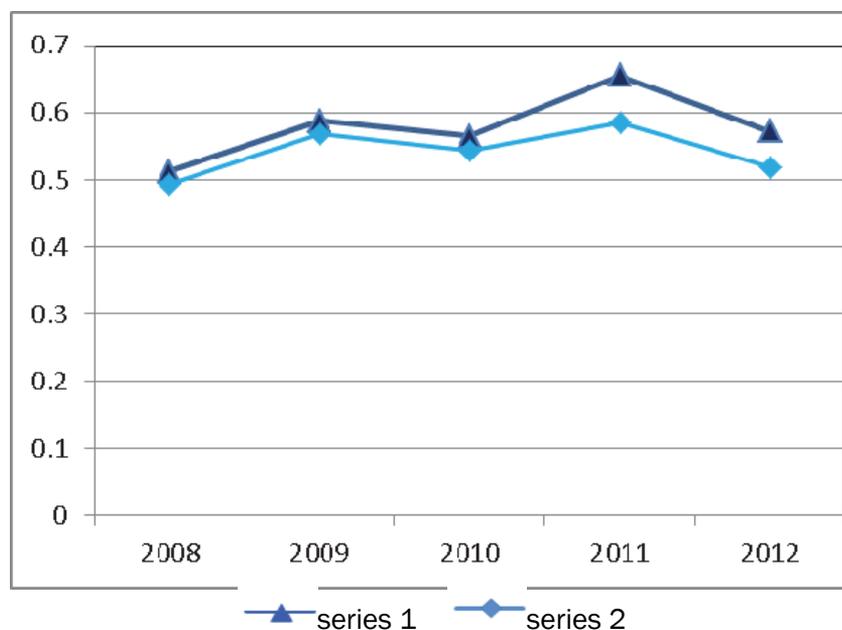
series 1   series 2

Table 13 provides the parameter estimates of model (5) for patents issued according to the data on 51 states of the USA. For comparison with the results presented in Table 14, the size of innovation space is calculated as $V_i = hei_i * com_i$ taking into account both the number of high-tech companies and the total number of businesses.

Table 13. Parameter estimates of model (5) with $V_i = hei_i * com_i$ for patents issued.

	2006	2007	2008	2009	2010	2011	2012
δ	0.669***	0.669***	0.685***	0.672***	0.683***	0.684***	0.672***
c	-3.729***	-3.812***	-4.102***	-3.850***	-3.773***	-3.739***	-3.505***
log likely	-56.801	-56.858	-57.342	-56.383	-55.593	-57.071	-54.150
sigma v	0.736	0.737	0.744	0.730	0.719	0.740	0.699
sigma u	0.011	0.016	0.011	0.010	0.013	0.011	0.018
w	0.0038	0.0033	0.0025	0.0032	0.0039	0.0042	0.0054

Figure 6 displays the estimates of elasticity of the number of patents issued within the size of innovation space $V_i = hei_i * com_i$ calculated for the period 2006-2012 subject to the total number of businesses in US states (series 1) and the size of innovation space $V_i = hei_i * htcom_i$ with regard to the number of high-tech companies for the period 2006-2010 (series 2). The maximum difference between the elasticity coefficients for each year of the 2006-2010 period does not exceed 0.01. The correlation coefficient of 0.991 indicates that the choice of estimation method for measuring the size of innovation space has no significant effect on the dynamics of the elasticity coefficients for patents issued.

