Fundamentals of the Application of the Mathematical Model in Economic Cybernetics

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Abstract: The relevance of the research lies in the fact that the era of technology today is spreading to the very heart of everyday life and, thanks to this, is actively involved in the intersubjective construction of realities, clearly marks the planetary triumph of the cybernetic paradigm. The purpose of the research is to consider aspects of the development of economic cybernetics in the world, as well as mathematical models and their comparative characteristics. The methodological base of the research includes the following approaches to the study of this topic: systemic, formal-model, dynamic. To create an economic cybernetics model, the various concepts of management should be given clear economic meanings, taking into account the characteristics of the macroeconomic system. The macroeconomic system belongs to the category of large systems, which, as a rule, are difficult to decompose accurately. The strong connection of each subsystem often causes difficulties in mathematical processing. Optimal management of macroeconomics is affected by the subjective factors of decision makers, since employees can draw very different conclusions from the same system. The results of the research determined the generations of the development of cybernetics, as well as its economic models, including mathematical ones. The practical significance lies in the analysis of the paradigm and development models of economic cybernetics in the modern world.

Keywords: Macroeconomics, Automatic Control, Control System, Computer Modelling, Automation.
JEL Codes: B16; B41.

1. INTRODUCTION

The idea of automatic control and its practical applications have a long history. The first automatic controller used in industry was the flying ball regulator invented by James Watt in 1769 to control the speed of a steam engine. Until 1868, the design of automatic control devices and systems was still at the stage of intuitive understanding. There was no systematic theoretical guidance, so problems often arose in the coordinated control of various characteristics, such as stability, accuracy and speed. In the second half of the 19th century, many scientists began to study the theory of self-control based on mathematical theory, which had a positive effect on improving the efficiency of the control system. In 1868, James Maxwell established a mathematical model for the differential equation of a flying ball controller and analyzed the stability of the system by solving the differential equation (Boulding, 1956). Before and after World War II, due to the need for automatic weapons, the demand for research and practice of control theory increased, which greatly contributed to the development of automatic control theory. In 1948, the mathematician N. Wiener (1961) developed "cybernetics", which has been continuously developed for more than half a century. Its content and research methods have changed greatly.

In brief, the development of cybernetics has passed through three periods: the first stage is the classical period of cybernetics from the late 1940s to the 1950s when the main focus was on the study of autonomous automation and the SISO solution – Single-Input Single-Output. Its main mathematical tools were differential equations, Laplace transformations,

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transfer functions, the time domain method, the frequency domain method, and the root locus method. The main problems were speed, stability and accuracy. The second stage is the period of modern control theory of the 1960s, focused on solving the problems of controlling MIMO – Multi-Input Multi-Output systems – in modular automation and biological systems. The tools included first-order differential equations, matrix theory, state space method, variational method, maximum value principle, dynamic programming theory. The emphasis was placed on optimal, stochastic and adaptive control, the main control device of which was an electronic computer (Piketty and Goldhammer, 2014; Babak et al., 2007). From a cybernetic viewpoint, human is the most ingenious and flexible control system. Human is good at responding correctly to changing conditions. Applying human intelligence to a real automatic control system is an important problem (Mason, 2012; Eremenko et al., 2020).

The third stage is the period of the theory of large-scale systems. Since the 1970s, people have not only solved social, economic, managerial, environmental and other systemic problems but also formed a new discipline to solve the simulation of human brain functions. The science of artificial intelligence, which is the frontier of the development of cybernetics, and the development of computer technology provide a solid foundation for artificial intelligence (Aizstrauta and Ginters, 2015; Stepanchuk et al., 2020). People improve artificial intelligence with the help of computers' powerful information-processing capabilities and use them to simulate the human brain (Beer, 1995; Babak et al., 2020). The system is capable of self-regulation, self-learning and self-organization in order to adapt to changes in the external environment and make appropriate decisions and controls. Science is developing, and cybernetics is developing too. Therefore, the word "modern" is added to "control theory". The controllability, observability and stability of the system are analyzed, and the problem of optimal control of the system is solved by the variational method, the principle of maximum or minimum value and the dynamic principle of programming. General systems theory considers its object of study as a whole, proposes patterns, principles and laws that apply to all systems, as well as singles out the system at the individual level, which helps to explain the organized system. The object of study of cybernetics is a system, without which it is impossible to further study the functions of the organization, controlling the adjustments within the system. Information is an important characteristic of an organizational system. It allows the system to achieve self-control and is the main way of communication between systems and the environment. System, information and management are inseparable (Snowdon, 2008; Leijonhufvud, 1969).

