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Forecasting Development of Economic Processes using Adapted Nonlinear Dynamics Methods

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***Abstract:** In this work authors propose using adapted nonlinear dynamics methods to prepare time series data for the forecast procedure in order to identify chaotic dynamics and to select forecast methods and models. Each step of the proposed set of methods for data preprocessing allows us to put forward proposals on certain properties of the studied time series. This, in turn, proves that to obtain reliable and reasonable conclusions about the type of behavior of the investigated system, the results of one of the many existing tests are not enough. Conducting a comprehensive analysis, will most correctly determine the type of behavior of the time series and its characteristics, which will make it possible to obtain a reliable forecast in the future.*

***Keywords :** non-linear trend, linear trend, visualization, Gilmore test, pseudophase space, attractor.*

I. INTRODUCTION

To determine the development goals of any economic system, calculate the volume of necessary resources to achieve these goals, implement long-term, medium-term and current planning, economic forecasts are used that are based on statistical data (time series). Thus, forecasting allows you to minimize possible risks and losses when planning and implementing development goals [10, 11, 12].

The authors propose using adapted methods of nonlinear dynamics for effective planning and forecasting the dynamics of economic processes [8, 12]. To obtain reliable and reasonable conclusions about the type of behavior of the investigated system, the insufficient results of one of the many existing tests. Only a comprehensive analysis will allow the most correct determination of the type of behavior of the time series (BP) and its characteristics, and obtain a reliable forecast [5, 6, 7].

II. MATERIALS AND METHODS

For the analysis of economic series, there are many different algorithms and research methods. A comprehensive time series analysis (BP) consists of three stages:

1. At the initial stage - preliminary processing of the time series:
   - plotting the time series before and after removing a linear trend;
   - the formation of a pseudophase space of dimension two;
   - testing for a drifting attractor;
   - performing a graphical test of Gilmore.

   The results of each step provide an opportunity to make a judgment about the properties that are inherent in the investigated time series.
2. At the second stage, metric characteristics are calculated, allowing to diagnose the type of dynamics, namely:
   - value of the correlation dimension;
   - the value of the maximum Lyapunov exponent;
   - measure of K-entropy of Kolmogorov;
   - value of the Hurst index N;
   - performance of the Broca residue test;
   - conducting shuffling diagnostics.
3. At the third stage, the forecast is constructed.

Each step of the proposed set of methods for preliminary data processing allows you to put forward suggestions about certain properties of the investigated time series, the following is a detailed description of each step:

I. The graph of BP shows the dependence of the values of the series on time, i.e. axis OX - date of observation, OY - value of BP. The construction of this graph allows you to determine the type of behavior of the investigated system and the presence of a linear trend. Further investigation of the time series by nonlinear dynamics methods is advisable if the BP behaves as random. At this stage, you can clear the time series from the trend using standard methods of classical statistics.

II. Pseudophase space shows the dependence of the current value of the time series (αi) on previous (αi-1). The construction of this graph makes it possible to judge the presence of a strange attractor and joker, which indicates the chaotic behavior of the system.

III. The drift attractor test shows the time dependence of the system parameters, which is manifested in the attractor drift. A positive test result means that the points belonging to the first and last quarters of the series form a set of points displaced relative to each other. When revealing such a dependence, it is necessary to clean the series from the nonlinear trend, which is due to the attractor drift.

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III. GILMORE'S GRAPHICAL TEST REVEALS UNSTABLE TRAJECTORIES, THE PRESENCE OF A JOKER IN THE SYSTEM, WHICH ARE SIGNS OF CHAOTIC BEHAVIOR.

It should be noted that the implementation of the proposed steps is difficult without specialized programs; in this work, the "Data Analysis" and MS Excel programs were used to build graphs and conduct tests. The proposed methods have been successively tested in the following time series: "Turpotok 1" - daily flow of tourists entering the Dombai ski village from May 1, 2015 to December 1, 2017, the number of observations is 927, and also taking into account the results of the "Tourist flow" decomposition approach 2 "- a weekly flow of tourists entering the village on Saturdays, the number of observations is 133 [4].

