Tools for Estimation of “Deterministic Chaos” of Economic Sectoral Mesodynamic

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Abstract. The purpose of the study is to substantiate the methodology and develop tools for evaluating the indicators’ dynamics of Russian regions’ industries. Sectoral mesodynamic is considered as open, nonlinear and weakly structured. The synergetic principle of “deterministic chaos” and the econophysics models are implemented for modeling. Approbation by the authors on the exploration mesodynamic data of 12 main sectors over 78 Russian regions during the period from 2005 to 2017. The results demonstrate a great adequacy of the applied tools, outlined a set of directions for its development and areas of possible application, including socio-dynamics. The prospects of applying nonlinear trends, mainly logistic ones, are shown. E. Slutsky’s theorem on modeling medium-term business cycles by the sum of three harmonics with non-multiple frequencies is confirmed. The adequacy of trajectories’ modeling is provided by supplementing the known structures of mesodynamic trajectories with additive-multiplicative interactions, and considering the stochastic component as a mixture of distributions with heavy tails. Exploratory results showed heterogeneity of institutional and economic development of regions, which creates imbalances in economic cycles, allowing to make forecasts for the development of regional economies, to form knowledge bases to characterize the cause-and-effect relationships of economic theory.

Keywords: Cycles · Mesodynamics · Nonlinear · Structures · Synergy · Trends

1 Introduction

The term “mesolevel” was first introduced in 1986 [11]. As an open economic system, the region is also affected by external macro- and microeconomic factors. Cyclical fluctuations are projected on the region horizontally (from the neighboring regions) and vertically (from other hierarchical levels), forming aggregative nonlinear mesodynamics [7, 10]. The mesolevel is often associated only with the regional economy and industries, but it should also include economic clusters, corporations, and other microlevel economic institutions that determine the possibility of sustainable development and macroeconomic systems [8, 18]. The subject of research for these objects is the study of their structures and the mechanisms that determine economic phenomena and measure the effects of their impact [22]. The rapid scientific and technical development of the world, especially in technologies, and significant political turbulence...
caused the transition from the policy of market fundamentalism, from scientific scholasticism to a new synergetic theory of the economy evolutionary development, considering it as a developing, complex and improving organism.

Now there is a need to change the methodology of economic science: from the theory of searching and maintaining a state of equilibrium to the theory of studying the laws of its development and retention within the increasing complexity of economic activity, an immanent regime of constant variability. Economic practice already shows that we should not only allow deterministic development trajectories, but also be prepared for “chaos”: the possibility of bifurcation points appearing within a short time that change the trajectory of dynamics of one or more attractors. They may not be fully implemented in practice due to the possibility of new attractors and the next search for mechanisms for retaining increasing complexity. The “deterministic chaos” differs from the regular dynamics in its probabilistic behavior, which originates from the object of analysis itself, and doesn’t require the influence of external factors. However, and it is very important, it can respond to scenarios of its regulation (determination).

2 Methodology

The most common characteristic of an analysis object’s modeling and forecasting is trajectory trends. Synergetic widely uses solutions of nonlinear dynamics differential equations for trends that reflect the essential properties of the analysis object, as well as “soft” (phenomenological) dynamic models, which are not always associated with theoretical assumptions, but are often adequate [6, 9]. Researchers analyze not only the specific values of trends, but also the topology of the phase space. They identify several main indicators in the dynamics (order parameters), adjusting all the others parameters to them. Thus, hundreds of economic indicators in such models can be replaced by a small number (from three to eight) of order parameters that characterize the evolution of the analysis object, determine the trajectory of its development, bifurcation points, and stable states trajectories.

The common industrial economy was guided by the production scale effect and negative feedbacks, while synergetic also considers (and creates) positive feedbacks of self-development. New relationships can be determined by the economic theory laws, solutions of the corresponding differential equations, and soft data processing models. It is necessary to compare the adequacy of the order parameters in the realized (and assumed) ranges of their values, as well as to evaluate the dependence on the ratio of the useful signal dispersion of the trajectories’ regular components and the stochastic component in the observations.

