A modified neuro-fuzzy model of the trajectory of world economic and technological development

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Abstract: The article describes the methodology of multicriteria neural network analysis of global technical and economic development (TED) for a set of quantitative and qualitative indicators, which characterizes the modern technological order, examines issues of technological and social measurement of the transition process to the 6th technological order. For a fuzzy separation of overlapping clusters, a new hybrid architecture is proposed - fuzzy clustering Kohonen cell maps (FSNN-SOM), based on it a modified neural-fuzzy network model of the trajectory of global technical and economic development, distinguished by a fairly simple but powerful strategy for improving clustering accuracy interpretability, with the assessment of the level of TED, the characteristics of the TED of individual countries and for predicting future values of the multidimensional process. Intercountry comparison of model characteristics on the etalon and national TED trajectories allows obtaining predictive estimates not only of speed, but also of the level of technical and economic development of each country.

Keywords: global modeling, cycles, technological structure, technical and economic development, social, technological dimension, neuro-fuzzy networks, forecast

1. Introduction

The relevance of the research topic is due to the fact that the problem of long-term fluctuations in economic dynamics and methods of global modeling of these processes occupied one of the central places in global studies of Russian and foreign scientists in the 20th century and especially attract the attention of modern scientists in this transition period from the 5th to the 6th technological order. In the last decade, based on the scientific schools developing the work of N.D. Kondratiev and J. Schumpeter, a new paradigm of economic science is being formed, the representatives of which have merged into the international research network GLOBELIX.

Cyclicity is the universal form of the movement of national economies and world economy as a whole. It expresses the uneven functioning of various elements of the national economy, the replacement of the revolutionary and evolutionary stages of its development, economic progress. Finally, cyclicity is the most important factor of economic dynamics, one of the determinants of macroeconomic equilibrium. Because of the complex, mutually intersecting trends of the various components of cyclicity, it is often extremely difficult to single out individual cycles. The most characteristic feature of cyclicity - movement - occurs not in a circle, but in a spiral. Therefore, cyclicity is a form of progressive development. Each cycle has its own phases, its duration. Characteristics of phases are unique in their specific indicators. In a particular cycle, there are no twins. They are original both in historical and in regional aspects.

The emergence of a market economy in a number of countries and their inclusion in the world economic space dispelled the myth of overcoming trends in cyclical dynamics and required new interdisciplinary approaches to retrospective analysis and the forecast of open N.D. Kondratieff [1] of large cycles of conjuncture (long waves of economic dynamics). The task is complicated due to the action in national economies of a number of factors deforming the course of economic cycles, the lack of sufficiently reliable and long-term time series. Due to unique features, each national economy has its own rational trajectory of future fuel and energy resources. Its planning, possible only in the form of approximate scenarios, should be based on global TED trends taking into account the above-mentioned national characteristics. The most important of these is the country's position in the intercountry hierarchy of TED. To conduct such an assessment, the model of the etalon fuel-energy trajectory, which sets a common reference frame and scale common to all countries, is relevant and serves as a basis for measuring the technical development of national economies.

Thus, in the opinion of the author, the correct assessment of the technical development of the national economy, its position in the world technical and economic development is related to finding an adequate method of measuring the level and rates of TED relative to the etalon trajectory.
2. Literature review

2.1. Cyclicality as one of the ways of self-regulation of a market economy

Due to the patterns of reproduction of social capital, the life cycle of the technological order in a market economy is reflected in the specific form of the Long Wave (LW) of the economic conjuncture. The so-called Long waves, or Kondratieff waves [2], are the subject of study of a special direction of economic research - analysis of long-term processes of social reproduction. In modern periodization, there are 5 long waves (Figure 1).

![Figure 1. Modern periodization of Kondratieff Long Waves](image)

In the empirical studies of the Long Wave, a fundamental one-pointedness of the technological changes taking place in different countries, the similarity of national TED trajectories, as well as the tendency to synchronize macroeconomic fluctuations and technological changes, was established.

