Modeling the Development of Regional Economy and an Innovation Space Efficiency

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Abstract

Forming the regional space of innovation is accompanied by the simultaneous development of various structures. The contemporary model of innovative development assumes interactions between government, industry, and universities. In this paper, the set of potential links between research organizations and the innovation activity of enterprises is characterized as the innovative space and is seen as a resource for innovation.

Obtaining quantitative characteristics of such links and interactions is one of the most difficult tasks in analysing innovation processes. Our hypothesis is that regional innovation depends on the size of the innovation space and on how effectively it is used. The econometric modeling results do not contradict our hypothesis.

Our estimates of the size of the innovation space used by regions of Russia when creating new production technologies confirm the high potential value of this resource. Using a Computable General Equilibrium (CGE) model that we developed, we analysed the innovative elements of regional economies (based on the example of the Republic of Bashkortostan) and quantitatively assessed the effects of different scenarios that aim to improve the socioeconomic system. We included an indicator of the effective use of the innovation space for a given region as one of the agents of the CGE model production function.

Our results indicate the important role of regional authorities in promoting cooperation between the state, industry, and the research and education communities as well as in developing regional innovation systems.

Keywords: regional economy; innovation; econometric modeling; check of hypotheses; stochastic border; efficiency assessment

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Accomplishing the following objectives would contribute to the development of the knowledge economy in Russia:

- Upgrading research institutes, including those in the system of the Russian Academy of Sciences;
- Upgrading the national education system;
- Integrating all elements of the innovation system i.e. universities, research institutes, and high-technology companies [OECD, 2014].

One of the main criteria that is used globally to measure the productivity of innovation systems is research and development (R&D) results, measured as output of innovative products, the number of new technologies, patents, and academic publications. Generally accepted indicators of the productivity of innovation activity include R&D expenditures (absolute or relative to GDP, and their unit cost effectiveness). Statistics indicate that Russia significantly lags behind OECD member countries in innovation. Thus, in 2012 R&D expenditures in Russia amounted to 1.13% of GDP [Rosstat, 2015] compared to an average of 1.97% of GDP spent on R&D among EU member states, and 2.4% of GDP in OECD countries [Russian Government, 2014]. Russia's public expenditures on education as a share of GDP and total government budget also remain below the OECD average at 3.9% and 10.9%, respectively, compared to the corresponding average figures of 5.6% and 12.9% for OECD countries [OECD, 2014].

At the same time, the 2015 National Report on Innovation in Russia noted that '*increased R&D expenditures do not result in the growth of inventions or ideas*', which is one of the '*major problems… with the current research environment*' [MED, RVC, 2015]. The authors of the report conclude that increasing R&D expenditures would be inappropriate. Others, such as Alexander Varshavsky [*Varshavsky*, 2016], hold a contrary opinion, noting the low level of R&D funding in Russia: '*in absolute terms, Russia came in 9th place globally for R&D expenditures in 2012 lagging behind not just the US, China, and Japan but also France, UK, and Taiwan.*' When these expenditures are measured as a share of GDP: '*Russia came in 29th place out of 37 countries [and] 28th in terms of per capita R&D expenditures.*' Between 2000 and 2013, the number of R&D personnel dropped from 888,000 to 727,000. As a result: '*Russia lies in 28th place out of 37 countries in terms of the number of researchers per 100,000 population.*' On the basis of these data, Varshavsky (2016) concludes that attributing the low productivity of innovation exclusively to problems within the research environment is incorrect. Reforming the higher education system and academies of sciences takes the form of closing down research organizations, steps which negatively affect the country's intellectual capital nationally and regionally. Such a reform approach leaves no chance for increasing the country's reserve of 'intellectual resources' or effectively using these resources. An analytical review of international university mergers [*Romanenko et al.*, 2015] emphasizes the difficulties in accomplishing such mergers and in managing the newly merged organization without conflict.

Surveys designed to measure Russian entrepreneurs' perceptions of the productivity of public spending on R&D, intellectual property protection, and on the development of innovation infrastructure also deserve a mention. The majority of respondents believed that efforts to set up a national innovation system in Russia remain largely fragmented, unsystematic, and limited [RVC, 2013; Ekspert-RA, 2012]. Producers are poorly motivated to be innovative partly because of the low level of competition in the market; meanwhile, the important role played by government in the economy makes the use of 'administrative resources' a more attractive option than technological development. Thus, in 2013 only 10.1% of Russian companies introduced innovations [Rosstat, 2013a], which is 80%-83% lower than in Germany or the UK. The share of high-tech products in total Russian exports is 10%, compared to 18% in the US and 27% in China [World Bank, 2013]. '*About one third of companies do not allocate any funds for innovation activities. A majority of the most active companies spent less than 5% of revenue on innovation activities in 2010, while only 7% of them spent more than 10% of their revenue on innovation.*' [*Ivanov et al.*, 2012].

An important aspect of developing an innovation-based economy is promoting regional innovation, and upgrading the regional innovation systems (RIS) as part of a national strategy. Linking innovative development with overcoming the resource-based development scenario both nationally and regionally has by now become a cliché. At the same time, regional development is seen as a '*systemic process… implemented mainly through the application of scientific, technological, and managerial innovations*' [*Kleiner, Mishurov*, 2011]. The major components of a RIS are R&D organizations, universities, innovative companies, and the infrastructure providing all actors with access to the necessary resources.

The latest model of regional innovation development (that of the Triple Helix) applied in the countries leading in innovation imply coordinated efforts by government, industry, and universities [*Etzkowitz*, 2008]. Such an approach is used in the US, UK, Germany, and France. Given Russia's well-developed basic research capabilities, this model can also be fully applied in Russia to the whole innovative cycle, from generating innovative ideas to the mass production of end products. Nevertheless, '*obviously the government, businesses, and the society have different ideas about universities' contribution to innovation development, while various regions face different challenges and have different potential to promote knowledge- and innovations-based economic growth*' [*Gibson, Butler*, 2013]. Various researchers have noted that a crucial factor of successful innovation processes is the ability of regional actors to work together [*Golichenko, Balycheva*, 2012; *Makarov*, 2010; *Efimova*, 2012; *Lapayev*, 2012; *Makoveyeva*, 2012; *Rumyantsev*, 2013; *Simachev*, 2012; *Shchepina*, 2011]. Communication networks connect groups (clusters) of companies, universities, and R&D centres. In addition to direct effects, such interactions create positive externalities and synergies [*Polterovich*, 2010].

Regarding the definition of a RIS, it has been noted that such systems are 'components of the national innovation system localised for specific territories. Most researchers agree about defining the *qualitative characteristics of regional innovation systems* (italics by authors). A RIS includes several connected elements (organizations and institutions) and has boundaries (limits) separating it from the surrounding environment [*Mikheeva*, 2014]. Measuring the *quantitative characteristics* of such networks, and their interactions, is one of the most difficult aspects of studying innovation processes. It involves improving metrics, performing calculations, and conducting experiments to assess the role of regions in the development of various national innovation systems [OECD, 2010].