A special feature of synergetic is that the distribution law of the stochastic component is considered as a mixture of distributions, which becomes an informative sign of the evolution presence, when there are distributions with heavy tails, for instance, Pareto, Levi etc. [4]. It is a common misconception that the normal distribution is generally applicable to stochastic component and that the least squares method can be used to test any statistical hypotheses. Next, however, we will also consider the possibility of transforming the distribution to normal when selecting a seasonal component, without giving up the task of monitoring evolution.
Distributions with heavy tails are not exotic because the sum of independently and equally distributed random variables converges to them. These distributions have a deep cognitive significance, since they are determined by the nonlinear dynamics of processes in mesoeconomics by its laws and the economic mechanism of self-organization and interaction. They may also contain a normal distribution formed by a large number of independent factors inside the nonlinear dynamics of the mesoeconomics object such as errors in measuring indicators, the influence of the shadow economy, failures and rounding in data transmission, computational errors in models’ identification, etc.

There are known and confirmed by practice universal but also hard for application methods of synergetic (the apparatus of game theory and production functions), specialized mathematical methods (agent-oriented modeling and simulation calculations), simulation modeling that takes into account some individual properties of objects of analysis, market models of imperfect competition, and others, an overview of which is presented in [13]. However, only mathematical methods of synergetic are usually not enough to assess the socio-economic development of an economic system. For real economic systems we need a fundamentally new tool with the almost common informative dynamics characteristics: regular and stochastic components and their mutual relations. Human-computer methods of developing various scenarios of economic systems’ behavior are also mandatory, depending on the control actions taken under these scenarios.

The results of the experiment gave a representative assessment of the adequacy of the adopted methodology and the proposed tools. The authors tested the principle of synergetic deterministic chaos [1–3] and several models of econophysics based on mesodynamic data from 12 main economical sectors over 78 regions of Russia during the period from 2005 to 2017 [13]. Time series of the following industries are considered: construction and building, retail trade, natural resources extraction and mining, crude oil and gas extraction, metal ores extraction, industry and manufacturing, chemical industry, production of rubber and plastics, pharmacy, metallurgy, production of electronics and optical devices. Up to 12800 panel data observations were processed for each industry indicator. The results of this study can be considered as the first exploratory step. They outlined a number of ways to expand the scope of models’ application and the extent to which they correspond to known theoretical assumptions, including the possibility of additional accounting and social processes in the region and in the country. The next step is the correction or formulation of new theoretical assumptions, their verification on empirical data, including forecasting and analyzing regional socio-dynamics [4, 13, 22].

For the purpose of evolution monitoring in the mesodynamic models smoothing and identification should be performed on relatively short samples of monthly observations. Classical statistics cannot be applied on such samples, so the researches should refer to bootstrap procedures that generate additional pseudo-samples from the original ones. With a large enough number of pseudo-samples, it is possible to apply the common traditional statistical hypotheses as well as point and interval accuracy estimates. Whatever the type of empirical distribution it is not difficult to determine which lower and upper bound of values should be selected to ensure the desired probability of getting sample statistics in a given confidence interval. Thus, the bootstrap technique
allows calculating various functions and functions from an experimental sample, without relying on a priori information.

During the modeling process the authors widely used the methods components’ decomposition and composition. We started the decomposition of economic sectors dynamical indicators with a periodic seasonal component, for which the period (one year) and the reporting periods (months and quarters) are fixed. A researcher with heterogeneous mesodynamics of regional economic sectors does not have sufficient grounds for choosing a particular distribution law of the stochastic component in seasonality. However, it is possible to estimate their abnormality. Its presence is not informative to solve the problem of evolution monitoring of the analyzed economic system. There is a desire to exclude the influence of abnormal values so that they do not affect the final goal of research related to the Pareto distribution, and at the same time, allow the usage of various statistical procedures that are prior to the final goal of the research. There are several ways to achieve this purpose.

For example, to eliminate seasonal fluctuations, we used the LOESS method with the STL function (Seasonal Decomposition of Time Series by Loess). The trend is smoothed using LOESS with parabolic polynomials. Then the trend is subtracted from the original series and the seasonal coefficients are smoothed for the same months. Unlike Census II method, it doesn’t just calculate the average over all the years, but also performs smoothing on a sample window. Thus, seasonal coefficients evolve from year to year, the faster the smaller is the sample window (7 years as minimum).