IV. RESULTS AND DISCUSSIONS

Step 1. At the first step of the visualization stage, histograms of time series are constructed. Further, a linear trend was removed from these BPs (in accordance with Figure 1).

1. Having built the time series graph in MS Excel, we obtain the equation of the trend line and find its values at each point x=[1;n], where n is the number of observations in the studied time series.

2. The values of the cleaned time series are equal to the difference between the initial values of the series and the values of the trend line.

The time series in Figure 1 have a clearly distinguished linear trend, i.e. have a dynamic, non-cyclic nature component, which describes the direct influence of long-term factors, the effect of which affects gradually.

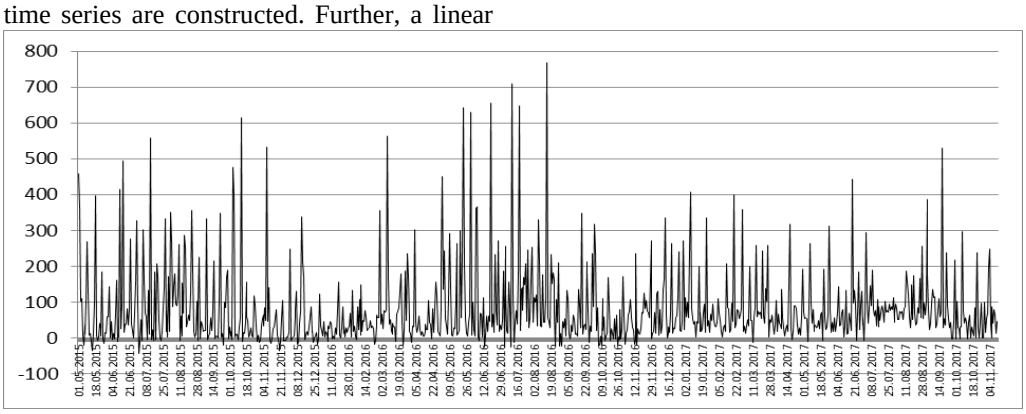


Fig. 1a. Graphical visualization of the values of the "Turpotok 1" time series after the linear trend removal procedure

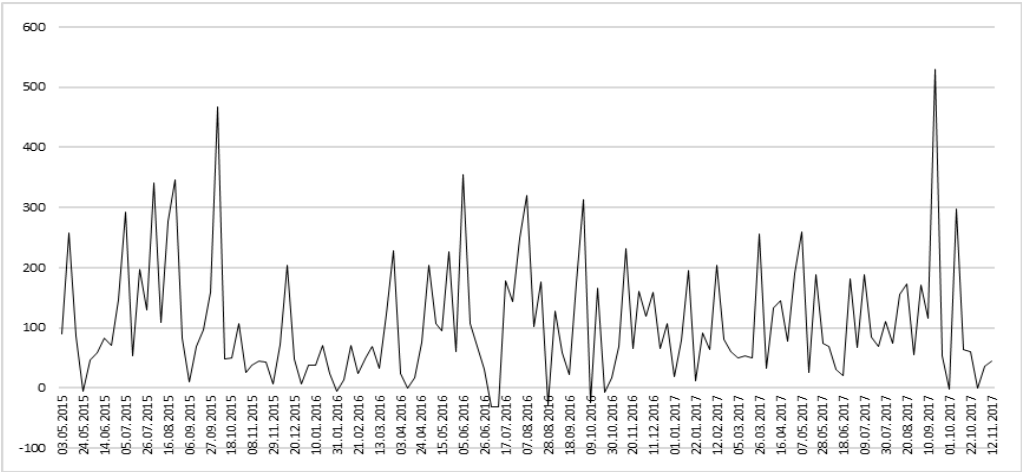
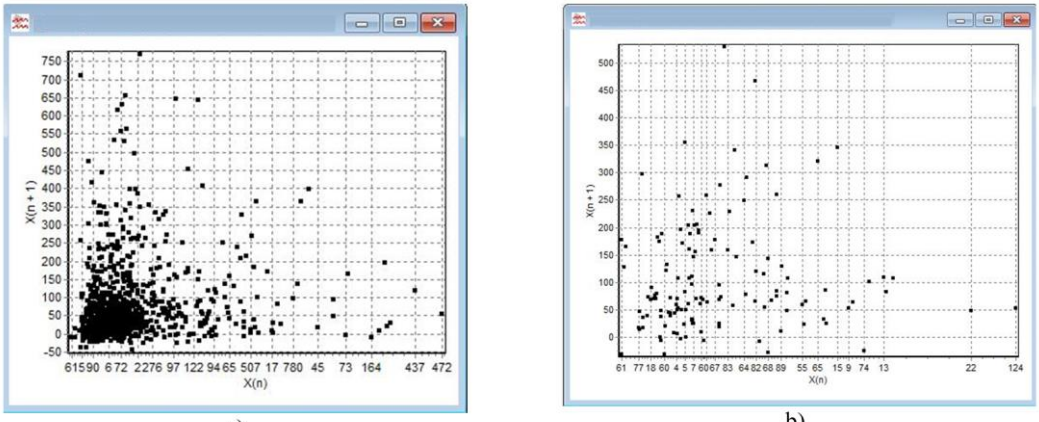