This paper analyses the potential links between various components of Russian RIS, namely the organizations generating new knowledge and innovative ideas; design bureaus and institutes; and innovative companies. The proposed methodology for collecting and verifying quantitative data on the role of science and industry in the innovation process allows us to estimate the intellectual resources absorbed by industry, and the potential for interaction between various actors at national and regional levels. Our hypothesis suggests that the emerging links within regional and national innovation systems serve as inputs for the innovation process, the productivity of which is in direct proportion to the share of effective interactions between R&D organizations and companies operating in a given region. Our estimates of the productivity of such cooperation are included in the innovation component of the Computable General Equilibrium (CGE) model of regional economy (based on the example of the Republic of Bashkortostan). We also present and analyse various scenarios to increase the productivity of the regional socio-economic system.

Assumptions, hypotheses, and models

We consider organizations which conduct R&D and generate new knowledge as the creators of innovative ideas. These include academy of science institutes, universities, and other research organizations. Innovations emerge as a result of interactions between new knowledge-creating organizations, design institutes and bureaus, and innovative companies. The institutional conditions for such interactions and its productivity are determined by the state. Thus the *overall innovation infrastructure* can be defined as the set of organizations which create new knowledge, innovative enterprises which help develop new technologies, products and services, and the institutional environment which affects this process. The *overall innovation space* – the totality of potential links between knowledge creators and innovative companies – is seen as a *resource for innovation activity.* The number of such links determines the size of the innovation space.

Innovations can be notionally divided into several types: technological, informational, organizational, and marketing. For the first kind of innovations, new production technologies are particularly important; Christopher Freeman considered the capability of developing these as an important characteristic of an innovation system [*Freeman*, 2011]. Experimental techniques for measuring the innovation space, which we apply here to new production technologies, are also relevant for other kinds of innovations. The concepts of 'overall infrastructure', 'overall space', and 'size of the overall space' are generalizable for each type of innovations.

Let S_i be the number of organizations generating new knowledge in region *i*; B_i — is the total number of innovative companies in region *i*.

Thus, the number of potential links between organizations creating new knowledge and innovative companies, i.e., the size of the overall innovation space $\overline{V}_i$ in region *i* will be limited by the value $\overline{V}_i = S_i B_i$.

Suppose we take a specific type of innovation. Let α_i be the share of R&D organizations participating in the creation of this kind of innovation in region *i* of the total number of R&D organizations; β_i is the share of innovative companies in region *i* cooperating with R&D organizations in developing innovations of this type out of the total number of innovative companies in the given region. Thus, the size of the innovation space for this type of innovation produced, $\overline{V}_i$ in region *i* equals $V_i = \alpha_i S_i \times \beta_i B_i = \alpha_i \beta_i S_i B_i = w_i \overline{V}_i$, where $w_i = \alpha_i \beta_i$ is the share of innovation space for this type of innovation of the total innovation space.

Let us introduce a production function describing how the number of newly created innovations of this type depends on the number of R&D organizations and their collaborating innovative companies, which we call the 'innovation resources'. Let Q_i be the number of innovations created in region *i* in a unit of time. Then $Q_i = f(\alpha_i S_i, \beta_i B_i)$. To simplify the analysis, we use the power function of the kind $Q_i = a(\alpha_i S_i)^{\delta_S} (\beta_i B_i)^{\delta_B}$. Let us introduce a normalizing condition $a = 1$ to determine the productivity of cooperation between the R&D organization and the regional company.

Assertion 1.

Let us assume that the condition $\delta_S = \delta_B = \delta > 0$ (1) holds true.

In that case, the number of innovations of a specific type created in the region directly depends on the size of the overall innovation space. If condition (1) holds true, it means that the elasticity of the number of newly created innovations to the number of R&D organizations is the same as the elasticity to the number of companies. Assertion 1 means that if condition (1) holds true, the results of innovation activities will be determined by the number of potential links between new knowledge-generating organizations and innovative companies operating in the region i.e. by the size of the overall innovation space.

Indeed, let us assume that condition (1) holds true. Then after applying a transformation, we get: $Q_i = (\alpha_i \beta_i)^{\delta} (S_i B_i)^{\delta} = w_i^{\delta} \overline{V}_i^{\delta}$.

In that case, the production function may be represented as $Q_i = d_i \overline{V}_i^{\delta}$, where $\overline{V}_i = S_i B_i$, $d_i = w_i^{\delta}$.

Thus if condition (1) holds true, the size of the overall innovation space can be seen as a resource for creating any specific type of innovation.

Hypothesis 1: The results of Russian regions' innovation activities directly depend on the size of overall innovation space.

To test hypothesis 1, it would suffice to check if condition (1) holds true. Let us designate $\delta_S = \delta$. Note that η can have a positive or negative value. Then after applying a transformation, we get: $Q_i = (\alpha_i \beta_i)^{\delta} (S_i B_i)^{\delta} (\beta_i B_i)^{\eta}$.

In that case, the production function may be represented as: $Q_i = b_i \overline{V}_i^{\delta} B_i^{\eta}$, where $b_i = (\alpha_i \beta_i)^{\delta} \beta_i^{\eta}$.

Empirical testing of hypothesis 1 is carried out by testing the statistical hypothesis[1] $H_0^1:\ \eta^2 = 0$. We present the results of this hypothesis testing using data on the number of newly developed production technologies in the next section. The productivity of the overall innovation space in terms of creating specific innovation types is measured on the basis of the stochastic frontier concept.

Assumptions:

1) α_i, β_i are random values;

2) the share $w_i = \alpha_i \times \beta_i$ of the innovation space for a specific type of innovation of the total innovation space can be presented as $w_i = \overline{w} e^{\varphi_i - \psi_i}$, where $\overline{w}$ is a constant, φ_i is a normally distributed random value with zero expectation, and ψ_i — a non-negative random value with semi-normal distribution.

If hypothesis 1 holds true, then:

$$Q_i = d_i \overline{V}_i^{\delta} = w_i^{\delta} \overline{V}_i^{\delta} = e^{\delta \ln w_i} \overline{V}_i^{\delta} = e^{\delta (\ln \overline{w} + \varphi_i - \psi_i)} \overline{V}_i^{\delta} = \overline{w}^{\delta} \overline{V}_i^{\delta} e^{v_i - u_i},$$

Where:

$v_i = \delta \varphi_i$ is a normally distributed random value with zero expectation;

$u_i = \delta \psi_i$ is a non-negative random value with semi-normal distribution.

The random component $v_i - u_i$ reflects how the innovation process is affected by uncertainty and productivity factors. Normally distributed random value v_i with zero expectation is applied to model the effect of the former: $v_i \in N(0, \sigma_v^2)$. The effect of productivity factors is modelled using an independent from v_i non-negative random value u_i with zero-truncated normal distribution and zero expectation: $u_i \in N^{+}(0, \sigma_u^2)$.

