ECONOMIC AND MATHEMATICAL MODELS FOR INCREASING THE EFFICIENCY OF PUBLIC HEALTH RISK MANAGEMENT IN ECOLOGICAL AND ECONOMIC URBAN AREA SYSTEMS

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Abstract: *The article proposes economic and mathematical models for evaluating health risks for urban populations in Russian highly dense areas. Such models are meant to assess financial and economic risks affordable to society at the beginning of the 21st century. The findings help understand intrinsic relations between a variety of parameters, during the planning and handling crucial issues such as economic development, public health and medical care systems. Decision makers, practitioners and scientist can find food for thought in assessing the affordability of risks and risk management methods, rooted in thorough methods of evaluation.*

Key words: *risk management, public health, economic and mathematical models, social responsibility, survival strategies*

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1. INTRODUCTION

The relevance of the topic in this research article derives from the fact that theoretically known economic risks are enhanced by such trends as globalization, border permeability, new types of financial and commodity flows that carry hidden risks, due to a number of hidden features of interdependent factors. Economic actors can be divided into two groups: those who voluntarily face risk factors and play in the field in order to gain profit or power, and those on whom risk is imposed, against their possibility to opt out or oppose. The production of risk places economic actors on asymmetrical situations: when the first group is exposed to intense negative stabilization, it develops rules of risk-taking solidarity, while risk consumers pay the bill for the risks and take over the role of risk absorbers. The first group acts upon the principle of social aggressiveness, resistance to social control, while the latter group is forced into the position of subduction and developing of survival strategies.

2. RISK ASSESSMENT – MATHEMATICAL MODELS

Risk is associated with external changes, such as social or economic; they can be planned or spontaneous, imported from outside or adaptive. Every change carries the risk, and the discussion in management terms is carried around the degree of acceptability: a given risk is considered to be either acceptable, or too expensive for a certain society.

Russian economy has evolved, in the past decades, in a highly dense risk environment, due to globalization factors that heavily influence the prices and trade of oil and gas on the global market. Structural risks grew to unprecedented values. The unreasonably high concentration of financial capital in the hands of a narrow group of owners and the monopoly on natural

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resources affects the behavior and policies of investors from the other economic sectors, not directly involved in the natural resources exploitation.

The «survival» strategy cannot fulfill the various needs in society. Its objectives and social development goals do not coincide with the functions and tasks of the economy. The «reduction» of risk of simplified economic structures means shifting risks of «non-usage» in society. The Russian consumer pays the risk of a «deteriorating diet», exposed to the danger of loss of resilience and illness caused by the uncontrolled import of low-quality and risk- taking goods in the categories of food and consumer goods groups.

The responsive risks are characterized by a decrease in social responsibility and loss of social control under the economic transformations. Structural imbalances in transition economy lead to the destruction of traditional institutions of social control, to the emergence of the shadow economy and a seemingly institutionalized support for the «easy money» type of mentality.

This article, rooted in the author's longtime research, proposes economic and mathematical models for evaluating health risks for urban populations in Russian highly dense areas, meant to assess financial and economic risks affordable to the 21st century Russian society.

On the basis of the risk theory [1], [2], we analyze comparatively the statistics of the most spread types of diseases in the target areas [3], [4]. The quantity of diseases taken into account $m = 20$ (see colon 1 in table 1), in a 6 years timeframe (2009-2014), refer to an evaluation over 100 thousand people.

As it is already proved [5], starting with Markowitz portfolio theory, in the mathematical models used for determining the financial and ecological risk we base our judgments on the main parameters in the paired form of: maximal expected profit, presented as a mathematical quantifier M , and the minimal risk, quantified either as the dispersion D, or as the result of the formula (СКО) $\sigma = \sqrt{D}$.