Therefore, the purpose of the research is to consider aspects of the development of economic cybernetics in the world, as well as mathematical models and their comparative characteristics.

2. MATERIALS AND METHODS

The methodological base of the research includes the following approaches to the study of this topic: systemic, formal-model, dynamic. The systemic method introduced the relevant theories and mechanisms of economic cybernetics, paying special attention to the prerequisites for the development of economic cybernetics, the creation of economic system management models, the analysis of their state space, the analysis of the stability of economic structures and manageability while highlighting the problems of performance and observability, feedback control strategies for economic systems, optimal management strategies using appropriate tools. This methodology made it possible to consider the system as a simple control with negative feedback of one control variable, but due to the limited understanding of the economic system within the framework of the model of an indefinite structure in accordance with the characteristics of the input variables. The systems research method is a further development of the decision research mechanism that consists in studying how the external economic structure adapts and coordinates in order to ensure smooth development. This is a process, in which the elements of the mechanism observe the market from time to time, detect and evaluate various factors in a timely manner.

The formal-model approach to the study of economic phenomena is very useful in a market economy. Modern decentralized market economies are complex adaptive systems including a large number of buyers and sellers, whose actions are interdependent. These interdependencies have given rise to macroeconomic patterns, such as common market protocols or norms of conduct, which in turn determine the nature of local interdependencies. The result is a complex dynamic system of recurring causal chains linking individual behavior, networks of interdependence, as well as social well-being. This interaction of microstructure and macrostructure has long been known to economists, but only cybernetic aspects have made it possible to model it quantitatively and take into account all its dynamic complexity. Cybernetics and formal economic models can be successfully applied in the analysis of dynamic economic processes. This method achieves the goal of understanding models by constructing and analyzing research proposals. For those object systems that cannot be studied directly, the goal of indirect study and understanding is achieved through design, construction, and analysis.

The dynamic method of the economic system of cybernetics included the analysis of stability, controllability, observability and optimization. Based on the mathematical model of a physical system, the current description of control problems is inherently complex, but the basic idea of control theory is quite simple and intuitive. The dynamic approach is interested in the time evolution of the behavior of complex systems. A complex system is defined in this case as a whole, comprising many interacting elements. Here, the methodology enabled determining the system and its complexity, because the system refers to the body in motion, and its constituent elements are different segments of the body. It was in this context of uncertainty that an alternative logic of dynamics arose, which was designed to take into account the cybernetic knowledge of the system, effectively mobilized, required and even transformed in practical situations. The imposition of time and the mutual interpenetration of actions make dynamic reality a formal reconstruction and a situational manifestation that can only be perceived in the dynamics of this process.

3. RESULTS AND DISCUSSION

With the mass digitization of information and the multiplication of data, the search for the effectiveness of processes has eliminated all anthropological questions. However, managerial control causes a certain approach to people, society and their environment in its way of collecting, sorting, analyzing and presenting the information. Key aspects of its considerations include such tasks: to integrate economic, social and environmental information; to be a node, through which digitized information passes, a control point that ensures the reliability and relevance of the transmitted information; to make sense of abstract information, turning numbers into a meaningful story for all stakeholders of the economic system (Babak et al., 2019). Cybernetics also translates the desire to mathematize knowledge about organisms not in the biological sense, but at the mechanical level of an organized structure that implies a connection between its parts (Espejo, 2022). This is primarily a semantic issue, because mathematics, compared to words, promotes clarity and precision through its symbolism. Thus, the concepts of correlation and pattern overlap with each other and oppose chaos generated by the general law of entropy, where all organisms function according to an individual model that structures the mechanisms of their bodily apparatus. Due to their method of structuring phenomena, both release the individual from their metaphysical conception in order to rationalize and model them mathematically (Nordhaus, 2015; Tashpulatov et al., 2018). They see form as movement, defending genetic geometry, which alone can give the affirmative or perfect definition of any mathematical object and even more of an individual that is part of physical and real beings.