According to the stochastic frontier concept [*Kumbhakar, Lovell*, 2004], $\overline{w}$ is the largest expected share of overall innovation space used by innovative regions, which determines the stochastic frontier production function $Q_i = \overline{w}^{\delta} \overline{V}_i^{\delta} e^{v_i}$. The stochastic frontier production function $Q_i = \overline{w}^{\delta} \overline{V}_i^{\delta} e^{v_i - u_i}$ can be presented as $Q_i = (\overline{w} e^{-\psi_i})^{\delta} \overline{V}_i^{\delta} e^{v_i}$. Then the random value $\widetilde{w} = \overline{w} e^{-\psi_i}$ can be interpreted as the share of overall innovation space effectively used by the region to create a specific type of innovation. Note that for any region, the inequality $\widetilde{w} \le \overline{w}$ holds true.

The function $Q_i = \overline{w}^{\delta} \overline{V}_i^{\delta} e^{v_i - u_i}$ in logarithmic form looks like this:

$$\ln Q_i = c + \delta \ln \overline{V}_i + v_i - u_i, \qquad (2)$$

Where: $c = \delta \ln \overline{w}$.

Since $\overline{w} \le 1$, then $c \le 0$. Given estimated parameters $c, \delta, \sigma_v^2, \sigma_u^2$ we have $\overline{w} = e^{c/\delta}$. We can also estimate the mathematical expectation [*Battese*, 1988]:

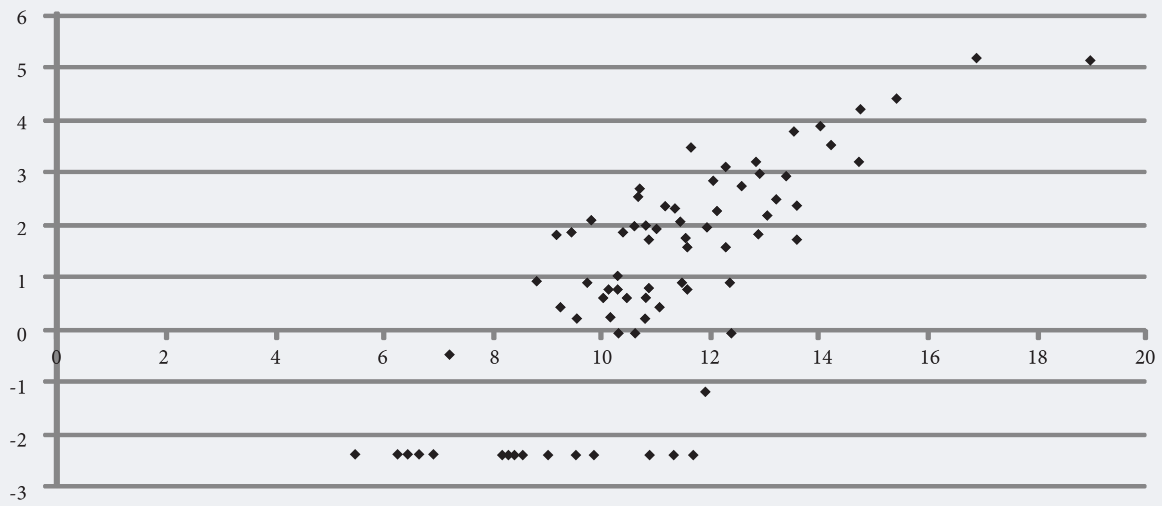
$$TE_i = E(e^{-u_i} \mid v_i - u_i) = \frac{\Phi(\widetilde{\mu}_i / \sigma_* - \sigma_*)}{\Phi(\widetilde{\mu}_i / \sigma_*)} \exp\{\frac{1}{2}\sigma_*^2 - \widetilde{\mu}_i\},$$

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

TE_i may be seen as an indicator of the region's effectiveness in making use of the overall innovation space to create a specific type of innovation. To measure $\widetilde{w}_i$ (the share in that space which is productively used by the region), the value $(\overline{w}^{\delta} \times TE_i)^{1/\delta}$ is applied. Then the value $\widetilde{V}_i = \widetilde{w}_i \overline{V}_i$ can be taken as the size of the innovation space for a specific type of innovation. Innovation dynamics and the number of innovations created in all regions are determined by the parameter $\overline{w}$. The latter's growth rate affects the growth of the stochastic frontier $Q_i = \overline{w}^{\delta} \overline{V}_i^{\delta} e^{v_i}$, i.e., the growth of expected number of innovations created in productive innovative regions.

[1] Establishing links between R&D organizations and companies, and creating innovation are seen as random processes. Therefore, the number of innovations created in a unit of time is also random.

Figure 1. **Dependency of the number of newly developed production technologies *teh*12$_i$**



(ordinate or vertical axis) on $\overline{V_i}$ (size of the overall innovation space in the region) (abscissa or horizontal axis) based on data for 2010–2012, in logarithms

Source: compiled by the authors.

The growth rate of $\overline{w}$ is determined by the ratio of parameters c and δ: since $c \leq 0$, if δ grows, $\overline{w}$ also grows; if c grows, so does $\overline{w}$. Simultaneous growth of these two parameters indicates an increased share of productively used innovation space and increased innovation activity overall. If c and δ change in opposite directions, growth of $\overline{w}$ will be determined by the growth of the ratio c/δ. An important advantage of applying the stochastic frontier concept to measure parameters c and δ is their tolerance of non-innovative regions' characteristics.

Thus if hypothesis 1 holds true, we can measure the share of overall innovation space the region uses to create innovations of a specific type. In subsequent sections of the paper, we present the results of testing hypothesis 1 and measuring the share of overall innovation space in Russian regions. We use official Russian statistical data from Rosstat on the number of newly developed technologies, R&D organizations, and innovative companies for the period 2008–2012.

Data, hypotheses testing, and the estimates of the model parameters

Table 1 below presents the indicators we used to test hypothesis 1 and to estimate the size of the overall innovation space in Russian regions. Table 1 also shows the labels used for these indicators and the sources of the data.

Using the above designations, the number of innovative companies in the region is determined by the value $B_i = P_i \times S_i$.

We also apply the following designations:

*teh*10$_i$ — the average number of production technologies annually developed in the region in 2008–2010;[2]
*teh*11$_i$ — the average number of production technologies annually developed in the region in 2009–2011;
*teh*12$_i$ — the average number of production technologies annually developed in the region in 2010–2012.

Figure 1 shows the logarithmic dependence of *teh*12$_i$ (newly developed production technologies) on $\overline{V_i}$ (the size of the overall innovation space) for 80 Russian regions based on data for 2010–2012.

To test statistical hypothesis $H_0^1:\ \eta^2 = 0$, the parameters were estimated for the following model:

Table 1. **Data sources**

Label	Indicator
teh_i	Number of new production technologies developed in the region [Rosstat, 2013c]
P_i	Number of companies in the region [Rosstat, 2013d]
I_i	Share of innovative companies out of the total number of companies in the region [Rosstat, 2013a]
S_i	Number of companies in the region which conduct R&D [Rosstat, 2013b]
Source: compiled by the authors.	

[2] An averaged out value is used because of the need to smooth out source data.

