Agent-based model of a knowledge economy for the large spatial country

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Abstract. The purpose of the research is to create an instrument for assessing the impact of various components of knowledge economy (number of scientists, innovative enterprises, distribution of them at large territory etc.) on macroeconomic and social indicators.

1. Quick outlook on basic dynamic models with a knowledge factor.

A large number of models dealing with factors of technological and related growth are described in the literature. All of them assume an economy with no spatial factor. The models with accumulated knowledge, which belong to a large class of economic growth models, have their principles laid in the works of classics of economic thought: A.Smith, D.Ricardo, K.Marx. Then followed the models for optimization of consumption function (Ramsey, 1928; Koopmans, 1964; Cass, 1965) and models which outlined the idea of substitution of economic growth factors (Harrod, 1939; Domar, 1946). The latter idea was fully implemented in Swan (1956) and Solow (1957). The neoclassical models, developed by Solow and other economists, assume that technological features of economy are set by the form and parameters of production function. The stationary state (or trajectory of balanced growth) is characterized by constant value for capital endowment (fixed capital per worker) and by a number of other indicators.

There are various ways in which models for economic growth account for the new knowledge, which leads to scientific and technological progress. The following models are commonly specified in the literature:

- with exogenous and endogenous scientific and technological development;
- with technological progress reflected or not reflected to the factors of economic growth (mainly, in labor or capital);
- with neutral or non-neutral type of technological progress.

Until recently, the models with exogenous scientific and technological growth have been frequently employed by researches due to the possibility of using a simple procedure for assessing parameters.

The new step was done when the models with endogenous scientific and technological progress where introduced. (Romer, 1990; Jones, 1998). The approach aims at considering new knowledge and ideas (for-profit research), the level of openness of economy and growth of human capital as the sources of scientific and technological progress. It is assumed that 1) scientific research leads to development of new and to improvement of old products, and 2) the number of “knowledge generating” scientists and specialists influenced on the economic growth.

The detailed review of models for knowledge economy may be found in the works by CEMI RAS researcher A.E.Varshavsky (Varshavsky, 1984; Varshavsky, 2003).

All the above mentioned models consider representative agent(s), which are an aggregation of a large number of heterogeneous firms or researchers with different levels of productivity. Consequently, one of the goals of our research is to develop an instrument, which would allow taking into consideration individual features of micro level agents. This enables obtaining realistic forecast for the impact of knowledge economy on commonly monitored macroeconomic indicators.

2. An approach of agent based models puts individual behavior into consideration.

An agent-based model arguably has essential advantages in comparison with classic models: 1) a closer to reality model of the system; 2) emergence; 3) flexibility; 4) parameter specification without knowledge about global relations.

Recently, a number of agent-based models for different aspects of knowledge economy have been developed according to the literature. Let shortly review some of them.

Researchers of Turin University (Italy) describe an agent-based model, where innovation is created in a stochastic way through the exchange of knowledge between agents (Antonelli, Ferraris, 2009). The agents of the model are usual workers, researchers and owners of firms (enterprises). Enterprises interact in the framework of the standard economic system. Enterprises may watch each other and copy technologies. Productions functions depend on two factors: 1) productivity and 2) the number of workers.

An important feature of the model is the fact that enterprises are simultaneously located in two two-dimentional spaces. These spaces are “physical” and “technological” grids, with the cells which may contain more than one enterprise. Location on “physical” grid determines possibilities of an enterprise to watch its competitors, abilities to compare the efficiency of work and copy technological decisions. Location on “technological” grid determines technological level and production possibilities of an enterprise. It should be noted that enterprises with similar level of technological development may be, nonetheless, far from each other on “physical” grid. Expenditure on innovation allows changing location on the two grids and, consequently, offers new opportunities to enterprises.

Enterprises offer their produced goods at the market. Demand is formed by consumers on the basis of their purchasing power and the level of salaries. The price is set through the equilibrium between supply and demand. A cycle of the model ends after enterprises sell all their goods, spend all revenues on salaries and on financing research and development. Then net profit is calculated. This net profit is compared with the average profit of neighbors in the grid. If financial result is worse than that of other enterprises with the same technological level, the enterprise increases expenditure on financing innovations in order to increase productivity.

The results of some simulations revealed that the speed for obtaining new knowledge depends on enterprise location on a grid, in other words, on concentration of enterprises with high technological level facilitates production and usage of knowledge.

The paper of the scientists from Germany and the UK (Pyka, Gilbert, Ahrweiler, 2006) employs an agent-based model to analyze the processes of innovative development in high technology industries.