The constant increase in the computing power of electronic machines makes it possible to simulate more and more natural or artificial systems. This processing power is all the more effective when an abstract mathematical model is available that summarizes the dynamics in a few symbols. The concept of a controlled system and control also allows the formation of many technical, economic or social systems. From a completely different viewpoint, scale-invariant systems in which "big is like small" seem to be approximated using "fractal geometry". One might wonder what are good papers on the dynamics of such systems. In addition, economic cybernetics introduces a dual mathematical model to describe, on the one hand, the free evolution of the system, and, on the other hand, the interactions between the observer and the system. For more than a century, control tools have been able to meet the needs of increasingly complex process control. The need to delegate decision-making as close as possible to actors while maintaining a global vision of processes has led to the development of numerous tools ranging from budgetary control to balanced scorecards, including costing and reporting. But managerial control is not only a tool for coordinating processes but also a tool that shapes organizational processes and influences social and environmental interactions (Bălăcian and Scarlat, 2021; Ginters et al., 2014).

In order to create a model of economic cybernetics, the various concepts of management must be given clear economic meanings. The creation of a model of economic cybernetics must fully take into account the characteristics of the macroeconomic system. The macroeconomic system is often constrained by the uncertainty of people and economic phenomena and is essentially a random non-linear structure. Considering it as a linear system is an approximation that introduces large errors, and sometimes even economic fluctuations (Bayro-Corrochano, 2018; Korzhyk et al., 2017). Identification and simulation data are mainly obtained by periodic sampling. The available data is insufficient, its reliability is low, and in most cases, there are serious noise interferences. The macroeconomic system belongs to the category of large systems, which, as a rule, are difficult to decompose accurately. The strong connection of each subsystem often causes difficulties in mathematical processing. Stability, controllability and predictability of the economic system are the main discussions that go through the development of macroeconomics. System identification mainly studies the stability, controllability and predictability of economic systems. The choice of the optimal economic policy in macroeconomics is actually an optimization method. The essence of the optimization method is to find an optimization mechanism and an element with a known system performance indicator and certain restrictions. Based on the mathematical model of a physical system, the mathematical description of problems is inherently complex. However, these important ideas can be found both in nature and in human evolution and behavior: feedback, filtering, shock fluctuation system, system characteristics, optimization methods (Soldatenko et al., 2020).

Mathematical simulation can deepen the knowledge of reality, using the mathematical apparatus not only as a descriptive tool but also as a research tool, where it is about emphasizing that mathematical formalization should reveal new facts that can bring closer to the essence of the phenomenon under study (Aizstrauts et al., 2015; Danchuk et al., 2021). Thus, mathematical formalism is the focus of this concept of cybernetic modeling, since it has an amazing power, characteristic of mathematics, from which it emerged, allowing to distinguish in the dimensions the elements, which have gone unnoticed. However, if a computer is used to process this model, then the mathematical formulation is automatically "transcribed" by a machine that is able to solve and calculate it. The use of computers enables convincing more experimenters of the need for a clear and precise formalization step. But, with the advent of computers, the change in the use of mathematical models, strictly speaking, is only quantitative in a more general sense, because mathematical modeling comes from a mathematical innovation of an essentially formal and logical type in a broad sense. In other words, in terms of a set of categories that serve to connect signs and express mathematical relations, cybernetic thought goes so far that in this context it represents a fundamental epistemological update that allows going beyond binarism, which is the bivalent logic that has reigned in science and philosophy since the time of Aristotle, in favor of polyvalent or even continuous logic (Ginters, 2019). The mathematical apparatus allows showing that after reaching a certain critical threshold, the system can choose a new adaptive behavior. When the target to be reached differs from the existing output performance, the system detects the difference and sends instructions to change the input in the desired direction (Youngblood, 2020; Perez, 2012).

