THE DYNAMIC MODEL OF THE INNOVATION FUNNEL INDICATORS AND THEIR TRAJECTORIES

Anatoly Selyaninov, Natalia Frolova

Abstract: *The article considers innovation system modeling by the instrumentality of integrated approach. This approach consists of three main parts: differential equation system and stability analysis, agent-based modeling, «innovation funnel». We have converted our model into a flight simulator where parameters and policies can be varied on the fly and the results are displayed immediately. The model user will be able to propose and vary different strategies: number of technology brokers, share of the educational expenditures in total federal budget, operating effectiveness of technology brokers and so on.*

Keywords: *agent-based modeling, innovation, innovation funnel, dynamic model simulation, complex system modeling.*

ACM Classification Keywords: *I.2. ARTIFICIAL INTELLIGENCE: I.2.11. Distributed Artificial Intelligence – Multiagent systems.*

Introduction

The development, selection, implementation and diffusion of innovative technologies is a complex process. Its character is determined by the laws of the innovation system. In this regard, it seems appropriate to study the features of innovative systems with the information technology instrumentality and tools of economic and mathematical modeling. That combines elements of qualitative and quantitative analysis. Modern socio-economic systems management (which include innovative system) due to its increasing complexity requires new, integrated models capable of learning a reality to a new level.

Thorough innovation system research and modeling was realized by the instrumentality of three approaches:

1) agent-based modeling [Макаров, 2012];

2) cumulative and stability development [Киршин, 2011; Семенычев, 2012];

3) innovational funnel [Селянинов, 2012].

Designed agent-based model of innovation system rest to a large extent on innovation funnel concept and logistic dynamics.

«Innovation funnel» is set forth in agent-based model of innovation system and is zeroed in on problem of sequential innovation appearance, selection and realization. Every innovation life cycle in «innovation funnel» begins with cumulative knowledge accumulation about certain innovation good (commodity, service, new resource type or new technology). At start time t_0 volume of innovation output is practically absent or equal zero. After certain period of time innovation life cycle reaches the first critical level t_1, which can cause qualitative transition to exponential growth of innovation process. As it approaches satiation state, gradual slowdown occurs (the second critical level t_2), exponential area of innovation process trajectory got replaced by logarithmic one.

Life cycle of certain innovation ends, curtailing production state and gradual market exit take hold (the third critical level t_3).

Innovation life cycle with patterns pointed out previously, can consistently designed and tested by the instrumentality of logistic curves [Киршин, 2011]. However, pictorial representation of life cycle trajectories is not enough to their analyses and decision support. Visual analysis of logistic trend enables logic identification and development tendency only in general terms. Therefore, it is necessary to design economic and mathematical models, which give us instrumentality of quantitative dynamics assessment, development gauge and innovation system properties research. Comprehensive whole innovation process can be described and examined as a differential equation system corresponding with logistic curve. Such description offer the challenge of forecasting, foreseeing and innovation system management at all.

The dynamics of the innovation system by means of systems of differential equations

For trajectory of indicators x_j, describing innovation system we proposed flexible instrument as a set of differential equations leads to logistic dynamics. Indictor x_j may be considered as a number of innovations on different stages of innovation funnel; therefore *j*-index corresponds to certain stage of innovation process (appearance, selection, support, realization, market exit). Existing models logistic dynamics often exclude immensely important features of this progressive process. In developed model interactions between economic agents on different stage of this process, self-generation of innovation, skewness in innovation development, phenomena of innovation replacement and restricted growth and so on are taken into account (1):

$$\begin{cases} \frac{dx_1}{dt} = x_1 k_1 = x_1(\alpha_1 - \beta_1 x_1) = \alpha_1 x_1 - \beta_1 x_1^2 \\ \frac{dx_2}{dt} = x_2 k_2 = x_2(\alpha_2 - \beta_2 x_2 + \gamma_{12} x_3) = \alpha_2 x_2 - \beta_2 x_2^2 + \gamma_{12} x_2 x_3 \\ \frac{dx_3}{dt} = x_3 k_3 = x_3(\alpha_3 - \beta_3 x_3 + \gamma_{23} x_2) = \alpha_3 x_3 - \beta_3 x_3^2 + \gamma_{23} x_3 x_4 \\ x_1(t_0) = x_1,\ x_2(t_0) = x_2,\ x_3(t_0) = x_3 \end{cases} \tag{1}$$

The system (1) k_j – growth coefficient on *j*-phase of innovation funnel, α_j, β_j, γ_{ij} – certain parameters, which describe innovation growth components.