In particular, the same shape of fuel and energy resources trajectories in countries with both market and directly managed economies has been identified in the structure of energy consumption, in metallurgy and in the extractive industry, in the dynamics of transport infrastructure and in other sectors of the economy [1]. The unidirectional nature of energy resources in different countries, as well as the formation of a single rhythm of the world economic system, is due to the establishment of a global market and the rapid expansion of international economic ties since the industrial revolution. The experience of macroeconomic research speaks not only of the possibility, but also of the fruitfulness of using cross-country comparisons to obtain both qualitative and fairly accurate quantitative conclusions, including the forecast character [2].

Many researchers note that global technological changes are generated by the countries leading in the life cycle of the corresponding technological orders [2]. Although the technological shifts that make up the content of the life cycle of each technological order take place on the scale of the world market, the economic structure of the leading countries most fully reflects the structure of the corresponding TUs, and the dynamics of their TED is the evolution of these technological orders. Therefore, as a etalon trajectory of TED, the trajectory of the actual TED of the leading countries of the corresponding technological order can be considered.

2.2. Classification of economic cycle theories

There are several types of economic cycles known as "waves." They are difficult to distinguish because of the multiplicity of their indicators, because of the temporary blurring of the boundaries between them. The so-called "long waves" (cycles) have a length of 40-60 years. The development of the theory of long waves was begun in 1847, when the Englishman H. Clark drew attention to the 54-year gap between the crises of 1793 and 1847. He suggested that it was not by chance that the gap was objectively conditioned [3]. A significant contribution to the development of the theory of long waves was made by his compatriot V. Jevons, who first drew statistics on price fluctuations to explain a phenomenon new to science.

K. Marx made a significant contribution to the theory of cyclicity. He paid all attention to the study of short waves, which in the economic literature received the name "periodic cycles," or "periodic crises of overproduction." Each cycle, according to Marx, consists of four phases: crisis, depression, revival, recovery, - which completely agrees with the theory of cyclicity [3].
The mention of long-term fluctuations can be found in the studies of M. Tugan-Baranovsky. The theory of cyclicity was reflected in the works of the Russian scientist A. Gelfand (Parvus). He made an attempt to prove that cyclicity is immanent to capitalism. The original statistical treatment of the material is contained in the works of Dutch scientists J. Gelderen and S. Wolf. The novelty of their studies was that they considered technical progress as a factor of cyclicity, and also analyzed the terms of the functioning of the transport infrastructure [3].

The understanding of the cyclical nature of the development of the economy became especially widespread at the end of the 19th and the beginning of the 20th centuries, when scientists of many countries drew attention to the dynamics of certain economic indicators. This gave grounds for classifying the theories of economic cycles, which U. Mitchell [3] presented most fully in his work "Economic cycles". The American economist distinguishes the following theories of economic cycles:

1) Theories that reduce economic cycles to natural-physical processes. These theories explained the cyclicity of economic life by cycles of solar radiation, the change in the position of Venus relative to the Earth, meteorological conditions.

2) Theories that reduce economic cycles to psychological causes that create either a favorable or unfavorable environment for economic activity. According to some economists, fluctuations in the mass sentiments of people precede fluctuations in wholesale prices, influence the decision-making in the economic sphere. The basis of these theories is a fact noted in public life, indicating the periodicity in the change in society of motivational structures, creative activity of the population, social moods. Cyclic changes in the socio-psychological variable, encompassing the "degree of activity" of the population, its enterprising, "optimistic outlook" and other individual and socio-psychological aspirations of people, determine long-term cycles of economic development.

3) Theories that reduce economic cycles to institutional processes. The essence of cyclicity, from the standpoint of these theories, is that economic cycles arise from changes in economic institutions. The greatest influence on the formation of the cyclical nature of economic development is provided by the functioning of existing economic institutions.