Feedback is now a commonly used concept in almost every field. In a system, positive feedback will cause the system to diverge, oscillate and become unstable, while negative feedback will cause the system to converge and keep the system stable. In economics, this state is called equilibrium. In fact, this means that there is a negative feedback loop in the own system, and autonomous action brings it to equilibrium. The basis of the cybernetic analysis is system identification, control, evaluation, appropriate macroeconomic modeling, macroeconomic control and regulation, as well as optimal policy and welfare analysis (Aizstrauts et al., 2013). Due to the application of feedback to the system, the system is kept stable. In the economic field, such a state is called equilibrium. Equilibrium was introduced relatively early in the economic field, such as the equilibrium price determined by the action of supply and demand. Regardless of the mathematical form or intuition, this really means that there is a negative feedback loop in its own system, and autonomous action brings the system to equilibrium. With the development of the economy, everyone realized that the state of equilibrium known in the past is a static concept and may even be a long-term concept. With the advent of Keynesianism, everyone gradually showed a strong interest in the short-term adjustment of the economy. From comparative static analysis to dynamic analysis, it can be described in cybernetic language as follows: although the system itself has negative feedback, it can be autonomous in the long run (Medina, 2020). A steady state is reached, but due to external shocks, it often deviates from the steady state equation. Even when the shock is too great, the system will deviate from the original equilibrium point, meaning the system is likely to be stable within a certain range of motion.

The economic system is essentially the same as other dynamic systems that can be described by mathematical language. It has its own characteristics, such as stationary and dynamic, which determine the static position of the system and the trajectory of the reaction under certain conditions of external shocks. This can be seen from the evolution path of the classical theory of economic crisis. Initially, during the Great Depression, Fisher attributed the cause of the financial crisis to "over-indebtedness". Based on this, he proposed an explanation for the financial crisis and its consequences through the "debt-deflation" theory of recession. According to it, a company over-borrows at an early stage, and when the economy cannot achieve the expected growth or asset prices fall, it is forced to facilitate and sell assets due to the inability to repay the debts owed, or even go bankrupt and reorganize. The spread of this situation leads to a decrease in the growth rate of deposit money and the rate of money circulation, which, in turn, leads to a decrease in the general level of prices. At a constant nominal interest rate, deflation will increase the real interest rate of debt and increase the debt burden of enterprises, causing the economy to fall into a vicious cycle of "excessive debt-deflation-debt increase-deflation increase". When the economy enters a growth phase, corporate profitability increases, balance sheets improve, asset prices for companies and households rise, default risk decreases, and credit availability increases, which can expand investment (Dubberly and Pangaro, 2015; Atamanyuk et al., 2016). As a result, both the financial and economic systems enter a phase of growth. When the economy enters a downturn, corporate profitability deteriorates, balance sheets shrink, corporate and household assets decline substantially, default risk increases, credit opportunities decline, and output and profits decline as well (Miethlich et al., 2022).

The term "filtering" comes from communication theory, which is a method of extracting useful signals from received signals containing noise. The received signal corresponds to the observed random process, and the useful signal corresponds to the estimated random process. In technology, it deals with a series of signals, while in economic systems it deals with a sequence of time series. Due to the limitations of observation methods and sampling periods, the data often contains a lot of noise, which also needs to be estimated by filtering. There are two types of filtering methods: the time domain method and the frequency division method. The time domain is the real time domain and the frequency domain is the mathematical construct after mathematical transformation. Time domain analysis uses the time axis as coordinates to express the relationship of dynamic signals. Frequency domain analysis transforms the signal into a frequency axis as coordinates for an expression. The moving average method in the time domain can smooth out fluctuations over a period of time, while high-pass filtering or low-pass filtering in the frequency domain can filter out signals within a specific frequency range (Batrakov et al., 2012; Bondarenko and Gorbenko, 2018). Although the proposal of a filtration theory was not originally intended for the purposes of economics, the ideas of the general filtration theory and the corresponding methods of information processing play a very important reference role in economics. The general theory of filtering offers a set of methods for extracting and analyzing the state of information confusion. The information referred to in economics differs from the information in communications and control. However, they have very similar descriptions of the nature of the phenomenon reflected by the information (Arca and Mariategui, 2020; Mancilla, 2020).

