Theoretical and methodological foundations for the development and formal model of behavior of a subject of a multi-level innovation environment with information asymmetry

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Abstract. This article provides an overview of the theoretical and methodological foundations for creating formal models of behavior of subjects in a multi-level innovation environment, where information asymmetry plays an important role. In the context of modern trends in innovative development, understanding the impact of information inequality on decision-making and interaction of participants is a key aspect for the effective management of innovation processes. The article discusses various methods for modeling the interaction of actors in an innovation environment, including game theory, agent-based modeling, network analysis and statistical approaches. These methods make it possible to create formal models that reflect the dynamics of the behavior of subjects and their strategies in conditions of information asymmetry. Particular attention is paid to analyzing the impact of information asymmetry on modeling results and assessing the effectiveness of various strategies for managing asymmetry in an innovation environment. The results of the article highlight the importance of further research in the field of modeling innovation processes taking into account information asymmetry to develop effective risk management strategies and create an enabling environment for innovation and development.

1 Introduction

The modern world is characterized by a dynamic and constantly changing innovation landscape, where the relevance and effectiveness of innovation play a key role in the development of the economy, society and technology. Understanding the theoretical and methodological aspects of developing a formal model of subject behavior in the context of a multi-level innovation environment is critical to achieving successful innovative results in conditions of information asymmetry.

Based on the study of extensive scientific literature and active research in the field of economics, management and innovation, this article aims to analyze and discuss the theoretical and methodological foundations underlying the development of formal models of

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subject behavior in a multi-level innovation environment where information asymmetry plays a significant role.

This article examines key concepts and theories related to information asymmetry, behavioral modeling, game theory, multi-level innovation systems, and the evolutionary approach to innovation. This scoping review will highlight important aspects of the study and provide insight into the current state of scientific knowledge in this area.

The purpose of this article is to summarize and analyze existing research, identify the main directions of research and develop the basis for further research work in the field of formalization of subject behavior models in multi-level innovation environments, taking into account information asymmetry

The study of the theoretical and methodological foundations for developing a formal model of subject behavior in a multi-level innovation environment with information asymmetry is a complex and multifaceted area of research. We need an analytical review of the literature in order to highlight the main concepts, approaches and research results, as well as to see the trends and directions of development in this area, reflecting the relationship between information asymmetry and modeling the behavior of a subject in a multi-level innovation environment. There are a number of works in this area that make important contributions to the understanding of this issue .

Analysis of the concept and structure of multi-level innovation systems as a system of interaction and transition between levels in innovation environments and their impact on information asymmetry are considered in the works of scientists such as Carayannis, E.G., & Campbell, D.F. (2009) , Leydesdorff, L., & Etzkowitz, H. (2000) , Lundvall, B. A. , Carlsson, B. (2006).

The basis and study of the theoretical foundations of the analysis of a subject's behavior model in conditions of information asymmetry and in an innovative environment were the developments of such scientists as Aghion, P., Dewatripont, M., & Stein, JC (2008) , Stiglitz, JE (2000). "The Contributions of the Economics of Information to Twentieth Century Economics". The Quarterly Journal of Economics, 115(4), 1441-1478. Assessing the impact of information asymmetry on the decisions of innovative actors and the development of innovative projects (for example, the works of Stiglitz (2000) , Akerlof (1970), Spence (1973).).

The role of signaling and information transfer strategies in the context of reducing information asymmetry and its impact on decision making in an innovative environment.

Analysis of formal models describing the behavior of innovative entities on multi-level platforms is presented in the works of Nelson & Winter (1982), Cyert & March (1963), Simon (1955). These researchers substantiated evolutionary approaches to modeling the behavior of a subject in an innovative environment, taking into account dynamic changes and adaptations.

A review of methods for formalizing models of subject behavior in innovative environments with information asymmetry (mathematical models, agent-based models and others) is presented in the works of Dosi, G., & Nelson, RR (2010) , Arthur, WB (2009) , Klevorick, AK, Levin, R. C., Nelson, R. R., & Winter, S. G. (1995) , David, P. A. (1985). The works of these unique researchers also present practical examples of the use of formal models for the analysis and forecasting of innovation processes in various industries and areas.

