The Analysis of Economic Indicators Based on the Information Model of N. Wiener

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Abstract. Mathematical models for determining the amount of entropy for analysis of future economic indicators are considered. Possibilities of application of mathematical models for the purposes of accounting in need of reflection of estimated values of future indicators in public reports of the companies are determined. The models are based on the information model of N. Wiener. The role of information uncertainty in the analysis problem is proved and the applicability of some approaches to uncertainty assessment of indicators is considered. The probabilistic-statistical approach, which most fully corresponds to the possibilities of using the Wiener’s information model, is highlighted among the approaches. On its basis the description model and mathematical expressions of determination of size of private entropy of an economic system object are constructed. The mathematical model of description the entropy of indicators of the economic system is constructed and its component is a model of private entropy. The created mathematical model allows to determine the amount of entropy for one and two variables, taking into account the correlation between them. The model is useful for assessing the state of the economic system at selected time intervals.

1. Introduction
Mathematical developments in the field of measurement of future information are of practical importance for the analysis of future economic indicators (e.g., estimated and contingent liabilities, contingent assets). One of the directions in economic science received the name "evolutionary economics", which is based on the application of the evolution laws to explain the non-equilibrium economic processes in the economic space [1]. The description of these processes is associated with the concept of entropy, the opportunities of which can be found in works [2, 3]. Despite the fact that there is no universal concept of entropy even in the natural Sciences, nevertheless, most of the concepts are associated with the description of the number of probabilistic system states.

Considering the economic system from the standpoint of its probabilistic states, as evidenced by [4, 5], an integral part of the analysis is information [6, 7, 8]. It is (in the simplest interpretation) information about parameters, variables and connections between elements, at the same time not excluding the modeling of possible states of the system.

The analysis of information implies the presence of the process of obtaining results that are acceptable for follow-up. Turning to the opportunities of time series analysis of economic indicators, let’s build mathematical models using theoretical calculations determining the amount of information according to N. Wiener.
2. Analysis of financial statements in the assessment of economic indicators

Today, the leading role in the assessment of future economic indicators belongs to economic analysis, namely the analysis of financial statements, as the most accessible form of information about the company. Analysis of the financial statements of an organization is characterized by the identification of connection and dependencies between the various indicators of its financial and economic activities included in the statements. The method of analysis of the financial condition depends on the goals and objectives, as well as information and methodological, personnel and technical support. The information base for financial analysis is the data of accounting and reporting, the analytical review of which should restore all the main aspects of economic activity and operations in a generalized manner, that is, with the necessary degree of aggregation for the analysis. The method of financial and economic analysis is understood as a systematic comprehensive study of the economy of production, enterprises, companies, stock exchanges, securities, in order to identify the achieved level of their financial development, the degree of rational use of material, labor and money resources, the definition of reserves and opportunities to improve all indicators of economic activity to increase economic efficiency.

When analyzing economic phenomena, abstract thinking is often used. Scientifically based abstraction deeper and comprehensive displays the reality. Today, the concept of integrated thinking and integrated reporting is the problem of analysis of non-financial information. And this method can find its place in solving this problem [9].

The main features of the method of economic analysis is to identify and determine the degree of connection and interdependence of indicators determined by the objective conditions of production and sale of goods. For example, the volume of output depends on three interrelated groups of factors - labor, means of labor and objects of labor. Each of these groups is subdivided into separate constituent elements. In carrying out the analysis, it is necessary to take into account the causal dependence in industrial and agro-industrial enterprises. Production and results of economic activity depend not only on technology and organization of production, but to a large extent on the quality of energy resources, raw materials, natural factors, capital and labor. These factors sometimes become decisive. And again there is the problem of evaluating these important non-financial indicators. Therefore, it is necessary to analyze the causal relationship very carefully and in detail. It should be borne in mind that the cause and effect are in a certain connection. In this regard, some phenomena and factors have a positive effect on the development of the enterprise, while others hinder the development and delay it. Therefore, one of the tasks of the analysis is to identify positive and negative phenomena and factors. Creating conditions for positive and eliminating (or neutralization of influence) of negative phenomena and factors will ensure the fulfillment of the volume of production.

Traditional methods of economic analysis: decomposition of the whole into parts (analysis) and generalization (synthesis), comparison, calculation of differences, chain substitutions, index method, grouping, balance method, correlation and linear programming [10].