Table 2. **Estimated parameter values for model (3)**

Estimates	Model (3) для *teh*10	Model (3) для *teh*11	Model (3) для *teh*12
(1)	(2)	(3)	(4)
δ	0.7814***	0.7140***	0.6808***
c	–5.7531***	–4.9016***	–4.4133***
η	–.1993	–0.1710	–0.1380
$H_0^2:\sigma_u^2=0$	rejected	rejected	rejected
Log likely	–116.56	–124.66	–130.83

Source: compiled by the authors.

$$\ln Q_i = c + \delta \ln \overline{V}_i + \eta B_i + v_i - u_i. \quad (3)$$

Rows 3-5 (Table 2) contain the estimated values of parameters δ, *c*, and η in model (3), calculated using the maximum likelihood method. Row 6 (Table 2) presents the results of testing the hypothesis $H_0^2:\sigma_u^2=0$ — *no inefficiency* [*Ayvazyan, Afanasyev*, 2015]. The last row contains the maximum values of the log-likely function.

In the models built for 2010, 2011, and 2012, the estimated η values are insignificantly different from zero (by about 10%). The statistical hypothesis H_0^1 is not rejected.[3] The results of testing the hypothesis H_0^1 do not contradict hypothesis 1 (that the results of Russian regions' innovation activities are directly dependent on the size of the overall innovation space).

The second, third, and fourth columns of Table 3 present the estimated values of the parameters δ and *c* in model (2) for each year (2010, 2011, and 2012). Rows 7-8 contain the computed values for c/δ and $\overline{w}$ respectively.

Next, we tested the following two hypotheses.

Hypothesis 2: the elasticity δ of the number of newly developed production technologies to the size of the overall innovation space is constant in time.

Hypothesis 3: the constant *c* in model (2) is constant in time.

To test hypotheses 2 and 3, we constructed model (4) with variable coefficients based on data for the three-year period 2010–2012:

$$\ln Q_{it} = c + c_0 t + (\delta + \delta_0 t)\ln \overline{V}_{it} + v_{it} - u_{it} \quad (4)$$

Column (5) in Table 3 contains the estimates of model (4) parameters. The estimate of parameter δ_0 in model (4) is significant at the 10% level. Hypothesis 2 is rejected in favour of an alternative: that the elasticity δ of the number of newly developed production technologies to the size of the overall innovation space decreases with time. The estimate of parameter c_0 model (4) is significant at the 10% level. Hypothesis 3 is rejected in favour of an alternative: that the constant *c* in model (2) increases with

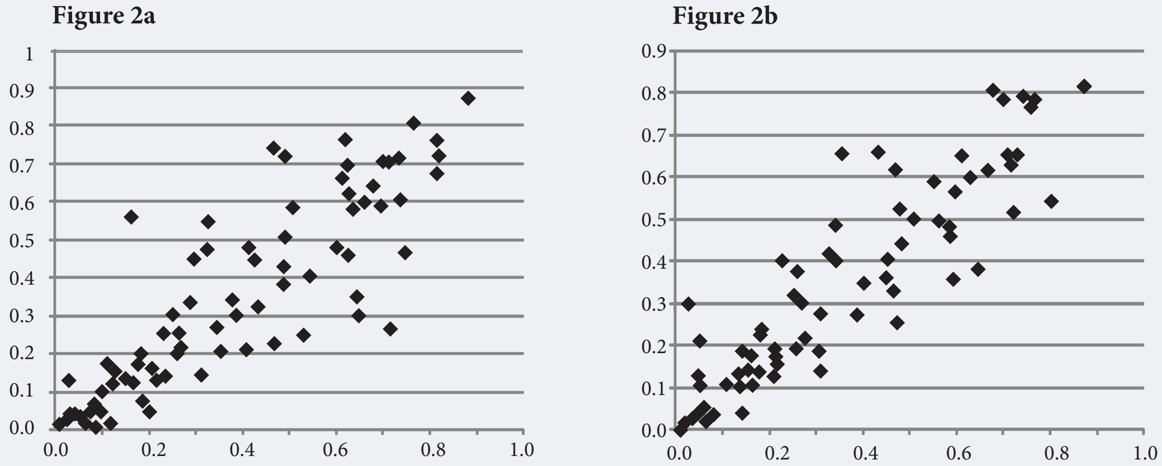
Table 3. **Estimated parameter values for models (2) and (4)**

Estimates	Model (2) for *teh*10	Model (2) for *teh*11	Model (2) for *teh*12	Model (4) for 2010–2012
(1)	(2)	(3)	(4)	(5)
δ	.6832***	.6465***	.6170***	.6816***
c	–5.2781***	–4.7775***	–4.1406***	–5.2571***
δ_0	—	—	—	–.0355*
c_0	—	—	—	.5618*
$H_0^2:\sigma_u^2=0$	отвергается	отвергается	отвергается	отвергается
Log likely	–116.72	–125.16	–130.88	–375.62
c/δ	–7.7249	–7.3889	–6.7107	
$\overline{w}=e^{c/\delta}$	4.42E-04	6.18E-04	1.22E-03	
рост $\overline{w}$ %		39.9	97.1	

Source: compiled by the authors.

[3] A positive and statistically significant estimated effect of δ in model (3) can be accompanied by an insignificant effect of η, due to possible multicollinearity effect. To additionally test the hypothesis H_0^1: $\eta^2 = 0$ against an alternative hypothesis $H_A^1:\eta^2>0$, we can use statistics $Lr = 2(\ln L(H_1^A) - \ln L(H_1))$, where $L(H_1^A)$ is the value of the likelihood function under the alternative hypothesis, and $L(H_1)$ is the value of the likelihood function under the zero hypothesis. Ayvazyan et al. [*Ayvazyan et al.*, 2012] show that if at a specified significance level of α value of test statistics Lr is bigger than the $\chi^2_{2\alpha}(1)$ fractile of distribution level $2\alpha\ \chi^2(1)$, hypothesis H_0^1 should be rejected.

Figure 2. **Distribution of regional overall innovation spaces' productivity values**



Source: compiled by the authors.

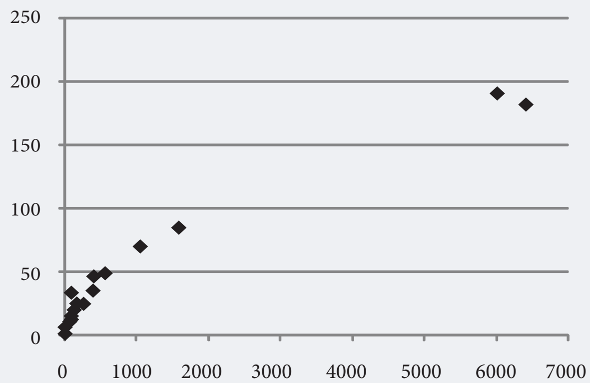
time. Although the estimated value of δ significantly decreases, the ratio c/δ is growing. Consequently, we observe a growth of the share $\overline{w} = e^{c/\delta}$ of the overall innovation space used by innovative regions to develop new production technologies. The last row in Table 3 shows the growth of $\overline{w}$ as a percentage.

For each of 80 Russian regions, we estimated the productivity of how well the regions use their overall innovation space $TE_i = E(e^{-u_i}/v_i - u_i)$: TE_i^{2010} — for 2010, TE_i^{2011} — for 2011, and TE_i^{2012} — for 2012 are presented in columns 5-7 in Table 4, respectively.

