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ASSESSMENT OF THE LEVEL OF ORDERLINESS OF THE ECONOMIC SYSTEM AND ITS INFLUENCE ON ADAPTIVE PROPERTIES (ON THE EXAMPLE OF THE ROSTOV REGION)

AVALIAÇÃO DO NÍVEL DE ORDENANÇA DO SISTEMA ECONÔMICO E SUA INFLUÊNCIA NAS PROPRIEDADES ADAPTATIVAS (TOMANDO COMO EXEMPLO A REGIÃO DE ROSTOV)

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Mikhail Grechko*
*Southern Federal University, Rostov-on-Don, Russia
Orcid: https://orcid.org/0000-0002-8196-3807
mvgrechko@inbox.ru

Georgy Gurdzhiev*
*Southern Federal University, Rostov-on-Don, Russia
Orcid: https://orcid.org/0009-0003-6496-8248
ggurdzhiev@sfedu.ru

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Abstract
This study evaluates the level of orderliness in the economic mesosystem of the Rostov region using entropy analysis. It explores the relationship between economic self-organization, adaptive properties, and the accumulation of knowledge regarding external environmental changes. A systemic and entropy-based approach is applied, integrating Shannon's entropy formula to quantify disorder in the economic system. The study assesses 81 major enterprises across 17 industries, analyzing their distribution patterns and adaptation potential. The entropy analysis shows that the Rostov mesosystem is 39% ordered, indicating a low level of economic adaptability. A hyperbolic distribution (Y = 1/X) of enterprises reveals an overreliance on wholesale trade, with underdeveloped manufacturing and service sectors. The study underscores that knowledge accumulation enhances adaptability and self-organization. Strategic recommendations include shifting towards knowledge-intensive industries, decentralized production, and increased technological integration. Improving adaptive management and reducing economic entropy are critical for sustainable regional economic development. This research provides a quantitative framework for assessing regional economic resilience and adaptability.

Keywords: Adaptive Management. Entropy Analysis. Orderliness of the Economic System.

Resumo
Este estudo avalia o nível de organização no mesossistema econômico da região de Rostov utilizando análise de entropia. Explora a relação entre auto-organização econômica, propriedades adaptativas e o acúmulo de conhecimento sobre mudanças ambientais externas. Uma abordagem sistêmica e baseada em entropia é aplicada, integrando a fórmula de entropia de Shannon para quantificar a desordem no sistema econômico. O estudo avalia 81 grandes empresas em 17 setores, analisando seus padrões de distribuição e potencial de adaptação. A análise de entropia mostra que o mesossistema de Rostov apresenta um nível de organização de 39%, indicando um baixo nível de adaptabilidade econômica. Uma distribuição hiperbólica (Y = 1/X) das empresas revela uma dependência excessiva do comércio atacadista, com setores de manufatura e serviços subdesenvolvidos. O estudo destaca que o acúmulo de conhecimento aumenta a adaptabilidade e a auto-organização. As recomendações estratégicas incluem a transição para indústrias intensivas em conhecimento, a produção descentralizada e o aumento da integração tecnológica. A melhoria da gestão adaptativa e a redução da entropia econômica são cruciais para o desenvolvimento econômico regional sustentável. Esta pesquisa fornece uma estrutura quantitativa para avaliar a resiliência e a adaptabilidade econômica regional.

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Mesosystem. Self-Organization of Economic Systems.

Palavras-chave: *Gestão Adaptativa. Análise de Entropia. Ordem do Sistema Econômico. Mesossistema. Auto-organização de Sistemas Econômicos.*

1 INTRODUCTION

As is well known, the development of economic systems is an uncertain and unstructured process, dependent on the ratio and distribution of probabilities regarding the state of the system, which are determined by the qualitative content of political, social, and economic factors. A quantitative measure for assessing the state of development of such macro-objects is entropy. Accordingly, the issue of evaluating the level of orderliness and its impact on the adaptive properties of an economic system is a complex scientific problem that requires understanding and describing intricate feedback mechanisms, emergent phenomena, and nonlinear processes that drive changes within these objects.

In the scientific domain, ideas related to studying development processes (or evolution) first emerged in the natural sciences, associated with the names of Jean-Baptiste Lamarck, Charles Darwin, and Alfred Wallace. Later, interest in evolution was noted among scholars in the social sciences, particularly in the works of the founders of the dialectical approach such as G.W.F. Hegel (2005), K. Marx (1960), V.I. Lenin (1969), G. Lukács (1991), E.V. Ilyenkov, G.S. Batishev (1997), and others. In the social sciences, there is a trend of applying the cognitive potential of the systems approach to represent the complex fluctuations of economic reality, as seen in the works of Michel Foucault, Talcott Parsons, Carl Menger (2005), and others.