The initial basis of the financial analysis is the data of accounting and reporting. The analytical review of these data allows to restore all the main aspects of economic activity and transactions in a generalized form, i.e. with the necessary degree of aggregation for the analysis. Given the above, the most rational way to assess the financial and economic condition of the enterprise today is a method based on the use of financial ratios and other indicators characterizing various aspects of this condition.

3. Measure of information uncertainty to solve the problems of analysis of indicators of various kinds

3.1. Modern models of analysis of complex economic systems

Let’s consider modern models of analysis of complex economic systems, which are socio-economic systems. The modern concept of the system analysis (based on synergetics models) allows to estimate in a new way the principles of the organization of objects with different types of connection. In addition, this connection are constructed not on the hierarchical principle.
In recent decades, an extensive scientific field has emerged in which these issues are treated as interdisciplinary, taking into account the generalized approach - synergetics (the doctrine of interaction). As shown in numerous works, including in our work [11], its results are relevant to social processes, although initially identified patterns were attributed to the processes of inanimate nature and biological processes. At the same time, self-organization provides systems with capabilities that, in the absence of self-organization, would require more resources and management costs, or the probability of their implementation would be extremely low.

Before turning to the main topic of the article, we consider it appropriate to recall the content of some principles of synergetics, since it is often perceived as combinatorics or systematics. Every system is subject to external conditions (or factors) of formation of uncertainty and risks. These conditions are described in the form of so-called control parameters. As shown mathematically in synergetics, in many cases, the behavior of a system close to such points of instability may depend on the behavior of very few variables, one can even say that the behavior of individual parts of the system is simply determined by these few factors. These factors are called “control parameters of the order”. H. Haken notes that “...here it is necessary to avoid the idea that these parameters only care about the order; they can also represent or control disorderly, chaotic states or control them” [12].

Uncertainties and risks [13, 14], which are based on the inner spontaneity of being, in other words, randomness as its immanent property, have a different side: every act of the birth of the new in nature and in society is somehow connected with randomness. Currently, only a person (and a social organization) can properly fit into society, provided that he is ready to perceive the new and has the ability to create something new, that is, creativity. In order to meet the requirements of an innovation-oriented society, social management must be essentially innovative, including taking into account the above provisions.

Analysis of future indicators, assessment and risk management of complex economic systems in the conditions of instability of the economic situation, market dynamics and increased competition is one of the topical issues [15]. Bankruptcy, the fall in the value of shares and the inability to manage the risks of complex socio-economic organizations are primarily due to the fact that most head of enterprise don’t pay enough attention to decision-making processes and strategic planning due to the lack of theoretical and practical opportunities.

In this regard, the role of initial data of accounting and reporting (that is, the database, based on which management decisions are made) is high. The information contained in the financial statements is intended to enable the users of the statements to assess both the current financial and economic situation of the company and its future state. There is a duty to disclose significant future events in both accounting and integrated reporting. The approach to integrated accounting, based on elements of the traditional accounting method facilitates a clear gradual transition to integrated reporting standards. However, there is a problem of finding methods for calculating and evaluating of future uncertain indicators in reporting.

3.2. Uncertainty of future economic indicators

The economic indicators (prices, sales volumes, profits/losses, etc.) often are expressed in the form of numerical values distributed over time. Such time series are related to the field of statistics, without excluding the presence of difficult to predict "bursts" of indicators, and the presence of stochastic and deterministic information.

Information analysis is the extraction of meaningful results from the mass of the data, without excluding the quantification of uncertainty [16, 17]. In turn, uncertainty depends on a ratio between the amount of information and its reliability [18, 19], thereby indicating the presence of a plurality of random events. For example, information analysis and uncertainties relate to accounting science and practices that seek to obtain high-precision results [20, 21, 22].

However, paying attention to need to obtain the desired results, users of the reporting are interested not so much in a high-precision picture of the past, but rather a reliable picture of the future of the enterprise. Therefore, the ideas of integrated reporting, designed to show both the present and the future
of the company, are becoming more widespread. Indeed, "we are entering a world characterized by a high degree of uncertainty, where almost every aspect of the economy, business and accounting profession will constantly change" [23]. In order to compile public reporting in a situation where it is necessary to analyze future economic indicators (for example, the cost of capital in the integrated reporting), it is necessary to determine the estimated values of future indicators. At the same time, mathematical developments in the field of measurement of uncertain future information are of practical importance.