Agents are innovative firms. They sell their goods to other agents-firms and to consumers. Firms buy raw and other materials for production and, what is most important, try to enhance their indicators with the help of innovations, cooperation with other firms and adaptation to the needs of consumers.

If an innovation, developed or used by a firm, was successful (e.g., helped exceed a certain threshold of profits) and implementation of this innovation was in cooperation with another firm, a network of cooperating firms may be created. According to the authors, the main purpose of their work is to develop an agent-based model to study topologies of such network structures.

Researchers of Imperial College (London) analyze exchange of knowledge between small and medium enterprises, which interact at the software market (Chli, Wilde, 2006). An agent-based model, with firms-agents and their services as bit-lines of fixed length, was created for technical implementation of interaction processes. Market demand is set exogenously as bit-lines of the same length as supply of services by firms. In initializing the model, the sequence of bits is randomly determined. The correspondence of services offered by a firm to the demand by final consumer is reveled in the course of interaction according to certain rules. In case of differences between supply and demand, the set of bit-lines is modified with the help of genetic algorithms. Firms may exchange the most successful technological ideas, which are similarly represented by bit-lines.

According to the authors, one of the important results is the fact that the strategy of exchanging knowledge is more profitable for firms than isolated production without interaction.

Scientists of Naval Postgraduate School (USA) constructed an agent-based model which studies methodological issues related to a phenomenon of "knowledge flows". The model analyzed the work of software producing enterprise. Computational simulations revealed the personnel structure which allows controlling flows of knowledge in a most efficient way (Nissen, Levitt, 2004).

3. The spatial agent based model to study knowledge economy.

Taking into consideration the experience of other countries, in 2009 the Central Economics and Mathematics Institute of the Russian Academy of Sciences developed an agent-based model of Russia`s knowledge economy on the basis of geographical information system (GIS). Geographical information systems allow constructing databases, which combine graphical and attributive presentation of heterogeneous information. These databases provide an opportunity for spatial data analysis and presentation of its results in a form, habitual to users (graphs, diagrams, tables, maps etc.)

Below we provide conceptual description of the developed model.

1. Life cycle of an agent consists of two main stages (birth and death) and intermediate stages, monitored at each step of the work of the model.

2. Agent does not participate in GDP production since his/her birth till a certain age (the default value is 18).

3. Agent may become a usual worker, a scientists or a worker who “applies” knowledge. The strata of scientists creates the basis for formation of the tier of “knowledge-applying” workers.

4. Upon reaching a working age, with a certain probability agent may become a scientist. If agent does not become a scientist till the age of 25, s/he will never be a scientist.

Scientists do not participate in production of GDP, yet:

- a scientist produces knowledge, consumed by «knowledge-applying» workers; and the latter participates in GDP production;
- scientists form the environment which influences the number of «knowledge-applying» workers.

5. Agent stops being a scientist (or «knowledge-applying» worker) due to low salary (if his/her salary becomes lower than the average value in the society, a scientist or «knowledge-applying» worker moves to other industries). A former scientist or «knowledge-applying» worker may return to science if salary in science or in applied science becomes higher than the average value in the society and if the time of interrupting scientific work is less than a certain threshold (5 years by default).

6. Life expectancy of a scientist or «knowledge-applying» worker is higher than of an average person (by default by 10 years). However, life expectancy is not taken into consideration in determining one`s profession.

7. With a certain probability (calculated on the basis of Russian statistical data) agents may have children. The child of a scientist or «knowledge-applying» worker has higher probability of becoming a scientist or «knowledge-applying» worker.

8. Average salary in the developed countries is an exogenous parameter of the model. If the average salary (in science or in other professions) is considerably lower than that in the developed countries, a scientist or «knowledge-applying» worker moves to other country and, consequently, leaves the economic system of Russia.

The model allows estimating the impact of:

- increase of salary (for all types of workers);
- launching of innovation centers;
- additional investment in science.

Specification of the agents in the model was conducted with regard to the following parameters (Fig. 1):

- age;
- life expectancy;
- profession of parent;
- place of work;
- region of habitation;
- income.

The following parameters were taken into consideration in specification of regions (elements of GIS):

- geographic borders;
- population;
- workers of different type;
- GRegionalP;
- per capita GRP;
- investment;
- investment per capita;
- average salary;
- average life expectancy;
- rate of population growth.

