DOI: 10.54861/27131211_2024_10_7

FORMALISM OF PHENOMENOLOGICAL THEORY IN MATHEMATICAL MODELING OF ECONOMIC PROCESSES

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Highlights

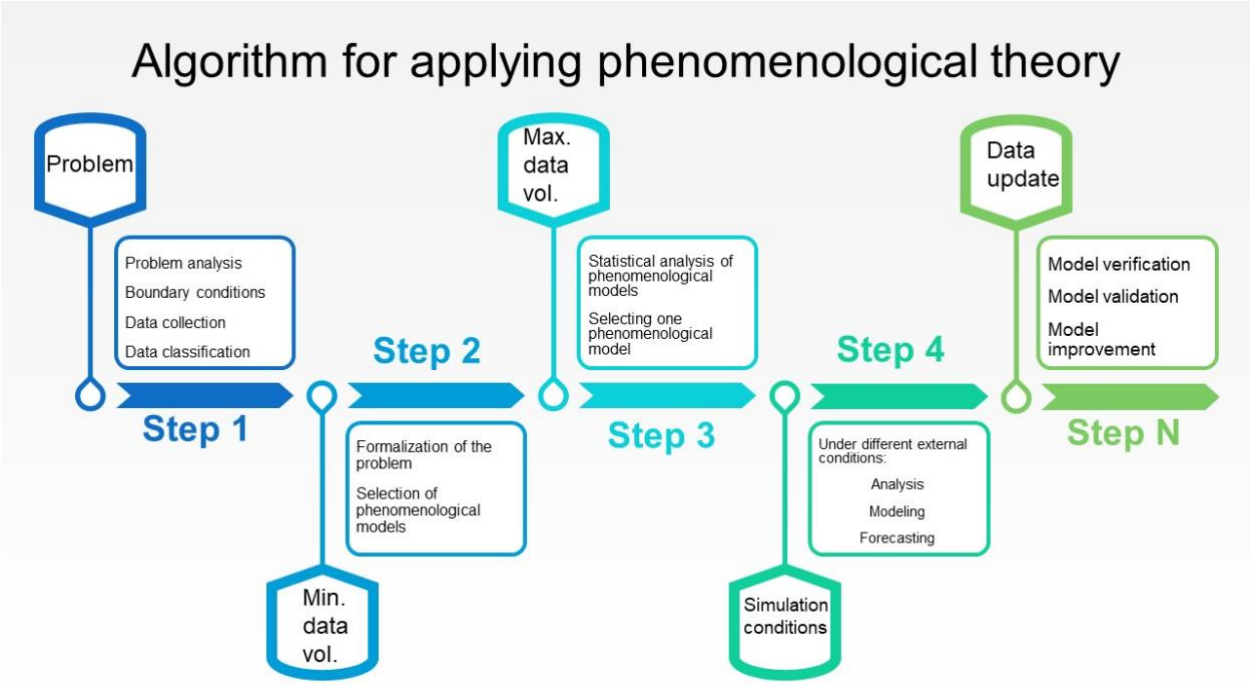
- The phenomenological approach in economic modeling is a convenient tool for analyzing and forecasting complex economic systems.
- The phenomenological approach takes into account the state of uncertainty.
- The phenomenological approach is universal and applicable in complex economies.

Abstract

I*ntroduction*: In contrast to neoclassical economics, where agents are rational, their actions are rational, and they strive for equilibrium, complex economics proposes to consider systems as evolving, complex, and not necessarily striving for equilibrium. The application of complex economics is particularly relevant in conditions of uncertainty and rapidly changing economic conditions. To develop the tools of complex economics, it is necessary to search for new mathematical approaches; a revolutionary approach in economics could be an approach based on the formalism of phenomenological theory.
M*ethods:* The formalism of phenomenological theory is used.
R*esults:* Four economic models are considered that can be built using the formalism of phenomenological theory. Using the example of analyzing changes in economic indicators caused by external factors such as magnetic storms, a modeling algorithm was implemented using phenomenological theory.
A*vailable data*: No available data
D*iscussion:* The article shows that phenomenological formalism can be used in both traditional and more modern economic paradigms, expanding the boundaries of theoretical and applied analysis. Based on observed patterns and empirical data, phenomenological models allow us to study the macroscopic characteristics of economies without delving into microscopic details. As shown above, the formalism of phenomenological theory can be used both within the framework of neoclassical economics and complex economics. The phenomenological approach is universal

and applicable in various areas of economic analysis, and the use of phenomenological theory allows us to take into account the elements of randomness and irrationality inherent in real economic processes, which is especially relevant for a complex economy.