There are two sources of system fluctuations. One is determined by the internal equation of the system, i.e., the fluctuation state is determined by positive feedback and negative feedback within the system. The other is an externally applied shock signal. The nature of the shock depends on the mathematical form. For example, a pulsed shock signal has strong differential characteristics, and this response decays exponentially with time. Economic volatility is also a fundamental issue in macroeconomics. The origin of volatility is a key issue. It is believed that economic volatility in itself is the greatest challenge to equilibrium theory. The values of each economic component in economic fluctuations are not the same, and the difference is also very large even in different countries. For example, in multiplicative economies, fluctuations in demand are the main macroeconomic factors, and supply factors are relatively stable, while in developing countries, economic fluctuations mainly occur on the supply side – investments. Economics basically divides the process of exogenous shocks into demand shocks, exogenous spending shocks, risk premium shocks, investment technology shocks, supply shocks, total factor productivity shocks, markup shocks, and policy shocks. In the basic DSGE (Dynamic Stochastic General Equilibrium) mainstream model developed on the basis of the RBC (real business-cycle) model, negative shocks are amplified through six transmission mechanisms: intertemporal substitution, uncertainty, irreversible investment, labor adaptation costs, concentration over time, and the role of financial markets (Helvey, 1971; Prokopenko et al., 2020).

Dynamic performance refers to the relationship between output and input during system operation, which can be expressed by a differential equation. If it is a discrete time series in economics, it can be expressed as a differential equation. In particular, the system deviates from the equilibrium point. To the characteristics of the movement back towards to the equilibrium point, the measurement indicators are the rate of adjustment, stability and overshoot (Babak et al., 2021). The static response characteristic refers to the state of the system in its equilibrium. Most of the time it refers to the steady-state error, i.e., fluctuations at the moment of equilibrium. In fact, this is a fundamental principle that is used in everyday life. In order to quickly adjust the system to the ideal equilibrium point, more feedback control can be applied to the manipulated variable so that the dynamic performance of the system is ideal, but this will overshoot even the bad static performance of the system, and even make it have poor static performance (Lorentz, 2002; Zaporozhets et al., 2020). The system deviates from the equilibrium point. Therefore, there is no need to apply excessively large and strong signals to immediately or directly bring the system to the desired state. If an excessive external force is applied, the system will deviate from stability. This concept was first proposed by Granville Stanley Hall in 1907 and by some engineers. Hall, comparing the behavior of political economists, believed that the reasonable operation of the law of supply and demand must allow fluctuations, and the operation of the system requires a certain degree of fluctuation, which is a very general principle.

Arithmetic or algebraic calculations are, by their very nature, fixed and deterministic. Obtaining certain data inevitably gives certain results. These results do not depend on anything other than the originally received data. And the question to be solved is or must be, moving towards a final solution of a number of infallible points, which are not subject to any change and modification. Having accepted this, one can easily imagine the possibility of constructing a mechanical part, which, taking a starting point in the data of the problem being solved, will continue its movement regularly, progressively, without any deviation towards the required solution, since these movements, no matter how complex they may seem, will be finite and deterministic. The thesis is that computation is mechanizable. For any calculation, it is possible to design a machine that can perform it (Shanken and Ascott, 2003; Ginters et al., 2010). Identifying computation with the operation of a machine is not, strictly speaking, demonstrable, but represents a kind of axiom that is justified by reflections on the concept of computation, and which, one might say, defines this concept. The well-known mathematician and economist Pierre Dupin summarizes the difference between analysis and mathematics with the following formula: "any calculation is not the analysis in itself" (Geipel, 2019). Calculus seems to represent the essence of mathematics. Thus, in its very extension, the notion of calculus retains certain vagueness. This also applies to the machine that has to perform these calculations.