Considering the quantitative evaluation of uncertainty of economic systems, according to [24], let’s allocate a number of approaches to the estimation of information uncertainty to justify the role of information model of Wiener. Data processing technologies using deterministic, probabilistic-statistical and interval-probabilistic approaches are widely used for uncertainty estimation. However, the following should be noted: any approach (due to the complexity and openness of the system) doesn't allow to adequately reflect the quantitative data in the model, which leads to the loss of information of other types.

Deterministic approaches to accounting for uncertain factors are generally not based on probabilistic estimates. The developed methods are focused on solving the problems of ensuring permissible behavior of the economic system in the totality of states. For example, it is possible to calculate the permissible values of system indicators using the technical and economic indicators of the functioning of the system and highlighting a number of important factors.

By controlling them, it is possible to support the system state in the area of permissible values of indicators. In deterministic models, statistical information on the probabilistic distributions of some parameters isn't considered. Here are the average values of the parameters, replacing the statistical distribution of random variables that testifies to lack of information about the probability distribution functions. In essence, the deterministic approach assumes the presence of information due to the permissible states of the system. From the point of view of application opportunities of models of information uncertainty in the analysis of economic indicators, the deterministic approach is of little use.

4. The interval-probabilistic and probabilistic-statistical approaches

The use of the interval-probabilistic approach is associated with the lack of information, since it is impossible to attribute the uncertainty factors to random nature. In this case, the uncertainty isn’t related to the statistics, as it is impossible to predict for certain neither the place of occurrence of the event, nor its probability. Here only property concerning the boundedness of an undesirable event becomes known. To approach the desired solution, the used model describes the factors in an interval form (when a range of possible values of variables is set). Using this model, it is possible to formalize the uncertainty, thereby to prove applicability of the probability theory by extending the probability values on the considered interval. Such models take into account several probability distribution laws suitable for the task, which cannot be justified due to the lack of sufficient statistics. In this case, it is necessary to specify a set of related probability distributions. With this approach to uncertainty formalization, the assumption of statistical homogeneity of observed events for the construction of probabilistic characteristics weakens.

It should also be noted that the statistical homogeneity of observed events is not visible for a number of economic and financial problems and for this reason, it is impossible to use the classical statistical probability hypotheses. In such information-fuzzy conditions, it is difficult to analyze the occurrence of rare events and to characterize them in the form of point estimates of the parameters of the probability distribution. Obviously, such events are caused by joint, one-stage influence of many factors with a high level of uncertainty. Finally, it is necessary to rely on the approach when the accurate estimates of the parameters of the observed law are unknown, blurred, and their permissible values lie in a certain interval. Considering the interval-probabilistic approach from the standpoint of its integration into the information model of Wiener, this kind of task is difficult to formalize due to requiring detailed theoretical study.
Probabilistic-statistical approaches to uncertainty evaluation include frequency/statistical interpretation of probability, which is identified with the relative frequency of occurrence of a mass random event at sufficiently long time intervals. In the case of consideration of a limited time interval, it is possible to obtain some selective estimates of the distribution density parameters, then the estimates of the mathematical expectation and variance will be close to their true values. The accuracy of statistical conclusions largely depends on the type of the distribution laws of a random variable and doesn’t tolerate significant assumptions. The occurrence of individual events (very rare events) has no frequency and, therefore, a valid probability. Therefore, the determination of statistical probability is only valid for quantitative assessment of events when statistical information is available. It is the most suitable for the implementation of the Wiener’s information model [25].

