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GAME THEORY AND BUSINESS SIMULATION GAME APPROACHES TO INNOVATION ECOSYSTEM ANALYSIS

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This paper presents a new business simulation game designed with a goal to simulate the interaction of the main innovation ecosystem stakeholders (like government, universities, industries, investors, civil society, etc.). The game represents and simulates their interaction on a R&D (a venture project development) phase, a new project implementation phase, and a new product commercialization phase. Each of these phases is connected with risks and uncertainty modeled by this game as well. The paper describes theoretical, methodological and instrumental fundamentals of the game, its structure, rules, and scenario, as well as game players' objectives, actions, payoffs, and outcomes.

Keywords: Innovation ecosystem, Triple Helix, Game Theory, Business simulation game.

Introduction

Recently, "innovation" is one of the most popular words in the modern world, both in developed economies and emerging economies. However, in many cases, especially in economies in transition, it remains to be used just as a word, not an action. One of a reason of this situation is a problem of weakly functioning innovation ecosystems which consist of such key stakeholders like government, universities and research centers, industries, investors, innovation consumers, and others.

So, the key question in this context is as follows: How can and should innovation ecosystem stakeholders effectively interact in order to produce new and right ideas and successfully commercialize them under risks and uncertainty of social and natural environment?

Looking for a way to analyze the interactions of innovation ecosystem stakeholders, we apply for some formal methods. This paper introduces a new business management game designed with a goal to educate, elucidate and analyze how the main innovation stakeholders multilaterally interact through a non-linear, multistage, efficient and transformative dialogue in order to reach a systemic compromise of their interests, objectives and behaviors in the innovation and entrepreneurship ecosystem and social, political, economic and natural environment fraught with risk and uncertainty.

The basic conceptual and contextual framework for this work and formalization is the concept of the Triple Helix of university-industry-government relationships (Etzkowitz and Leydesdorff, 1995). This concept reflects the shift from a dominating industry-government dyad in the Industrial Society to a growing triadic relationship between university-industry-government in the Knowledge Society. Therefore, the Triple Helix accents a more prominent role for the university in the production, transfer and application of knowledge. This way, a classical understanding of a university as a knowledge creator and transmitter is added with a concept of Entrepreneurial University that also actively promotes knowledge in a society and puts knowledge to use in the interaction with other innovation actors and stakeholders. Entrepreneurial universities also have an enhanced capacity to generate technology that has changed their position, from a traditional source of human resources and knowledge to a new source of technology generation and transfer. In the Triple Helix, Government also acts as a public entrepreneur and venture capitalist, in addition to its traditional regulatory role in setting the rules of the game (Ranga and Etzkowitz, 2013).

We consider this game as a prototype of an innovation ecosystem which could be extended to more complex systems with more categories of participants: investors, community, etc. As an example, the concept of the Triple Helix has been further developed toward the Quadruple Helix (Carayannis and Campbell, 2009) by adding "civil society" (citizens) as a fourth helix and the Quintuple Helix (Figure 1) that adds an Environment as a challenge and driver for innovation (Carayannis, Barth and Campbell, 2012). Such development of the initial conception of the Triple Helix leads toward to the N-tuple Innovation Helix (Park, 2014).