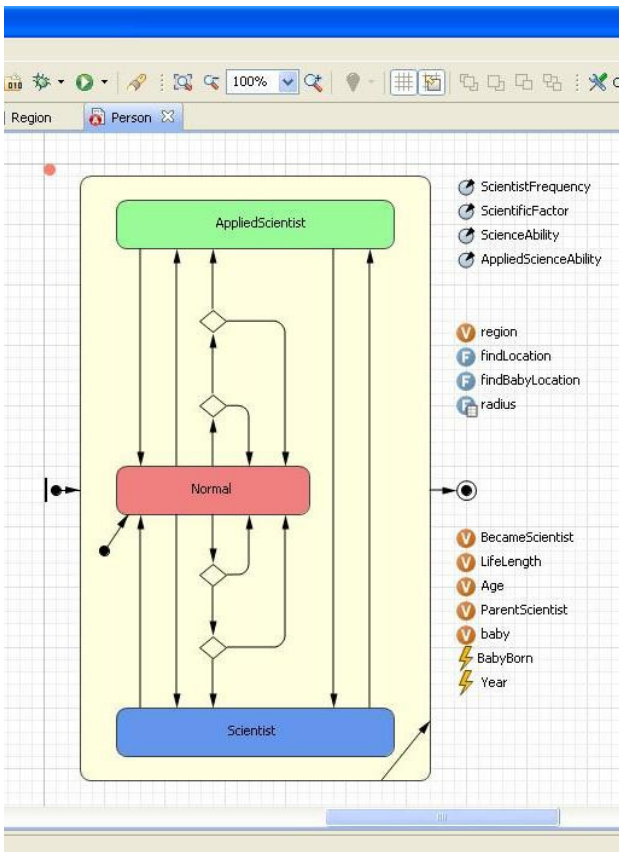

Fig. 1. Specification of agents in AnyLogic (see www.xjtek.com)

Statistical volumes by the Federal Statistical Agency of Russia and sociological data (Russian Longitudinal Monitoring Survey) were used in filling the model with data. The results obtained with the help of computable model for knowledge economy (Makarov, Bakhtizin, Sulakshin, 2007) were employed in specifying parameters of production functions.

Fig.2 demonstrates a working window of our agent-based model. GIS enable obtaining most recent information about social and economic situation of all Russian regions in the course of work of the model. This may be done according to maps and graphical information, which depends on the values of endogenous parameters and changes in real-time.

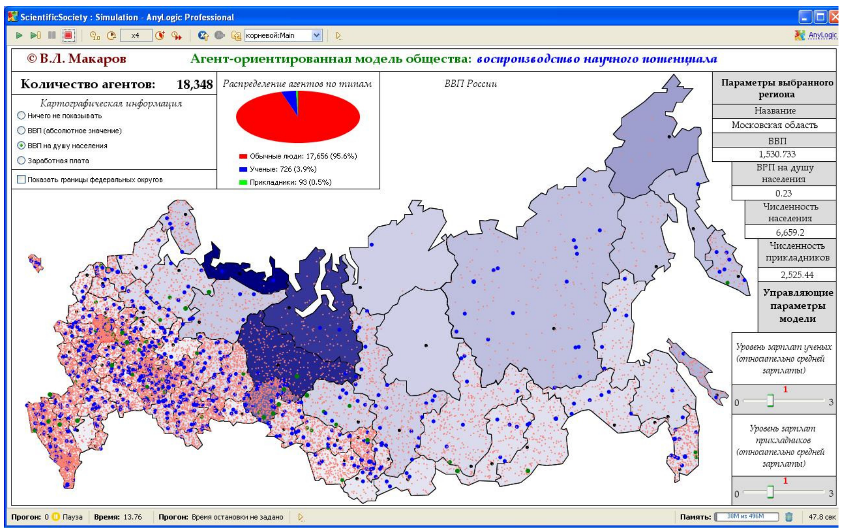

Fig. 2. Working window of agent-based model for Russia`s knowledge economy

4. Simulations.

The first question, we are interesting in, is the influence of the factor of concentration of scientists and knowledge-applying workers in certain sites on various objectives. The number of calculations shows, that Russia needs relatively small number of places for concentration of scientists in contrast with big variety of places to locate knowledge-applying workers. It means in particular, that knowledge-applying workers should be located near from centers of population and production concentration.

The model seems good instrument to calculate long run consequences of today's economic policy. We simulated different policies of the government in the sphere of regulating wages for scientists and knowledge-applying workers in comparison with the average level of wages, rate of inflation, regional differentiation in living conditions.

An interesting but anticipated result says that to create new center of science takes much more time then to extinguish it.

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