The system (2), in contrast to system (1), due to additive $\theta_j(t)$ takes into account innovation self-generation possibility:

$$\begin{cases} \frac{dx_1}{dt} = x_1(\alpha_1 - \beta_1 x_1) + \theta_1(t) = \alpha_1 x_1 - \beta_1 x_1^2 + \gamma_{12} x_1 x_2 + \theta_1(t) \\ \frac{dx_2}{dt} = x_2(\alpha_2 - \beta_2 x_2 + \gamma_{12} x_3) + \theta_2(t) = \alpha_2 x_2 - \beta_2 x_2^2 + \gamma_{12} x_2 x_3 + \theta_2(t) \\ \frac{dx_3}{dt} = x_3(\alpha_3 - \beta_3 x_3 + \gamma_{23} x_2) + \theta_3(t) = \alpha_3 x_3 - \beta_3 x_3^2 + \gamma_{23} x_3 x_4 + \theta_3(t) \\ x_1(t_0) = x_1,\ x_2(t_0) = x_2,\ x_3(t_0) = x_3 \end{cases} \tag{2}$$

In case of absence of self-generation innovation effect $\theta_j(t) = 0$. If self-generation innovation effect ($t \to 0$) appears only on initial stage of innovation process, we can use, for example $\theta_j(t) = \frac{a}{b + t^{2k}}$.

Every innovative product, service or technology sooner or later lose novelty and become uninnovative. So, from certain point of time (t_{crit}) growth coefficient changes:

$$\tilde{k}_j(t_{\text{crit}}) = \begin{cases} \bar{\alpha}_j - \bar{\beta}_j x_j(t) + \bar{\gamma}_{ji} x_i(t) + \zeta, t < t_{\text{crit}} \\ -(\underline{\alpha}_j - \underline{\beta}_j x_j(t) + \underline{\gamma}_{ji} x_i(t) + \zeta), t > t_{\text{crit}} \end{cases} \tag{3}$$

Moreover, it is taken into account exogenous disturbance ζ in formula (3). In other words we can consider the following differential equation system:

$$\begin{cases} \frac{dx_1}{dt} = x_1 \tilde{k}_1 + \theta_1(t) \\ \frac{dx_2}{dt} = x_2 \tilde{k}_2 + \theta_2(t) \\ \frac{dx_3}{dt} = x_3 \tilde{k}_3 + \theta_3(t) \\ x_1(t_0) = x_1,\ x_2(t_0) = x_2,\ x_3(t_0) = x_3 \end{cases} \tag{4}$$

Model (4) application let us describe change in number of innovation as a result of two simultaneous differently directed processes: new commodities, services and technologies appearance and gradual market exit, obsolescence. Thus, system (4) is general case of system (1) и (2).

Optimal control criteria for stable progressive innovation system development can be stated like this: It is necessary to replace innovation when $x_j(t)$ target approaching inflection point *M*, in other words when previous innovation approaching its growth limit (see Fig. 1).

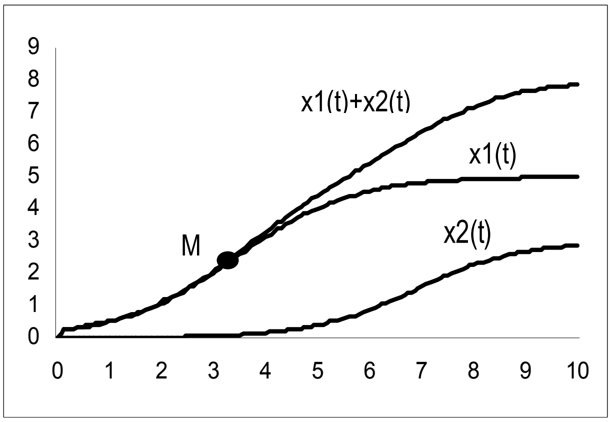

Figure 1. *Optimal introduced innovation replacement*

Of course, special cases of innovation dynamics require special consideration. Appropriate nonlogistic model can be designed. Not every single product has life cycle which consists only of determined market states: market entry, growth, maturity and decline. We can observe multilogistic products too, for instance we can consider «reiterated cycle» (or double-humped cycle):

$$x(t) = \frac{rt^{\beta}}{k}(1 + Ae^{-\alpha kt}) \tag{5}$$

$$\frac{dx}{dt} = \frac{x}{t} - \frac{r}{k} t^{\beta} Ae^{-\alpha kt} \tag{6}$$

Model (5) - (6) illustrates pattern under the code name «new start» or «unsuccessful start», when innovation product after certain interest fading receives new life or second wind due to restyling, repositioning or rebranding. It is possible to use such models, but it is rather difficult to consider such models as a complex differential equations, interpret parameters and carry out thorough research.