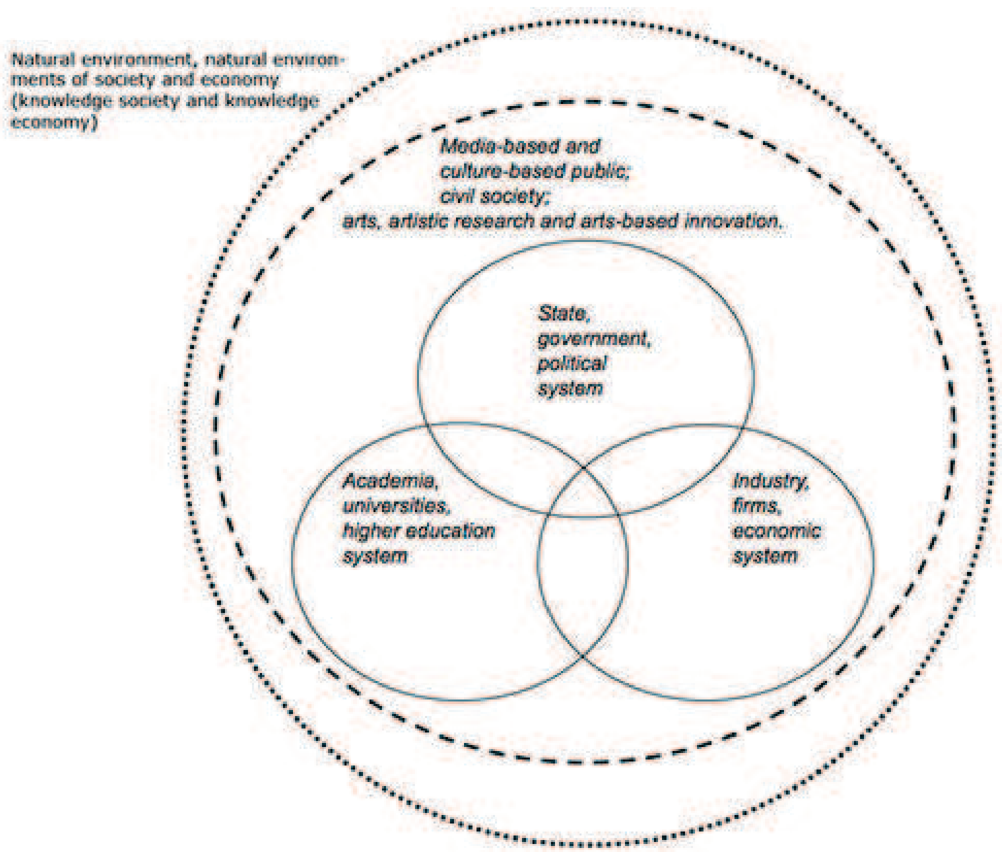

Figure 1. The concept of the Quintuple Innovation Helix
Source: Carayannis, Barth and Campbell, 2012

In different economies, the roles of different "innovation helix" actors also differ, as well as general strategies for innovative development. For example, in Russia, China, some Central Asian, Latin American and Eastern Europe countries, government plays a leading role, driving academia and industry (Ranga and Etzkowitz, 2013). Such an interaction configuration defines a dominated "top to bottom" innovation strategy. In the US and many Western Europe countries, there is a laissez-faire configuration, characterized by a limited state intervention in the economy and a limited control over universities which are more active in initiating social, political, economic and technological innovation, with industry as the driving force for innovation (a "bottom-top" innovation strategy). Such a difference in economic and innovation models requires making specifications in the developed game respectively to what kind of economy the players are.

In any case, an innovation ecosystem's main stakeholders have to interact on different stages and phases, like a venture project development (R&D) phase, a new project implementation phase, and a new product commercialization phase. Each of these phases is connected with risks and uncertainty. So, the developed game represents and simulates the interaction on all of these phases under risk, uncertainty and unpredictability.

This paper describes theoretical, methodological and instrumental fundamentals of the game, its structure, rules, and scenario, as well as game players' objectives, actions, payoffs, and outcomes.

Goals and Objectives of the Game

This game has been designed with pursuing several goals and objectives, depending on the game "maturity".

First of all, it is an educational goal that is very canonical for business management games. This game has been created like a game type educational platform for teaching and training the following issues via the "learning by playing" principles:

- a conceptual model of the N-tuple Innovation Helix;
- possible strategies and ways of the interaction of the main innovation stakeholders (government, universities, industries, and civil society);
- game-theoretic principles of optimal strategic and tactical decision-making;
- the influence of uncertainty and risk on decision-making of the stakeholders;
- "best practices" of the interaction of the main innovation stakeholders.

The second goal relates to a next stage of its development and it has an analytical character (Figure 2). This stage assumes creating a game type simulation platform for empirical analysis based on observed interactions and outcomes. After testing internal validity, this game will be used to observe, systematization, analysis and identification stable patterns in the observed interactions and outcomes of the game players who make their decisions on some rational, irrational and meta-rational "implicit (latent) models" of behavior. Such an inductive method can contribute to a forming theoretical framework of N-tuple helix of innovation.