Fig. 1b. Graphic visualization of the values of the "Turpotok 2" time series after the linear trend removal procedure

Removing a linear trend from BP prepares them for further study in step 2.

Step 2. In the second step in the Data Analysis program, pseudophase spaces are constructed for all the studied BPs, which reflect the dependence of the values of the time series on the previous ones. Based on the visualization of pseudophase space, one can make a judgment about the presence of a strange attractor (in accordance with Figure 2). The presence of a strange attractor is characterized by such points of the pseudophase space of BP that are grouped around the bisector of the positive orthant of the Cartesian coordinates. The scatter of the points of the pseudophase space for BP "Turpotok 1" and "Turpotok 2" does not allow us to draw a similar conclusion. To confirm the hypothesis of the presence of a strange attractor in the present case, it is necessary to determine the presence of the dependence of the system parameters on time, expressed in the drift of the attractor.



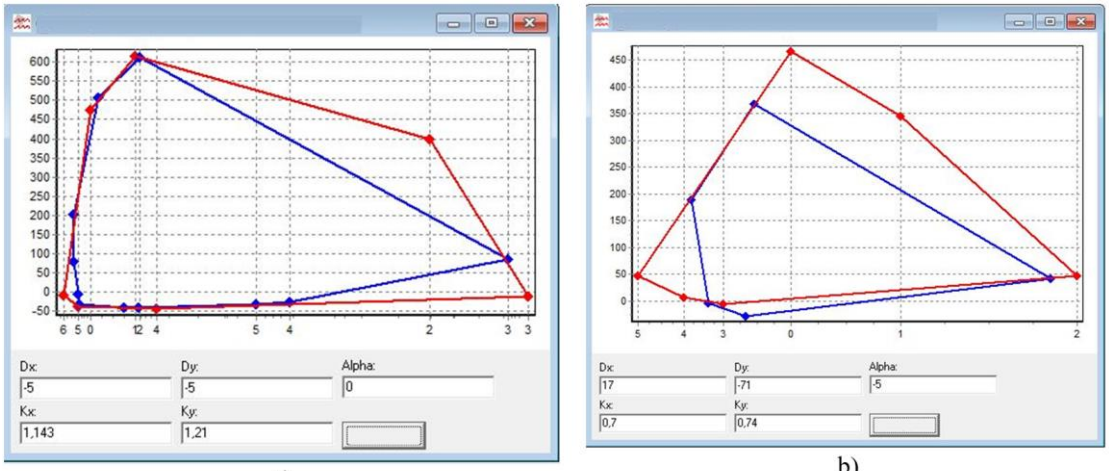
a) b)

Fig. 2. Pseudophase spaces of time series: (a) BP "Turpotok 1"; (b) BP "Turpotok 2"