In Figure 2a, each dot represents the productivity of the regional innovation system. The abscissa (horizontal) axis shows regional TE_i^{2010} values for 2010; the ordinate (vertical) axis — TE_i^{2011} for 2011, with a correlation coefficient of 0.8876. The productivity estimates for the next two years are strongly dependent. In Figure 2b, the abscissa (horizontal) axis shows TE_i^{2011} values for 2011, the ordinate (vertical) axis — TE_i^{2012} values for 2012, with a correlation coefficient of 0.8959. The correlation between the productivity estimates which determines the stability of regions' rankings over time is equally high. Measuring the productivity of innovation space provides important characteristics of regional innovation activities, supplementing their estimated technological productivity as described in [*Ayvazyan et al.*, 2016].

Table 4 (columns 2–4) shows the estimated values $\widetilde{V}_i = \widetilde{w}_i \overline{V}_i$ of the size of the innovation space used by each of the 80 Russian regions to develop new technologies, based on data from 2012. Figure 3 illustrates the correlation between the number of newly developed production technologies (the ordinate or vertical axis) and the value $\widetilde{V}_i = \widetilde{w}_i \overline{V}_i$ – the size of the innovation space that Russian regions made use of to develop such technologies (the abscissa or horizontal axis). The two dots in the upper right section of Figure 3

Figure 3. **Correlation between the number of newly developed production technologies and the value $\widetilde{V}_i = \widetilde{w}_i \overline{V}_i$ - the size of the innovation space used to develop these technologies (2012 data)**



Source: compiled by the authors.

Table 4. **Estimates for the size of the technology innovation space (columns 2–4), and productivity of use of the overall innovation space in Russian regions (columns 5–7)**

	$\widetilde{V}_{i\ 2010}$	$\widetilde{V}_{i\ 2011}$	$\widetilde{V}_{i\ 2012}$	TE_i^{2010}	TE_i^{2011}	TE_i^{2012}
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Belgorod Region	18.587	26.421	34.315	0.812	0.76	0.769
Bryansk Region	9.197	17.81	23.376	0.736	0.718	0.632
Vladimir Region	14.898	6.62	19.06	0.53	0.249	0.314
Voronezh Region	59.947	78.764	103.936	0.635	0.582	0.482
Ivanovo Region	1.212	6.724	20.214	0.162	0.559	0.495
Kaluga Region	30.483	43.397	99.066	0.879	0.873	0.814
Kostroma Region	2.044	1.181	3.955	0.641	0.353	0.655
Kursk Region	0.046	0.245	2.167	0.024	0.04	0.131
Lipetsk Region	0.046	0.671	1.358	0.028	0.131	0.133
Moscow Region	460.693	956.31	1583.051	0.409	0.48	0.445
Orel Region	5.809	5.159	4.958	0.618	0.46	0.329
Ryazan Region	0.683	1.93	3.096	0.113	0.171	0.14
Smolensk Region	5.584	2.635	2.108	0.647	0.302	0.19
Tambov Region	0.681	0.04	0.039	0.12	0.017	0.011
Tver Region	5.778	4.534	6.528	0.352	0.209	0.173
Tula Region	8.757	10.112	34.847	0.375	0.34	0.484
Yaroslavl Region	16.891	19.004	52.712	0.432	0.325	0.413
City of Moscow	2304.145	3934.007	6415.534	0.12	0.121	0.118
Republic of Karelia	0.253	0.242	5.179	0.079	0.05	0.212
Republic of Komi	0.685	1.234	3.998	0.108	0.178	0.237
Arkhangelsk Region	22.089	22.884	41.637	0.734	0.607	0.652
Vologda Region	2.508	1.951	4.07	0.231	0.14	0.188
Kaliningrad Region	4.534	5.913	7.257	0.679	0.644	0.381
Leningrad Region	11.66	16.601	26.15	0.611	0.663	0.615
Murmansk Region	0.048	0.04	0.039	0.014	0.014	0.011
Novgorod Region	3.431	5.23	10.273	0.622	0.697	0.781
Pskov Region	3.061	2.578	2.047	0.486	0.383	0.272
City of St. Petersburg	1150.927	2743.222	6034.485	0.284	0.336	0.407
Republic of Adygei	0.043	0.037	0.035	0.076	0.055	0.048
Republic of Kalmykia	0.041	0.035	0.032	0.267	0.212	0.16
Krasnodar Region	24.805	42.081	78.579	0.249	0.304	0.275
Astrakhan Region	11.609	13.711	14.453	0.615	0.767	0.781
Volgograd Region	2.643	1.314	0.264	0.091	0.058	0.018
Rostov Region	34.521	49.317	67.456	0.232	0.255	0.197
Republic of Dagestan	16.186	11.074	26.254	0.763	0.804	0.541
Republic of Ingushetia	0.041	0.035	0.033	0.205	0.16	0.108
Republic of Kabardino-Balkaria	2.316	4.606	5.662	0.508	0.586	0.456
Republic of Karachai-Cherkessia	0.042	0.036	0.033	0.138	0.126	0.112
Republic of Northern Ossetia – Alania	0.045	0.038	0.036	0.036	0.036	0.031
Chechen Republic	0.041	0.035	0.033	0.263	0.202	0.129
Stavropol Region	0.048	0.041	0.04	0.013	0.01	0.007
Republic of Bashkortostan	16.682	20.068	25.166	0.162	0.13	0.107
Republic of Mari El	0.045	0.038	0.037	0.044	0.036	0.024
Republic of Mordovia	6.54	11.903	19.157	0.817	0.725	0.65
Republic of Tatarstan	47.622	81.455	261.866	0.179	0.173	0.225
Republic of Udmurtia	5.887	11.677	35.67	0.262	0.254	0.376
Republic of Chuvashia	16.388	17.393	22.625	0.69	0.592	0.356
Perm Region	59.635	105.258	150.129	0.295	0.448	0.363
Kirov Region	0.694	0.041	0.04	0.086	0.011	0.008
Nizhny Novgorod Region	356.293	409.947	569.755	0.657	0.596	0.567
Orenburg Region	8.879	3.642	5.336	0.309	0.148	0.141
Penza Region	16.387	15.005	41.563	0.741	0.467	0.616
Samara Region	102.141	133.777	156.808	0.489	0.507	0.501