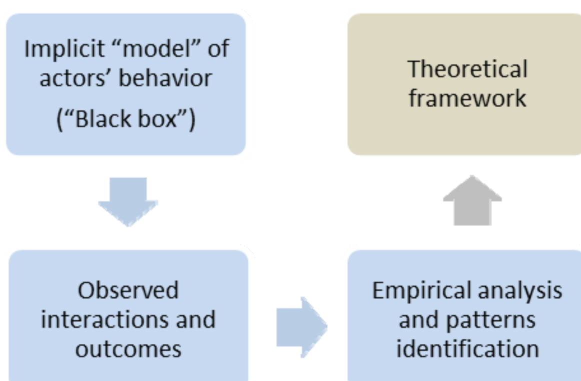

Figure 2. Empirical analysis of the player's behavior

The third main goal of designing this game relates to conditional forecasting and policy support (Figure 3). Playing the game with representative samples can help to define and predict a change direction in the players' behavior. Based on a controlled experiment with a change of some game conditions and further observations and empirical analysis of changes in the players' behavior and strategies, it could be possible to predict a change direction of their behavior after certain interventions. Such an approach could contribute to policy support.

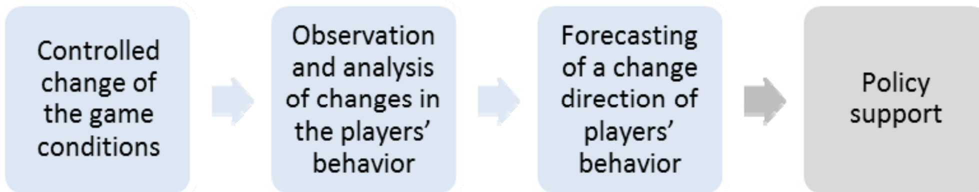

Figure 3. Functions of forecasting and policy support

An additional objective for designing this game is creating a platform for networking of real innovation stakeholders and making real tactical and strategic decisions.

Theoretical, Methodological and Instrumental Fundamentals of the Game

The game is based on the conceptual principles and methodological approaches of Game Theory, including but not limited:

- The principle of allocentrism (the term "allocentrism" relates to a personal attribute whereby people center their interest, attention, and actions on other people rather than themselves, and thus exhibit a capacity for empathy (Carayannis and Dubina, 2014));
- Systemic compromise (Algazin, 2009) of interest, incentives and actions;
- Equilibrium[1] (in term of Von Neumann, Nash, Stackelberg, Bayes-Nash, etc.) (s details, e.g., in (Dubina, 2010));
- Optimality and Efficiency principles (Von Neumann, Nash, Pareto, Kaldor-Hicks) (see details, e.g., in (Musshoff and Hirschauer, 2011; Dubina, 2010)).

The following conceptual approaches have been also applied to designing this game:

- The conceptual framework of institutional interactions and structure of action situation (Ostrom, 2005);
- The concept of innovation game levels (Baniak and Dubina, 2012);
- The conceptual approach to structuring, formalizing and simulating innovative activities and interactions (Dubina, 2013);
- Theoretical and methodological approaches to designing and developing economic experiments and business management games (Musshoff, Hirschauer and Hengel, 2011; Hohmann, 2013);
- Linear and Non-Linear Optimization Theories and Methods (Optimal Allocation of Resources / Transportation Theory; Simplex Method and Nonlinear conjugate gradient method).

This game simulates interactions of the main innovation stakeholders on a R&D (a venture project development) phase, a new project implementation phase, and a new product (product results) commercialization stage. Each of these innovation phases is connected with risks and uncertainty. This game simulates risks and uncertainty at all the considered phases (Figure 4) with use of random variables (μ, ϕ, ξ).

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[1] A Nash equilibrium is a game-theoretic configuration (a set of players' strategies) in which no player has anything to gain by changing only his own strategy, that is, no player has an incentive to change his chosen strategy (Dubina 2010). John Nash, a Nobel Prize winner in economics, proved the theorem that every game with a finite number of players and finite numbers of strategies has a Nash equilibrium. From a practical point of view, this means that when we have a good sense of the incentives and other behavioral determinants of innovation agents and policymakers, we can deduce their best strategies in terms of a Nash equilibrium configuration.