Some aspects of agent-based designing

There are a number of various definitions of Agent Based Modeling in the scientific literature. From the viewpoint of practical applications agent based modeling can be defined simply as essentially decentralized, individual-centric (as opposed to system level) approach to model design. When designing an agent based model the modeler identifies the active entities, the agents (which can be people, companies, projects, assets, vehicles, cities, animals, ships, products, etc.), defines their behavior (main drivers, reactions, history, ...), puts them in a certain environment, maybe establishes connections, and runs the simulation. The global (system-level) behavior then emerges as a result of interactions of many individual behaviors.

The study retrieves data from activity report, performance report, memoranda, annual account of more than 30 venture investors, business incubators, industrial parks and others technological brokers. We use also data from Russian and foreign press and materials, from official site belonging to various economic agents.

Profiles of economic agents are based on content analysis of information resources and have been thoroughly identified. Economic agent profile is the set of attributes, set of the main parameters which describe its features and role during innovation process. For instance, technology broker profile includes such characteristics as area, establishment year, number of residents, number of jobsite, rental payment and so on. Some of the profile attributes are unique for every certain agent, the others may coincide.

So, properties, interactions and rules running in innovation system are specified naturally by the instrumentality of equations. Such equations consist of profile variables, and entire «innovation funnel» is described by sets of such variables. So, in other words constructed equations and sets of equations are the projection of real relations and rules.

During modeling we have fulfilled consecutive projection real world of economic agent to virtual world of artificial society. In turn, in artificial society was accomplished subsequent move from set-theoretical model to functional one. Final stage was software implementation by the instrumentality of AnyLogic simulation tool.

ABM of innovation system may be described as a formalized aggregate of 3 sets:

$$< A, R, E >,$$

$A = A_1 \cup A_2 \cup \ldots \cup A_N$ – set of agents; $R \subseteq A_1 \times A_2 \times \ldots \times A_N$ – set of relations between agents with ordered elements $(a_1, a_2, \ldots, a_N)$ for every possible $a_1 \in A_1$, $a_2 \in A_2$, … , $a_N \in A_N$; $E = E_1 \cup E_2 \cup \ldots \cup E_M$ – set of generated experiments.

Interrelationship between theoretical description and functional description of innovation system can be formalized (see Fig. 2).

Practical significance of conducted research consists in realization designed innovation system model as Java application. This application let us put interactive innovation system model on web-sites as an applet and launch it on majority modern platforms without necessity of installing special software. Model was realized in simulation environment program AnyLogic, as a part of complex model «innovation funnel» [Селянинов, 2012]. AnyLogic uses Runge-Kutta 4th order method and Euler method for differential equation system solution. Before simulation launch user can choose either method.

Mathematical models and methods of economic dynamics together with agent-based approach and innovation funnel conception give adequate methodological basement for innovation process description and simulation. Distinctive feature of designed synthetic computer model is possibility to conduct complex scenario-analytical calculations. Such calculations let users explore various aspects of innovation system development.

Experiments have shown that model corresponds with common sense; all conclusions are logical and plausible. As needed model can be adjusted, adapted and utilized to innovation system improvement with regard to certain region or country.