Table 4 continued

	$\tilde{V}_{i\ 2010}$	$\tilde{V}_{i\ 2011}$	$\tilde{V}_{i\ 2012}$	TE_i^{2010}	TE_i^{2011}	TE_i^{2012}
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Saratov Region	47.392	49.843	94.334	0.712	0.709	0.628
Ulyanovsk Region	6.533	18.636	35.529	0.461	0.741	0.785
Kurgan Region	0.253	0.04	3.906	0.078	0.018	0.302
Sverdlovsk Region	232.885	592.361	1062.763	0.32	0.477	0.522
Tyumen Region	44.015	46.814	48.776	0.344	0.275	0.224
Chelyabinsk Region	126.056	241.501	432.767	0.701	0.709	0.644
Republic of Altai	0.044	0.039	0.037	0.066	0.024	0.022
Republic of Buryatia	7.256	2.658	5.015	0.711	0.265	0.302
Republic of Tuva	0.612	0.751	0.561	0.49	0.722	0.513
Republic of Khakassia	0.043	0.037	0.035	0.081	0.071	0.045
Altai Region	5.111	6.852	6.785	0.151	0.136	0.102
Zabaikalskiy Region	0.659	0.229	0.035	0.212	0.135	0.041
Krasnoyarsk Region	33.851	94.745	184.217	0.323	0.55	0.587
Irkutsk Region	38.744	30.549	130.824	0.486	0.427	0.66
Kemerovo Region	18.293	26.684	43.465	0.624	0.629	0.597
Novosibirsk Region	109.523	261.62	394.804	0.422	0.452	0.405
Omsk Region	25.345	20.193	33.751	0.54	0.402	0.351
Tomsk Region	10.309	16.298	17.936	0.177	0.206	0.193
Republic of Sakha (Yakutia)	1.825	0.244	1.378	0.199	0.046	0.109
Kamchatka Region	0.249	0.68	1.376	0.101	0.103	0.11
Primorskiy Region	5.164	13.469	28.742	0.126	0.155	0.18
Khabarovsk Region	7.001	2.858	1.484	0.187	0.073	0.039
Amur Region	0.045	0.039	0.037	0.036	0.027	0.019
Magadan Region	4.955	9.253	8.047	0.812	0.678	0.801
Sakhalin Region	1.119	0.651	2.765	0.467	0.223	0.4
Jewish Autonomous Region	0.039	0.034	0.032	0.385	0.305	0.14
Chukchi Autonomous Region	0.035	0.032	0.031	0.597	0.474	0.255

Source: compiled by the authors.

represent the cities of Moscow (on the right) and St. Petersburg (on the left). The dots in the lower left section represent the remaining 78 regions. The six dots visually distinguishable from the rest represent Moscow, Sverdlovsk, Nizhny Novgorod, Chelyabinsk, Novosibirsk, and Kaluga regions.

Table 5 lists 11 regions of Russia ranked by the average annual number of production technologies they developed between 2010 and 2012. Their combined share amounts to about 75% of the total number of such technologies. The table also presents a ranking of regions' productivity in terms of making use of their overall innovation space. Two regions – the cities of Moscow and St. Petersburg – develop significantly more new technologies than the others (Figure 3). However, the leaders in terms of productivity of using their overall innovation space are Kaluga, Irkutsk, and Chelyabinsk regions.

Makarov et al. [*Makarov et al.*, 2014] group 80 Russian regions based on their industrial production structure. Using the principal components method and the commonality criteria described in the aforementioned work, they propose five groups of regions: basic regions (with a balanced economy), manufacturing, mining, agricultural, and developing regions (column 4, Table 5). Each of the five groups can be put into one of two groups – 'basic' (with a balanced economic structure) or 'manufacturing' regions.

In Table 5, regions marked with * are among the top ten, and those marked with ** among the top 20 leaders in terms of the Innovation Development Index compiled by the Association of Innovative Regions of Russia [AIRR, 2015]. This ranking is based on 23 indicators, including 'Internal R&D expenditures as a percentage of gross regional product (GRP)', 'revenues from technology exports as a percentage of GRP', 'fixed assets replacement ratio', 'GRP per worker employed in the region', 'Share of high-technology and research-intensive industries' output as a percentage of GRP.'

[*Ayvazyan, Afanasyev*, 2015] propose an agent-oriented model of new production technologies' development based on cooperation between business and science. This model includes, along with other regional economic characteristics, estimates of the productivity of the innovation space. We present the latter in Table 4 and subsequently used them to add an innovation component to the Computable General Equilibrium (CGE) model, as discussed in the next section.

Table 5. **Characteristics of Russian regions' innovation activities**

№	Region	Productivity ranking	Group
1	City of St. Petersburg*	9	basic
2	City of Moscow*	11	basic
3	Moscow Region*	8	basic
4	Sverdlovsk Region*	6	manufacturing
5	Nizhniy Novgorod Region*	5	manufacturing
6	Chelyabinsk Region**	3	manufacturing
7	Novosibirsk Region**	10	basic
8	Kaluga Region*	1	manufacturing
9	Krasnoyarsk Region**	4	basic
10	Irkutsk Region	2	basic
11	Samara Region**	7	basic

Source: compiled by the authors.

Regional CGE model with an innovation component

Experts are familiar with numerous models based on various factors of science and technology (S&T), including the accumulation of knowledge. These belong to the group of economic growth models traceable all the way back to the theories of Adam Smith, David Ricardo, and Robert Solow (for example, see [*Solow*, 1956; *Afanasyev*, 1988]). In the 1990s, endogenous growth models became popular in economic theory, of which the best-known are those proposed by Paul Romer [*Romer*, 1990] and Charles Jones [*Jones*, 1998]. These models were based on indicators such as knowledge obtained via R&D, human capital, and technologies. In Romer's model, the rate of S&T progress was determined by the number of researchers and their productivity. In other words, as these two indicators grew, so too did the rate of S&T progress (a statement not always confirmed empirically). Jones's model was based on Romer's and includes the level of technological development as an additional indicator. Both these models imply that the number of researchers and knowledge producers are proportional to the country's population. Detailed reviews of models of knowledge production can be found in [*Varshavsky*, 1984, 2003; *Makarov*, 2009].

Without going into the mathematical finer points of the above-mentioned and other existing models, we note that none of the models enable us to measure the multiplicative effects of changes in the sphere of innovation on the wider economy. On the contrary, our proposed model does accomplish this, both in the mid- and long-term. It is also distinctive by applying the Computable General Equilibrium (CGE) theory to economic modelling. As far as we know, our model is the first large-scale dynamic model which deals with sectors of the knowledge economy (or the 'new economy') individually, while taking into account their interconnections with the overall economic system. The impact on the latter can be measured by monitoring changes in the following quantitative indicators:

1) Investments in R&D and educational organizations, innovative and other companies;
2) VAT, corporate and organizational tax, property tax, personal income tax, and unified social tax rates;
3) Salaries in the R&D and education sector, and wages paid by innovative and other Russian companies and organizations;
4) Deposit interest rates for companies and individuals;
5) Volume of social payments to households (pensions, benefits, etc.);
6) Supply of money in the economy.

The first version of the model focused on the whole Russian national economy, and was not modified to match specific regional conditions [*Makarov et al.*, 2009]. Subsequently, we adjusted the model in line with the regional features of the Republic of Bashkortostan, thanks to the efforts of local researchers (N.Z. Solodilova and D.N. Beglov). During the next stage, we included in the set of economic agents' production functions the indicator to measure the productivity of using the overall innovation space when developing production technologies (TE_i) in the Republic of Bashkortostan for the years 2010, 2011, and 2012.

Brief description of the model

The model comprises seven economic agents, of which the first three are producers:

1) R&D and education sector, which provides training for students and knowledge creation services, and includes public and private higher education institutions, as well as R&D organizations;
2) Innovation sector – all the innovative companies and organizations in the Republic of Bashkortostan;
3) Other industries in the Republic of Bashkortostan;
4) All consumers – made up of all households in the Republic of Bashkortostan;

5) Regulatory authorities;
6) Banking sector;
7) Outside world.

