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AGENT-BASED MODELING OF THE IMPACT OF ADVERTISING ON THE REGIONAL ECONOMIC CLUSTER LIFECYCLE

The aim of the study is the development and testing of an algorithm for modeling the impact of advertising on various stages of the life cycle of economic clusters. It is assumed, that the life cycle of the cluster consists of the stages: a diffuse group, a hidden cluster, an evolving cluster, a mature cluster, a collapsing cluster. Using the agent-based simulation methods, hierarchical clustering and chaos theory, the following results were obtained: a conceptual model of the behavior of cluster members for cluster formation processes at each stage of the cluster life cycle and an imitation model of the influence of advertising on the life cycle of the economic cluster; the patterns of various stages of the life cycle of the economic cluster and the functioning of the cluster without influence and under the influence of advertising were revealed. Advertising reduces the time at the stages of the associated life cycle of the cluster, increases the stage of maturity of the cluster. Companies that do not comply with the principles of clustering are under the influence of advertising and promotional activities. Such enterprises most often arise in the cluster at the stages of its formation.

Keywords: economic clusters, stages of the cluster life cycle, advertising and promotion, simulation and modeling, computational experiment

Introduction

Modern economic trends and acceleration of scientific and technological processes lead to increasing numbers of start-ups, development of new production systems and, consequently, to the formation and development of cluster structures in modern world economy, which makes the need for research in this sphere really urgent [1, 2, 3, 4, 5, 6, 7, 8]..

Although there is vast literature on cluster development, further research is needed to investigate the life cycle of economic clusters, its stages and the factors affecting it. In-depth understanding of these aspects is particularly important when managing the processes of cluster formation in highly changeable modern economy. Theoretical studies on regional clusters apply simulation techniques and computational experiments, which requires the development of appropriate methodological tools.

Bibliographic analysis shows that in recent years modern science has been actively trying to solve the problems of cluster structures by modelling their life cycle [9, 10, 11]. There are studies analyzing evolutional changes in economic clusters [12, 13]; simulating economic clusters' life cycle with the help of various techniques, including chaos theory, in order to study regularities in cluster development under different conditions [4, 14, 15, 16, 17]. Special attention is paid to the impact of various factors on formation and functioning of economic clusters, for example, the influence of the available resources or how a cluster interacts with other clustered structures.

At the same time, the mechanisms underlying the behavior of actors on the market and the impact of various factors on clusters' life cycle are not quite clear yet. One of the major factors that shapes actors' behavior is advertising and promotion activities, which affect formation and functioning of economic clusters.

All the above-mentioned considerations define the main objective of this study, which is to develop an agent model of the impact that advertising has on the life cycle of regional economic clusters and test this model by conducting a computational experiment.

Methodology

In this paper, we use the term 'regional economic cluster' to refer to the association of independent, non-institualized economic reflexive entities in the joint arrangement based on proximity (territorial, sectoral, and cultural); complementarity (product, resource, and process); and interconnectivity (material, immaterial, and informational) [18]. Hereinafter a regional economic cluster will be referred to simply as a 'cluster'.

The behavior of cluster agents depends on certain parameters that are determined by these agents' views and preferences.

Cluster formation processes involve two types of agents: agents-manufacturers and agents-consumers.

Agents-manufacturers are responsible for production within the cluster and can be divided into two subtypes: agents-manufacturers producing goods or products of the cluster and agents-manufacturers providing the necessary resources to produce cluster products.

Agent-consumers purchase and use cluster products. Their behavior is determined by the ability to do the following:

- to purchase the necessary resources in sufficient quantities to satisfy their needs (views);
- to manufacture cluster products or resources necessary for the cluster's production in sufficient quantities determined by the market volumes and by the predefined indicators, which are relevant to agent-consumers' ideas and views on the products (resources);
- to organize advertising and promotional campaigns to increase the volume of sales;
- to restructure production to improve the indicators of the manufactured products and increase their attractiveness for consumers.

The main aim of agents-manufacturers is to gain the maximum profit from selling their products or resources.