4) Other theories proceed from the assertion that cycles arise because of the imbalance in the processes of total production and consumption of goods. Favorable trade and industrial conditions lead to a rapid growth of industrial equipment, later to an increase in output and, ultimately, to a fall in the marginal prices of demand for consumer goods. A consequence of this is depression, during which the growth in the number of industrial equipment and products is interrupted. In the end, the marginal prices of demand for consumer goods rise again, and a new period of recovery begins.

The most profound development of the concept of economic cycles is primarily connected with the works of the national economist N.D. Kondratieff [3]. He put forward a hypothesis about the mechanism of long cycles in the economy ("large cycles of conjuncture" in his terminology), linking them not only with the price dynamics, but also with the process of capital accumulation, the growth rates of production and the dynamics of innovation, with the constant evolution of the national economy. The motion of long-term oscillations according to Kondratieff proceeds according to the following principle. Before the start of a large cycle, a sufficient amount of free funds accumulates - the growth of bank reserves, which allows creditors to reduce the interest rate. The percentage of long-term premises is low. During the previous period of the decline, a significant amount of technical novelties (inventions) accumulated. If these conditions exist, capital investment in large facilities begins to increase, which causes serious changes in the conditions of production (technical opportunities for generating profits are generated), while production becomes profitable, and then, respectively, the upswing of a large cycle of economic conjuncture.

The main modern theories of long waves:

1) Innovative theory (J. Schumpeter). Its essence is that there are people who want to get entrepreneurial profit. They invest in new technologies and industries, followed by followers. This is a period of recovery. Gradually, the market is saturated, profit is reduced, and people withdraw their funds from production - this is a recession.

2) The theory of overaccumulation in the capital sector (D. Forrester). The capital sector, which produces the means of production, provides machines and equipment not only for industries that produce consumer goods, but also for themselves. The growth of consumption causes an even faster growth of the means of production, that is, the accelerator acts between the two branches. The magnitude of this accelerator in real life is much greater than that required for the equilibrium motion. All these factors contribute to overaccumulation in the capital sector. Orders first increase sharply, and then abruptly contract. This is sufficient for the appearance of long-term oscillations [5].

3) Theories related to labor (K. Freeman). This group of theories is based on consideration of the theory of long waves from the point of view of the laws of the labor force. Mechanism: the introduction of new
technologies brings to life new industries. In the early stages of the application of pioneer technologies, the demand for labor is limited. This is due to the fact that the volumes of new production are not yet large and require not a mass, but a particularly skilled labor. Gradually, production increases, demand for labor begins to increase. This growth continues to saturate demand for both labor and related goods. In parallel, wages are rising and costs are increasing. There is a need for labor-saving innovations. There is an outflow of labor, a decline in wages, and general demand, that is, a decline in the economy.

4) Price theories (U.W. Rostou). In the theories examined, the prices of goods either were not considered at all, or played the role of indicators of the processes taking place in the sphere of production. However, the pricing process and the price dynamics are directly related to the explanation of the long-term cycle and its turning points. Changes in the demand and supply of raw materials and food products, and, consequently, the prices for them, affect the innovation activity that determines the sequence of the leading industries and itself depends on them.

2.3 Methodological approaches to the study of crisis cycles

In the structure of the cycle, the higher and the lower points of activity and the phases of recession and ascent lie between them. The total cycle time is measured by the time between two neighboring higher or two adjacent lower activity points. Accordingly, the duration of a decline is the time between the highest and the next lowest activity points, and the rise is the opposite. The National Bureau of Economic Research stated that in the development of the US economy from 1854 to 1991, there were 31 cycles; The average time between the two highest points was 53 months; of which 18 months accounted for the recession and 35 months - on the rise.

In more detailed analysis, the economic cycle is divided into four phases (Figure 2).