Figure 6. The estimates of elasticity of the number of patents issued within the size of the US states according to model (5) for the period 2008-2012: series 1 for $V_i = hei_i * com_i$ (data from Table 13), series 2 - for $V_i = hei_i * htcom_i$ (data from Table 11)
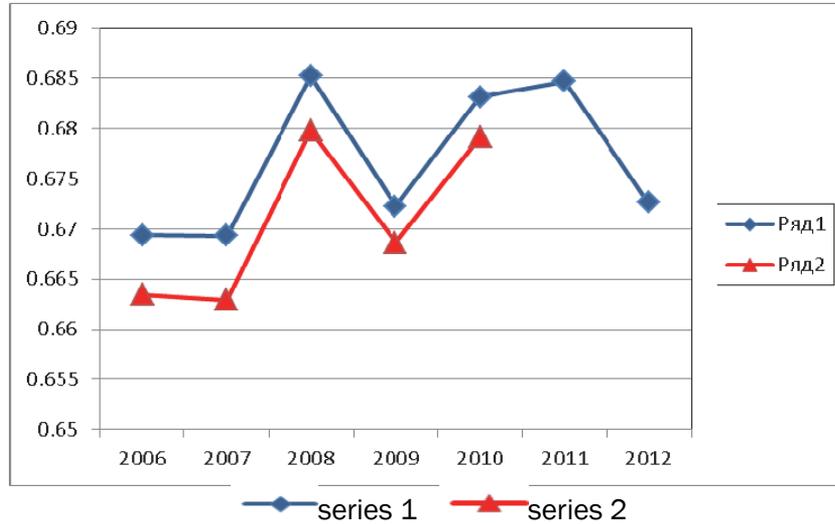
Thus, the elasticity estimates demonstrate weak dependence on the method of innovation space evaluation. Their dynamics is consistent with different estimation methods. It should be noted that the method of evaluating the innovation space affects the constant of the model, which scales the x-axis.

Property 2. For most regions of the Russian Federation the technical efficiency in the use of innovation space estimated by the number of organizations engaged in R&D and innovation active businesses is close to technical efficiency in the use of innovation space of the US states, estimated by the number of higher education institutions and high- tech companies.

The estimated parameters σ_v^2, σ_u^2 enable to estimate mathematical expectation

$$TE_i = E(e^{-u_i} \mid v_i - u_i) = \frac{\Phi(\tilde{\mu}_i / \sigma_* - \sigma_*)}{\Phi(\tilde{\mu}_i / \sigma_*)} \exp\{\frac{1}{2}\sigma_*^2 - \tilde{\mu}_i\}$$ (Battese, Coelli, 1988), where

$$\tilde{\mu}_{it} = -(v_i - u_i)\sigma_u^2 / \sigma^2, \quad \sigma_*^2 = \sigma_u^2 \sigma_v^2 / \sigma^2, \quad \sigma^2 = \sigma_u^2 + \sigma_v^2.$$

According to the stochastic frontier concept (Kumbhakar, Lovell, 2004), the value TE_i characterizes the technical efficiency of innovation space use in the region. Technical efficiency estimates TE_i are relative characteristics of regional efficiency. Their values can vary from year to year. However, the regions ranks determined by the technical efficiency estimates, are the sustainable characteristics of their innovation activity. Table 14 provides the values of Spearman's rank correlation coefficients of efficiency estimates obtained by model M1 (see Table 15) for 2008, 2009 and 2010 for the totality of 131 subjects of the Russian Federation and the US states that demonstrate their high dependence over time.

Table 14. Spearman's rank correlation coefficients of efficiency estimates TE_i by model M1

	_2008	2009	2010
2008	1.000		
2009	0.933	1.000	
2010	0.897	0.933	1.000

In (Aivazyan, Afanasyev, 2015) it has been argued that the value $w = e^{c/\delta}$ assumes being interpreted as the expected share of the size of innovation space used by the region, effectively creating[2] discrete results of innovation activity. As an estimate $\widetilde{w}_i$ of the share of innovation space used by the region when creating the innovations of a specific type the value $(w^\delta \times TE_i)^{1/\delta}$ can be taken. Then the value $\widetilde{V}_i = \widetilde{w}_i V_i$, calculated for the relevant year, can be considered as an estimate of the innovation space size used by the region to generate a specific outcome of innovation activity. Dynamics of regions' innovation activity results is determined by the dynamics parameter w. The growth of parameter w is associated with an increase in the expected number of results generated by the innovation efficient regions.

The estimates of the value w of patents issued to the subjects of the Russian Federation are provided in the last row of Table 6. In the last row of table 11 these estimates are presented for the US states. The estimates vary by an order of magnitude due to differences in the size of innovation space used by the subjects of the Russian Federation and the US states. For the same reason the values w vary by the same order of magnitude in tables 11 and 13 for the US states obtained with the different methods of evaluating the innovation space.

The dynamics w is determined by the ratio of the parameters c and δ: since $c < 0$ and $\delta > 0$, and with increase of δ the value w grows, too; an increase in c drives the growth of w.