An analysis of works that use an evolutionary approach to understand the development and change of innovation processes includes the works of Nelson, R. R., & Winter, S. G. (1982) , Dosi, G. (1982) , Dosi, G. (1988).

Methodologists for analyzing innovation systems are reviewed in works such as Edquist, C., & Johnson, B. (1997). "Institutions and organizations in systems of innovation". In Systems of Innovation (pp. 41-63). Routledge and Lundvall, B. A. (Ed.). (1992). "National

Systems of Innovation: Towards a Theory of Innovation and Interactive Learning." Pinter Publishers.

Consideration of game models and game theory in the context of innovative interactions and strategic behavior of subjects in conditions of information asymmetry , as well as analysis of decisions made by participants in an innovative environment taking into account uncertainty and risk are most fully presented in the studies of Fudenberg, D., & Tirole, J. (1991) and Reinganum, J. F. (1989) . These authors consider not only methods for formalizing models of subject behavior in innovative environments with information asymmetry (mathematical models, agent-based models, etc.) , but also practical examples of the use of formal models for analyzing and forecasting innovation processes in various industries and areas.

The reviewed works cover key studies on the theoretical and methodological foundations for developing a formal model of subject behavior in a multi-level innovation environment with information asymmetry. Researchers in these fields are actively working to increase understanding of innovation processes, behavioral aspects of agents, and the role of information asymmetries in innovation environments. This analysis of scientific literature presents different approaches to the theoretical and methodological foundations for modeling the behavior of a subject in the context of multi-level innovation environments with information asymmetry. Researchers pay attention to the role of information asymmetry, game theory, dynamic capabilities of organizations, the evolutionary aspect of innovation and the formalization of models for understanding and analyzing innovation activity at different levels.

2 Material and research methods

To develop a formal model of subject behavior in a multi-level innovation environment with information asymmetry, data from various sources was used. It was based on scientific articles covering the theoretical foundations of innovation, economic theory and technological development. Additional data were obtained from statistical reports on the innovative activity of enterprises and organizations, as well as from the results of experiments and surveys conducted as part of research into the innovation environment. To create a formal model of subject behavior in a multi-level innovation environment with information asymmetry, data from several sources were used. Key data sources include statistical reports on the state of innovation activity, analytical data on the interaction of actors in the innovation environment, and the results of previous studies related to information asymmetry in the field of innovation.

The methodological approach to the development of a formal model was based on an analytical review of existing models of behavior of subjects in an innovation environment, game theory, and the concepts of information asymmetry. Methods of system analysis, mathematical modeling and statistical data analysis were used to build and verify the model.

To analyze and develop a formal model, a combined methodological approach was used, including the analysis of theoretical models of behavior of subjects, as well as empirical methods of data collection and processing. When developing the model, the basic concepts of game theories, information theory and decision-making models under conditions of uncertainty were taken into account.

The study included a review and analysis of key models and concepts, including information asymmetry theory, models of agent behavior in innovation environments, and game theory. These models and concepts were used as the basis for developing a formal model of subject behavior in a multi-level innovation environment. Key models and concepts such as models of behavior of firms in an innovative environment, the theory of information asymmetry, game theory and decision theory were reviewed and analyzed. The selection of

these models was carried out on the basis of their applicability to the problems under consideration.

Approaches to analysis . Methods of system modeling, analytical and numerical solution of models, statistical data analysis were used to test hypotheses and assess the impact of information asymmetry on the behavior of subjects in an innovative environment. The study used mathematical models that took into account various levels of information asymmetry.

To analyze data and model the behavior of a subject in a multi-level innovation environment with information asymmetry, methods of statistical analysis, modeling of dynamic processes and machine learning algorithms were used. These methods made it possible to take into account the variety of factors influencing decision-making by subjects in an innovative environment. The study was carried out by analyzing the literature, collecting data from various sources, developing and testing models of subject behavior taking into account information asymmetry. The stages of the study included the formulation of hypotheses, the development of mathematical models, as well as their analysis and verification based on research data and literature review.