The production potential of the first three economic agents in our model can be estimated using a modified Cobb–Douglas function. The resulting value reflects the added value created by the relevant sector in the form of end products:

$$Y_{i(t)} = A_i^r \cdot \left(\left(K_{i(t-1)} + K_{i(t)} \right) / 2 \right)^{A_i^k} \cdot \left(D_{il(t)}^{p1} + D_{il(t)}^{p3} \right)^{A_i^l} \cdot e^{\left[\alpha_i \cdot \left(\frac{\sum_{\lambda=1}^{t-1} D_{iz(\lambda)}^{p1}}{t-1} \right) + \beta_i \cdot \left(\frac{\sum_{\lambda=1}^{t-1} D_{ir(\lambda)}^{p1}}{t-1} \right) + \gamma_i \cdot \left(\frac{\sum_{\lambda=1}^{t-1} D_{in(\lambda)}^{p1}}{t-1} \right) + \delta_i \cdot TE_i \right]}, \quad (5)$$

Where:

i = 1, 2, 3 — number of an economic agent;
A_i^r — dimension coefficient;
A_i^k — capital assets coefficient;
A_i^l — labour input coefficient;
α_i — coefficient of the sector's expenditures on new knowledge, primarily R&D;
β_i — coefficient of the sector's expenditures on training and education;
γ_i — coefficient of the sector's expenditures on innovative goods;
δ_i — coefficient of the sector's productivity in using the overall innovation space.

The production function has the following components: capital assets (average values for the beginning ($K_{i(t-1)}$) and the end ($K_{i(t)}$) of the year); demand for labour at public (P_{3l}) and private (P_{1l}) prices.

The last multiplier of the function is a bit more complex: it represents the effect that the sector's spending on knowledge, training and education, and innovative products has on the added value created. As we can see, formula (1) takes into account demand for these production factors during the preceding period. Thus, if no investments were made in these areas during the previous period, we have $e^0 = 1$, i.e., R&D and innovation activities did not affect the output at all. Yet as such investments (however small they may be) are made annually, the production function – with this 'intellectual' component growing all the time – positively affects the sector's output of end products.

We highlight certain features of the function applied in our model which distinguish it from other models, i.e., models that take S&T progress into account. Exogenous S&T progress functions are the most commonly used in economics due to the relatively simple procedures for evaluating parameters. Note that S&T progress can be factored in in three different ways: via labour, capital, and output parameters. In the last case (the most common one), S&T progress is presented as an exponentially growing time function with a constant growth rate. In other words, changes in the S&T progress parameters in this case remain outside the economic system they describe.

We can see from equation (5) that in our production function (where S&T progress is also applied as an exponential factor), expenditures on knowledge, training and education, and innovative products are used as endogenous values. Thus, our function belongs to the group of endogenous S&T progress functions mentioned in the introduction of this paper. Its primary difference from other functions of the same group (e.g. the Romer function) lies in the fact that our function takes into account capital assets and all knowledge creation costs.

A significant difference of the production function compared with its previous version is the presence in equation (5) of the indicator to measure the productivity of using the overall innovation space TE_i for the region in question. This indicator captures the 'degree of cooperation between research and industry in the region' i.e. effectively, the institutional conditions put in place by the government for developing the regional innovation system. Thus, the model takes into account not only the sectors' expenditures on innovation, education and training, and new knowledge, but also the impact of existing economic institutions. Figure 4 presents a conceptual scheme of the model overall.

According to Figure 4:

I. The R&D and Education sector (*economic agent 1*) provides services whose consumers can be divided into three groups:

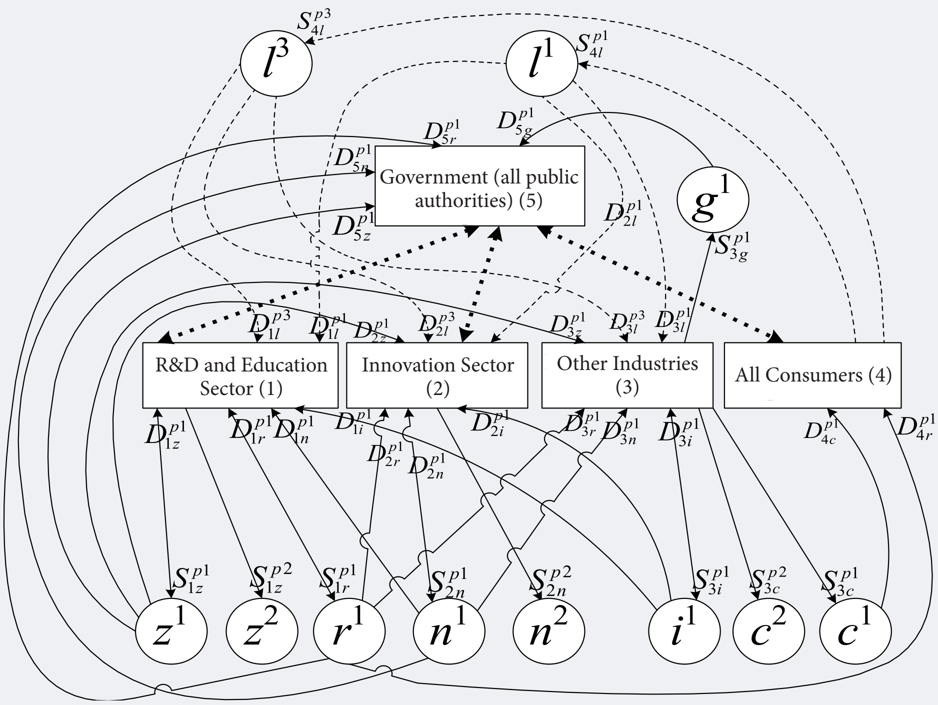
1) The Innovation sector (mostly R&D services); other sectors of the economy; and *economic agent 5*. According to the System of National Accounts (SNA) classification, this concerns non-marketed R&D services whose consumers include, among others, the sector itself. In the model these services are represented by the variable S_{1z}^{p1};

2) *Economic agent 5* (free educational services according to the SNA methodology); paid education and training services for the innovation sector; other sectors of the economy; and households. Some of these services are consumed by the sector itself. In the model, these services are represented by the variable S_{1r}^{p1};

3) Services for the outside world: R&D services paid for by research grants: S_{1z}^{p2}.

II. The Innovation sector's (*economic agent 2*) output is sold in two main types of markets:

Figure 4. **Conceptual scheme of applying the CGE model to innovation sector**



Graphic symbols:

— economic agent;

— market where the product is distributed among the economic agents included in the model;

— the agent is selling a product in the market;

— the agent is buying a product;

— agents' actions in connection with labor supply and demand;

— taxes and subsidies.

Parameters

c^1 — end products market for households;
c^2 — end products market beyond the region;
g^1 — end products market for economic agent 5;
l^1 — labor market for private companies;
l^3 — labor market for public sector organizations;
n^1 — innovative products market;
n^2 — innovative products market beyond the region;
z^1 — knowledge market;
z^2 — knowledge market beyond the region;
r^1 — education and training services market.