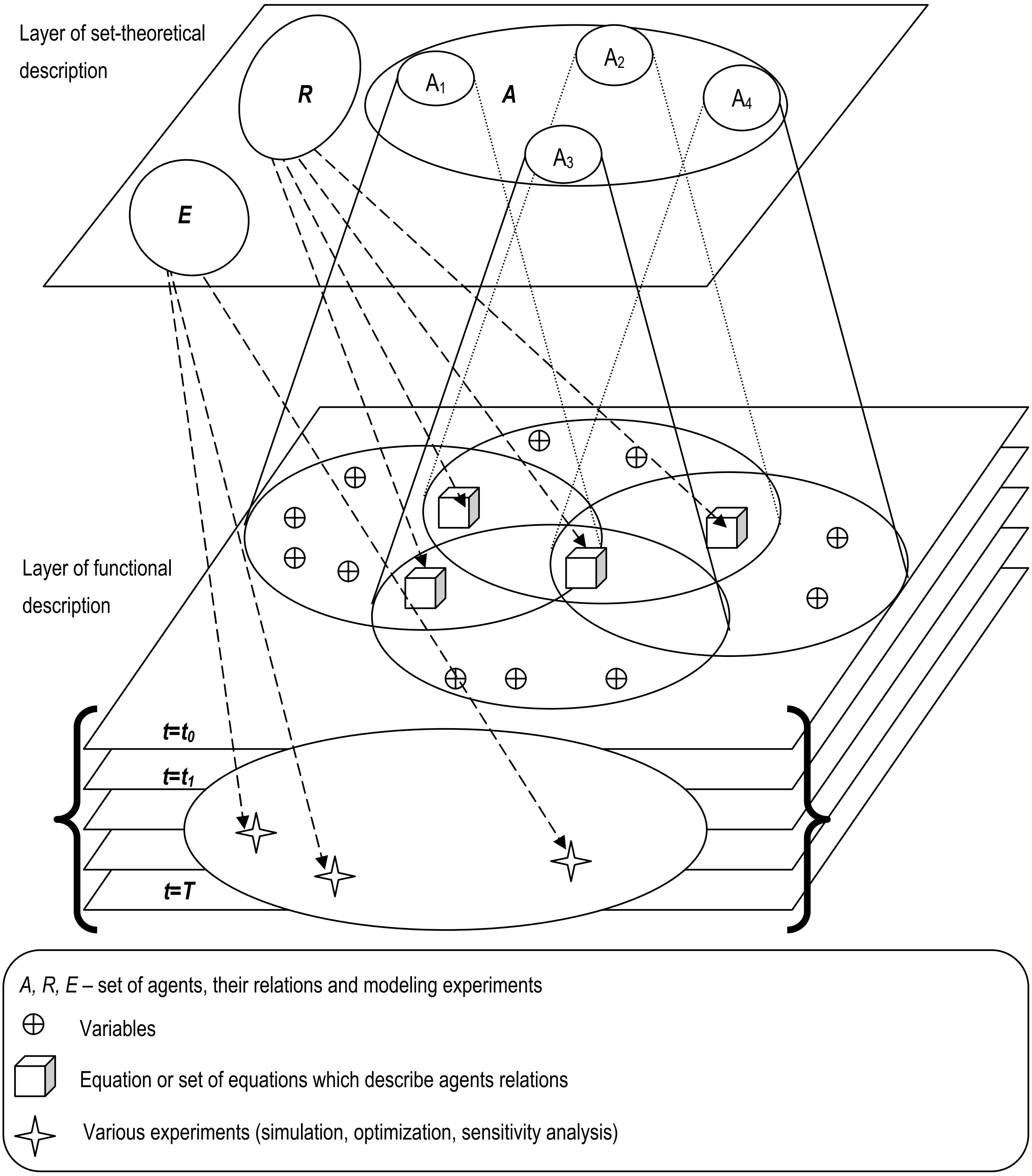

Figure 2. Interrelationship between theoretical description and functional description

Bibliography

[Киршин, 2011] Киршин И.А Моделирование динамики инновационного цикла [Текст] / И. А. Киршин, А. В. Титов // Экономические науки. - 2011. - N 6. - С. 31-35.

[Макаров, 2012] Макаров В.Л. Искусственные общества / В. Л. Макаров // Экономика и математические методы. – 2012. – Том 48, № 3. – С.3-20.

[Селянинов, 2012] Селянинов А.В. Агент-ориентированная модель инновационного процесса появления, отбора и реализации инновационных идей / А.В.Селянинов, Н.В.Фролова // Вестник Пермского государственного университета. Серия «Экономика», 2012. Спец. вып. (12).

[Селянинов, 2012] Селянинов А.В. Исследование двухуровневой структуры «инновационной воронки» с использованием агент-ориентированного моделирования / А.В.Селянинов, Н.В.Фролова // Инновационная экономика и промышленная политика региона (ЭКОПРОМ-2012) / под ред. д-ра экон. наук, проф. А.В.Бабкина : Труды Международной научно-практической конференции. 24 сентября -3 октября 2012 г. Т.2. – Спб.: Изд-во Политехн. ун-та, 2012.-341 с.

[Семенычев, 2012] Семенычев В.К. Моделирование экономической динамики логистическими кривыми с произвольной асимметрией / В.К. Семенычев, В.Н. Кожухова // Вестник Поволжского государственного университета сервиса. – Тольятти, 2012. №4(24). – С. 86-91.

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