Graphical abstract



Keywords
Phenomenological Approach, Mathematical Modeling, Forecasting of Economic Processes, Dynamics of Economic Systems, Complex Economics.

JEL classification: C02, C53, C83.

For citation: Artamonov A.A. (2024). Formalism of phenomenological theory in mathematical modeling of economic processes. *Progressive Economy*, 10, 7–18. DOI: 10.54861/27131211_2024_10_7.

The article was submitted to the editorial office: 07/22/2024. Approved after review: 10/01/2024. Accepted for publication: 10/07/2024.

Introduction

With scientific and technological development, the complexity of processes in the global economy increases [1]. New paradigms for describing these processes appear [2]. The so-called complex economics [3] is replacing neoclassical economics. Unlike neoclassical economics, which assumes the rationality of agents [3], the predictability of their actions, and the system's desire for equilibrium [4], complex economics suggests considering economic systems as evolving, complex, and not necessarily striving for equilibrium [4; 5]. The use of complex economics is

especially relevant in conditions of uncertainty and rapidly changing economic conditions [6]. For example, this approach allows for more accurate modeling of the behavior of financial markets, taking into account the emergence of market psychology, price bubbles, and crashes [7]. These phenomena are difficult to capture using traditional methods, but they become visible when using the methods of complex economics [8]. Complex economics offers new opportunities for the development and analysis of economic policy [2]. In contrast to the neoclassical paradigm, which focuses on achieving equilibrium through the adjustment of taxes, regulations, and quotas, complex economics allows for the diversity of agents and their behavior, the impact of fundamental uncertainty, and possible unexpected consequences of policy decisions or random factors [9].

Complex economics represents an important step in the development of economic science, allowing for a deeper understanding of the complexity and dynamics of real economic systems [10]. Rejecting strict assumptions about equilibrium and rationality opens up new prospects for analyzing economic processes, identifying new phenomena, and developing more realistic and effective policies [5]. This approach not only expands the boundaries of economic theory, but also provides powerful tools for solving pressing economic problems associated with globalization, technological change, and uncertainty [11]. Of course, the development of tools for complex economics requires a search for new mathematical approaches; an approach based on the formalism of phenomenological theory can become a revolutionary approach in economics [12].

Thus, the purpose of this article is to provide a methodological description of the development of mathematical models for analyzing and forecasting economic processes using the formalism of phenomenological theory.

Methods

Introduction to Phenomenological Theory

Phenomenological theory [13] is one of the approaches to studying complex systems, including economic ones. The phenomenological theory is based on the idea that instead of a detailed description of all the microprocesses of a system, one can focus on its macroscopic properties and generalized dependencies that determine the behavior of the system as a whole [14]. This approach allows us to simplify the analysis and forecasting of complex systems, based on observed patterns and their mathematical description [15].

The main principles of the phenomenological approach in economics include:

– the macroscopic level of analysis, within which the phenomenological approach in economics focuses on macroscopic variables, such as aggregate demand, inflation, gross domestic product (GDP), etc., instead of studying the behavior of individual agents, general patterns at the level of the entire system are studied [16];

- an empirical basis, according to which phenomenological models are based on empirically observed data and correlations between macroscopic variables and are developed to describe patterns that directly follow from observations [5]; - simplicity and universality, which, unlike microscopic models, require detailed information

about the interactions between individual elements of the system. Phenomenological models can be applied to a wide range of economic systems [17]; - mathematical modeling is the main tool of the phenomenological approach, allowing one to formalize observed patterns and make predictions about the behavior of the system in the future [18].