![Figure 2. The economic cycle phases](image_url)

I. The crisis phase (recession). The main manifestation of the crisis is a fall in production volumes and a reduction in the size of gross national product. Accordingly, the production capacities of enterprises are not fully loaded, the profit is falling, the share price is falling, the employment of the population is falling, the level of wages is falling, the living standard of the population is falling, and poverty is increasing. As a result, the aggregate demand decreases, in response to this, production is further reduced and, accordingly, the supply. In general, this phase is characterized by an excess of the aggregate supply of aggregate demand. To ensure macroeconomic balance, it becomes necessary to reduce production.

Over time, the crisis can last from several months to several years, as it was during the Great Crisis of 1929-1933.

II. The phase of depression. This phase is characterized by the fact that after the liquidation during the crisis of commodity stocks, the production decline ceases, but there is still no growth. Accordingly, employment is at a low level, but unemployment has already stopped, stabilized, albeit at a low level, wages and profits of enterprises, their business activity is not high. Depression can last from a few months to several years. For example, the depression that began in 1933 after the Great Crisis lasted until 1938, that is, practically until the war itself.

III. The phase of recovery. The name of the phase speaks for itself. It is characterized by a revival of the economy, some gross national product growth is occurring, the demand for labor, on loan capital is increasing. The most important thing is that the investment activity of enterprises is intensified. Usually this phase does not last long, it quickly passes into the next phase.

IV. Lifting phase. This phase is also called a boom, since it is characterized by fairly rapid economic growth. There is an increase in employment, unemployment is resolving, and sometimes in some industries there is a shortage of labor. The wages are rising, the aggregate demand is growing, the volume of sales is growing, the profit of enterprises is increasing. The population and enterprises have free money, their offer on money...
markets increases, so the interest rate does not increase, and sometimes it starts to decline. Comparatively inexpensive is credit. The share price of many enterprises has a tendency to grow.

The problems of the theory of economic cycles cause the application of complex dynamic models using differential equations [6, 7].

To characterize the economic situation, a number of economic indicators are used (gross national product, unemployment rate, personal income, industrial output, price level and many others). Depending on how the value of economic parameters varies during the cycle, they are divided into pro-cyclical, countercyclical, and acyclic. The procyclical parameters in the ascent phase increase, and in the cycle phase they decrease (loading of production capacities, aggregates of the money supply, the general level of prices, corporate profits, etc.).

Countercyclical parameters are indicators whose value decreases during the recession, and decreases during the ascent (unemployment rate, number of bankruptcies, stocks of finished products, etc.).

Acyclic parameters are called whose dynamics do not coincide with the phases of the economic cycle (for example, the volume of exports).

In addition, there are three types of parameters on the basis of the synchronization on the classification of the National Bureau of Economic Research USA - forward-looking, and the corresponding delayed. Leaders reach a maximum or a minimum before approaching the peak or the lowest point (these are changes in stocks, money supply, etc.). The laggards reach a maximum or a minimum after a peak or a low point (the number of unemployed, the specific costs of wages, etc.). The coinciding parameters change in accordance with the fluctuations in economic activity (gross national product, inflation, industrial production, etc.).

Currently, statistics and economists are not able to give accurate forecasts of the economic situation, but can only determine its general trend. First, it is difficult to take into account all the factors, especially during the period of economic instability and political turmoil. Secondly, the international environment has a significant impact on the national economy. Thirdly, even correctly determining the trend, it is difficult to predict the exact dates of the passage of phases and change the economic policy in time. Finally, the actions of entrepreneurs can exacerbate undesirable deviations in the conjuncture [2].