In Russian scientific thought, interest in studying economic systems can be observed in the works of I.T. Pososhkov and N.D. Kondratiev (1991). There is also an application of systems theory elements in the development of entropy theory, particularly in the contributions of Ilya Prigogine (1985), Andrey Kolmogorov (1938), and Israel Gelfand (1999).

The methodological foundation for entropy in macro-systems is based on mathematical theory (Claude Shannon (1949), Jeremy England, A.Ya. Khinchin (1956)), supplemented by principles of theoretical physics (Rudolf Clausius, Walther Nernst, J. Willard Gibbs).

Several prominent scholars specialize in researching the problems of regional socio-economic systems and their components. Various aspects of these issues are explored in the works of S.B. Avdasheva, A.G. Granberg (2009), N.N. Kolosovsky, V.V. Kotilko, N.I. Larina, V.N. Lexin, T.G. Morozova, G.G. Muftiev, N.N. Nekrasov, B.B. Rodoman, N.M. Rozanova, and A.N. Shvetsov.

Today, some researchers have developed the perspective that entropy serves as a specific methodological tool for investigating deep socio-economic issues (Chepyuk, 2016). Entropy is applied both to assess the development level of regional systems and to evaluate individual economic entities (Krasnov et al., 2009).

Special attention should be given to the contributions of the "Don Scientific School", particularly reflected in the works of V.A. Dolyatovsky (2020) and V.N. Kurochkin (2023), such as in the assessment of the orderliness of economic systems to evaluate their efficiency and other related topics (Arkhipov et al., 2023; Grechko, 2023; Grechko & Gurdzhiev, 2025; Grechko & Kurochkin, 2015; Kurochkin et al., 2025).

However, it should be noted that some aspects, such as entropy assessment in regional economic systems, are still only partially reflected in the modern body of scientific knowledge, indicating the potential for filling these research gaps.

2 METHODOLOGY

The term "method" generally refers to a set of principles and cognitive tools that are employed for the study of a particular subject or problem. Methodologically, this study is based on the holistic approach, which enables an analysis of the object in its entirety. It also incorporates a systemic approach, supplemented by mathematical modeling, as well as a natural-physical approach used for the mathematical description of the regional economic system. Additionally, the study applies graphological and entropy analysis.

Furthermore, to ensure comprehensiveness across the diverse range of studies dedicated to various aspects of regional economic systems, the study adopts the "systemic economic theory paradigm", integrating elements of neoclassical, institutional, and evolutionary economic theories (Kleiner, 2022).

The proposed methodological framework is considered both necessary and sufficient, allowing for a comprehensive examination of the research problems and enabling the formulation of relevant conclusions and recommendations.

3 RESULTS

It is well known that the economy is a multifactorial phenomenon by nature. Various factors (elements) that make up the economic framework are interconnected and interact with one another, forming a complex system. For such a system to function effectively, it is essential to make high-quality adaptive management decisions.

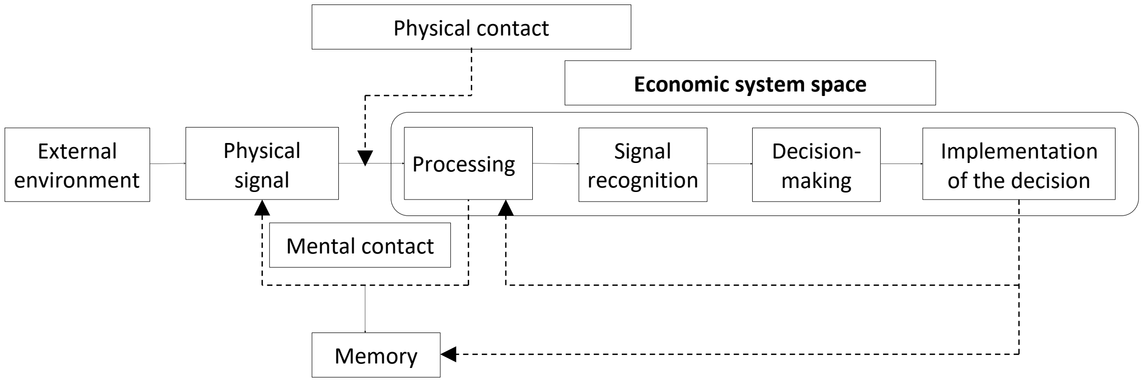
From a theoretical perspective, system management is the process of purposefully influencing controllable variables. At the core of any system lies its structure, whose elements are interconnected through a system-forming factor: the objective function. If a system lacks structure, it ceases to function. A fully deterministic structure allows for the most precise control over output parameters. However, in the real world, complex economic systems cannot be entirely deterministic due to the stochastic nature of their subsystems.