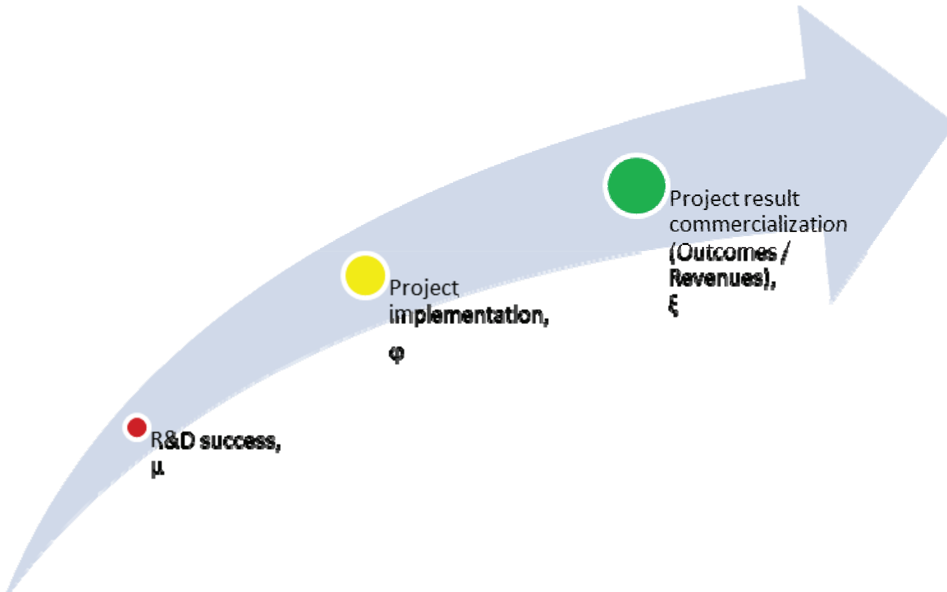

Figure 4. Innovation project phases reflected by the game and uncertainty simulation

Game Structure

According to a general Game-Theoretic approach (see (Dubina, 2010)) and institutional approach to structuring interactions and situation (Ostrom, 2005), the main structural elements of this game are

- players,
- players' objectives,
- players' actions, and
- player's payoff.

There are five categories of participants (players) with different positions and functions:

- Government (a policy-maker; project initiator; investor);
- Universities (project initiators; ideas, knowledge and technology generators; investors);
- Industries (project initiators; technology generators; idea implementers);
- Investors (who may invest or co-invest R&D and project implementation phases);
- Civil Society (innovation consumers; project initiator and promoter; investor).

Each player category consists of 1 to 3 groups of players and a group in each category may include from 2 to 5 persons.

A game is couched, facilitated and moderated by a Game Moderator and one or two Facilitators and a technical Assistant.

Players' objectives are defined as follows.

- Government is maximizing the total possible revenue (social welfare) from all the implemented projects;
- Universities are maximizing R&D funds got from other stakeholders;
- Industries are maximizing profit from the implemented projects;
- Inventors are maximizing their profit from investments into R&D and project implementation); and
- Civil Society is maximizing a number of innovation projects successfully implemented according to the budget of all stakeholders.

Players' actions are defined as follows.

- Government set priorities for R&D support, allocate possible grants, subsidies and taxation benefits for R&D investors and implementers, and make a decision about a choice of venture projects and amount to invest in;
- Universities make a choice of a venture project(s) and allocate resources to invest in their research and development;
- Industries may invest in development and implementation of certain venture project(s) and (or) invest in a standard (no-risk) project;
- Civil Society may support some venture project(s) and (or) invest in a standard (no-risk) project.

Besides these "formal actions", each player (a group) can apply some "informal actions" (non-regulated by the game rules) through their interactions. Each player tries to achieve an own goal taking into account others' interests and incentives. Each group may interact with all other groups and consequently influence their decision-making. Therefore, the designed game is a collaborative and competitive (cooptative) game, since all categories of players cooperate with each other, and groups in categories 2 (Universities), 3 (Industries) and 4 (Investors) may both cooperate and compete against each other.