3. Technological and social dimension of TED

Prior to the results of the comparative analysis of TED, two factors should be distinguished. On the one hand, the objects and territories of states, regardless of their size and role in overall economic development, are not self-sufficient economic entities and, despite the existence of internal trends and interrelations, can not plan their development based only on their own dynamics and proportions. On the other hand, although the countries united by the international division of labor are developing along the general lines of technical and economic evolution, they differ significantly in terms of the absolute level of TED indicators (measured in relative units - per inhabitant or unit of national income), even if they are on the same level TED. This is explained by historical, scientific, educational, cultural, psychological, natural and climatic and other features of each country, which are reflected in its economic structure [8]. Therefore, in order to construct an adequate model of the fuel-energy trajectory in the group of parameters studied, the author introduced a qualitative growth component-the index of productivity of primary resources, which is measured as the ratio of gross national product to the value of primary raw materials consumed by the economy [8]. Primary raw material resources are a set of such primary organic and inorganic resources that are massively used both for consumption of the population and for further processing in the process of material production (food, construction materials, fuel and energy resources).

Leading countries that have the lowest energy and material intensity for the main types of resources, nevertheless consume 1.5-2.5 times more primary raw materials per capita than less developed countries such as Russia, Brazil, India and China [9].

Productivity as an indicator of the effectiveness of resource use reflects the progress of science and technology. Even in the period of recession (1991-1998), Russia was experiencing quite intensive processes to improve the quality of products and services (Figure 3).

This was reflected in the fact that the productivity of primary resources increased by an average of 2.3% per year. Taking into account the fact that during this period the dynamics of the quality component of growth for the USA decreased substantially (to 0.95% per annum compared to 2.3% a year on average over the previous 30 years), the index of improving the proportions of exchange for the Russian economy was 1.016.

Since 1998, during the recovery period, the dynamics of the quality component of growth for Russia has increased to almost 4% per year. However, as the qualitative growth component for the US also increased during this period (up to 2.4% per year), the index of change in the proportions of the exchange changed insignificantly - to 1.017.
Therefore, the gap in the economic development of Russia and the US can be completely overcome if the growth of productivity (science and technology) in Russia is outstripping growth. When modeling the TED trajectory, it is necessary to take into account that innovations reveal and define the essence of the technical process at the present stage of history. Selected quantitative and qualitative indicators of technical and economic development were supplemented by the author with indicators of the country's innovative potential, divided into 4 groups [8, 10]:

1) indicators characterizing the financial component of the innovation potential (the share of investment relative to gross national product, the share of investments in their total volume, etc.);
2) indicators that characterize the material component of the innovation sphere (the number of organizations associated with scientific activity, the value of their fixed assets, the specific weight of scientific organizations).
3) indicators characterizing the personnel component of the innovation potential (the number of workers associated with innovation, their average salary, average age, their specific gravity).
4) indicators characterizing the resulting component of the innovation potential as a factor of economic growth and showing its ability to produce an effect (sales volumes, costs and profits associated with innovation, the number of created, exported and imported technologies, filed patent applications and issued patents, their specific weight).

4. Results and discussion

As a TED trajectory, a multidimensional time series is modeled, which is a collection of several one-dimensional time series, each of which describes the change in time of any of the listed characteristics characterizing the object of researches (Figure 4).

For each year \( t \), a particular country is represented by a point in the multidimensional space of quantitative and qualitative characteristics.

In the author's opinion, statistical processing of data for the description of the TED trajectory can not be recognized as a reliable and adequate tool for solving such weakly structured tasks. It does not allow you to establish the cause-effect relationships of the parameters of the predicted system as a whole. In addition, the construction for each country of its generalized TED curve by linear contraction of the input vector space and their intercountry comparative analysis is not entirely incorrect due to, firstly, the "fluid" nonequilibrium nature of technical and economic development, with waves of falling and take-off (waves Kondratieff); And secondly, which is very important - the input parameters for trajectory construction, in our opinion, should not be rigidly specified - they depend both on the national system of accounts in each country, and on historical, cultural-psychological, natural-climatic and other Features of the country at the time of observation \( t \), while the significance of the same parameters for the construction of the model will be different for different technological structures and phases of cycles.