Step 3. We determine the presence of the dependence of the system parameters on time. To conduct the test, the BP values are divided into k = 4 parts and determine the parameters of the drift (non-linear trend) [1] to remove it from the time series. Using the interactive procedure, convex hulls are constructed, shown in Figures 3a and 3b, and the parameters of the affine transformation are determined: compression along the abscissa axis OX-kx, compression along the axis OY-ky, rotation angle α, transfer along OX-dx and OY- dyThe found values allow us to calculate the magnitude of the attractor drift parameters, i.e. speed: linear displacement, compression and rotation [1]. The found parameters are presented in tables 1-2:

Table – I: Affine transformation parameters of studied BP drifting attractor

Affine Transformation Options	BP "Turpotok 1"	BP "Turpotok 2"
Dx	1,141	0,7
Dy	1,21	0,74
Kx	0	17
Ky	-5	-71
α	-5	-5



a) b)

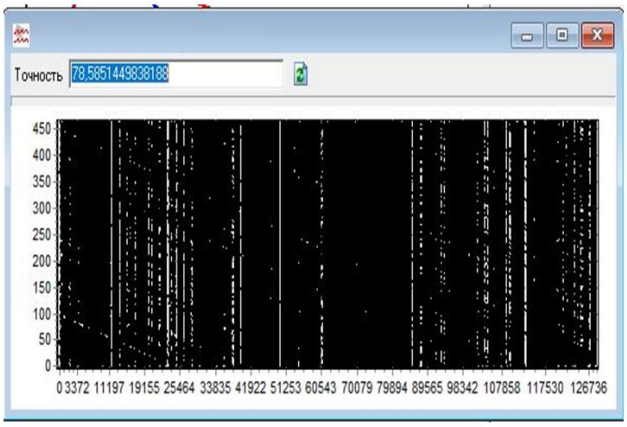
Fig. 3. Convex hulls combination of time series
(a) BP "Turpotok 1"; (b) BP "Turpotok 2"

Table – II: Attractor drift parameters estimate of investigated BP

Attractor drift parameter estimation	BP "Turpotok 1"	BP "Turpotok 2"
linear displacement speed (υ_x)	-0,00539	0,12782
linear displacement speed (υ_y)	-0,00539	-0,53383
compression rate (υ_{rx})	1,000142	0,997322
compression rate (υ_{ry})	0	1,006918
turning speed (ω)	0	0,009648

Step 4. At step 4, the Gilmore test [1, 9] was carried out (in accordance with Figure 4), which allows one to detect signs of chaotic behavior. On graph 4b (the result of the Gilmore test for BP "Turpotok 2"), we observe the presence of empty areas characteristic of the interval joker [2,3], which suggests the possibility of using these series for further research using a

class of models such as dynamical systems with the joker. On another chart, empty areas and bands are expressed implicitly or are not observed, it is impossible to conclude that there is a joker for BP “Turpotok 1”.



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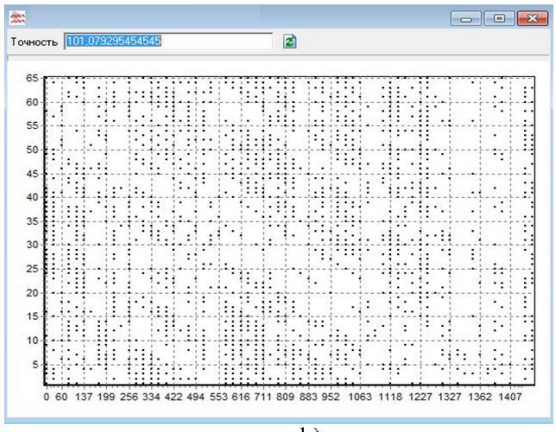

b)

Fig. 4. Gilmore test results: (a) BP "Turpotok 1"; (b) BP "Turpotok 2".

V. CONCLUSION

Thus, as a result of the first stage of the analysis, time series are obtained that are cleared of a linear trend. The calculated drift estimates allow us to clear the studied time series from a nonlinear trend and prepare them for further analysis (second stage), on which metric characteristics are calculated (correlation dimension; Lyapunov exponent; Kolmogorov K-entropy measure; Hurst exponent N; performance of Brock's residual test ; testing shuffling diagnostics), which allow you to determine the type of dynamics and, accordingly, choose the most suitable forecast models.

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