We perform two attempts of the model identification: with additive and multiplicative structures. The implementation of the STL in R, which was used by the authors, assumes only an additive model structure, so for the multiplicative structure a normalizing transformation is required (taking the logarithm). After calculating seasonal coefficients, they are converted back from logarithms to the original values. For each attempt, deseasonalization is performed (seasonal coefficients are subtracted from the original series or divided by them) and partial autocorrelation is calculated for the adjusted series. The choice between the additive and multiplicative structure is made by the autocorrelation of order 12 (for months) – the closer it is to zero, the better the time series are adjusted of seasonality. A more complex and promising alternative is the Yeo-Johnson transformation [21], which, in comparison with other known transformations, takes into account zero and negative values of observations in calculations. The Yeo-Johnson transformation converts anomalous distributions into normal law, thus allowing the usage of the least squares method when performing statistical procedures that characterize the seasonal component.

Trend growth curves could be grouped into three types. The first type includes curves for describing the monotonous development of an economic system without inflection and extremum points. The second type includes S-shaped logistic curves which are also monotonous but have an inflection point and two asymptotic levels (upper and lower, the level of non-expanding demand). And if the curve has the extremum point and two inflation point so it is growing to the maximum and then returns back to the asymptotic level (bell-shaped curves) it is considered as a third type. More complex trends (for instance, multimodal) can be constructed as a combination of these three basic types. In other approach logistics trends are grouped together and can be considered either cumulative (S-shaped) or impulse (bell-shaped) depending on the
available data length and stages of the object’s life cycle. Models with arbitrary (configurable) asymmetry and separate phases of the life cycle should be considered promising for expanding the scope of logistics models [14]. The latter model is of particular interest, since this is a common case for several known logisticians with certain parameter values.

The Fig. 1 shows both increasing (solid line) and decreasing (dash line) cumulative logistic curves with their asymptotic levels (dash-dot horizontal lines). Impulse logistic curves can be obtained as a result of their differentiation. In Russian synergetic studies only two models are usually considered: symmetrical Verhulst model (also known as a sigmoid) [20] and Gompertz model [5] with fixed right asymmetry while the authors of the article proposed the complex of over twenty different logistic curves including both known models and models proposed by the authors. This complex seems to be more adequate for real economic practice. As a result of computation on our exploratory data and comparation of all the considered model types we found out that in over 90% of the cases logistic curves of both types are more accurate than growth curves [13]. Although exponential curve was applicable for short time periods.

As we expected the wide usage of liner trend on mesodynamic is unproper since it assumes constant value of the model derivative (growth/decline speed) which seems unrealistic in real economy especially on longer time periods. The amount of time series in our experiment which can be adequately described by linear trend is only 3.4% and they are mostly time series with almost no trend (only constant level) that describes stagnation. Using polynomial parabolic trend is also questionable because it assumes the second derivative (acceleration) to be constant while the first is linear. It seems to be even more unachievable condition. As the practice shows parabolic trend has high forecasting errors. Although this model is non-linear towards time variable it still cannot be considered as an evolotional one since it is reversible. The object model is significantly non-linear and irreversible if at least one of the model components is non-linear towards its parameter. This property can be achieved if any type of trend would be complemented by at least one harmonic function (which is implied in seasonal and cyclical components). This circumstance explains the popular “illusion” of modeling adequate nonlinearity of mesodynamics by the sum of linear trend and harmonic functions.
We should also mention that all the considered trend models are generalized by adding a constant (intercept) which allows more flexibility and free moving along the ordinate axis but restricts possibility of the models’ linearization using logarithm, inverse, etc. Thus, we have to use computational methods to evaluate the models’ parameters. In traditional additive structures of the time series the stochastic component is considered as additive against the regular, determinate components. The possibility of the multiplicative structure was already considered above on elimination of the seasonal component.

The authors considered additive and mixed additive-multiplicative structures [13]:

\[ Y_t = T_t + C_t + S_t + \varepsilon_t, \]
\[ Y_t = (T_t + C_t)(1 + S_t) + \varepsilon_t, \]

where \( Y_t \) is the original time series, \( t \) – time (ordering indices), \( T_t \) – trend values, \( C_t \) – cyclical component values, \( S_t \) – seasonal component levels, \( \varepsilon_t \) – stochastic component.