Agents' behavior is determined by consumers' ability to purchase cluster products that meet their requirements (needs). This aspect determines the goal of agents-consumers: they purchase cluster products if the differences between the vectors characterizing cluster production and their needs are below the specified threshold.

Agents' behavior depends on commercial advertising. Advertising is a set of information flows aimed to increase the number of agents-consumers purchasing cluster products [19].

Clusters, like all economic actors, have their own life cycles, which includes the following phases or stages:

- defuse group;
- latent cluster;
- developing cluster;
- mature cluster;
- collapsing cluster [20].

The initial phase in cluster development is the stage of defuse group. This stage is the starting and at the same time the final point in the life-cycle of a cluster. There are no processes of cluster formation at this stage. At this stage, an economic entity, which then emerges in the course of cluster formation, is just a set of interactions of the above-mentioned agents in a framework of manufacturing and selling activities. There are no informational, tangible and intangible flows connecting these agents into a unified single system that possesses synergetic properties. Agents of each type are not involved into the network that allows the cluster to develop and function.

At the second, latent stage of a cluster, a real cluster is starting to emerge. At this stage of cluster formation, cluster products vary significantly in their indicators, the output production by agents-manufacturers remains either constant or slightly increasing. The volumes of purchased products by agent-consumers remain at the same level or slightly increase as well. Moreover, the indicators defining the use of funds by agents-consumers and product purchase by agents-manufacturers change slightly. Accumulation of resource potential is necessary for the cluster's transition to the stage of development. Within this stage,

marketing research is conducted to examine the individual preferences of consumers, and the restructuring is done to minimize the differences between the products manufactured by the cluster's agents-producers. When restructuring of the production processes is completed, the latent stage finishes and the cluster enters the following stage. At the latent stage, the bifurcation points appear on the graphs characterizing various indicators of agents.

At the stage of development, the cluster output grows intensively; differences between the products produced in the cluster are minimal.

At the mature stage, the intensity of processes of cluster formation is at its peak, but the volumes of produced and purchased products vary only slightly; the differences between the products produced in the cluster are minimal. The internal capacity of member enterprises is increasing. Further development of this capacity increases the entropy of the cluster as the new trajectories of its evolution and innovation, including sabotage, appear. These processes contribute to the cluster's transition to the stage of decay and collapse.

At the stage of a collapsing cluster, the volumes of produced and purchased cluster products are decreasing; new products appear on the market, the difference between cluster products increases. At this stage, the processes of cluster formation are slowing down and then stop completely and the cluster moves into the last phase of its life cycle, that is, the diffuse group phase.

Results and discussion

As our analysis shows, the most significant stage in cluster development is the latent phase. It is the stage when the resource potential is formed to be used at the following phases – development and maturity. Thus, it can be said that this is the stage which determines the whole life cycle of a cluster. These considerations define the choice of the latent stage for modeling and conducting a computational experiment.

We are going to briefly outline the agent model of cluster formation: the participants are divided into two types – agents manufacturing cluster products and agents consuming products. Resource-producing agents are not included in the model.

When modeling, we assume that agents-manufacturers produce only one cluster product, agents-consumers purchase it and spend all their funds on this purchase, if the cluster products correspond to their needs or views.

When modeling, logistics and warehousing tasks are not considered, that is, the output is equal to the volume of production purchased by agents-consumers.

Agents-manufacturers produce cluster products; the number of manufacturing agents is 5. All of them manufacture products with certain attractiveness for agents-consumers, which we shall refer to as the 'attractiveness vector'. Every agent-manufacturer makes products with unique values of the attractiveness vector. The values of this vector are changing in the course of restructuring, which is carried out by the manufacturing agents.

The following indicators are included into this vector:

- adaptability (this figure varies between 0 and 5, 0 corresponds to the minimum value and 5, to the maximum);
- quality (the indicator score ranges from 1 to 5, that is, from minimum to maximum);
- price (ranges from 120 to 200 C.M.U.).

Agents-consumers purchasing the cluster's products are guided by their preferences, that is, the preference vector, which includes the following indicators, similar to the values of the attractiveness vector:

- adaptability;
- quality;
- price.

