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Using Game Theory in Investing

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***Abstract* — In this paper, we analyzed the developed methodology for the optimal distribution of public and private investment research in order to obtain the maximum economic effect in a particular block of the industrial cluster. By industrial cluster blocks, we define: block 1 - "R & D", block 2 - "Procurement and Financial Support", block 3 - "Production and Technological Activities", block 4 - "Staffing Support", block 5 - "Realization of Production equipment". In this article, we offered methodology for the distribution of investment in blocks of an industrial cluster using game theory. In order to determine the investment strategy, we built a payment matrix. In order to confirm the hypothesis to determine the best solutions, we used the classical and derived conformity criteria: Bayesa, Laplace, Sauvage, Gurviz, Hodge-Lehmann. As a result, we obtain the most optimal investment strategy, which shows the effective distribution of public and private investments in the industrial cluster blocks.**

Keywords* — *industrial cluster, optimal investment strategy, payment matrix

I. INTRODUCTION

Famous scientists proved the advantage of the merger of industrial enterprises in the region. Therefore, it was decided to form a model that would reflect the effect of combining the tangible and intangible resources of industrial enterprises and research centers in order to implement import substitution, in particular, food engineering. Scientists have determined that the joint activity of machine-building enterprises is an important component in determining the development of import-substituting and export-oriented production [1, 2]. The principle of combining a group of enterprises into a cluster will make it possible to form complete production and technological chains in the territory of the Russian Federation [3]. Business combinations will support domestic suppliers of raw materials. We propose to form blocks of the industrial cluster: block 1 - "R & D"; block 2 - "Procurement and Financial Support"; block 3 - "Production and Technological Activities"; block 4 - "Staffing Support"; block 5 - "Realization of Production equipment". We compared investment strategies and blocks of the industrial cluster. The optimal strategy will be developed on the basis of the obtained economic effects in the cluster blocks [4].

II. RESEARCH METHODS

Today, scientists have developed a huge number of methods and models of resource allocation of enterprises. Such methods are dynamic modeling, time series analysis, correlation and regression analysis, brainstorming, game theory. Each of them has its advantages and disadvantages. We decided to expand the use of game theory methods. We considered this area of research insufficiently studied. In the course of the study, we relied on the works of such scientists as J.V. Neumann, M.E. Porter, L.V. Kantorovich [5–7]. We tried to use several matching criteria in the face of un-certainty. The relevance of the research is related to a weakly developed cluster structure in Russia.

III. RESEARCH BASE

In the process of research, we used game theory. For the effective distribution of public and private investment in order to form the mechanism of import substitution, the authors propose a method of game theory [8]. The study of games is connected with building a payment matrix. In practice, this is the most time-consuming step in the process of preparing to make a certain decision [9].

TABLE I. INVESTMENT DISTRIBUTION MATRIX.

		Effect in cluster units (j)				
Strategies investing (*i*)		**Y_1**	**Y_2**	**Y_3**	**Y_4**	**Y_5**
	X_1	332	325	123	98	101
	X_2	211	197	198	201	199
	X_3	193	182	175	163	156
	X_4	152	163	169	176	183
	X_5	120	111	124	135	149
	X_6	115	105	99	93	89
	X_7	145	175	204	215	230
	X_8	119	125	146	168	236
	X_9	101	95	118	189	332

Displayed equations are centered and set on a separate line.

When constructing Table I, we will assume that the industrial cluster should strive to maximize the effect in the target area Y_t, and minimize the share of borrowed funds from the state and potential investors X_t [10]. We have designated: Y_1 – economic effect in block 1 "R & D"; Y_2 – economic effect in block 2 - "Procurement and Financial Support"; Y_3 – economic effect in block 3 - "Production and Technological

Activities"; Y_4 – economic effect in block 4 - "Staffing Support"; Y_5 – economic effect in block 5 - "Realization of Production equipment".

To solve the payment matrix, the authors proposed to calculate the optimal investment strategy by the criteria of the maximum expected gain [11]. To obtain more reliable information on the adoption of a rational managerial decision, it is necessary to conduct an inspection according to classical criteria (Bayesa, Laplace, Sauvage criterion) [12] and derived criteria (Hodge-Lehmann) [13]. According to the calculated values, you should choose the strategy that will match the values of the criteria. In the case of the repetition of 2 strategies according to different criteria, it is necessary to form the payment matrix again, taking into account the opinions of experts [14].