Development of Mathematical Models Using the Phenomenological Approach

Mathematical models developed using the phenomenological approach usually include equations describing the macroscopic parameters of the economic system. These equations can be linear or nonlinear, deterministic or stochastic, depending on the nature of the process under study. The approach developed by the author of this article is based on the fact that any process or phenomenon (including in economics) has an analogue in physics or mathematics. Unlike other sciences, mathematics and physics have methods of analysis and a well-developed mathematical apparatus in their arsenal. Thus, it remains to reformulate the observed process or phenomenon in a suitable mathematical or physical analogue, where the theory of similarity is used. As a result, it is possible to obtain a ready-made suitable mathematical apparatus and formulate meaningful conclusions about the observed phenomenon. To understand the methodology of the formalism of the phenomenological theory, two models of neoclassical economics (the first two models) and two models of complex economics, which already take into account the element of randomness and irrationality, will be presented. For the last model of complex economics, a real model calculation of the influence of magnetic storms on economic indicators will be presented.

Results

Model 1. Linear Model of Supply and Demand

One of the simplest examples of a phenomenological model in economics is the linear model of supply and demand. Let Q_d denote the demand for a good (1.1) and Q_s the supply (1.2). Then:

$$Q_d = a - bP \quad (1.1)$$

$$Q_s = c - dP \quad (1.2)$$

where P is the price of the product, a, b, c, d are coefficients determined empirically. The equilibrium point on the market is determined from the condition of equality of supply and demand (2):

$$Q_d = Q_s \quad (2)$$

which leads to the following equation for the equilibrium price P^* (3):

$$P^* = \frac{(a-c)}{(b+d)} \quad (3)$$

Accordingly, the equilibrium volume of production Q^* is equal to (4):

$$Q^* = \frac{(ad + bc)}{(b + d)} \quad (4)$$

Model (1–4) is easy to implement and interpret, and its use allows us to predict how changes in parameters *a*, *b*, *c*, *d* affect the equilibrium values of price and output. And, in fact, equation 2 reflects the fundamental physical law of nature – every action is equal to every reaction. Thus, we were able to easily move from the physical law to the description of the patterns of supply and demand in economic theory. Using the linear model of supply and demand, we can estimate the impact of changes in the minimum wage on employment. Let Q_d be the number of jobs for which there is demand, and Q_s be the number of workers willing to accept work at a certain wage *P*. An increase in the minimum wage may lead to a decrease in the demand for jobs, which will affect equilibrium employment. This analysis can be used to develop employment policy and regulate the minimum wage.

Model 2. Nonlinear Business Cycle Model

Another example of a phenomenological model is the nonlinear business cycle model. Let *x(t)* denote the deviation of real GDP from its trend value. Then the dynamics of *x(t)* can be described by the nonlinear differential equation (5):

$$\frac{dx(t)}{dt} = \alpha x(t) - \beta x(t)^3 + \gamma \cos(\omega t) \quad (5)$$

where α, β, γ, ω – parameters of the model. The first term on the right side of the equation is responsible for the linear growth of deviations, the second – for their saturation (due to nonlinearity), and the third – for cyclical fluctuations associated with external influences. The solution to this equation allows us to study the presence of cyclical fluctuations in the economy, their amplitude and frequency depending on the values of the parameters α, β, γ, ω.

Equations similar to equation 5 are widely represented in the physics of oscillations and are a whole class of anharmonic oscillations (anharmonic oscillations, periodic oscillations that differ in form from harmonic oscillations) [19; 20]. The use of a nonlinear model of business cycles allows us to predict fluctuations in GDP in the coming years. By solving a nonlinear equation with certain initial conditions and parameters, we can estimate the probable periods of recessions and upswings in the economy. This can be useful for businesses in strategic investment planning and risk management.