In order to identify and calculate players' payoffs, we need to formalize some game outcomes:

- Total revenue from the implemented projects (GDP);
- Total revenue from the implemented venture projects (I(innovation)DP);
- Total cost of innovation (TCI), that is cost of the developed and implemented project, total investment into venture project;
- Total investment into venture and non-risk projects (TIP);
- Added value (ADV=GDP-TIP);
- Added value from innovation (ADI=IDP-TCI);
- Total profit of the Industries (IPR);
- Total profit of the Investors (INP)
- Taxes as certain percentage of IPR (TAX);
- Amount of funds collected for venture project development by Universities (FUN);
- A number of venture projects successfully implemented (NUM).

Using this formalization, players' payoffs relate to the following outcomes:

- Government — GDP, IDP, ADV, ADI, TAX;
- Universities: — FUN;
- Industries — IPR;
- Investors — INP;
- Civil Society — NUM, GDP, IDP, ADV, ADI, TAX.

Therefore, all the players have more or less different interests that may produce some sort of a conflict, so the general goal of all players is to define and come to some sort of a systemic compromise and equilibrium during this game. The interests of the Government and Civil Society are most correlated in this game.

Generally, this game rules assume that

- all players have different resources to invest in R&D and innovation;
- there are several R&D projects to develop and implement which are characterized with different costs and expected outcomes;
- Government and Civil Society may set priorities for supporting R&D and innovation projects;
- Universities and Industries choose projects for development and implementation;
- other players can support innovation by investing in these or those projects.

There is no only winner in this game, since the goal of the game is to find a systemic compromise through interaction and defining the best (optimal or sub-optimal) strategies which can bring all the players to a strategic situation that satisfy all players enough. However, "local winners" can be identified in categories 2 (Universities), 3 (Industries) and 4 (Investors). Groups 1 (Government) and 5 (Civil Society) can also express their actual and potential "satisfaction" taking into account the scale, novelty, quality and other characteristics of the implemented projects.

Advanced details of the game formalization are provided in the next sessions.

A Basic Game-Theoretic Model

In this section, we present some mathematical aspects of a basic formalization of the business simulation game described above. In order to simplify the model we consider an innovation ecosystem based on the Triple Helix conception. So, this game is a prototype of an innovation ecosystem which could be extended to more complex systems with more categories of participants: investors, community, etc.

Formally, this game is a 3 stage dynamic game with the inputs as follows:

n=3 is a number of players;
R_i is amount of resources available to player i, $i=1,\dots,n$;
m is a number of venture projects available in the game;
$Cmin_j$, $Cmax_j$ are minimum and maximum cost of the development of project j, $j=1,\dots,m$;
$CImin_j$, $CImax_j$ are minimum and maximum cost of the implementation of project j;
ER_j is the expected output (revenue) from project j;
α is a parameter of interest (yield) of investing in a standard (no-risk) project.

From a game-theoretic point of view, there is also such player as "Nature" that brings to the game risks of a R&D project realization and an innovation project implementation, as well as uncertainty of players' payoffs and game outcomes. This game simulates risks and uncertainty at all the considered phases using random variables (μ, ϕ, ξ).

This game can be formalized as a multiple reciprocal principal-agent model as follows:

Players' actions:

X_{ij} is fund provided by player i for the development of project j, $i=1,\dots,n$; $j=1,\dots,m$; $\sum_i X_{ij} \le R_i$.
Y_{ij} is fund provided by player i for the implementation of project j, $i=1,\dots,n$; $j=1,\dots,m+1$, where Y_{im+1} is fund invested in a standard (no-risk) project by player i.

Game outcomes:

$FD_j = \sum_i X_{ij}$ ($j=1,\dots,m$) is fund collected for project j research and development (R&D);
$p_j = (FD_j - CDmin_j)/(CDmax_j - CDmin_j)$ ($j=1,\dots,m$) is probability of successful development of project j, $0 \le p \le 1$;
μ is a random variable with uniform distribution (e.g. generated by MS Excel RAND() function), $0\le \mu \le 1$; if $\mu \le p$, the project is successfully realized (developed) and can potentially bring some outcome to the investor. If $\mu > p$, the project is not developed and the investor gets nothing from it;
$FI_j = \sum_i Y_{ij}$ ($j=1,\dots,m$) is fund collected for project j implementation;
$q_j = (FI_j - CImin_j)/(CImax_j - CImin_j)$ ($j=1,\dots,m$) is probability of successful development of project j, $0 \le q \le 1$;
ϕ is a random variable generated by RAND(), $0\le \phi \le 1$. If $\phi \le q$, the project is successfully realized (implemented) and bring some revenue to the investor; if $\phi > p$, the project is not implemented and the investor gets nothing from it;
ξ is a random variable which characterizes commercial success of an implemented project, the variable can be generated by RAND() or NORMDIST(…);