Bayes criterion. By Bayesian criterion, that strategy (pure) is taken as optimal. X_i at which the average gain is maximized a minimizes the average risk r [15]. Let us calculate values $\sum(a_{ij} \cdot p_j)$

$$\sum(a_{1,j} \cdot p_j) = 143 * 0.2 + 114 * 0.2 + 94 * 0.2 + 84 * 0.2 + 65 * 0.2 = 100$$

$$\sum(a_{2,j} \cdot p_j) = 128 * 0.2 + 110 * 0.2 + 98 * 0.2 + 92 * 0.2 + 72 * 0.2 = 100$$

$$\sum(a_{3,j} \cdot p_j) = 119 * 0.2 + 100 * 0.2 + 102 * 0.2 + 98 * 0.2 + 81 * 0.2 = 100$$

$$\sum(a_{4,j} \cdot p_j) = 109 * 0.2 + 98 * 0.2 + 100 * 0.2 + 104 * 0.2 + 89 * 0.2 = 100$$

$$\sum(a_{5,j} \cdot p_j) = 97 * 0.2 + 91 * 0.2 + 107 * 0.2 + 110 * 0.2 + 95 * 0.2 = 100$$

$$\sum(a_{6,j} \cdot p_j) = 86 * 0.2 + 89 * 0.2 + 109 * 0.2 + 114 * 0.2 + 102 * 0.2 = 100$$

$$\sum(a_{7,j} \cdot p_j) = 78 * 0.2 + 85 * 0.2 + 114 * 0.2 + 117 * 0.2 + 106 * 0.2 = 100$$

$$\sum(a_{8,j} \cdot p_j) = 70 * 0.2 + 84 * 0.2 + 118 * 0.2 + 120 * 0.2 + 108 * 0.2 = 100$$

$$\sum(a_{9,j} \cdot p_j) = 61 * 0.2 + 79 * 0.2 + 105 * 0.2 + 113 * 0.2 + 142 * 0.2 = 100$$

On the basis of the data, we construct Table II.

We choose from $(100; 100; 100; 100; 100; 100; 100; 100; 100)$ maximum element, $\max = 100$.

Conclusion: we choose a strategy, $i = 2$.

TABLE II. MATRIX OF INVESTMENT STRATEGY SELECTION BY BAYES CRITERION

		Effect in cluster units *(j)*					$\sum(a_{ij} \cdot p_j)$
		Y_1	**Y_2**	**Y_3**	**Y_4**	**Y_5**	
Strategies investing (i)	**X_1**	28.6	22.8	18.8	16.8	13	100
	X_2	25.6	22	19.6	18.4	14.4	100
	X_3	23.8	20	20.4	19.6	16.2	100
	X_4	21.8	19.6	20	20.8	17.8	100
	X_5	19.4	18.2	21.4	22	19	100
	X_6	17.2	17.8	21.8	22.8	20.4	100
	X_7	15.6	17	22.8	23.4	21.2	100
	X_8	14	16.8	23.6	24	21.6	100
	X_9	12.2	15.8	21	22.6	28.4	100
probability	p_j	0.2	0.2	0.2	0.2	0.2	

Laplace criterion. If the probabilities of states of nature are plausible, they are estimated using the principle of the insufficient basis of Laplace, according to which all states of nature are assumed to be equally probable (1), (2):

$$q_1 = q_2 = \cdots = q_n = 1/n \quad (1)$$

$$q_i = 1/5 \, . \quad (2)$$

We construct table III, in which we reflect the sum of the obtained values.

We choose from $(100; 100; 100; 100; 100; 100; 100; 100; 100)$ maximum element, $\max = 100$.

Conclusion: choose a strategy, $i = 2$.