Model 3. Solow Model of Economic Growth

Another example is the phenomenological model of economic growth developed by Robert Solow (R. Solow model). This model describes long-term economic growth using a production function and the capital accumulation equation. The production function has the form (6):

$$Y(t) = A(t)K(t)^{\alpha}L(t)^{1-\alpha} \quad (6)$$

where *Y(t)* is the output at time *t*, *K(t)* is capital, *L(t)* is labor, *A(t)* is the technological level, α is the share of capital in output. Capital accumulation equation (7):

$$\frac{dK(t)}{dt} = sY(t) - \delta \mathrm{K(t)} \quad (7)$$

dK(t)/dt = sY(t) - δK(t), where s is the savings rate, δ is the capital depreciation rate.

In a steady state, the capital growth rate *dK(t)/dt = 0*, which leads to the following equation:

$$sY^{*} = \delta \mathrm{K}^{*} \quad (8)$$

where *Y** and *K** are the stationary values of output and capital. Using the production function equation, we obtain (9):

$$Y^{*} = \left(\frac{sA^{*}\,L^{*}}{\delta}\right)^{\frac{\alpha}{1-\alpha}} \quad (9)$$

This model helps to analyze the impact of savings, depreciation, population growth, and technological progress on economic growth in the long run. The physical interpretation and application of this model are illustrated in [21; 22; 23].

Using the Solow model, one can analyze the impact of technological progress on economic growth in the long run. For example, assuming that *A(t)* grows exponentially at a rate g, one can estimate how a change in the rate of technological progress affects the level of stationary output *Y**. Such an analysis can be useful for governments developing policies to stimulate innovation and investment in science and technology.

Model 4. Stochastic Inflation Model

Phenomenological models can also include stochastic elements to account for random fluctuations in the economy. Consider a stochastic inflation model, where the inflation rate π(t) is described by equation (10):

$$\pi(\mathrm{t}) = \pi_0 + \alpha(\mathrm{Y(t)} - \mathrm{Y}^{*}) + \sigma \mathrm{W(t)} \quad (10)$$

where π_0 is the target inflation rate, *Y(t)* is the current output, *Y** is the potential output, α is the coefficient of inflation sensitivity to output deviations from the potential, σ is the volatility coefficient, *W(t)* is the Wiener process modeling random fluctuations. Model (10) is used to forecast inflation taking into account possible random shocks affecting the economy. The main result of such modeling is the ability to estimate the probability of achieving a certain level of inflation in the future.

Using the stochastic inflation model, one can estimate the probability that inflation will exceed a certain threshold in the future. Let, for example, the target inflation rate π_0= 2%, and consider a period of one year. By setting the values of the parameters α, σ and the initial conditions, one can conduct a simulation using the Monte Carlo method to obtain the distribution of possible inflation values in a year. The modeling results can be used by central banks to make decisions on adjusting interest rates. The physical analogue of the process described by equation (10) is the well-known Wiener process, the key property of which is that it is scale invariant or, in simple terms, self-similar. At the same time, the Wiener process describes random fluctuations, including extremely rare ones. Of particular interest are cases of complex economics, where there is a component of randomness and irrationality of economic processes.

To demonstrate the real application of the phenomenological theory, we will consider the problem of modeling the impact of magnetic storms on such an economic indicator as the disease burden (expressed in terms of the number of person-years with temporary disability or disability caused by the influence of magnetic storms). In our example, we consider magnetic storms because this example fully reflects the problems that a complex economy faces and which can be solved by the formalism of the phenomenological theory. As was said above, a complex economy considers economic processes where agents react to stochastic external factors in an unpredictable way, while economic processes evolve in a complex way and do not necessarily strive for equilibrium. If we consider the problem of the impact of magnetic storms on medical and economic indicators, we note the important initial conditions:

– magnetic storms are a rather rare phenomenon associated with the activity of the Sun, its solar activity cycles. It is impossible to predict the occurrence of magnetic storms, but they can be mathematically described within the Wiener process;

– a reliable mechanism of the effect of magnetic storms on the human body has not been established;

– there is some interest on the part of society (individual members of society) in magnetic storms and for this reason, a geomagnetic disturbance forecast is published along with a short-term weather forecast;

– it has been empirically established that the number of ambulance calls increases on days of magnetic storms and the following days [24].