Agents-consumers purchase products if the values of the distance between the above-described vectors is less than the specified threshold value. When modeling, we use the Euclidean distance calculation.

In the initial cycle of modeling time, agents-manufacturers have zero funds. An increase in funds is caused by the purchase of manufactured products by agents-consumers minus the expenses on manufacturing products, on advertising, and on restructuring of the production.

The total number of agents-consumers in the initial cycle of modeling time is 1,000. Their number increases by 20 % in the cycle of modeling time when an advertising campaign is being prepared; in the next cycles of modeling time, the number of consuming agents returns to the original values.

The computational experiment is conducted for seven classes of agents-consumers. In each class, the number of agents-consumers is different: in the first class, it is 150; in the second class, 270; in the third class, 210; in the fourth class, 70; in the fifth class, 120, in the sixth class, 160; in the seventh class, 20.

Each class is characterized by the same values of the funds for every agent in the initial cycle of modeling time as well as identical values of the preference vector, which defines agents-consumers' wish or reluctance to purchase cluster products. Each class of agents-consumers has the same thresholds that characterize the differences between the preference vector while choosing cluster products and the attractiveness vector.

Agent-consumers' funds spent on cluster products have a certain initial value. This value increases in every cycle of modeling time. If a consumer does not use their funds to purchase the products, the funds are saved and can be spent in the next cycle of modeling time.

The latent stage of the cluster life cycle begins with the first cycle and ends with the restructuring of production carried out by all agents-manufacturers on the basis of their marketing research.

Marketing research uses mathematical clustering methods and is simulated by calculating the values of generalized preference vectors for consuming agents. We use the Ward hierarchical clustering method [21]. For each agent-consumer group the generalized preferences vector is calculated with the help of the mathematical clustering method to choose cluster products as a mathematical cluster profile. The number of mathematical clusters defining agent-consumer groups and taking into account the original agent-consumer groups determines the number of the vectors. Independent firms are supposed to do the marketing research. It is free for manufacturing agents and its results are available to them.

Based on the generalized preferences vectors for agents-consumers to choose cluster products, agents-manufacturers restructure their production. The values of attractiveness vectors are changing by approximating it to the agent-consumer generalized preferences vector in order to reduce the threshold value that defines the distance between the vectors characterizing the products and agents-consumers' wish to purchase these products.

Production restructuring is based on the capabilities of every class of agents-manufacturers. It means that agents-manufacturers cannot completely and totally change their products so that all indicators of the values of the product attractiveness vector would coincide with the generalized preferences vector for agents-consumers. In restructuring, agents-manufacturers can partially change the product's attractiveness vector in order to approximate it to the generalized preferences vector for agents-consumers. Production restructuring can be done gradually through partial accumulation of funds – 60% of what is needed.

The simulation is performed with the help of programming language Python 3.

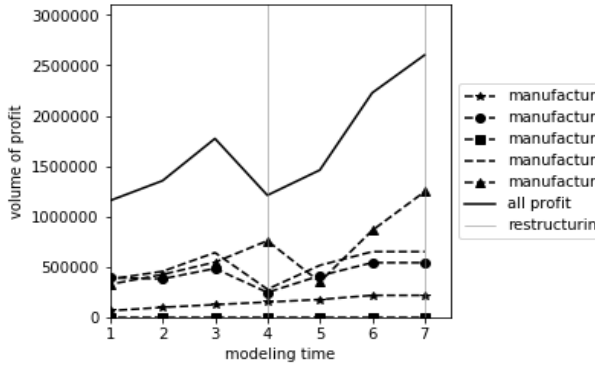
The initial data for the computing experiment is shown in Table 1.

Table 1.