TABLE III. MATRIX OF INVESTMENT STRATEGY SELECTION ACCORDING TO THE LAPLACE CRITERION

		Effect in cluster units *(j)*					$\sum(a_{ij})$
		Y_1	**Y_2**	**Y_3**	**Y_4**	**Y_5**	
Strategies investing (i)	**X_1**	28.6	22.8	18.8	16.8	13	100
	X_2	25.6	22	19.6	18.4	14.4	100
	X_3	23.8	20	20.4	19.6	16.2	100
	X_4	21.8	19.6	20	20.8	17.8	100
	X_5	19.4	18.2	21.4	22	19	100
	X_6	17.2	17.8	21.8	22.8	20.4	100
	X_7	15.6	17	22.8	23.4	21.2	100
	X_8	14	16.8	23.6	24	21.6	100
	X_9	12.2	15.8	21	22.6	28.4	100
probability	p_j	0.2	0.2	0.2	0.2	0.2	

Savage Criterion. Minimum risk criterion Savage recommends choosing as the optimal strategy the one in which the magnitude of the maximum risk is minimized in the worst conditions, i.e. the condition is fulfilled:

$$a = \min(\max(r_{ij})). \quad (3)$$

The Savage Criterion focuses statistics on the most adverse states of nature, i.e. this criterion expresses a pessimistic assessment of the situation. Find the risk matrix, i.e. a measure of inconsistency between the various possible outcomes of adopting certain strategies [13]. Maximum gain in *i*-st column $b_j = \max(a_{ij})$ characterizes the auspiciousness of the state of nature.

1. We calculate the 1st column of the risk matrix.

$r_{11} = 143 - 143 = 0$; $r_{21} = 143 - 128 = 15$; $r_{31} = 143 - 119 = 24$; $r_{41} = 143 - 109 = 34$; $r_{51} = 143 - 97 = 46$; $r_{61} = 143 - 86 = 57$; $r_{71} = 143 - 78 = 65$; $r_{81} = 143 - 70 = 73$; $r_{91} = 143 - 61 = 82$;

2. We calculate the 2nd column of the risk matrix.

$r_{12} = 114 - 114 = 0$; $r_{22} = 114 - 110 = 4$; $r_{32} = 114 - 100 = 14$; $r_{42} = 114 - 98 = 16$; $r_{52} = 114 - 91 = 23$; $r_{62} = 114 - 89 = 25$; $r_{72} = 114 - 85 = 29$; $r_{82} = 114 - 84 = 30$; $r_{92} = 114 - 79 = 35$;

3. We calculate the 3rd column of the risk matrix.

$r_{13} = 118 - 94 = 24$; $r_{23} = 118 - 98 = 20$; $r_{33} = 118 - 102 = 16$; $r_{43} = 118 - 100 = 18$; $r_{53} = 118 - 107 = 11$; $r_{63} = 118 - 109 = 9$; $r_{73} = 118 - 114 = 4$; $r_{83} = 118 - 118 = 0$; $r_{93} = 118 - 105 = 13$;

4. Let us calculate the 4th column of the risk matrix.

$r_{14} = 120 - 84 = 36$; $r_{24} = 120 - 92 = 28$; $r_{34} = 120 - 98 = 22$; $r_{44} = 120 - 104 = 16$; $r_{54} = 120 - 110 = 10$; $r_{64} = 120 - 114 = 6$; $r_{74} = 120 - 117 = 3$; $r_{84} = 120 - 120 = 0$; $r_{94} = 120 - 113 = 7$;

5. Let us calculate the 5th column of the risk matrix.

$r_{15} = 142 - 65 = 77$; $r_{25} = 142 - 72 = 70$; $r_{35} = 142 - 81 = 61$; $r_{45} = 142 - 89 = 53$; $r_{55} = 142 - 95 = 47$; $r_{65} = 142 - 102 = 40$; $r_{75} = 142 - 106 = 36$; $r_{85} = 142 - 108 = 34$; $r_{95} = 142 - 142 = 0$;

TABLE IV. MATRIX OF INVESTMENT DISTRIBUTION ACCORDING TO THE SAVAGE CRITERION

		Effect in cluster units *(j)*				
		Y_1	**Y_2**	**Y_3**	**Y_4**	**Y_5**
Strategies investing (i)	**X_1**	0	0	24	36	77
	X_2	15	4	20	28	70
	X_3	24	14	16	22	61
	X_4	34	16	18	16	53
	X_5	46	23	11	10	47
	X_6	57	25	9	6	40
	X_7	65	29	4	3	36
	X_8	73	30	0	0	34
	X_9	82	35	13	7	0

The results of the calculations are arranged in the form of table V.