The evolutionary dynamics of socio-economic systems drive the transition from a stable, monotonous state to a dynamically changing (unstable) form. Under such conditions, determining the system's adaptive potential, as well as its individual properties and characteristics, becomes increasingly important.

Several authors (Dolyatovsky V.A., Ovchinnikov V.N., Kurochkin V.N., and Grechko M.V.) have demonstrated that adaptation involves the continuous accumulation of current knowledge, which is then embedded into new structures. In its most general form, the mechanism of system adaptation can be represented in the following schematic diagram (Figure 1).

Figure 1

Schematic diagram of the economic system adaptation mechanism



The economic system receives information from the external environment in the form of a physical signal (market capacity, product price, orderliness, etc.), after which the process of its processing begins. The quality of information processing is directly influenced by the level of knowledge in the system about the external environment, obtained in the form of a mental signal, i.e., based on existing experience and precedents. Subsequently, corresponding decisions are developed along with their implementation mechanism. Such changes lead to the emergence of new structures and an increase in the structural complexity of the object and corresponding entropy, which, in turn, promotes self-organization. Accordingly, the process of system evolution occurs through an increase in its functional complexity. Ultimately, the system adapts only through accumulated experience, i.e., through mental contact – a signal that undergoes reflection, experience, and precedent-based processing before information is analyzed.

The proposed scheme will be applied to assess the level of orderliness and its impact on the adaptation of the economic system. The object of study is the economic mesosystem of the Rostov region.

A mesosystem is an element of a more complex higher-order system characterized by high dimensionality, nonlinearity, the presence of many interacting subsystems, and significant uncertainty in behavior. In the socio-economic context, a mesosystem represents a linking level of organization between the micro-level (individual entities, firms) and the macro-level (national economy, global market), functioning in two forms: (1) territorial and (2) sectoral-industry organization and production-economic system operation.

It is characterized by a complex structure, including the interaction of many relatively autonomous yet interconnected agents (firms, organizations, communities). Unlike a microsystem, the behavior of a mesosystem cannot be described as a simple sum of the actions of individual participants. The interaction of agents generates emergent properties that are not reducible to the properties of individual components. Thus, the mesosystem possesses the necessary continuum for forming a mechanism that ensures the balance of the entire socio-economic macrosystem "vertically" due to its ability to link the settings of microeconomic business entities with the gradient of macroeconomic processes.

When characterizing the adaptation process of a mesosystem, its main mechanism – self-organization – should be highlighted. According to the research, self-organization is "the ability of a complex system to transform its characteristics without external influences, under the influence of its goals and internal potential" (Grechko & Kurochkin, 2015, p. 37). Ontologically, self-organization precedes the managed organization of the system and occurs from a state of maximum entropy (uncertainty) towards negentropy, acquiring new connections and restructuring its structure. In his work, V.A. Dolyatovsky (2020) states that "self-organization arises in non-equilibrium systems, often at the boundary of chaotic states" (p. 67).

The issue of self-organization is at the focus of representatives of political economy. For instance, B.V. Salikhov writes about self-organization in the context of the synergy of political-economic relations, which arise at a certain level of dissipation and are based on individual freedom of choice and decision-making (Salikhov & Salikhova, 2024). In the given scheme, the individual acts as (1) an "attractor" – a center of socio-economic interactions, (2) a (nano)form of creativity and innovation reproduction, and (3) an organic unity (integrator) of individual and collective aspects. It should not be forgotten that ultimately, it is the individual who makes economic decisions, relying on the optimal balance between market self-regulation and state planning.

Instrumentally, to assess the level of self-organization of the system, the following model can be used:

$$S(S,Q) = -\int \Delta H^{Q}\big(\varphi(Q)d(Q)\big) \qquad (1)$$

where:

S – the level of self-organization of the system;
Q – the distribution law of external influences on the system;
$\triangle H^Q$ – the change in the system's entropy level relative to its maximum values;
φ(Q) – probability density.