Source: compiled by the authors.

1) Internal market. Here we mean end products made using technological and other innovations. According to the Rosstat methodology, this indicator is based on the volume of shipped innovative products. Their consumers include all production sectors together with the innovation sector itself (their R&D and technological innovations costs), and *economic agent 5* (public funding allocated to support innovation activities). In the model, these products are represented by the variable S_{2n}^{p1};

2) Outside world: S_{2n}^{p2}.

III. Other industries (*economic agent 3*) make the following product types (divided into four groups):

1) End products for households (S_{3c}^{p1}) — products for everyday consumption (food, etc.); consumer durables (household appliances, cars, etc.); and services;

2) End products for *economic agent 5* (S_{3g}^{p1}), including the following:

a) End products for government agencies (according to the SNA methodology, government agencies' expenditures on procurement of finished products), including:

- Free services for the population provided by health and culture organizations (except educational services, which are provided by *economic agent 1*);
- Services for the whole of society, such as public administration, law enforcement, national defence, basic research, communal and housing services, etc.;

b) End products for non-profit organizations serving households, i.e. free social services;

3) Investment products – expenditures to upgrade produced and non-produced material assets i.e. capital assets (S_{3i}^{p1}). According to the SNA methodology, this product type is defined as the sum of gross accumulated capital assets and increased tangible current assets, minus the costs of acquired new and existing capital assets (except write-offs).

To make products and provide services, *producing agents 1–3* acquire the following production elements:

1) Labour (at public and private sector prices): D_{1l}^{p3}, D_{1l}^{p1}, D_{2l}^{p3}, D_{2l}^{p1}, D_{3l}^{p3} and D_{3l}^{p1};

2) Investment products: D_{1i}^{p1}, D_{2i}^{p1}, and D_{3i}^{p1};

3) Innovative products: D_{1n}^{p1}, D_{2n}^{p1}, and D_{3n}^{p1};

4) Knowledge provision services (e.g. R&D): D_{1z}^{p1}, D_{2z}^{p1}, and D_{3z}^{p1};

5) Educational and training services (commercial education and training): D_{1r}^{p1}, D_{2r}^{p1}, and D_{3r}^{p1}.

IV. All consumers (*economic agent 4*) acquire end products produced by other industries: D_{4c}^{p1}. Households also use paid educational services (D_{4r}^{p1}), while the sector provides labour for private companies (S_{4l}^{p1}) and public organizations (S_{4l}^{p3}).

V. Economic agent 5 sets tax rates, determines the amount of public funding and subsidies allocated to producers and social recipients, and acquires end products (D_{5g}^{p1}) produced by other industries. In addition, as already noted, agent 5 creates demand for innovative products (D_{5n}^{p1}), non-market R&D services (D_{5z}^{p1}), and free educational services (D_{5r}^{p1}).

VI. The Banking sector sets deposit interest rates.

After iterative recalculations using the model, combined demand and supply in each product and service markets even out due to two different mechanisms applied depending on the pricing mode. It should be noted that in most cases prices are set on the basis of price indices for the reference period. When products' or services' prices are set by the government, the balance is achieved by adjusting the budget; in the case of legal or shadow markets, the balance is set by changing the actual price.

The number of markets in our model is as follows: end products for households, end products for economic agent 5, investment and innovative products, education and knowledge provision services are sold in six internal markets. Additionally, the model takes into account three external markets: innovative products (n^2), knowledge (z^2), and other exported products (c^2). Thus we have nine product markets, and two labour markets.

Results

In the present study, we analysed four different options for changing the funding arrangements for innovation activities, R&D and educational organizations:

1. Increasing investments in innovation activities, R&D and education by 30% compared with the current level, at the cost of proportionally reducing expenditures in other economic sectors;

2. Reducing investments in innovation activities, R&D and education by 30% compared with the current level, while proportionally increasing expenditures in other economic sectors;

3. Reducing overall taxation of innovative companies, R&D and educational organizations by 30% compared with the current level, i.e. reducing the amount of collected taxes by 30% and leaving these funds in the organizations' bank accounts.

4. Increasing investments in innovation activities, R&D and education by 30% compared with the current level, while at the same time also reducing overall taxation of innovative companies, R&D and educational organizations by 30%.

Our calculations performed using the model indicated that in the long-term, investments in innovation result in a higher growth rate than do investments in other sectors of the economy. The same holds true for providing tax breaks to research-intensive companies. The actual calculated results for the four above-mentioned options are presented below (Table 6).[4]

[4] These results are described in more detail in the report on research conducted in the framework of the National Science and Technology Programme of the Republic of Bashkortostan, entitled 'Long-term S&T Foresight for the Republic of Bashkortostan.'

Table 6. **Changes of average annual gross regional product growth rates by 2030 (*as a percentage of the basic scenario*)**

Option 1	+0.684
Option 2	–0.124
Option 3	+0.316
Option 4	+1.112
Source: compiled by the authors.	

In our opinion, the methodology for building CGE models to analyse the economic system's innovation component can also be applied in other Russian regions.

Conclusions

The approach to studying the emergence of a knowledge economy in Russian regions, and the conditions required for its development, is focused on an important innovation resource: namely, the potential links between R&D organizations and innovative companies. The potentially significant role of this resource is due to the fact that its effective use directly affects regional innovation performance and overall economic growth on macro- and meso-levels.

The number of new production technologies developed in regions is proportional to the size of the overall innovation space, which is determined by the number of potential links between R&D organizations and innovative companies operating in the region. The results of the study do not contradict our hypothesis.

Between 2010 and 2012, the share of the innovation space used by innovative regions to develop new technologies grew. For each year during this period, we estimated the size of the overall innovation space used by Russian regions to develop new production technologies.

Regional authorities play an important role in promoting partnerships between the state, industry, and the research and education community, as well as in further developing the RIS. Their contribution may lead to a bigger overall innovation space in the region, and to its increased productivity in terms of creating specific types of innovation.

We developed a CGE model to analyse the innovation component of a regional economy (based on the example of the Republic of Bashkortostan) and estimate in quantitative terms the consequences of various scenarios aimed at increasing the productivity of a socio-economic system. In our opinion, the methodology for building CGE models which take into account S&T progress can also be applied in other Russian regions.

In the long-term, investments in innovation result in a higher growth rate compared to investing equal amounts in other sectors of the economy. The same holds true for providing tax breaks to research-intensive companies. At first glance, returns on investments into the innovation sector are not as high as could be expected. On the other hand, supporting high-technology sectors, while this does not yield quick results, enables the existing S&T potential to be maintained. This can subsequently provide the basis for diversifying the regional economy. We emphasize that our proposed model allowed us to estimate just the overall effect of the scenarios for the whole economic system, while analysing specific sectors of the economy would provide higher-quality data. However, models disaggregated by economic sectors would require inter-industry data as inputs, which are currently unavailable. Nevertheless, we emphasize that supporting R&D, education, and innovation should be seen as a regional development priority as confirmed by our calculations.

We added an indicator to measure the productivity of using the overall innovation space in a given region into the production function of economic agents in the CGE model. This makes the model more realistic because it takes into account the institutional structure of the environment in which the agents operate.

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