To improve the modeling quality, the author [8] proposed a complex neural network analysis of quantitative and qualitative indicators, which in the training process are ranked by weight coefficients by the level of significance for solving the problem. Based on the available data samples, a time series of Kohonen self-
organizing neural networks [11] was constructed, reflecting the dynamics of global technical and economic development (Figure 5).

![Figure 4. One-dimensional time series by country](image)

Figure 4. One-dimensional time series by country 
(indicator - percentage of expenditure on R & D in gross national product)

![Figure 5. The model of the TED trajectory as a time series of Kohonen self-organizing neural networks in the multidimensional feature space](image)

Figure 5. The model of the TED trajectory as a time series of Kohonen self-organizing neural networks in the multidimensional feature space

The main difference between Kohonen's self-organizing maps and other models is the visibility and usability (Figure 6).
These networks make it possible to simplify a multidimensional structure, they can be considered one of the methods of projecting a multidimensional space into a space with a lower dimension, the total distance from the data to the nearest nodes of the topographic grid in the space of input attributes:

\[ E = \frac{\sum (r^a - r^a_0)^2}{\sum (r^a - \mathcal{F}^a)^2}. \]

Figure 7 shows a neural network model of the world technical and economic portrait reflecting the current hierarchy of countries in 2010.

Each country in terms of its TED level in the current year is displayed by a specific cell on the map. Cells with the same coordinates contain countries with a close state of TED. The further on the map the coordinates of the countries, the more their technical and economic portrait differs from each other.
Based on the results of the training, four clusters of countries with the similar levels of TED relative to the reference value were identified (Table 1).

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Cluster neurons</th>
<th>Group of countries</th>
<th>Color on the map</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Leaders of TED</td>
<td>Red</td>
</tr>
<tr>
<td>2</td>
<td>3,4,5,7,11,12</td>
<td>Developed countries</td>
<td>Orange</td>
</tr>
<tr>
<td>3</td>
<td>8,9,10,13,17,18,21,22,23</td>
<td>Countries with a moderate level of TED</td>
<td>Yellow</td>
</tr>
<tr>
<td>4</td>
<td>14,15,25</td>
<td>Developing countries</td>
<td>Green</td>
</tr>
<tr>
<td>1/2</td>
<td>2,6</td>
<td>?</td>
<td>Black</td>
</tr>
<tr>
<td>2/3</td>
<td>16</td>
<td>?</td>
<td>Black</td>
</tr>
<tr>
<td>3/4</td>
<td>19,20,24</td>
<td>?</td>
<td>Black</td>
</tr>
</tbody>
</table>

Thus, network neurons that are located on the boundaries between linearly inseparable, intersecting clusters form additional clusters 1/2, 2/3 and 3/4. For more accurate separation of clusters, the author developed the fuzzy cell neural network of Kohonen (FCNN-SOM), which contains 3 layers (Figure 8):

1) the input (receptor) layer;
2) a layer of Kohonen neurons with lateral connections trained by the cellular automaton [12-14] for determining centroids of intersecting clusters;
3) an additional (output) layer of fuzzy clustering that calculates the levels of belonging of the current vector to each cluster, using the Bezdek C-average algorithm [15] instead of the WTA algorithm [11], with disconnected lateral links in the Kohonen layer.

![Figure 8. The architecture of the fuzzy cell neural network of Kohonen (FCNN-SOM)](image)

Figure 9 shows the results of fuzzy clustering using the developed FCNN-SOM, for clarity, two-dimensional interpolation with splines is used here.
Figure 9. Modified Neuro-Fuzzy model of World technical and economic portrait in 2010 based on FCNN-SOM

Each country in the i-th year of observation is characterized by a set of parameters \((Y_i, A_i, B_i, C_i)\), where:

- \(Y_i \in [0; 1]\) - level of fuel and energy resources of the country in the i-th year;
- \(A_i\) – the actual distance (the number of years elapsed since the reference level of the FER parameter corresponded to the level of the country in question in the i-th year of observation);
- \(B_i\) – the prospective distance (the number of years that will be required by a given country, starting from the i-th year, to reach the standard level of technical development in the i-th year of observation);
- \(C_i\) – conditional distance (the number of years that this country needs to enter the reference trajectory).