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Table 1

Types of diseases

		2009	2010	2011	2012	2013	2014
1	General illness	6432	6646	7054	6974	3911	3653
2	Infections	6551	4241	2163	4722	3991	3697
3	Neoplasms	2528	2296,33	2297,33	2308,67	10600	3613
4	Endocrine	1306,93	3053,667	3211	3669,33	4281,33	4744,1
5	Tireotom	202,6	147,7	161,73	143,96	124,13	130,96
6	Diabetes	1460,46	1340,23	1368,4	1411,06	1472,16	1451,0
7	hematopathy	189,53	169,2	236,2	275,63	203,6	409,7
8	Mental illnesses	4628,43	5052,23	5235,8	3673,23	5084,7	5744,5
9	Nervous system	3835	3973	4819	3465	3178	2332
10	Peripheral nervous system	2452,93	2832,7	6626,6	3776	2051,3	1656,6
11	Diseases of the circulatory system	5129	5065	5210	5526	8291,17	7163,8
12	hypertensive heart disease	1896,16	1835,2	1404,9	1650,9	1104,2	2208,5
13	Respiratory system	3903	1869	4513	1629	4049	3241
14	Allergic rhinitis	315,86	230,16	286,36	288,6	197,36	209.43
15	Bronchial asthma	371,46	305,7	380,36	339,56	308,9	321,56
16	Digestion disease	4299,86	4244,26	4262,8	3969,76	3685,26	3499,1
17	Gastric ulcer	876,66	807,7	854,8	903,66	927,1	919,83
18	Gastritis	1286,73	1198,66	1195,1	980,13	726,9	769.96
19	MPS	3047,63	2291,6	2888,7	2870,83	2431	2903,2
20	Obesity	153,03	154,06	398,93	154,8	190,26	210,46

In our opinion, the classical dispersion D carries less information than its neighboring parameters, D^- and D^+, where D^- (D^+) consists of terms summed to determine the random variable values (VV) of smaller (larger) mathematical expectations M [6].

From the point of view of the theory of choice and decision-making [7], it is highly desirable to adhere to the conditions of co-measurement of performance vector of the objective function (VOF), in this case in the form of the VOF «profit-risk» [5], [6]. It follows that instead of the D dispersion it is more fruitful to evaluate risks according to CKO σ. Because the dispersion is an additive function of a given probability distribution, it seems natural to consider, instead of the indicators D^- and D^+, such indicators as $\sigma^- = \sqrt{D^-}$ and $\sigma^+ = \sqrt{D^+}$.

In the case of small samples it is not possible to speak of a probability distribution for consideration evaluating VV. The analyst is left with the option to work with the empirical values M, D, D^-, D^+, σ^-, σ^+ [8]. This statement applies to such additional risk criteria as the coefficient of variation $V = \frac{\sigma}{M}$, the coefficient of asymmetry [8] $A = \frac{\sum_{S=1}^{n} (W_S - M)^3 P_S}{\sigma^3}$ and the coefficient of excess $E = \frac{\sum_{S=1}^{n} (W_S - M)^4 P_S}{\sigma^4}$.[2]

Currently the definition of economic and financial risks can be regarded as the assertion that the measure of risk should reflect the degree of danger of financial loss. A narrowing, focused explanation of the above is expressed in the phrase: «Risk means the likelihood that the revenue of the producer is smaller than the required, planned, intended revenue» [9]. It is assumed that this probability is estimated on the basis of D or σ, while with a multi-criteria estimation [6] this probability takes into account VOF, consisting, for example, from the criteria σ^-, σ^+, A, E^-, E^+, where $E^- = \frac{\sum_{W_S<M} (W_S - M)^4 P_S}{\sigma^4}$, $E^+ = \frac{\sum_{W_S>M} (W_S - M)^4 P_S}{\sigma^4}$.

In economic tasks the parameters D^+, σ^+, A, E^+ represent maximizing criteria, i.e. the growth of their value can be interpreted as «the risk of large or very large income». In our situation, when evaluating the social and environmental effects of the population exposure to a particular type of disease, the parameters D^+, σ^+, A, E^+ represent the criteria of risk minimization, since the growth of the value of the parameter can be interpreted as «the risk of a sharp increase in the number of diseases among the population».