In the presented model, the key parameter is entropy (H). A decrease in entropy leads to an increase in the degree of organization of the system's elements, meaning its orderliness. The orderliness of an economic system is understood as the value (R), which determines the extent of the system's (S) deviation from an equilibrium state. The degree of system orderliness is directly influenced by several characteristics, including the level of structural complexity, the number of elements (subsystems), their type and interconnections, external environmental factors, management quality, adaptive potential, and others. In our case, one of the significant indicators determining the level of system orderliness is entropy (H). To assess the level of orderliness in a complex economic system, the following well-known formula can be used:

$$R = 1 - \frac{H_{real}}{H_{max}} \qquad (2)$$

where:

R – a value characterizing the degree of orderliness of the system;
H_{real} – the actual level of entropy in the examined system;
H_{max} – the maximum possible level of entropy in the examined system.
It is worth noting that in a fully deterministic system, R = 1, and H_{real} = 0. In a completely disordered system R = 0, and $H_{real} = H_{max}$.

The entropy level in a system can be determined as the sum of the products of the probabilities of different system states and the logarithms of these probabilities. This sum must be taken with a negative sign (-), meaning with an inverse sign. For the mathematical description of the entropy process, Claude Shannon's formula is used:

$$H = -\sum_{i=1}^{n} P_i log_2 P_i \qquad (3)$$

where:

H – entropy;

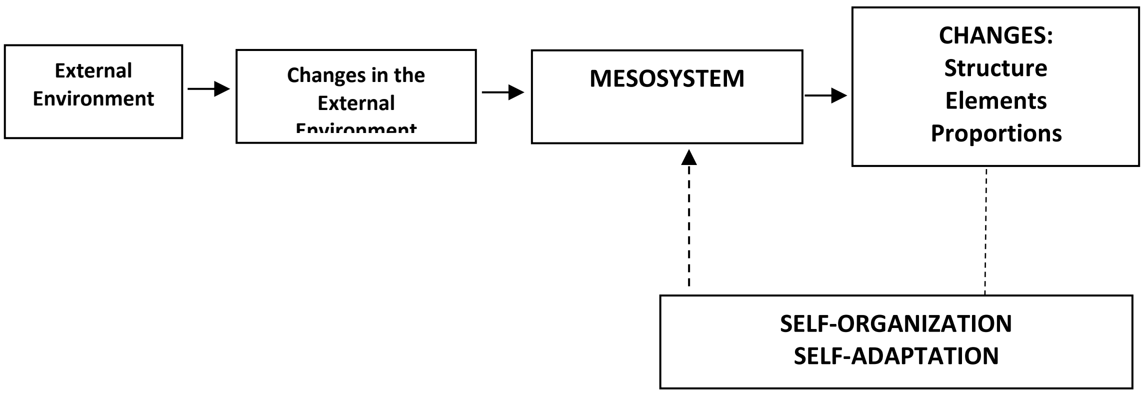
P_i – the probability of the occurrence of the i-th event or state of the economic system.

In this formula, entropy is defined as a conditional value, which therefore requires specification and refinement for socio-economic macro-objects. The proposed model makes it possible to measure the degree of uncertainty in the economic system and can be used to assess its development efficiency and guide subsequent adjustments.

Self-organization of the system leads to an increase in its orderliness and, consequently, to greater manageability. Such systems, relying on the mechanism of self-organization, are capable of transforming their internal structure under the influence of external environmental factors and, as a result, adapting to changes (Figure 2).

Figure 2

Adaptation of the mesosystem to environmental changes based on self-organization



In the process of self-organization, the number of elements (e.g., the number of economic entities) within the mesosystem changes, thereby transforming its structure. Each element of the mesosystem can be characterized by at least two parameters:

X – the subject (enterprise) or value

Y – the rank (order) within the general population U.

It is important to note that the internal entropy of the mesosystem and the entropy of external environmental factors are interconnected. If the mesosystem contains a certain number of statistically significant categories of entities (n), then the maximum entropy, necessary to determine the orderliness of the system, can be calculated as:

$$H_{max} \approx log_2 n \qquad (4)$$

Accordingly, our formula for calculating the empirical distribution of entropy in the economic mesosystem also changes:

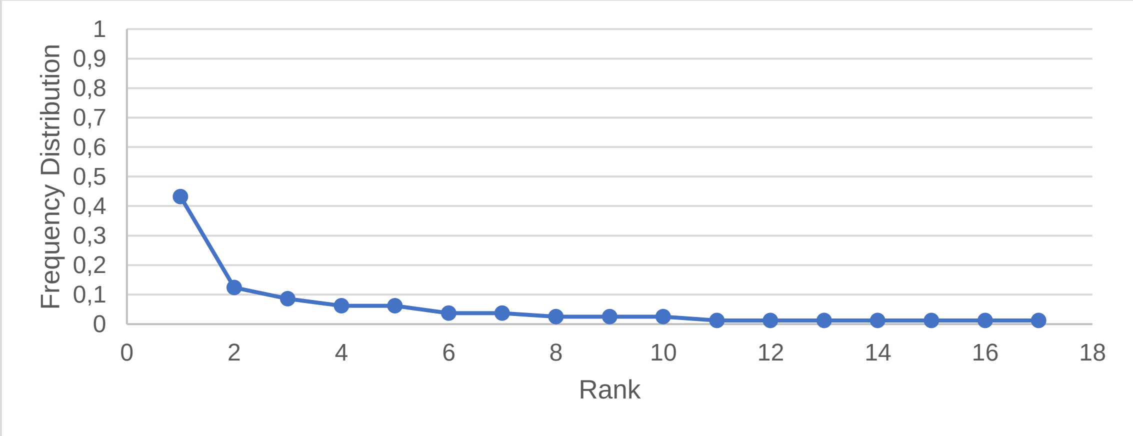
$$H_{real} = -\sum_{i=1}^{n} P_i log_2 P_i \qquad (5)$$

By comparing the calculated values of H_{real} and H_{max} we can determine the degree of deviation of the distribution from the desired state △H. Empirically, △H indicates the level of adaptation of the mesosystem to external influences, which depends on the level of accumulated knowledge, i.e., according to Figure 1, on the amount of physical information gathered and its subsequent processing.

At the same time, the overall state of the economic system can be reduced to a few dominant parameters (relevant macro-variables). In our case, one such relevant macro-variable, which characterizes the number of statistically significant entities (n), is the number of leading enterprises that act as drivers of economic development in the Rostov region. These enterprises are included in the list of the 250 largest companies in the Southern Federal District (SFD) as of 2023 (Ekspert Yug, 2024). There are 81 such enterprises, distributed across 17 industries according to a hyperbolic distribution law (Figure 3), following the form: Y = 1/X. This distribution can be characterized as relatively stable.

Figure 3

Distribution curve of enterprise types in the mesosystem of the Rostov Region by ranks



where:

Wholesale Trade – 35 units

Mechanical Engineering and Metal Processing – 10 units

Retail Trade – 7 units

Food Industry – 5 units

Agro-Industrial Complex (AIC) – 5 units

Ferrous and Non-Ferrous Metallurgy – 3 units

Construction – 3 units

Transport and Communication – 2 units

Chemical Industry – 2 units

Coal Industry – 2 units

Oil and Gas Industry – 1 unit

Light Industry – 1 unit

Finance – 1 unit

Tobacco Industry – 1 unit

Energy Sector – 1 unit

Service Companies – 1 unit

Housing and Utilities Sector (HUS) – 1 unit

The obtained data indicate that wholesale trade enterprises dominate the economy of the Rostov region. Specifically, 42 out of 81 enterprises (more than half) belong to the trade sector (wholesale and retail). At the same time, processing industries and the service sector are underdeveloped, as reflected by a declining trend in both the number of enterprise types and their total number.

This situation necessitates strategic changes aimed at increasing the share of manufacturing and knowledge-intensive industries within the mesosystem structure. In particular, the following strategic measures are recommended:

- Shifting production priorities from mass production to robotic, personalized manufacturing, tailored to the region's specific development needs.
- Localizing and developing production facilities closer to the end consumer to enhance accessibility and efficiency.
- Expanding integration in the development of VR/AR-based solutions, in combination with other advanced technologies such as artificial intelligence, the Internet of Things (IoT), and blockchain.
- Establishing continuous collaboration between universities, businesses, and government institutions, to accelerate the practical application of research and innovations within the mesosystem.

Next, an entropy analysis will be conducted to determine the orderliness of the economic mesosystem.

To begin, the maximum entropy level (Hmax) must be determined. We assume that all events are equally probable, meaning that the probability (P) is equal to 1/17, where 17 represents the number of industry categories with equal likelihood. In this case, the maximum entropy is calculated as:

$H_{max} \approx \log_2 17 \approx 4{,}0875$.