RR_j, j=1,…,m, is a real outcome / revenue gained from project j and it may differ from the expected outcome / revenue (ER_j); if ξ is generated by RAND(), $0 \leq \xi \leq 1$, a real outcome can be calculated, for example, as follows: $RR_j = ER_j\ (1.5 - \xi)$. So, in this case, a real income may differ from the expected income 50% both sides. This rule can be conventionally changed before the game starts. For example, if $RR_j = ER_j(1.25 - \xi/2)$, a real income may differ from the expected income 25% both sides;
$NR_i = Y_{im+1}\ (1+\alpha)\ (i=1,\ldots,n)$ is revenue of player i from investment in a standard (no-risk) project;
$TRI = \sum_j RR_j\ (i=1,\ldots,n,\ j=1,\ldots,m)$ is the total real revenue gained from the venture projects (VDP);
TR= $TRI + \sum_i NR_i$ is the total revenue in this game (GDP).

Based on this formalization, all players' objective functions and payoffs in this basic game can be identified as follows:

Universities: U_{Uni}=max$\sum_{ij}(X_{1j} - X_{1j})$ (maximization of funds collected for developed projects by a choice of X_{1j} values controlled by Universities);

Government: U_{Gov}=max$\{\sum_{ij} p_j(X_{ij}) q_j(Y_{ij}) ERj + \sum_i NR_i(Y_{im+1})\}$ (maximization of total expected revenue by a choice of those X_{2j} and Y_{2j} values which are controlled by Government);

Industries: U_{Ind}=max$\{\sum_j p_j(X_{ij})\ q_j(Y_{ij}) ERj + \sum_i NR_3(Y_{3,m+1}) - X_{3j} - Y_{3j}\}$ (maximization of Industries' profit by a choice of those X_{3j} and Y_{3j} values which are controlled by Industries);

These objective functions are to be specified for a game with certain number and character of players. Such a game-theoretic model requires further development in term of an algorithm and a software tool for solving this game, but it opens a perspective for defining a Nash equilibrium, Pareto optimal situations, and Kaldor-Hicks improvements in this game. This way, it could serve a possible benchmark for real interactions.

A Business Simulation Game

Based on the presented formalization as well as on the experience of designing business management games, or "innovation games" (Musshoff et al., 2011; Hohmann, 2013), we developed and tested a series of business simulation games. Those games included the three categories of players as indicated in the Triple Helix conception (Government-Universities-Industries) and additional actors (Investors and Civil Societies (or Innovation Consumers)).

This game includes four main stages. The first one is an *introductory and preparatory stage*, when the Facilitator explains the game rules to the participants, forms the groups of players, briefly presents available projects and separately informs the groups on the amount of resources they have.

At the second stage (*a making-an-initial-choice stage*) Government prepares and announces the R&D and innovation policy (a set of priorities for R&D support, possible grants, subsidies and taxation benefits for R&D investors and implementers). The level of information available for the players is regulated by Government. During playing the game and interaction with other groups on the next stage, Government may change its priorities. If priorities are changed, a penalty fee is imposed. At the same time, Civil Society prepares and announces the preferences in new technologies and projects. During playing the game and interaction with other groups on the third stage, Civil Society may change its priorities. If priorities are changed, a penalty fee is imposed. Universities separately initiate (choose) a venture project(s). Industries may also initiate (choose) a venture or a standard (non-risk) project(s). During playing the game and interaction with other groups on the third stage, Universities and Industries may change their choices. If choices are changed, a penalty fee is imposed.