The present study focuses on the problem of modeling the social and environmental risks in the medical care system. In constructing a corresponding mathematical model we proposed a two-level representation of a set of criteria that characterize the state of the analyzed system. At the top level we take into consideration the types of diseases, enumerated with the help of the index $k = 1, 2, ..., m$. Each index $k \in \{1, 2, ..., m\}$ is characterized on the lower level according to its VOF, which consists only of the minimizing criteria:

$$M_k \to \min, \sigma_k^+ \to \min, A_k \to \min, E_k^+ \to \min, \quad (1)$$

where $M_k, \sigma_k^+, A_k, E_k^+$ – represent sample values of the indicators of the mathematical expectation M, the right side CKO σ^+, asymmetry A and right excess value E^+, calculated as empirical values [2], [5] for the k - type of disease, $k = \overline{1, m}$.

The set of criteria (1) can be considered as a vector index:

$$F_k = (M_k, \sigma_k^+, A_k, E_k^+), \quad (2)$$

representing a vector, i.e. a multi-criteria evaluation of such a systemic indicator as the «level of concern» (CO). The ultimate goal of the initial analysis of the totality of the statistics by type of diseases is considered the ranking of the types of diseases in such a way, that CO should not increase its values. This ranking can take the form of the sequence:

$$k_1, k_2, ..., k_m \tag{3}$$

Taking into account our purpose of obtaining the sequence (3) with the inclusion of the entire set of *m* varieties, we note that in the context of the vector index (2) we do not take into consideration the famous Pareto principle [7]. Therefore, the present study does not require the analysis of such a secondary goal as the multi-criteria optimization of the totality of these elements.

Table 2 presents the values of the criteria, which represent a vector (multi-criteria) evaluation of such a system indicator as the «level of concern».

The question of rationing of all or some of these criteria arises in case that the following conditions are not met: 1° Uniformity of the extreme type: either all of the given VOF criteria can be minimized, or all of them can be maximized. 2° Commensurability: all of the criteria of the given VOF have the same measurement type. 3° The set of values for the numerical criteria values: the units of the $F_k(x)$ parameter reflect the same contribution to the local utilities of these values in the integral value of the given VOF.

Table 2

Values of the criteria

k	M	σ^+	E^+	A
1	5778,4	840	0,02	– 0,89
2	4227,7	970	1,7	0,37
3	3940,68	2718	3,83	2,32
4	3377,72	679	0,49	– 0,97
5	151,85	21	2,5	1,35
6	1417,23	31	2,2	– 0,55
7	247,31	67	2,8	1,56
8	4903,15	381	0,6	– 1,07
9	3600,9	3951	2,72	– 0,12
10	1116,11	1401	17,5	0,92
11	6064,5	624	2,16	1,2
12	1683,32	239	0,95	– 0,29
13	3201	1621	3,8	– 0,54
14	254,63	31	3,9	0,01
15	337,92	22	63	0,48
16	3993,53	195	0,33	– 0,67
17	881,62	25	0,38	– 0,85
18	1026,25	144	0,47	– 0,35
19	2738,85	164	0,3	– 0,85
20	210,26	77	3,67	2,13

The term «normalization» for the criteria of a given VOF means converting them into a manner that satisfies the conditions1° – 3°.

The Table 2 points to the fact that M_k and σ_k^+ are measured by the number of diseases, while A_k and E_k^+ – represent coefficient; therefore the condition 3° is broken, due to the fact that the measuring units are not of the same kind. In order to deal with this contradiction, and ensure the fulfillment of the condition 3° it is necessary to normalize the values of M_k and σ_k^+, $k = \overline{1, m}$ by applying the corresponding normalization coefficient a_k: $\overline{F_k} = a_k F_k$, $F_k \in \{M_k, \sigma_k^+\}$. For M_k the value $a_k^M = \dfrac{1}{M_k^{\max} - M_k^{\min}} = \dfrac{1}{6064{,}5 - 151{,}85} = 0{,}00017$, and for σ_k^+ the value

$$a_k^\sigma = \frac{1}{\sigma_k^{\max} - \sigma_k^{\min}} = \frac{1}{3951 - 21} = 0{,}00025.$$

The results of the normalization operation of the units presented in table 2 are given in the table 3.