Calling an ambulance is usually associated with the seriousness of the situation, associated with risks to the health and life of the patient. As shown in the study [25], an increase in the number of ambulances calls on days of magnetic storms is largely associated with acute episodes of cardiovascular diseases associated with a high level of severe disability (strokes, heart attacks). At the same time, the load on ambulance stations and inpatient departments increases, and the number of person-years with temporary disability or incapacity increases. To model this influence, we will use the fact that the frequency of magnetic storms is described by a Wiener process.

Using the stochastic model (equation 10), we will estimate the probability that the number of person-years with temporary disability or incapacity will exceed a certain threshold in the future.

Let us redefine some parameters of equation (10). Let us redesignate π(t) as a function of the time of population disability, expressed in person-years with temporary disability or incapacity. Since we need to take into account the influence of magnetic storms on this indicator, and magnetic storms are described within the Wiener process, we can use equation (10). The equation itself will remain the same, but all the variables included in it will be redesignated (11):

$$\pi(t) = \pi_0 + \alpha(Y(t) - Y^*) + \sigma W(t) \quad (11)$$

where π_0 is the target indicator (set by the Ministry of Health), *Y(t)* is the current level of disability of the population, *Y** is the potential level of disability of the population, α is the sensitivity coefficient, σ is the coefficient of variability (taking into account the influence of magnetic storms), *W(t)* is the Wiener process modeling random fluctuations.

Part of the equation $\pi_0 + \alpha(Y(t) - Y^*)$ – This is a well-predicted value that reflects the growth of the incidence rate, and we will not consider it. For our problem, the most important component of equation 11 is σW(t). The parameter σ* we find from the publication [26], and it is a statistically reliable value equal to 1.205 - which means an increase in the number of ambulances calls for stroke or heart attack cases by 20.5% during geomagnetic disturbances. The parameter σ is related by the equation $\sigma=(\sigma^*-1)\ \pi_0$. Thus, we are faced with the task of modeling changes in π(t) over time associated with magnetic storms Δπ(t)~σW(t).

By the definition of the Wiener process, changes in any time interval satisfy equality (11):

$$\Delta\pi(t) = \sigma W(t) = \sigma\chi\sqrt{\Delta t} \quad (12)$$

where χ is a random variable that follows the standardized normal distribution *f(0,1)*. Based on equation (12), we estimate Δπ(t) in units of π_0 on two-time scales (with a step of one month and a step of one year). The simulation result is presented in Figure 1 (simulation step of 1 month) – Δπ(t), and Figure 2 (simulation step of 1 year) – Δπ(T).