TABLE V. MATRIX OF INVESTMENT DISTRIBUTION ACCORDING TO THE SAVAGE CRITERION

		Effect in cluster units *(j)*					$\max(a_{ij})$
		Y_1	**Y_2**	**Y_3**	**Y_4**	**Y_5**	
Strategies investing (i)	**X_1**	0	0	24	36	77	77
	X_2	15	4	20	28	70	70
	X_3	24	14	16	22	61	61
	X_4	34	16	18	16	53	53
	X_5	46	23	11	10	47	47
	X_6	57	25	9	6	40	57
	X_7	65	29	4	3	36	65
	X_8	73	30	0	0	34	73
	X_9	82	35	13	7	0	82

We choose from (77; 70; 61; 53; 47; 57; 65; 73; 82) minimal element, min $= 47$. Conclusion: we choose a strategy, $i = 5$.

Hodge-Lehmann criterion. For each line, we calculate the value of the criterion using the following in (4):

$$W_i = \mu \cdot \sum_{j=1}^{n} a_{ij} \cdot p_j + (1 - \mu) \cdot \min\left(a_{ij}\right). \quad (4)$$

Next, we calculate W_i for each line:

$$W_1 = 0.5 \cdot 100 + (1 - 0.5) \cdot 65 = 82.5$$

$$W_2 = 0.5 \cdot 100 + (1 - 0.5) \cdot 72 = 86$$

$$W_3 = 0.5 \cdot 100 + (1 - 0.5) \cdot 81 = 90.5$$

$$W_4 = 0.5 \cdot 100 + (1 - 0.5) \cdot 89 = 94.5$$

$$W_5 = 0.5 \cdot 100 + (1 - 0.5) \cdot 91 = 95.5$$

$$W_6 = 0.5 \cdot 100 + (1 - 0.5) \cdot 86 = 93$$

$$W_7 = 0.5 \cdot 100 + (1 - 0.5) \cdot 78 = 89$$

$$W_8 = 0.5 \cdot 100 + (1 - 0.5) \cdot 70 = 85$$

$$W_9 = 0.5 \cdot 100 + (1 - 0.5) \cdot 61 = 80.5.$$

The resulting values distributed in columns $\sum(a_{ij}p_j)$, $\min(a_{ij})$, W_i in Table VI.

TABLE VI. MATRIX CALCULATIONS ACCORDING TO THE HODGE-LEHMANN CRITERION

		Effect in cluster units *(j)*					$\sum(a_{ij}$	$\min(a_i$	W_i
		Y_1	**Y_2**	**Y_3**	**Y_4**	**Y_5**			
Strategies investing (i)	**X_1**	0	0	24	36	77	100	65	82.5
	X_2	15	4	20	28	70	100	72	86
	X_3	24	14	16	22	61	100	81	90.5
	X_4	34	16	18	16	53	100	89	94.5
	X_5	46	23	11	10	47	100	91	95.5
	X_6	57	25	9	6	40	100	86	93
	X_7	65	29	4	3	36	100	78	89
	X_8	73	30	0	0	34	100	70	85
	X_9	82	35	13	7	0	100	61	80.5
probabilities		0.2	0.2	0.2	0.2	0.2			

We choose from $(82.5;\ 86;\ 90.5;\ 94.5;\ 95.5;\ 93;\ 89;\ 85;\ 80.5)$ maximum element, max $= 95.5$.

According to the calculations for this criterion, it is necessary to consider the optimal investment strategy, $i = 5$.

Generalized Hurwitz criterion. This criterion is a certain generalization of the criteria of extreme pessimism and extreme optimism, and is also a special case of the generalized Hurwitz criterion regarding winnings under the following assumption:

$$\delta_1 = 1 - \delta,\ \delta_2 = \delta_3 = \ldots = \delta_{n-1} = 0, \delta_n = \delta, \text{where } 0 \leq \delta \leq 1.$$

Then the indicator of efficiency of the investment strategy i according to Hurwitz is:

$$G_i = (1 - \delta) \cdot \min(a_{ij}) + \delta \cdot \max(a_{ij}). \quad (5)$$

The optimal strategy *i* will be the strategy with the maximum value of the performance indicator.