Table 3

Results of calculations

k	$\overline{M_k}$	$\overline{\sigma_k^+}$	E_k^+	A_k
1	0,9	0,21	0,02	– 0,89
2	0,7	0,24	1,7	0,37
3	0,6	0,67	3,83	2,32
4	0,5	0,17	0,49	– 0,97
5	0,02	0,005	2,5	1,35
6	0,2	0,007	2,2	– 0,55
7	0,04	0,02	2,8	1,56
8	0,8	0,09	0,6	– 1,07
9	0,6	0,9	2,72	– 0,12
10	0,2	0,35	17,5	0,92
11	1	0,15	2,16	1,2
12	0,3	0,06	0,95	– 0,29
13	0,5	0,4	3,8	– 0,54
14	0,04	0,007	3,9	0,01
15	0,06	0,005	6,3	0,48
16	0,7	0,05	0,33	– 0,67
17	0,14	0,006	0,38	– 0,85
18	0,17	0,03	0,47	– 0,35
19	0,46	0,04	0,3	– 0,85
20	0,03	0,02	3,67	2,13

In order to determine the values of $F_k = (\overline{M_k}, \overline{\sigma_k^+}, E_k^+, A_k)$, $k = \overline{1, 20}$, we apply the following decision rules (DR) [10]:

$f_k^1 - MINSUM$, $f_k^2 - MINMAX$, f_k^3 – «distance to the ideal point», determined with the help of the formulas:

$$f_k^1 = \overline{M_k} + \overline{\sigma_k^+} + E_k^+ + A_k \rightarrow \min,$$

$$f_k^2 = \max\,(\overline{M_k}, \overline{\sigma_k^+}, E_k^+, A_k) \rightarrow \min,$$

$$f_k^3 = \sqrt{(\overline{M}_k - M^0)^2 + (\overline{\sigma}_k^+ - \sigma^0)^2 + (E_k^+ - E^0)^2 + (A_k - A^0)^2} \rightarrow \min,$$

Where the «ideal value»

$$M^0 = \min_{1 \le k \le m} \overline{M}_k,\ \sigma^0 = \min_{1 \le k \le m} \overline{\sigma}_k^+,\ E^0 = \min_{1 \le k \le m} E_k^+,$$

$$A^0 = \min_{1 \le k \le m} A_k.$$

By using the data from Table 3 and the DR *MINSUM*, *MINMAX* and «distance to the ideal point» we can represent the results as given below:

Table 4

Calculus of distance to the ideal point

№	MINSUM	MINMAX	Distance from ideal point
1	0,240	0,9	17,785966
2	3,010	1,7	15,936377
3	7,420	3,83	13,677785
4	0,190	0,5	17,347827
5	3,875	2,5	15,089809
6	1,857	2,2	15,612955
7	4,420	2,8	14,777131
8	0,420	0,8	17,256831
9	4,100	2,72	14,985393
10	18,970	17,5	1,7036725
11	4,510	2,16	15,399107
12	1,020	0,95	16,790182
13	4,160	3,8	14,013194
14	3,957	3,9	13,856953
15	6,845	6,3	11,424107
16	0,410	0,7	17,45169
17	– 0,324	0,38	17, 455146
18	0,320	0,47	17,279919
19	– 0,050	0,46	17,519135
20	5,850	3,67	13,893175

With the help of the iterative procedure proposed by [10], called «generalized decision rule» (GDR), we shall analyze the types of diseases in the order that does not lead to the increase of social concern CO. Several dozens of iterations lead to the sequence:

(10, 15, 3, 14, 20, 13, 7, 9, 5, 11, 6, 2, 12, 8, 18, 4, 16, 17, 19, 1) (4)

Here the diseases are ordered by placing the highest concern at the beginning, while the following decrease in intensity. As a consequence of such a hierarchy, specialists in the medical care system should pay their utmost attention to the diseases at the top of the sequence and the sequence as a whole can serve for further types of analyses.