To evaluate the modeling results, criteria were used for the effectiveness of decision making, the accuracy of predicting the behavior of subjects, as well as the degree to which information asymmetry in the innovation environment is taken into account. The results were assessed based on a comparison of model forecasts with actual data, as well as on the basis of the correspondence of the scenarios predicted by the model with existing theoretical ideas about the behavior of subjects in an innovative environment with information asymmetry.

3 Results and discussion

Formalization of a model for analyzing the behavior of a subject in an innovative environment with information asymmetry can be performed in various ways, depending on the specific characteristics of the study and the expected relationships between variables. Below is a general concept of a model that can be used to analyze this situation.

Description of the basic elements of the model:

1. Agents:
   - Innovative subjects: Enterprises, individual entrepreneurs or other participants in innovative activities.
   - Information asymmetry: Some agents have more information than others.
2. Model variables:
   - Level of information among agents: Displays the degree of awareness of agents about the market environment, competitors, new technologies, etc.
   - Behavioral strategies: Decision-making by agents based on available information and their preferences in an innovative environment.
   - Innovation processes: Speed of development and implementation of new products/technologies.
   - Efficiency of adopted strategies: Evaluation of the results obtained by agents when applying selected strategies in conditions of information asymmetry.
3. Relationships and functions:
   - Decision functions: Modeling agents' decision making based on available information and their preferences.
   - Information exchange: Modeling the transfer of information between agents depending on their market positions or other factors.
   - Innovation flows: Displaying the dynamics of innovation development depending on the actions of agents and their strategies.
4. Parameters and limitations:

- Level of information asymmetry: Determining the degree of difference in information resources among different agents.
- Strategy Constraints: Parameters that limit the possible strategies that can be applied by agents under conditions of asymmetry.

This model concept can be supplemented with more specific equations, decision functions, or other elements depending on the specifics of the study and the goals of the modeling. This is only the general outline of a formal model, which can be refined and expanded for a more in-depth study of the influence of information asymmetry on the behavior of subjects in an innovative environment.

Building a formal model for analyzing the behavior of a subject in an innovative environment with information asymmetry is a complex task that requires taking into account many factors, context and specifics of the study. Here is the basic structure of the model that can be used to analyze the behavior of a subject with information asymmetry in an innovation environment:

- Subjects (Agents): Modeling of innovative subjects making decisions in an innovative environment.
- Each subject has a level of information and makes decisions based on available information and strategies.

Innovation Environment:

- Representation of an innovation environment where actors interact and implement their strategies.
- The level of information and structure of the environment, including relationships between subjects and other parameters.

Information Asymmetry:

- Modeling the inequality of available information between subjects in an innovative environment.
- A description of how information asymmetry affects actors' decision making and strategies.

Figure 1 presents a basic framework that can be expanded and refined depending on the specific objectives of the study, as well as the context of the innovation environment that is envisaged with model.

In a multi-level innovation environment with information asymmetry, the strategies of subjects can be varied, and they depend on the specific goals, conditions and characteristics of this environment. Here are some typical strategies that subjects may adopt:

Exploiting Information Asymmetry: Some actors may attempt to capitalize on information advantage by hiding information or distorting it to gain competitive advantage. This may include the use of disinformation or manipulation of information.

Adaptation and information seeking: Other actors may seek to seek and adapt new information to compensate for information asymmetries. They can actively seek out new sources of information and establish network connections to gain access to additional data.

Information Sharing Strategies: Entities may develop information sharing strategies, such as forming partnerships or agreements that allow them to exchange information of mutual benefit.

Use of technology and tools: Some entities may use technology, data analytics, or tools to reduce information asymmetries or improve their analysis and decision-making abilities.

Collaboration and Cooperation Strategies: In conditions of information asymmetry, actors may also seek to cooperate and join forces to jointly solve problems and exchange information for mutual benefit.

Managing risks and constraints: Some entities may develop strategies to manage risks associated with information asymmetries, for example, through diversification or the creation of systems to protect against potential negative consequences.

Adapting to Change: Entities can also develop flexibility and adaptation strategies to quickly respond to changes in the information environment.