The third stage is an *interactive stage* and it consists of two sub-stages, namely project development and project implementation stages. At *the project development sub-stage*, all groups interact with each other according to a schedule provided by the Facilitator (depends on a number of groups). The main subject of the interaction and discussion is a set of projects for investment, developed and implementation. Each group may use a corresponding set of "informal actions" and subjects for discussion, specifies them, as well as generates and suggests new tactical and strategic actions in order to sure support, development and implementation of the projects which they are interested in. They suggest and discuss actions and direct and indirect benefits resulted from the project, and reach an agreement regarding supporting (investing) these or those projects. This way, all groups make their decision regarding venture projects development. A status of each project chosen for development is defined and indicated based on investment amount and a "state of the nature" simulated with a random variable μ.

Similarly, at the *project implementation sub-stage*, all groups interact with each other according to a schedule provided by the Facilitator and discuss a set of projects successfully realized at the project development sub-stage for their further investment and implementation. When all groups make their decision regarding the projects investment and implementation, a status of each project is indicated (based on the investment amount and a "state of the nature" simulated with a random variable ϕ).

At the fourth and final stage (*a concluding stage*), game outcomes and the players' payoffs are calculated and the participants moderately discuss the players actions, strategies, payoffs, and game outcomes; and the Facilitator(s) and Moderator wrap the game up.

In order to record input data and players' actions (choices), calculate the players' payoffs and present the game outcomes, a Microsoft Excel template has been developed.

We tested such a business simulation game in several student groups in Altai State University (Russia). And we have also piloted a business management game (called "Lab to Industry") that simulates the interaction of several groups really representing such categories of innovation stakeholders like Government, Universities, Industries, and Investors in Bauman State Technological University and Skolkovo School of Management (Moscow, May 18-20, 2015).

As a particular result, this game has clearly demonstrated a huge intercommunication and inter-understanding gap between the main innovation stakeholders (government, universities, industries and investors) because of their unwillingness and inability of searching for a compromise. And that seems to be a systemic problem not just for Russia, but also for many other economies in transition.

Such a game really helps to better understand motives, interests, possible strategies and ways of the interaction of the main innovation stakeholders and may serve as an instrument of developing mutual understanding and compromises. Recently, we have started replicating this game in Russian universities, local government and businesses, "innovation fairs", "innovation saloons", etc.

Optimal Resource Allocation Theory as a benchmark

A possible benchmark could be also a case when all the stakeholders have agreed to act as one decision-maker for allocating their resources in the most effective way. That case would be equivalent to a canonical approach of the transportation theory (optimal allocation of resources) by L. Kantorovich. As a particular case, such an optimization problem can be formalized as follows.

- *Objective function:* $\max\{\sum_{ij} p_j(X_{ij}) q_j(Y_{ij}) ERj + \sum_i NR_i\ (Y_{im+1})\}$ (maximization of total expected revenue by a choice of X_{ij} and Y_{ij} values);
- *Constrains:* $\sum_j (X_{ij} + Y_{ij}) + Y_{im+1} \leq R_i,;\ p_j \leq 1;\ q_j \leq 1;\ i=1,...,n,\ j=1,...,m.$
- This nonlinear optimization problem can be solved, for example, with the nonlinear conjugate gradient method realized in MS Excel Solver. A benchmark for game outcomes can be defined this way.

An example of a contrast of a decision-making in a group interaction within a conducted business simulation game and an application of this method for 10 (j=1,…, 10) venture projects and a non-risk project (j=11) is presented by Figures 2 and 3. The total resources and investments in the both cases were 48 units, while the total revenue and profit for the first case were 94 and 46 units correspondingly, and the same values for the second case were 136 and 88 units correspondingly.