5. Determining the entropy of the object state

5.1. Model of private entropy

Time series presented in the form of an ensemble of data [26] are subject to evaluation of information uncertainty that is to determine the amount of information carried by the indicators characterizing the state of the economic system. Logarithmic probability measure is widely used to measure information [27, 28]. Let’s denote its role: a priori it is known (from previous experiences/experiments or assumptions) that the considered variable lies between the values \((a, b)\), and we also know a posteriori that it will be in the interval \((a, \beta)\) inside the interval \((a, b)\). In this case, the amount of information that we extract from the a posteriori knowledge can be determined by the expression:

\[
-\log \frac{\text{measure of interval } (\alpha, \beta)}{\text{measure of interval } (a, b)}.
\]  

(1)

Let’s now consider the participation of the values of the indicators in obtaining the amount of information. A priori it is known that the probability of finding the considered value between \(x\) and \(x+dx\) is \(f_1(x)dx\), and the posteriori probability is \(f_2(x)dx\). Considering functions of the form \(y=f_1(x)\) and \(y=f_2(x)\), we have curves representing the probability density. Let’s turn to the uniform distribution law of the variable \(x\). With this distribution, since \(f_1(x)\) is the probability density, then:

\[
\int_{-\infty}^{\infty} f_1(x)dx = 1.
\]  

(2)

If to consider the area under the curve \(y=f_1(x)\), then the average logarithm of the width of this area can be taken as the average height of the logarithm of the inverse value of this function. Under this assumption, the measure of the amount of information will be the value:

\[
\int_{-\infty}^{\infty} f_1(x) \log_2 f_1(x) dx.
\]  

(3)

In fact, the expression (3) is used to determine the entropy in tasks of statistical data processing. Considering the special case, let’s assume that there is a uniform distribution law:

\[
f_1(x) = \begin{cases} 
0, & x < a; \\
\frac{1}{b-a}, & a \leq x \leq b; \\
0, & x > b.
\end{cases}
\]  

(4)

Then, based on this law, the amount of information:

\[
\int_{-\infty}^{\infty} f_1(x) \log f_1(x) dx = \frac{b-a}{b-a} \log \frac{1}{b-a} = \log \frac{1}{b-a}.
\]  

(5)

Comparing the amount of information received by (5) with the logarithmic measure (1), the one in the numerator indicates that the event will occur, that is, the value \(x\) will be in the interval \((a, b)\). Then we will have a measure of the difference:

\[
\log \frac{1}{b-a} - \log 1 = \log \frac{1}{b-a}.
\]  

(6)
Expression (6) refers to the determination of the private entropy of an object \( i \). It can be a priori determined through the probability of events \( p_i(x) \) in the interval \( (a, b) \) by expression:

\[
h_i = -\log p_i(x). \tag{7}\]

Private entropy can be determined not only by considering one variable \( x \), but also by considering in two or more dimensions [29]. According to [25] the function \( f_i (x, y) \) for the two-dimensional case:

\[
\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f_i(x, y) dx dy = 1. \tag{8}\]

The amount of private information will be equal to:

\[
\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f_i(x, y) \log f_i(x, y) dx dy. \tag{9}\]

Assume that \( f_i(x, y) \) has the form \( \varphi(x) \psi(y) \) and the following conditions are satisfied:

\[
\int_{-\infty}^{\infty} \varphi(x) dx = 1 \quad \text{and} \quad \int_{-\infty}^{\infty} \psi(y) dy = 1,
\]

then

\[
\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \varphi(x) \psi(y) dx dy = 1. \tag{10}\]

Assuming that each of the variables \( x \) and \( y \) are generated independently by the object and the condition (10) is satisfied, then the amount of entropy is additive:

\[
\int_{-\infty}^{\infty} \varphi(x) \log \varphi(x) dx + \int_{-\infty}^{\infty} \psi(y) \log \psi(y) dy. \tag{11}\]

5.2. Entropy model of the system of indicators

Since \( f_i(x) \) determines the amount of private entropy by (6), then the entropy of the object states is also caused by function of the form \( y = f_2(x) \), which is the density of a posteriori probability. Probability of occurrence of a random variable \( x \) having a uniform distribution over the interval \( (a, \beta) \) and belonging to the interval \( [a, b] \):

\[
P(\alpha < X < \beta) = \int_{\alpha}^{\beta} f_2(x) dx = \int_{\alpha}^{\beta} \frac{1}{b - a} = \frac{\beta - \alpha}{b - a}. \tag{12}\]

In such formulation of the question about information, the expression for the determination of entropy will have the form:

\[
\int_{-\infty}^{\infty} f_2(x) \log f_2(x) dx = \frac{\beta - \alpha}{b - a} \log \frac{1}{b - a}. \tag{13}\]