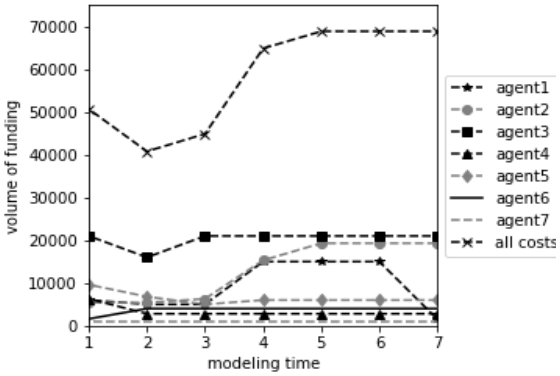
Input data map for modeling the impact of advertising on the cluster life cycle

Agent type	**Number of classes**		**Parameters of death/reproduction**		
Agents-manufacturers	5		Constant		
Agents-consumers	7		Changing when modeling		
	Agents-manufacturers				
	1	2	3	4	5
Indicators of agents-consumers					
Indicators of cluster manufacturing products					
Product manufacturability, score	5	3	5	3	1
Product quality, score	4	2	5	5	3
Product price, conventional monetary units (C.M.U.)	180	130	200	160	140

Product cost, conventional monetary units	100	60	180	90	80		
Additional expenses of agents-manufacturers							
Advertising costs, USL. C.M.U.	2000						
Production restructuring costs, C. M. U.	340000	450000	360000	430000	600000		
Restructuring rules[a]							
Product manufacturability, mark	0	0	0	0	+2		
Product quality, score	+1	+1	0	0	+1		
Product price, C.M.U.	-20	0	-30	-40	+10		
Product cost C.M.U.	100	65	140	90	90		
Indicators of consumer agents							
	Classes of agents-consumers						
	1	2	3	4	5	6	7
The number of agents in the class, u.	150	270	210	70	120	160	20
Percentage of agents purchasing cluster products before advertising,%	90						
Percentage of agents purchasing advertised cluster products,%	100						
Funding, C.M.U.	1000	1000	2500	1000	2000	3000	4000
Threshold value describing the differences between the vectors and preference indicators of cluster products	21	10	8	15	9	5	5
Preference indicators for choosing cluster products							
Product adaptability, score	2	2	3	5	3	5	5
Product quality, score	5	2	3	1	5	5	5
Product price, C.M.U.	150	140	150	120	150	120	180
Modeling time settings							
Number of cycles	7						
Model time cycle (tact)	1						
a. These rules are based on the results of mathematical cluster analysis performed on the profiles specifying the attractiveness for agents-consumers. The first cluster includes agents-consumers of Classes 1, 2, 3, and 5; the second cluster includes agents-consumers of Classes 3 and 6. First cluster profile: adaptability of products, 5 points; product quality, 3 points; product price, 120 min. C.M.U. Second cluster profile: product manufacturability, 3 points; quality products, 4 points; product price, 154 min. C.M.U.							



a) Dynamics of profits for manufacturing agents in a modeling time cycle



b) Dynamics of funding changes for agents-consumers

Fig. 1. Input data map for modeling the impact of advertising on the cluster life cycle

The computational experiment is conducted in two phases. In the first phase, simulation is developed without promotional advertising, which is aimed at accelerating the accumulation of funds necessary for production restructuring. At this stage, manufacturing agents consider advertising as a regular event in the specified cycle of modeling time. Advertising is necessary to change agents-consumers' behavior and increase the sales of cluster products.

In the second phase of the experiment, in the second and third model time cycle, the impact of promotion and advertising is simulated by using an advertising campaign which changes the number of agents-consumers wishing to purchase cluster products, thus increasing the profits of manufacturing agents.

In the first phase of the experiment, at the simulated life cycle stage, not all agents-consumers purchase cluster products. Classes of consuming agents 3, 5 and 6 do not purchase cluster products because of its low attractiveness. Agents-consumers of Class 1 purchase cluster products from agents-manufacturers of Class 4; agents-consumers of Class 2, from agents-manufacturers of Class 5; agents-consumers of Class 4, from agents-manufacturers of Class 2; agents-consumers of Class 7, from agents-manufacturers of Class 1. Therefore, agents-manufacturers of Class 3 do not sell their products and, therefore, they will not be able to restructure their production on time and thus will not be able to catch up with the cluster's general formation processes, which will negatively affect the cluster's efficiency.

The process of selling and buying of cluster products extends over the entire period that determines the stage of formation in the cluster life cycle.