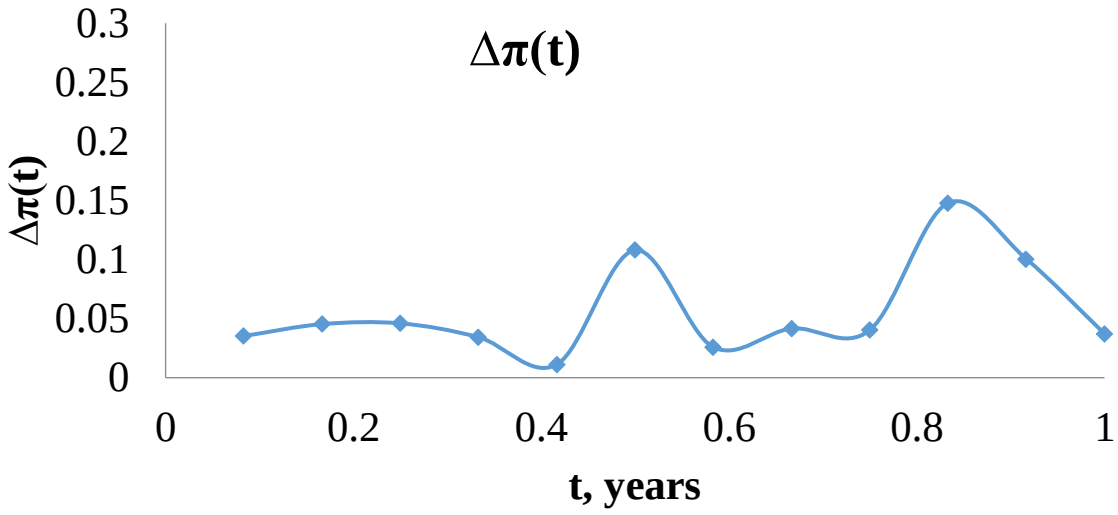


Fig. 1. Result of modeling Δπ(t). Modeling step 1 month
Source: modeling performed in MathCad 11

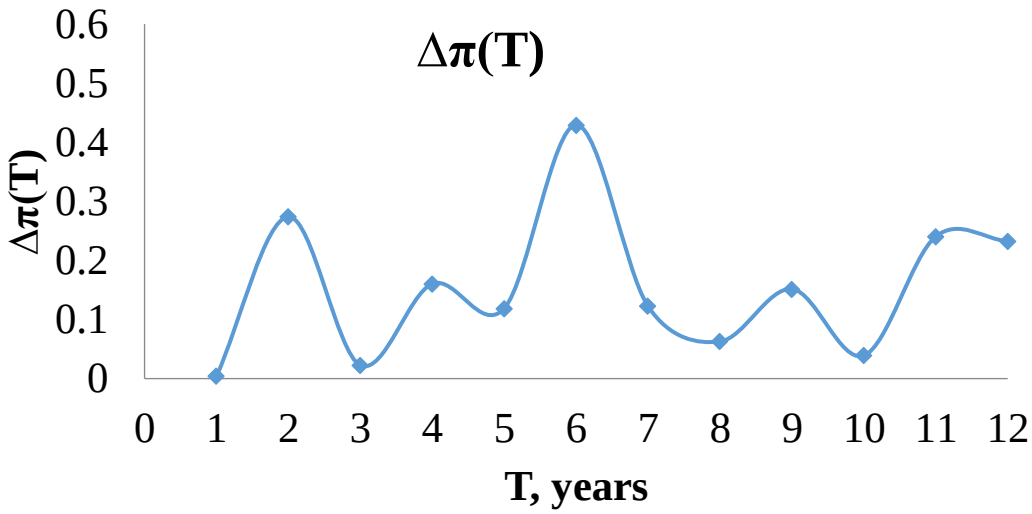


Fig. 2. Result of modeling Δπ(T). Modeling step 1 year
Source: modeling performed in MathCad 11

The conducted modeling of the influence of magnetic storms on medical and economic indicators indicates a significant relationship between these phenomena. The used stochastic model based on the Wiener process demonstrates that the variability of the disability indicator is directly related to magnetic storms, which allows predicting cases of exceeding a certain threshold of health deterioration during geomagnetic disturbances. The modeling results emphasize the need to take into account external geophysical factors for a more accurate analysis and forecast of their impact on the economy and public health.

Available data

No available data.

Discussion

The article shows that phenomenological formalism can be used in both traditional and more modern economic paradigms, expanding the boundaries of theoretical and applied analysis. Based on observed patterns and empirical data, phenomenological models allow us to study the macroscopic characteristics of economies without delving into microscopic details. As shown above, the formalism of phenomenological theory can be used both in the framework of neoclassical economics and complex economics. The phenomenological approach is universal and applicable in various areas of economic analysis, and the application of phenomenological theory allows us to take into account the elements of randomness and irrationality inherent in real economic processes, which is especially relevant for a complex economy.

CRediT authorship contribution statement

A.A. Artamonov Coordination. Data interpretation, Writing- Original draft preparation.

Declaration of competing interest

The author declare that he has no conflicts of interest.

Acknowledgements

The work was carried out within the framework of topic FMFR-2024-0042 of the program of fundamental scientific research of the Russian Academy of Sciences.

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