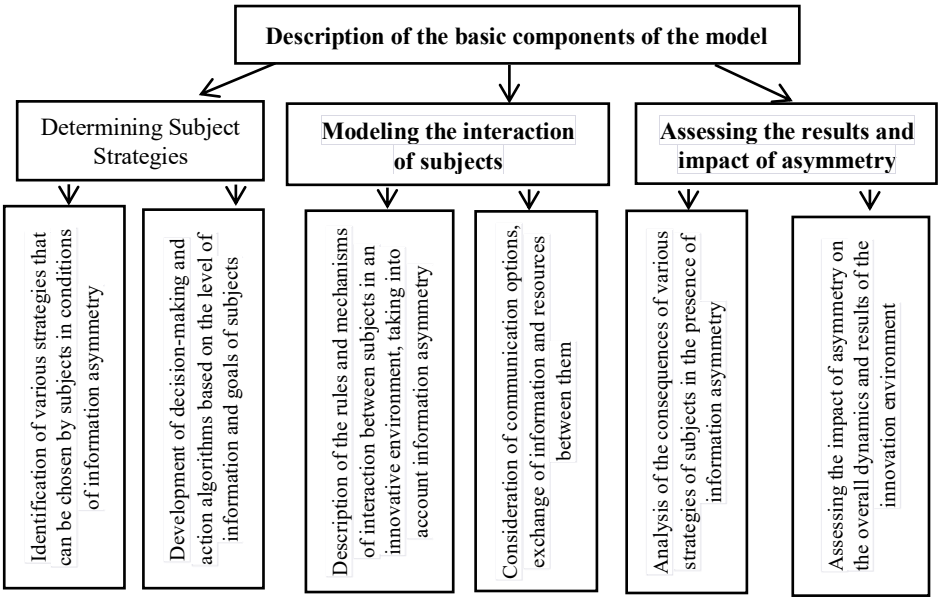

Fig. 1. Basic structure of the behavior model of a subject of a multi-level innovation environment with information asymmetry

The choice of a specific strategy depends on the goals of the entity, available information, resources, the degree of influence of information asymmetry on a specific area or industry, as well as their ability to adapt to changing conditions

Modeling the interaction of subjects in a multi-level innovation environment with information asymmetry can be performed using various approaches. Here are some modeling techniques that can be applied:

Game theory: Using game theory to model interactions between actors. This allows us to analyze and predict the strategies that subjects choose in conditions of information asymmetry, taking into account their interaction and influence on each other.

Agent-Based Modeling: Creating models where each subject is represented as an agent making decisions based on certain rules or strategies. These models allow us to explore how interactions between agents lead to different outcomes under conditions of information asymmetry.

Network modeling: Analysis of networks of interaction between subjects of the innovation environment, taking into account information asymmetry. This allows us to study the structure and dynamics of information exchange, identify the central participants of the network and their influence on the dissemination of information.

Statistical modeling: The use of statistical methods to analyze data and predict the behavior of subjects in conditions of information asymmetry. This may involve modeling decision probabilities, assessing risks, or analyzing dependencies between variables.

Computer modeling and simulation: Creation of computer models that allow you to recreate the innovative environment under study and conduct virtual experiments to study the behavior of subjects under various conditions of information asymmetry.

These modeling methods can be used either independently or in combination to create more complete and accurate models of interaction between subjects in an innovation

environment with information asymmetry. The specific choice of method depends on the goals and characteristics of the particular study.

Assessing the results and impact of information asymmetry in the behavior model of subjects in a multi-level innovation environment may include several steps and methods:

Analyzing Decision Strategies: Studying the strategies that actors adopt in the face of information asymmetry may be an important first step. Evaluating the strategies chosen (e.g., asymmetry exploitation, additional information seeking, exchange strategies) and their effectiveness can help understand how asymmetry influences behavior.

Exploring the impact on outcomes: Analyzing how information asymmetry affects the outcome of the model. This may include studying the impact of asymmetry on the effectiveness of decisions made, the level of competitiveness of entities, innovative opportunities and risks.

Assessing balance and stability: Studying model stability under conditions of asymmetry. This includes analysis of the presence of equilibrium states, their stability or instability when the level of information asymmetry changes.