The design of real-time self-regulating control systems for a planned economy was studied by the economist O. Lange, the cyberneticist V. Glushkov, as well as other Soviet cyberneticists in the 1960s. By that time, information technology was advanced enough to make computer-based economic planning possible. Cybernetics, developed simultaneously with the mathematical theory of communication by engineer K. Shannon, is part of the development of the so-called information theory, where it was determined that some economic systems are unstable without feedback, but if the economic system can be controlled, then the closed system can be stabilized due to feedback. In problems of optimal control of economic systems, many equilibrium states are saddle points. For a two-dimensional system, its structure is assumed to have two real eigenvalues, one positive and one negative. The straight line of the disequilibrium point, in which the eigenvector corresponding to the positive eigenvalue is located, is called the unstable arm, and the straight line of points is called the stabilizer arm. Influenced by social development, this era was indeed a period of development of "system analysis" and "systematization" in its applications, which are sometimes the most bizarre. However, it encourages strengthening contacts with cybernetics. It should be remembered that the mathematician N. Teodorescu was then an influential person in the field of applied mathematics. An entire school of cybernetics soon formed around him. In 1963, building on his interdisciplinary experience in applied mathematics dating back to the late 1940s, he published a work in Romanian that extolled the virtues of this new method of formalization, mathematical modeling. He defended the idea that cybernetic modeling deals with a new stage of mathematization and that it should be considered a break from the previous stage of biometrics (Geipel, 2019; Batrakov et al., 2016; Baylis, 1971).

In the same way, the pattern of N. Wiener (1961), the founder of cybernetics, includes the dynamic principle of feedback, without which the organism as such would not exist. This is why the form of the individual is a geometric abstraction that can only be understood paradoxically by refusing to separate its element from the efficacy of physical mechanisms. The mathematical rule that governs the functioning of an individual, contrary to vision, is produced by the activity of that organism, and not vice versa. Thus, it is not talking about translating a quantitative relation, but about expressing a qualitative model characterized by its dynamism, and then the difficulty lies in the algebraic form of this relation or individual model since the mathematical language is fixed by numerical values. A ratio, and even more so a regularity, is not so much a number as an operation, i.e., a logical relationship that a mathematical function can completely restore. Indeed, the logarithm embodies both the dynamic aspect of mathematics and the possibility of taking into account individual homeostasis. On the other hand, feedback is the process of stabilizing the initial state or control towards an acceptable state, which allows a particular system to respond to the action of an external element while maintaining itself. However, the trends of conservation and increase are paradoxical but complementary, and they manifest themselves in the cyclic causality of the logarithmic function. The logarithm causes the repetition of the same operation, a dynamism that preserves the logic, according to which a number raised to a certain power increases its value. Thus, through the apparent immobility of an algebraic function, which has nothing incompatible with the dynamism of its curve variations, mathematization contributes to mastering the mechanisms of the economy (Warburton, 1955).

4. CONCLUSIONS

Thus, models of economic cybernetics are always associated with an epistemological context, a set of scientific as well as literary discourses that make its conceptualization possible. Digital posthumanity is primarily a paradigm shift in relation to the development of computing and not a modification of the modern look by technology. The corresponding determinism is related to the fact that the dynamic model can be translated into the form of mathematical relations, where computer algorithms act as a means of digitizing the system by restoring processes that create order and a single sequence of ideas, as well as actions arising from them. From this, it follows that the system is equal to the lines of the program in its interactions with the exterior, which modifies it retroactively without violating its integrity. In economic cybernetics, one should not see the threat of dehumanization controlled by the economic system, which provides only for productivity and inhuman use of a person. As for the digitization of personality, it has nothing to do with virtual imitation and the totality of physical and mathematical processes that form it on a material basis, the infinite variability of which reveals a fundamentally plastic individual. The digital system is not dematerialized and its existence is internally connected with the existence of an infinitely open and developing body.

The mathematical difference between economic systems allows for determining their dynamic model, program. This operational image, in contrast to the digital aspect, captures the structure of a functional system, which can be translated into an algorithmic form in order to be transmitted, reproduced, or multiplied. Its effective interactions also reveal the plasticity of the material form, capable of radical transformation. Considering the system as a computer seems obvious, especially in regard to thinking, because automatism goes far beyond the mechanisms of the body alone. A computer is an information processing software structure, i.e., it works on the basis of a series of instructions that cause it to perform operations in a certain way and in a certain order, as indicated by its etymology. The connection with cybernetics is obvious, which explains why memory is understood as a certain sequence of ideas enveloping the nature of things outside the human body. Indeed, cybernetics has no absolute distinction between transmission types. By mathematizing what makes the notion of a model explicit, the system can be communicated in such a way that the hypothetical instrumental mechanism can rearrange the mechanical elements appropriately and is able to continue the processes that existed before.

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