The simultaneous increase of these two parameters indicates an increase in the share of effectively used innovation space and the overall innovation activity growth. With a multi-directional change of c and δ, the dynamics w is determined by the dynamics of the relationship c/δ. An important advantage of using the of stochastic frontier concept under model (5) parameters c and δ estimation is their stability in relation to the characteristics of innovation passive regions.

The value of the parameter c of the model (5) depends on the method of evaluating the size of innovation space and may be considered as a scaling option with regard to the size of innovation space. An estimate $\widetilde{w}_i$ of innovation space share used by a region is relative, as it depends on parameter c and technical efficiency estimate TE_i which is also a relative characteristic of a region. However, the dynamics of estimates $\widetilde{w}_i$ reflects a change in both innovation activity and the size of innovation space. The estimates $\widetilde{w}_i$ of the innovation space share used by regions of the Russian Federation under the creation of new production technologies for the period 2009-2013 and the analysis of the factors affecting their dynamics are presented in the research paper by Aivazian, Afanasiev (2015).

The verification of Hypothesis 3 testing evidences that the dependence of the innovation activity results on the size of the innovation space for the subjects of the Russian Federation

---

[2] Estimate TE_i for a region, whose technical efficiency in the use of innovation space equals one

and the US states is described by a generic model M1 (see Table 12). In Fig. 7a across the x-axis to the vertical line 80 subjects of the Russian Federation are distributed according to the classification adopted by the Rosstat (see, for example, Razrabotannyye..., 2013). After the vertical lines 51 states of the USA in alphabetical order are displayed (see, for example, Number of Patents..., 2014). The axis of ordinates on a logarithmic scale shows the values of the innovation space size in these regions. Among the 6 regions with the largest size of the innovation space from the total number of subjects of the Russian Federation and states of the USA by the 2010 data are the two subjects of the Russian Federation, i.e. Moscow and Saint Petersburg. At that, the innovation space size of Moscow exceeds the size of the innovation space of any of the US state. In Fig. 7b across the x-axis the subjects of the Russian Federation (before the vertical line) and the US states (after the vertical line) are arrayed in the same way as in Fig. 7a. Y-axis for each region displays the number of patents issued using a logarithmic scale. The maximum number of patents issued is in the state of California. The second biggest region in the number of patents issued is Moscow. Among the 15 regions the next highest in the number of patents issued is Saint Petersburg.

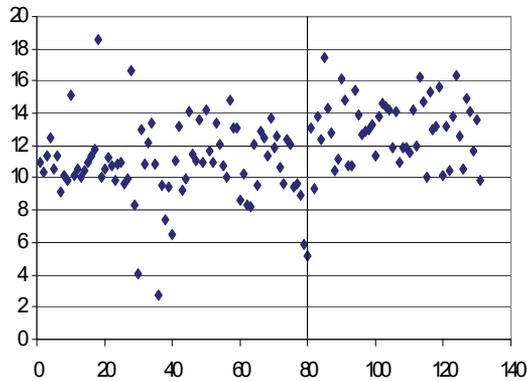**Figure 7a.** The size of innovation space on a logarithmic scale

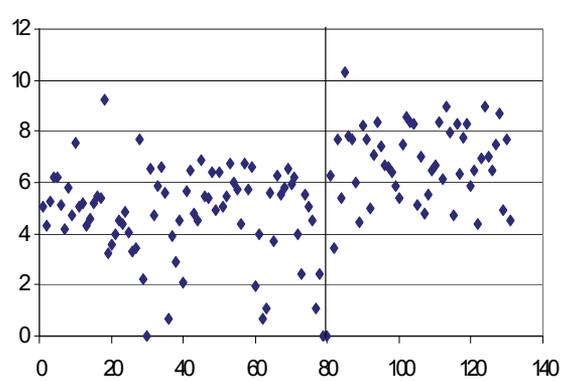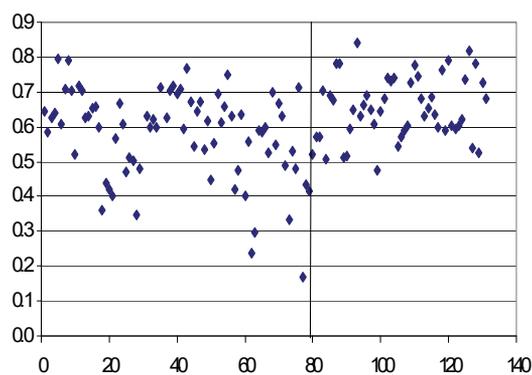**Figure 7b.** The number of patents issued on a logarithmic scale