Let’s consider the entropy model of the system from the standpoint of event independence. A posteriori each event related to the object \( i \) lies in the interval \( (\alpha_i, \beta_i) \) and their number is equal to \( n_i \). All independent events are distributed over the entire interval \( [a, b] \) that allows to determine the probability of the event \( i \): \( p_i = n_i / n \), provided \( \sum p_i = 1 \). Then the entropy of the system can be determined by the expression:

\[
H = \sum_{i=1}^{n} H_i = \sum_{i=1}^{n} p_i H_i = -\sum_{i=1}^{n} p_i \log p_i(x). \tag{14}\]

The amount of information, according to (14), is some negative entropy, which is determined by the value of the negative logarithm, considered as probability. If to pass to the consideration of relationship between objects, then it will be a question of presence of correlation [30]. According to [24], let there are two probability densities \( \varphi(x) \) and \( \psi(y) \) of an uniform distribution on \( (a, b) \), then \( [\varphi(x) + \psi(y)]/2 \) is also the probability density and entropy of the two variables:

\[
\int_{-\infty}^{\infty} \frac{\varphi(x)}{2} \log \varphi(x) dx + \int_{-\infty}^{\infty} \frac{\psi(y)}{2} \log \psi(y) dy. \tag{15}\]

In accordance with (15), the amount of information is determined by the expression:
\[ I = \frac{1}{2} [p(x) \log p(x) + p(y) \log p(y)]. \] (16)

According to (16), the maximum information (enclosed in the sum \( \phi(x)+\psi(y) \)) will be reduced by half due to overlapping areas \( \phi(x) \) and \( \psi(y) \). Let two random variables \( x \) and \( y \) have different probability density distributions \( \phi(x)+\psi(y) \). Then the statistical relationship (correlation) between sets \( x \in X \) and \( y \in Y \) will characterize the presence of mutual information \( I(X,Y) \), which is a quantitative measure of the intersection of these sets. The entropy of the system decreases by the amount of this information:
\[ H(X,Y) = H(X) + H(Y) - I(X,Y). \] (17)

According (17) it can be seen: the more mutual information, the closer the correlation and the less system entropy \( H(X,Y) \). Let’s express it via a logarithmic measure for random variables \( x \) and \( y \):
\[ H(x, y) = -p(x) \log p(x) - p(y) \log p(y) + \]
\[ + \frac{1}{2} p(x)p(y) \log p(x)p(y). \] (18)

or
\[ H(x, y) = [1 - \frac{1}{2} p(y)]H(x) + [1 - \frac{1}{2} p(x)]H(y) \] (19)

where \( H(x) = -p(x) \log p(x), \ H(y) = -p(y) \log p(y). \)

In case of statistical variety of random pairs \( (x_i, y_i) \), the entropy of the system is:
\[ H(X,Y) = \sum_{i=1}^{\infty} [1 - \frac{1}{2} p_i(y)]H_i(x) + [1 - \frac{1}{2} p_i(x)]H_i(y)] \] (20)

From expression (20) the following is visible. Considering the statistics of economic indicators and determining the probabilities of their falling into the selected intervals, one can determine the entropy of the object state, and for two objects – entropy taking into account the correlation by merging areas of private entropy. Comparing the quantitative values of entropy with the private entropy allows analyzing the state of the object relative to its expected capabilities.

6. Conclusion
In economic sciences, including financial accounting, search for reliable methods of analysis and evaluation of future uncertain events is conducted. The use of probabilistic and statistical approach to the analysis of future economic indicators doesn’t exclude the participation of information uncertainty measure, which involves the determination and participation of frequency or statistical probability. A priori probability is caused by the presence of a relative frequency of occurrence of a mass random event during tests or at sufficiently long intervals of time. This probability can serve as a basis for determining the private entropy of the considered object of the system generating events with predicted indicators. With regard to the role of the object in system condition assessment, when considering even a limited time interval, it is possible to obtain some selective estimates of the parameters of the distribution density of the a posteriori probability. Its application together with the private entropy allows to determine the entropy of the object participation in the behavior of the system. The correlation between the two objects generating the events reduces the growth of entropy due to the information of the combined events. The greater the magnitude of merge of areas of probabilities, the more information and less entropy. Clarifying the uncertainty of the situation, we mostly have an increase in information. The obtained models are applicable in the analysis of the system states through information uncertainty of its indicators.

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