Let us build auxiliary matrix VII. Pessimist approach. δ is selected from the condition of non-increasing average:

$$\delta = \frac{b_1}{b_1 + b_5} = \frac{693}{693 + 1102} = 0.386. \quad (6)$$

Therefore, we calculate G_i:

$$G_1 = 0.386 \cdot 65 + (1 - 0.386) \cdot 143 = 112.886$$

$$G_2 = 0.386 \cdot 72 + (1 - 0.386) \cdot 128 = 106.38$$

$$G_3 = 0.386 \cdot 81 + (1 - 0.386) \cdot 119 = 104.329$$

$$G_4 = 0.386 \cdot 89 + (1 - 0.386) \cdot 109 = 101.279$$

$$G_5 = 0.386 \cdot 91 + (1 - 0.386) \cdot 110 = 102.665$$

$$G_6 = 0.386 \cdot 86 + (1 - 0.386) \cdot 114 = 103.19$$

$$G_7 = 0.386 \cdot 78 + (1 - 0.386) \cdot 117 = 101.943$$

$$G_8 = 0.386 \cdot 70 + (1 - 0.386) \cdot 120 = 100.696$$

$$G_9 = 0.386 \cdot 61 + (1 - 0.386) \cdot 142 = 110.728.$$

Optimistic approach. δ is selected from the condition of non-decreasing average:

$$\delta = \frac{b_5}{b_1 + b_5} = \frac{1102}{693 + 1102} = 0.614.$$

Therefore, we calculate G_i:

$$G_1 = 0.614 \cdot 65 + (1 - 0.614) \cdot 143 = 95.114$$

$$G_2 = 0.614 \cdot 72 + (1 - 0.614) \cdot 128 = 93.62$$

$$G_3 = 0.614 \cdot 81 + (1 - 0.614) \cdot 119 = 95.671$$

$$G_4 = 0.614 \cdot 89 + (1 - 0.614) \cdot 109 = 96.721$$

$$G_5 = 0.614 \cdot 91 + (1 - 0.614) \cdot 110 = 98.335$$

$$G_6 = 0.614 \cdot 86 + (1 - 0.614) \cdot 114 = 96.81$$

$$G_7 = 0.614 \cdot 78 + (1 - 0.614) \cdot 117 = 93.057$$

$$G_8 = 0.614 \cdot 70 + (1 - 0.614) \cdot 120 = 89.304$$

$$G_9 = 0.614 \cdot 61 + (1 - 0.614) \cdot 142 = 92.272.$$

We choose from $(112.886;\ 106.38;\ 104.329;\ 101.279;\ 102.665;\ 103.19;\ 101.943;\ 100.696;\ 110.728$ max element, max $= 112.89$.

TABLE VII. MATRIX OF CALCULATIONS BY GENERALIZED CRITERION OF HURVITZ

		Effect in cluster units (*j*)					min(	max(*a*	Pessimist approach	Optimist approach
		Y_1	Y_2	Y_3	Y_4	Y_5				
Strategies investing (i)	X_1	65	84	94	114	143	65	143	112.88	95.11
	X_2	72	92	98	110	128	72	128	106.37	93.62
	X_3	81	98	100	102	119	81	119	104.32	95.67
	X_4	89	98	100	104	109	89	109	101.27	96.72
	X_5	91	95	97	107	110	91	110	102.66	98.33
	X_6	86	89	102	109	114	86	114	103.18	96.81
	X_7	78	85	106	114	117	78	117	101.94	93.05
	X_8	70	84	108	118	120	70	120	100.69	89.3
	X_9	61	79	105	113	142	61	142	110.72	92.27

Conclusion: We choose the strategy $i = 1$.

IV. CONCLUSION

Finally, the result research of solving a statistical game according to various criteria, the strategy was more often recommended, $i = 5$.

From the obtained values, we see that with a specific amount of investment with the main goal to outperform the market in scientific and technological terms, the presented model allows you to distribute money evenly across all blocks to achieve goals.

The formed investment vector must be spread by investment to include it in the management income statement.

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