Figure 7c. The estimates of technical efficiency of innovation space on a logarithmic scale

The size of the innovation space of the US states on the average significantly exceeds the one of the RF subjects (Fig. 7a). The number of patents issued in the United States significantly exceeds the number of patents granted to the RF subjects (Fig. 7b). However, the estimates of technical efficiency in the use of innovation space by the majority of the Russian Federation subjects are comparable to respective estimates of the US states. In Fig. 7b across the x-axis

the subjects of the Russian Federation (before the vertical line) and the US states (after the vertical line) are arrayed in the same way as in Fig. 7a. Y-axis for each region displays the technical efficiency estimate TE_i. Among the 13 most efficient regions there are 3 subjects of the Russian Federation (Ivanovo, Kursk and Ulyanovsk oblasts) and 10 US states (Idaho, Vermont, Washington, Connecticut, Rhode Island, Oregon, Delaware, New Hampshire, New Jersey and Massachusetts). Among the 25 most efficient regions there are 12 regions of Russia and 13 states of the USA. For the majority of subjects of the Russian Federation the results of INNOVATION ACTIVITY to the same degree correlate to the innovation space size as for the US states.

If under evaluation of the parameters of model (5) for the totality of 131 regions we use the underestimation of the size of innovation space $V_i = hei_i * inn_i$ of Russian Federation subjects, among the 13 most efficient regions are the 7 subjects of the Russian Federation (Ivanovo, Kursk, Ulyanovsk, Penza, Kaluga, Saratov and Tomsk oblasts) and 6 US states (Idaho, Vermont, Washington, Connecticut, Rhode Island and Oregon). However, when comparing the technical efficiency estimates we should take into account that patent regulations of the Russian Federation and the United States are different. Moreover, patenting activity in the US exhibits a wider range of participants, apart from high-tech companies. Therefore, the estimates of the size of innovation space of the US states are too low, and the estimates of innovation space technical efficiency are inflated, respectively. Yet, these estimates were obtained using the official statistics information, and thus can serve as a basis for identifying the factors of innovation space technical efficiency.

Property 3. The elasticity of innovation activity result by the size of innovation space reflects the possibility of enhancement of innovation system at the regional and national levels through extensive development of business, education and science.

Under the elasticity δ the change in the number of innovation active businesses in a region i at $g_i\%$ and in the number of organizations engaged in R&D (higher education institutions) at $q_i\%$ drives a $\delta(g_i + q_i)\%$ variance in the innovation activity result. For such innovation activity outcomes as the number of patents issued and the number of new production technologies the elasticity estimates exceed 0.5 and range from 0.5 to 0.65. Therefore, the increase in the number of research organizations in a region by 1% and the number of innovation active businesses by 1% should be accompanied by the regional innovation activity growth by more than 1%.

6. CONCLUSIONS

The number of organizations creating new knowledge, as a characteristic of the region's research potential and the number of innovation active enterprises as a characteristic of business success affect the overall result of innovation activity of the Russian Federation subjects, i.e. the number of production technologies developed and the number of patents issued.

The results of innovation activity in the regions of the Russian Federation depend on the size of the innovation space, which is determined by the number of potential pairwise relationships between organizations, creating new knowledge, and innovation active businesses.

The parameters of the function describing the dependence of the number of patents issued on the size of innovation space used by the Russian Federation subjects, *estimated by the number of organizations engaged in R&D and innovation active businesses* do not differ significantly from the parameters of the function governing the relationships between the number of

patents issued and the size of innovation space of the US states, measured by *the number of higher education institutions and high-tech companies*.

For the majority of the Russian Federation subjects the results of innovation activity to the same extent correlate to the size of innovation space as of for the US states. For such subjects of the Russian Federation the estimates of innovation space technical efficiency are close to the respective technical efficiency estimates of the US states.

A method of estimating the size of the innovation space for the subjects of the Russian Federation (subject to the number of higher education institutions, or the number of organizations engaged in R&D) and for the US states (with regard to the number of high-tech companies, or the total number of firms) has no significant effect on the estimates of the elasticity of innovation activity results by the size of innovation space and their dynamics.

The elasticity of innovation activity result by the size of innovation space reflects the possibility of enhancement of innovation system at the regional level through extensive development of business, education and science.