In, which is then used to calculate the level of TED, the characteristics of the individual country's fuel and energy resources and to predict future values of the multidimensional process. Their comparison on the
reference and national TED trajectories makes it possible to obtain a reliable estimate not only of the speed, but also of the level of the technical and economic development of each country.

Based on the results of the modified neuro-fuzzy clustering of data, the countries under study are divided into 4 main categories according to the level of their TED (Table 2), which takes the value from 1 for the reference level of TED to 0.1 for the minimum level of development. For each country, the growth rate of TED for the five-year period is also calculated. For each five-year plan, the calculation is based on the output values of FCNN-SOM, reflecting the change in the level of TED by multidimensional characteristics for this period.

Table 2. Country categories, distinguished by the level and rate of TED by results Neuro-fuzzy modeling (2005-2010)

<table>
<thead>
<tr>
<th>Group</th>
<th>Leaders of growth (&gt; 4 %)</th>
<th>Countries with an average growth rate (2 – 4 %)</th>
<th>Countries with low growth rate (1 – 2 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaders of TED</td>
<td>Canada</td>
<td>USA, UK, Italy, France, Germany</td>
<td>Japan</td>
</tr>
<tr>
<td>Developed countries</td>
<td>Ireland, Denmark, Sweden, Switzerland</td>
<td>Iceland, Slovenia</td>
<td>Belgium, Luxembourg, Netherlands</td>
</tr>
<tr>
<td>Countries with moderate levels of TED</td>
<td>India, Brazil, China, Russia, Cyprus, Estonia</td>
<td>Hungary, Lithuania, Poland, Portugal, Finland, Slovakia</td>
<td>Norway, Spain, Malta</td>
</tr>
<tr>
<td>Developing countries</td>
<td>Turkey, Bulgaria, Romania</td>
<td>Greece, Latvia</td>
<td>Croatia, Serbia</td>
</tr>
</tbody>
</table>

The results of calculations for the parameter “actual distance” are presented in Table 3.

Table 3. Country categories identified by the “actual distance” parameter based on the results of neural-fuzzy modeling (2010)

<table>
<thead>
<tr>
<th>The actual length</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10 years</td>
<td>Switzerland, Finland, Germany, Denmark, Sweden, UK</td>
</tr>
<tr>
<td>10 – 20 years</td>
<td>Russia, Czech Republic, Greece, Malta, Portugal, Hungary, Lithuania, Bulgaria, Poland, Slovakia, Italy, Norway, Spain</td>
</tr>
<tr>
<td>&gt; 20 years</td>
<td>Romania, Latvia, Turkey, Croatia</td>
</tr>
</tbody>
</table>

5. Conclusion

On the basis of many domestic and international scientific research, a methodology for multicriteria neural network analysis of global technical and economic development has been developed for a set of quantitative and qualitative indicators, including the technological and social dimension of TED. Based on it, a flexible neural-fuzzy network model of the trajectory of global technical and economic development is constructed in the form of a dynamic series of fuzzy clustering Kohonen cellular maps that are distinguished by a fairly simple but powerful strategy for increasing the clustering accuracy without compromising interpretability with an estimate of the level of fuel and energy resources. To predict future values of a multidimensional process. Their comparison on the etalon and national TED trajectories makes it possible to obtain a reliable estimate not only of the speed, but also of the level of the technical and economic development of each country.

To build a predictive model on a neural network, there is no requirement for stationarity of the process. Neural networks, being a universal tool, are able to identify with the necessary accuracy nonlinear regularities and interrelations between the components of multidimensional random processes. Using fuzzy clustering allows for a more accurate separation of intersecting clusters.

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6. References