It is also reasonable to consider other mixed structure types as alternatives for decomposition purposes. To expand nonlinearity presence the following additive-multiplicative models can be considered:

\[ Y_t = (T_t + C_t)S_t + \varepsilon_t, \]
\[ Y_t = T_t(1 + S_t) + C_t + \varepsilon_t, \]
\[ Y_t = T_t(1 + C_t) + S_t + \varepsilon_t, \]
\[ Y_t = T_t(1 + C_tS_t) + \varepsilon_t, \]
\[ Y_t = T_t(1 + C_t + S_t) + C_t + \varepsilon_t, \]
\[ Y_t = (T_t + S_t)C_t + \varepsilon_t. \]

As an addition to the considered additive-multiplicative structures even more sophisticated interactions of trend and other, fluctuational components can be considered. Thus, fluctuational component can be both additive and multiplicative or be weighted by the amplitude [12, 16]. The fluctuations can also change their frequency decreasing on the higher values of the trend and increasing on the significant logistic decline. Other methods of logistic curves transformation and adaptation for time series evolution were also introduced in [13, 15]. This widely expands their application field.

In some studies the urgency of evaluating the interaction of growth models with the beginning of the increasing phases of cycles is noted. However, their proposals are characterized by the specificity of the choice of exogenous factors, and the identification of cyclical development of regions is based either on descriptive approaches, or is associated with the scientific and logical justification of the theoretical hypotheses and assumptions put forward. Our research allows us to implement instrumental support for this assessment on real data.
For the first time, according to our knowledge, the authors of the article confirmed the hypothesis of Slutsky about modeling aperiodic cycles of mesoeconomics by the sum of three harmonics (sinuses) with non-proportional frequencies [19]. The regional industry cycle defines the dynamic process of fluctuations in economic activity within the life cycle of the industry, characterized by the repeatability of successive stages of decline and recovery in the region’s industry.

3 Results

Figure 2 illustrates the obtained results on the economic sector “production of rubber and plastic products”. On the left models (trend, cycles, seasonal) for Altai Region is shown as an instance of one of the 78 observed regions of Russia. On the right there is shown generalization of the cycles over all the 78 regions as well as average (dark line), median (light line) and quantiles (light dotted lines) [13]. Each point on the right plot represents scaled cyclicity of a single region at the given timestamp. The darker the point the farther it is from the average. These results showed heterogeneity of the institutional and economic development of Russian regions for different sectors of the economy, which creates imbalances of economic systems and regional cycles.

![Fig. 2. Production of plastic and rubber (left – model for Altai Region, right – generalization over all the Russian regions) (Source: authors, compiled with the authors’ program in R language)](image)

It is also possible to solve new problems [13]:

– to clarify the spectrum of potential impact of the sectoral regional cycle on the stability and balance of spatial development of regions and macroregions,
– to assess the level of imbalance and stability of regional development in the medium term,
– to develop directions for improving the level of stability and balance of the Russian economy;
– to identify homogeneous regions along the length of the cycle and identify groups of regions that are most promising for investment,
– to make proposals on strategic directions of high-tech regional development and improving the balance and sustainability of regional development.
The language R and numerical methods of non-linear least squares, ARMA (autoregression – moving average) models, genetic algorithm, simulated annealing method and RPROP (resilient backpropagation algorithm) were used for modeling mesodynamics of economic indicators [13, 17]. The research allowed us to start forming a knowledge base for describing the cause-and-effect relationships of the economic theory of mesodynamics.

4 Discussion

Such components of scientific knowledge as precision measurement and identification, reasoning of factors involved in the generation of cyclical industries mesodynamic model of “deterministic chaos” is still not used by economists. This largely predetermined the subjectivity of the received assessments and conclusions. With appropriate results and recommendations for scenario planning to set benchmarks in a situation of uncertainty, regional authorities can potentially be effective participants in the sustainable smoothing of the regional business cycle. Attempts to use scenario planning are known in Russia and abroad, but it is necessary to expand the scope of its application. The data we relied on in this article was focused on the innovative development of Russian regions in the context of economic sanctions. At the moment, the coronavirus epidemic makes the task of obtaining them even more urgent. The analysis of a certain duration of degradation of mesodynamic will be required, it may be the continuation of the development of appropriate tools on it, and then its subsequent application.

5 Conclusion

The results of the study have shown the heterogeneity of the regional institutional and economic development, which creates imbalance that drives out equilibrium in economic systems and underlying business cycles. This also includes obtaining development forecasts as well as forming a knowledge base to characterize the causal links in economic theory. The application of the project consists in providing an array of data for making managerial decisions by the authorities of the country, macro-regions, and regions. The conclusions and recommendations can be used by the enterprises’ administrations, scientists in research organizations, graduate and post-graduate students.

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