The current reform of the education system of the Russian Federation is aimed at consolidation of higher education institutions and is carried out through universities mergers. The reform of the Russian Academy of Sciences also suggests incorporation or alliance of academic institutions. In conditions of economic crisis it is hardly likely this reduction would be offset by an increase in the number of innovation active businesses. Therefore, one can expect a reduction in the size of innovation space at the regional level and, as a consequence, a decline in innovation activity results.

The limitation of this research is that the above models do not account for specific features and the intensity of interaction between individual research organizations and businesses. Under the innovation space reduction the results of innovation activity can still show a growth trend by enhancing the intensity of interaction between particular actors. However, such variant of innovation system development can be defined as optimistic. Given the above research findings a more realistic option is the one when the reduction in innovation space would apparently affect the decline in innovation activity of the Russian Federation subjects.

Implementation of the strategy of development against the background of reduction of the innovation space might challenge targeted investments that exceed the cost of maintenance of the achieved size of innovation space if the current number of research organizations and higher education institutions is retained. Based on the results obtained it can be concluded that the increase in innovation activity of the Russian Federation subjects assumes that state and regional governments would create the environment facilitating the expansion of regional innovation space through new research organizations and higher education institutions start-ups, increase of overall innovation activity of businesses.

REFERENCES

Aivazyan, S.A., Afanasyev M.Yu. (2014), *Modelirovaniye proizvodstvennogo potentsiala na osnove kontseptsii stokhasicheskoi granitsy [Modelling of production potential under a stochastic frontier concept]. Metrologiya, rezultaty empiricheskogo analiza.* Krasand, Moscow.

Aivazyan, S.A., Afanasyev M.Yu. (2015), "Assessment of Innovative Activity of Regions in the Russian Federation", *Montenegrin Journal of Economics*, Vol. 11, No. 1, pp. 7-21.

Batler, D., Gibson, D. (2013), „Issledovatel'skie universitety v strukture regional'noj innovacionnoy sistemy: opyt Ostina, shtat Texas" [*"Research Universities within regional innovation system: Austin, Texas Case study"*], *Forsait*, T. 7, No. 2, pp. 42-57.

„Vysshie uchebnyie zavedeniya regiona…" (2013) *["Regional Higher education institutions…"]*, *Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli*, http://aeer.cctpu.edu.ru (accessed July 2015).

Golichenko, O.G., Balycheva, Yu.Ye. (2012), „Tipichnyie modeli innovacionnogo povedeniya predpriyatiy"*["Typical models of enterprise innovative behavior"]*, Innovatsii, No. 2, pp. 19-28.

Ivanov, D.S., Kuzyuk, M.G., Simachev, Yu.V. (2012), „Stimulirovanie innovacionnoy deyatel'nosti rossiyskikh proizvodstvennykh kompaniy: vozmozhnosti i ogranicheniya"*["Enhancing the innovation activity of Russian manufacturing companies: opportunities and limitations"]*, Forsait, T. 6, No. 2, pp. 18-42.

„Innovacionnaya aktivnost organizaciy" (2013) *["Organizations' innovation activity"]*, *Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli*, http://www.gks.ru/bgd/regl/b12_14p/IssWWW.exe/Stg/d03/22-15.htm, (accessed June 2015).

Itskovits, G. (2010), „Troynaya spiral'. Universitety–predpriyatiya–gosudarstvo. Innovatsii v deystvii"*["Triple spiral. Universities–Businesses–State. Innovations in action"]*, http://courier-edu.ru/cour1112/0007.htm, (accessed January 2016).

Larina, Ye.O. (2012), „Formy innovatsionnykh institutsional'nykh struktur v regionakh Rossii", *Sovremennyie issledovaniya social'nykh problem ["Types of innovation institutional structurs in Russian regions"]*, No. 1, pp. 283-298.

Makarov, V.L., Aivazyan, S.A., Afanasyev, M.Yu., Baxtizin, A.R., Nanavyan, A.M. (2014), „Otsenka effektivnosti regionov RF s uchetom intellektual'nogo kapitala, kharakteristik gotovnosti k innovatsiyam, urovnya blagosostoyaniya i kachestva zhizni naseleniya"*["Efficiency evaluation for the regions of the Russian Federation subject to intellectual capital, innovation readiness characteristics, well-being and population life quality"]*, Ekonomika regiona, No. 4. pp. 9-30.