The DR and GDR [10] employed in this paper belong to the so-called direct methods of choosing and decision-making [7]. In the application of these methods for further statistical data analysis we resort to the so-called criterion of the relative importance of the coefficients, in the designing of a DR.

For instance, for the data comprising the above presented DR of the type *MINSUM* f_k^1 - the criteria $\overline{M_k}$, $\overline{\sigma_k^+}$, E_k^+, A_k we may use expert values of the relative importance of factors equal to, respectively, 0,5; 0,3; 0,1; 0,1. Similarly, for the DR of the type MINSUM, MINMAX, «distance to ideal point» we may determine the coefficients of relative importance. We draw a special attention to the fact that, for the sake of brevity and simplicity, we presented in numerical data Table 4, as well as in the sequence (23) obtained without using the factors of relative importance.

3. DISCUSSION AND CONCLUSIONS

At the initial stage of analytical epidemiological studies it is important to establish the presence or absence of statistical indicators of morbidity in the groups exposed and not exposed to the hypothetical risk factor (cohort studies).

At the same time one should pay special attention to on whether general patterns in the level and structure of morbidity are discernible or not, what is their prevalence in age groups, what is the stability of the ratio of individual nosological forms, groups and classes of diseases throughout the studied period of time. If by comparison with previous years or with other areas a high rate of incidence or growth of parameters is encountered, the magnitude and values of such excess has to be noted. In addition, it is relevant to look into the presence or absence of statistical indicators characterizing the degree of exposure to a hypothetical risk factor of groups of patients and patients who display or not the disease under study (a study of the type «case-control»). In such a manner we can determine statistical relationships between the hypothetical factor of risk and morbidity. If such a link can be established, its causal nature has to be thoroughly scrutinized.

The following occurrences hint in favor of the cause-effect nature of statistical evidence:
the repeatability of the results obtained in the analysis of disease manifestations in each of the three dimensions (location, group, time) of a cohort study, as well as the repeatability of the results obtained in cohort studies of the type «case-control»;

1. The quantitative relationship between the strength of the hypothetical risk factor and severity of the consequences (morbidity rate) of the type «dose – effect»;
2. the specificity of links, i.e. the presence of links in a particular disease and the lack of them in other cases;
3. the anticipatory actions of the hypothetical risk factor;
4. a greater force of the morbidity in association with a hypothetical risk factor;
5. the verification of the results of epidemiological studies against the entire set of data characterizing the pathology under analysis.

An element that fosters the determination of the relationship is the supplementary analysis of morbidity in specially formed groups, on one hand, and the study of the factors (properties, time and intensity of action) on the other.

The additional analysis of morbidity bears a comparative character. It is used in the cases when a noticeable change is detected in the level, structure, or ratio of known clinical entities, as well as the registration of a previously unknown disease. In such cases it is customary to resort to several comparison groups (groups that are characterized by the presence of a particular disease, by the intensity of the factor affecting the environment etc.). The method requires the determination of resilient groups or groups having an increased sensitivity to toxicants, such as children.

In assessing the impact of environmental factors it is essential to make right choices of groups, not affected by the toxicant. Three approaches can be suggested for the identification of such influence:
1. Internal comparison; in such situations the analysis focuses on a group with sufficient numbers of exposed and unexposed persons.
2. External comparisons; the focus is on the exposed group, and efforts are made to find another group, not exposed, but similar to the first on other grounds (sex, age, place of work, etc.).
3. Comparison with the «general» population (population); the exposed group is determined and the incidence of disease presence is compared with the incidence of the same disease in the total population (considered as «unexposed»).

During risk assessment it often happens that the effect of specific environmental factors on health can significantly distorted or modified, depending on the situation. For example, when evaluating the impact of air pollution on the state of lung ventilation in the experimental and the control area it can happen that in a pollution-free area the population displays worse indicators than in the polluted area. This result occurs when the research does not take into account the proportion of smokers and the age structure in either samples or areas.

Therefore, the presented characteristics of risk assessment methodologies in the medical care systems make possible the practical application of these methods for identifying risks of anthropogenic pollution on public health and underpin environmental and health recommendations for managing the quality of environmental management.

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