From this, we determine the actual entropy H_{real}, of the studied system. To find Hreal, we first calculate the probabilities for each enterprise category. Since the total number of enterprises is 81, the probabilities are determined as the ratio of enterprises in each of the 17 categories to the total number: $P_1 = 35/81$, $P_2 = 10/81$. Substituting these probability values into Formula 5, we obtain the empirical entropy distribution, yielding a real entropy value of $H_{real} \approx 2{,}499$.

Based on the obtained H_{max} and H_{real} we calculate the degree of deviation from the desired state:

$$\Delta H = H_{max} - H_{real} = 4{,}0875 - 2{,}499 = 1{,}5885 \quad (6)$$

The obtained value essentially characterizes the level of adaptation of the mesosystem to external influences, which depends on the accumulated physical information and its subsequent processing. In other words, the economic mesosystem possesses adaptive potential, which requires adjustments aimed at increasing its capacity.

The values of H_{max} and H_{real} also allow us to calculate the orderliness of the economic mesosystem of the Rostov region. Applying Formula 2, we obtain: 1 – (2,499/4,0875) = 0,39. This means that the system is 39% ordered, which is considered a low indicator. Accordingly, strategic changes are needed to improve the quality of management processes, which should be implemented based on adaptation principles.

The entropy level in economic systems of any scale, by itself, is not very informative. If the entropy level is high, it is necessary to analyze the state of the system being studied.

In a stagnant or inertial system, a high level of entropy indicates a significant decline in the orderliness of elements (i.e., a decrease in the quality of management processes) and suggests that the system is in a regression phase (Phase III).

A high level of entropy is also characteristic of systems in the genesis phase (Phase I) due to the constant increase in structural complexity. Conversely, the lowest entropy levels are typical for systems at their peak development (Phase II) as well as fully deterministic systems.

To clarify this, consider a complex, evolutionarily developing system (S1) with a finite countable number of states A1, A2, …, Ai, …, Ak and corresponding evolutionary trajectories SA1, SA2, …, SAi, …, SAk. According to entropy theory, the measure of uncertainty in system S1 is represented by entropy H(A).

Entropy H(A) equals zero in only one case: when the system's dynamics are fully predictable with absolute certainty. In all other cases, entropy is positive, and the greater the system's uncertainty (disorder), the higher the entropy value H(A).

Ultimately, the orderliness of an economic system can be reduced to the level of knowledge we possess about it. Thus, the adaptive properties of the system and its structural transformation (self-organization) are significantly influenced by the amount of accumulated knowledge about external environmental changes. The accumulated knowledge (i.e., precedents) is inversely proportional to the amount of information the system requires for adaptation.

The growth of structural complexity (dE) in an economic system will inevitably be accompanied by an increase in internal (structural) entropy (dH) and will depend on the ratio of dI – the current level of accumulated knowledge within the system – to M, the newly acquired knowledge:

$$dE = \frac{M}{dI} \quad (7)$$

According to the previously presented schematic adaptation mechanism of a complex system, the knowledge obtained through interactions with the external environment undergoes evaluation and processing and is then fixed in the form of structural changes. As a result, new structures emerge within the system, meaning that the system adapts according to the selected mechanism.

4 CONCLUSION

The study conducted has led to the following conclusions:

Firstly, a schematic model of the economic system adaptation mechanism (Figure 1) has been presented, outlining the logic of assessing the level of orderliness and its impact on the adaptation of the economic mesosystem of the Rostov region.

Secondly, a distribution curve of enterprise types within the mesosystem of the Rostov region by rank has been constructed. A total of 81 economic entities within the economic mesosystem of the Rostov region, which are among the 250 largest companies in the Southern Federal District as of 2023, are distributed across 17 industries in accordance with hyperbolic distribution law (Figure 3), following the equation Y = 1/X. This distribution can be characterized as relatively stable.

Thirdly, an entropy analysis has been conducted to determine the orderliness of the economic mesosystem. The results demonstrate that the economic system of the Rostov region is 39% ordered, which is considered a relatively low indicator. Accordingly, strategic changes are needed to enhance the quality of management processes, which should be implemented based on adaptation principles.

Fourthly, it has been substantiated that the adaptive properties of the system and its structural transformation (self-organization) are significantly influenced by the amount of accumulated knowledge about external environmental changes. The accumulated knowledge (precedents) is inversely proportional to the amount of information required by the system for adaptation. The relationship between the structural complexity of the economic system and the level of structural entropy and accumulated/acquired knowledge has been established.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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