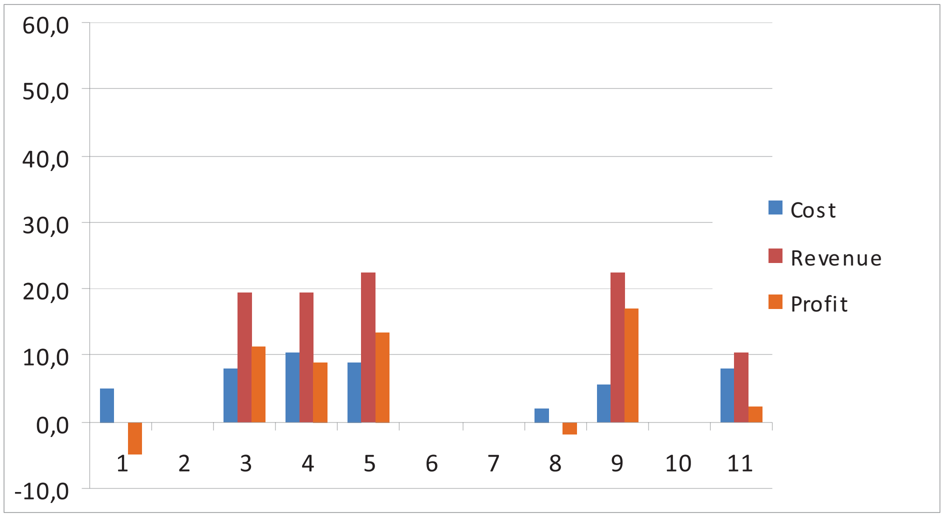

Figure 5. The distribution of resources and results among the projects in a business simulation game

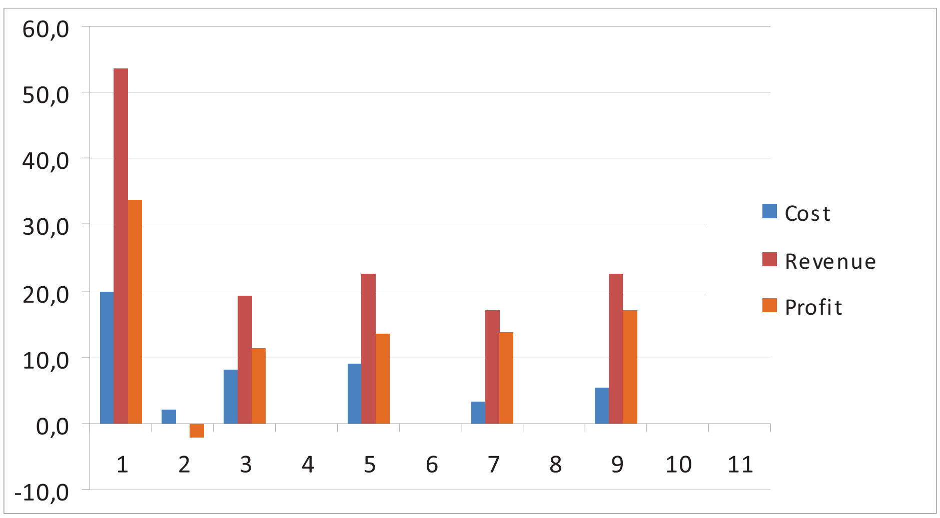

Figure 6. The distribution of resources and results among the projects according to the theory of optimal allocation of resources

Summary and Future Trends

This paper describes a conceptual, theoretical, methodological and instrumental aspects of a new business simulation game that is concurrently rather complex by its structure (taking into account the recent experience of designing and conducting business management games (see, for example, (Musshoff, Hirschauer and Hengel, 2011; Hohmann, 2013)) and very prospective and promising in terms of variety of its applications.

Due to a very sophisticated character of an innovation ecosystem, the interaction of its active elements, namely the main innovation stakeholders (government, universities, industries, investors, and civil society in our case) are very complicated. So, as we emphasized in our earlier papers (Dubina and Carayannis, 2014; Carayannis and Dubina, 2014; Carayannis, Dubina and Ilinova, 2015), in this complex, dynamic and non-linear landscape of public-private collaboration and competition, game-theoretic and game-experimental perspectives can be powerful tools for theory, policy, and practice, allowing to deal with as well as leverage related challenges and opportunities.

The presented business simulation game may serve as an empirical platform for analysis and support of decision-making for innovation policymakers and practitioners. At the same time, a formal mathematical model of the interaction of the key innovation stakeholders may contribute to a general theoretical framework for Innovation Economics and Management. In particular, the game-theoretic solutions regarding the optimal strategies of the key stakeholders of an innovation ecosystem may serve as a benchmark for their real interactions.

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