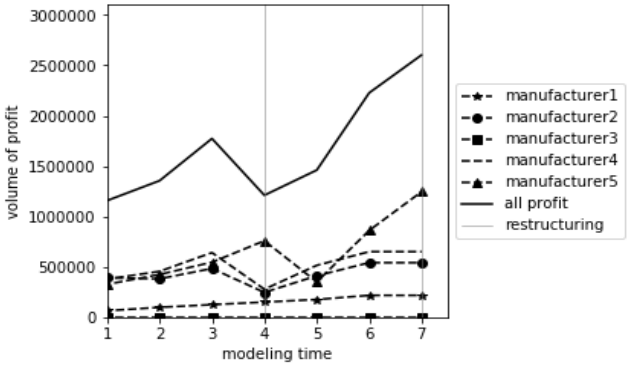
During the second cycle of modeling time, agents 2 and 4 accumulate the funds necessary for restructuring; during the third cycle, they start restructuring their production in accordance with the rules given in Figure 1. Manufacturing agents 5 accumulate funds in the third cycle of modeling time and start to restructure production during the next cycle of modeling time.

In the given period (seven cycles of modeling time), manufacturing agents 1 can accumulate only a portion of the funds – about 60 % – needed for restructuring of production, therefore, they will not be able to change the parameters of manufactured products. If these agents-manufacturers accumulate sufficient funds and start to change their production by the seventh cycle of modeling time, they still won't be able to finish their restructuring. In the former case, agents-manufacturers cannot start the next stage and will, therefore, leave the cluster. In the latter case, these agents-manufacturers with some degree of probability will be able to enter the cluster at the next stage of its development.

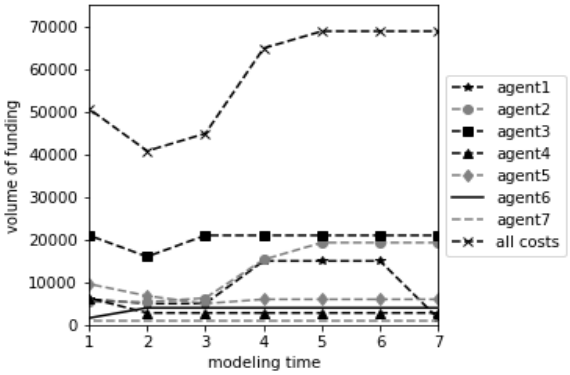
Manufacturing agents 3 cannot restructure their production due to the lack of profit. These agents leave the cluster.

The restructuring of production for agents-manufacturers 2, 4, and 5 ends in the sixth cycle of modeling time. In the seventh cycle, preparations start for transition from the latent stage to the stage of development.

Fig. 2 (a-b) shows the changes in the basic parameters of agents-manufacturers and agents-consumers when we conducted the computing experiment at the first stage.



a) Dynamics of manufacturing agents' profits in a modeling time cycle



b) Dynamics of the changes in agents-consumers' funding

Fig. 2 (a-b). Dynamics of changes of the basic parameters of the agents-manufacturers and agents-consumers when conducting computing experiment at the first stage

The second phase of the computing experiment reveals that preparation of a promotional or advertising campaign shortens the period of cluster formation. The period of accumulating funds for restructuring is shortened, too. Manufacturing agents 2 and 4 in the first cycle of modeling time have already accumulated sufficient funds for restructuring of production. After the third model cycle, these agents-manufacturers present products to the market with new cluster indicators after the restructuring. Agents-manufacturers 2 have improved the product quality and agents-manufacturers 4, in turn, have reduced the cost of production. By using advertising, two agents-manufacturers have managed to start the restructuring earlier, within one cycle of modeling time, which would positively affect their profits in the future.