Makoveyeva, V.V. (2012), „Setevoye vzaimodeystvie - klyuchevoy faktor razvitiya integraytsii obrazovaniya, nauki i biznesa"*["Network interactions as a key factor in developing integration of education, science and business"]*, *Vestnik Tomskogo gosudarstvennogo universiteta* , No. 354, pp. 163-166.

„Organizatsii, vypolnyayushshiye nauchnyie issledovaniya" (2013) *["Organizations engaged in R&D"]*, *Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli,* URL: http://www.gks.ru/bgd/regl/b12_14p/IssWWW.exe/Stg/d03/22-15.htm (accessed June 2015).

Polterovich, V.M. (2010), Strategiya modernizatsii rossiykoy eonomiki *[Strategy for modernisation of Russian economy]*, Alteiya, Moscow.

„Postupleniye patentnykh zayavok i vydacha okhrannykh dokumentov" (2013) *["Submission of patent applications and patent granting"]*, *Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli,* URL: http://www.gks.ru/bgd/regl/B13_14p/IssWWW.exe/Stg/d3/21-12.htm

„Razrabotannyie novyie tekhnologii" (2013), *["New technologies developed"]*, *Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli,* URL: http://www.gks.ru/bgd/regl/b1414p/IssWWW.exe/Stg/d03/21-13 (accessed June 2015).

Rumyantsev, A.A. (2013), „Osnovnyie svoistva i problemnyie polya nauchno-innovatsionnogo prostranstva regiona"*["Basic characteristics and problem areas in regional reseach and innovation space"]*, *Prostranstvennaya ekonomika*, No. 2, pp. 103-118.

Simachev, Yu.V. (2012), „Partnerstvo biznesa i nauki v innovacionnoy sfere"*["Business and research partnership in the ininnovation area"]*, *Atomnaya strategiya XXI veka*, No. 6, 8-10.

„Stoimist osnovnykh fondov" (2013) *["Fixed assets cost"]*, *Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli,* URL: http://www.gks.ru/bgd/regl/B13_14p/IssWWW.exe/Stg/d2/11-01.htm (accessed June 2015).

„Chislennost personala, zanyatogo nauchnymi issledovaniyami i razrabotkami, po kategoriyam" (2013), *["The number of personnel engaged in R&D], Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli,* RL: http://www.gks.ru/bgd/regl/B13_14p/IssWWW.exe/ Stg/d3/21-02.htm (accessed June 2015).

„Chislo predpriyatij regiona" (2013) *["The number of businesses in a region"], Regiony Rossii. Sotsial'no-ekonomicheskie pokazateli,* URL: http://www.gks.ru/bgd/regl/b14_14p/ IssWWW.exe/Stg/d02/12-01.htm (accessed June 2015).

„All business establishments: Census Bureau, the Business Information Tracking Series" (2014), *Science and Engineering Indicators 2014,* Table 8-53, High-technology establishments as a percentage of all business establishments, by state: 2003-2010 URL: http:// www.nsf.gov/statistics/seind14/index.cfm/state-data/download.htm (accessed January 2016).

Battese, Coelli (1988), „Prediction of Firm-level Technical Efficiencies with a Generalized Frontier Production Function and Panel Data", *Journal of Econometrics*, Vol. 38, pp. 387-399.

Freeman, C. (1987), *Technology Policy and Economic Performance: lessons from Japan*, Pinter, London.

„High-technology establishments" (2014), Census Bureau, the Business Information Tracking Series (various years), *Science and Engineering Indicators 2014,* Table 8-53, High-technology establishments as a percentage of all business establishments, by state: 2003-2010, URL: http://www.nsf.gov/statistics/seind14/index.cfm/state-data/download.htm (accessed January 2016).

Kumbhakar, S., Lovell, K. (2004), *Stochastic Frontier Analysis*, Cambridge U.P.

„Number of Patents Granted as Distributed by Year of Patent Grant: U.S. U.S. Patent and Trademark Office" (2014)**,** A Patent Technology Monitoring Team Report*, (December, 2014)* URL: http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm (accessed January 2016).

Number of institutions (2010), „U.S. National Center for Education Statistics, Digest of Education Statistics", annual. URL: http://www.nces.ed.gov/programs/digest (accessed January 2016).