Sensitivity analysis: Examines how sensitive the model's results are to changes in the level of information asymmetry. This can help determine which aspects of the model are most vulnerable or change most significantly when the level of asymmetry changes.

Validation and comparison with reality: Verifying the realism of simulation results by comparison with existing data, statistics or observations from a real innovation environment. This helps determine the accuracy and applicability of the model to real-world conditions.

Predicting the impact of asymmetry management measures: Using a model to predict the impact of various information asymmetry management measures on actors' behavior and outcomes. This may help identify effective strategies for managing asymmetries.

All these methods help to understand how information asymmetry affects the behavior pattern of subjects in an innovation environment and allow for a more in-depth analysis of its impact on various aspects of this environment.

Thus, the purpose of modeling the behavior of a subject in a multi-level innovation environment with information asymmetry can be multifaceted and depends on the specific tasks and goals of the study. The use of models can help to better understand the complex interactions and behavior of actors in innovation environments, taking into account information asymmetries, which in turn can be useful for developing strategies, policies and decision-making in such environments.

However, in general, such modeling objectives may include:

Understanding the dynamics of interaction: Modeling allows us to understand how different actors in an innovation environment interact with each other at different levels. This can be useful for studying the effects of influence of some subjects on others, as well as for predicting the possible consequences of changes in the actions of one or more participants in the system. Thus, studying how information inequality affects the decision-making of subjects in an innovative environment is a qualitative result of modeling , demonstrating which factors and mechanisms play a key role in the presence of information inequality.

Analysis of decision-making strategies: Simulation helps to study various decision-making strategies of subjects under conditions of information asymmetry. Through modeling, it is possible to explore various behavioral strategies of subjects and determine optimal approaches to achieve goals in conditions of limited information. This may involve assessing the benefits of using certain strategies in the face of imperfect information.

Resource optimization and risk management: Modeling can help identify risks and vulnerabilities in the innovation environment due to information asymmetries, allowing for the development of measures to mitigate or manage them. Modeling allows us to study the optimal distribution of resources of subjects in an innovative environment and manage risks associated with information asymmetry.

Forecasting and analyzing results: Modeling can help predict the possible results of various scenarios for the development of the innovation environment, as well as assess their effectiveness and consequences for subjects. Namely , how subjects will act in conditions of information asymmetry. This may be useful for developing management strategies or policies to improve the innovation environment.

Research on the impact of policy and regulation: Simulation can be used to study the effects of various policy or regulatory actions on the behavior of actors in an innovation environment with information asymmetry. Understanding how information asymmetries influence the behavior of actors can help design policies or regulations aimed at creating a more efficient and equitable innovation environment.

To achieve these goals, modeling can be based on economic, social, or game models that take into account the behavior of various actors under conditions of limited information and asymmetry.

4 Conclusion

This article examined the theoretical and methodological aspects of creating formal models of behavior of subjects in a complex innovation environment, where information asymmetry plays a significant role. Innovative activity in the modern world requires a deeper understanding of how information inequalities affect decision-making and interaction of actors at different levels. Various approaches to modeling the interaction of subjects in a multi-level innovation environment are considered , including the use of game theory, agent-based modeling, network analysis, statistical methods and computer simulations. These methods make it possible to create formal models that reflect the dynamics of interaction between subjects and their strategies in conditions of information asymmetry.

It is important to note that modeling such a complex system as an innovation environment is a complex task that requires taking into account many factors, the dynamics of change and various strategies of participants. Information asymmetry, being one of the key aspects in this environment, has a significant impact on decision-making, innovation processes and the competitiveness of entities.

Assessing the results and impact of information asymmetry in modeling subject behavior highlights the need for further research in this area. Understanding the impact of information asymmetries on various aspects of the innovation environment will help develop effective strategies for managing, reducing risks and creating an enabling environment for innovation.

Thus, the development of formal models of subject behavior in a multi-level innovation environment with information asymmetry is a relevant and important task, contributing to a deeper understanding of the processes of innovation and the development of effective management strategies in a dynamic and heterogeneous information environment.

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