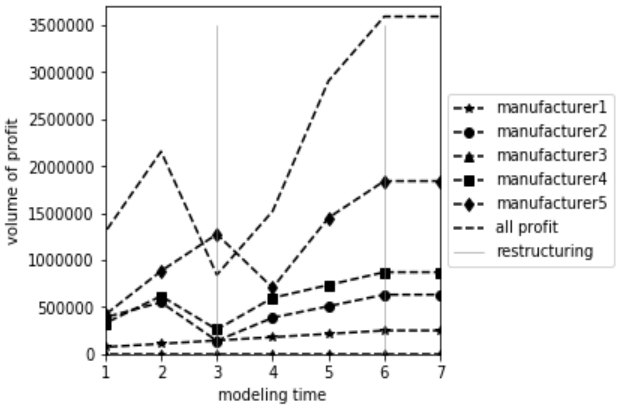
Promotional activities and advertising also affect agents-manufacturers 5, who can accumulate enough funds in the third cycle of modeling time and by the beginning of the fourth cycle of modeling time start the restructuring of production, which allows them to bring products with new parameters to the market. Product adaptability has been improved as well as its quality; its price has risen slightly. This will increase the cluster's sales for this class of agents-manufacturers, which will be beneficial for their profits.

Promotion and advertising have slightly affected manufacturing agents 1; the growth in profit is slow, which does not allow the agents to accelerate accumulation of funds and catch up with the other agents. Agents-manufacturers 1 will be able to restructure their production only on the fifth cycle of modeling time, which negatively affects their profits. Since most classes of agents-manufacturers have already completed their restructuring in the fourth cycle, there is a possibility that manufacturing agents 1 will leave the cluster at the formation stage.

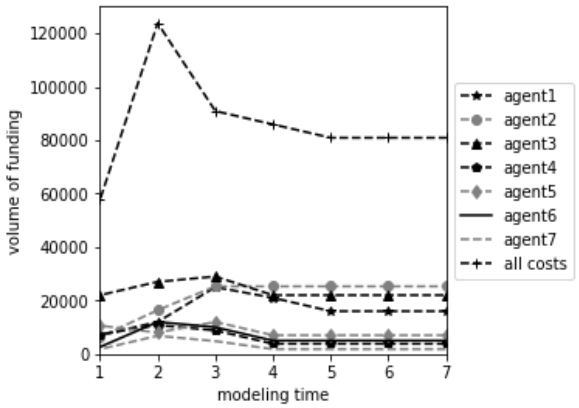
Therefore, without manufacturing agents 1 and 3, the process of transition from the latent stage to the development stage will start in the fifth cycle of modeling time.

Manufacturing agents 3 do not start restructuring and leave the cluster. Promotional advertising has not been effective for them.

Fig. 3 (a-b) shows dynamic changes of the basic parameters of agents-manufacturers and agents-consumers when we conducted the computing experiment at the second stage.



a) Dynamics of manufacturing agents' profits in a modeling time cycle



b) Dynamics of the changes in agents-consumers' funding

Fig. 3 (a-b). Dynamics of changes of the basic parameters of the agents-manufacturers and agents-consumers when conducting computing experiment at the second stage

The computing experiment reveals the following patterns in the impact of advertising on the life cycle of clusters.

1. Advertising enhances growth in manufacturers' sales profits at all stages of the cluster life cycle, which enhances the formation of the cluster's resource potential.

2. Advertising and promotion enhance cluster formation by coordinating consumers and increasing their number as well as by reducing the time of transition from the stages related to the cluster's formation and development to the maturity stage.

3. For businesses that do not meet the cluster's criteria, the impact of advertising and promotion is weak or has no effect. These companies leave the cluster at one of the stages of the cluster life cycle, usually at the stages of formation and development.

Conclusion

Our research identifies the patterns and regularities in the cluster formation process in modern economy as well as the impact of advertising on the life cycle of economic clusters. Advertising positively influences the operation of an economic cluster and helps it accelerate its development and extend its life cycle by increasing the potential of the member enterprises. This process favorably influences not only the enterprises themselves but the consumers of cluster products because they purchase the products which are more relevant to their needs and which reach the market earlier than if the cluster formation processes developed less intensively and the process of cluster formation deaccelerated.

The companies and firms that do not comply with the principles of cluster operation gain little or no benefit from advertising and promotion. Such firms tend to leave the cluster more often at the stages of formation and development.

The discovered patterns can be used to develop economic activities within regional clusters, which form the economic potential of the countries and contribute to their industrial development, including innovation and modernization.

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