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Economics of Digital Ecosystems

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Abstract: This paper examines a new approach to defining digital ecosystems. Within the digital economy of ecosystems, competition is eliminated, and organizations form unions and alliances in order to work together and cooperate to reach a set goal. This means a digital ecosystem can be viewed as a complex environment in which organizations without any hard ties operate. Digital ecosystems differ from traditional ecosystems in many ways. The business organization of the latter is based on management decision making by people. This paper presents theoretical foundations for developing digital ecosystems based on a literary review. Based on the logic of scientific search using the keywords "ecosystem" and "biological ecosystem", the commonality of the properties of the digital ecosystem and the biological ecosystem is shown. The aim of the study is to identify common characteristics in biological, economic and digital ecosystems in order to substantiate the possibility of using the same approaches for research and modeling of such systems. A definition of a digital ecosystem is proposed by the authors which points out the main features of this kind of system and highlights the dominant role of modern digital technologies in the formation of the digital ecosystem. The paper looks at the distinctive features of digital ecosystems and characteristics similar to the characteristics of biological ecosystems, such as ecosystem participants, presence of limiting impacts, lack of vertical hierarchical communication. The developed model can be used to model digital ecosystems. The authors believe that the emergence of a trend in the transformation of ecosystems in the direction of expanding the collaboration of economic agents is reasonable. At the same time, digitalization helps to replace competition with collaboration. The paper finishes with a discussion of the obtained results and a plan for further research.

Keywords: digital ecosystems; economics of ecosystems; network and platform connections

1. Introduction

Taking into account the concept of open innovation dynamics at the economic ecosystem, it could be agreed with [1] that digital technologies are being adopted at a faster pace than previous waves of innovation with the great impact on administration and business, as well as the consumer behavior and social interactions. The modern ecosystems have gotten a significant impact from open global markets, rapid transportation, and the high-speed communications noted by M. Porter [2], who defined clusters as critical masses in one place of linked industries and institutions—from suppliers to universities to government agencies—that enjoy unusual competitive success in a particular field.

In recent years, there is a significant technological acceleration, with various sectors having been affected [3]. The new bio-technological wave risks having even greater effects on the traditional and advanced tertiary sectors. New generation cumulative self-learning models and algorithms are able to transform machine tools, through computer technologies and nanotechnologies, into increasingly flexible and ductile instruments and means of production.

The results of the research presented in the work [4] show that the leaders and owners of agri-food enterprises consider innovation activity as one of many methods of increasing profits, and therefore their attitude to the organization of innovation activity is based on the perception of innovation activity as being a traditional form of commercial activity, which dramatically reduces its effectiveness. The traditional perception of innovation activity, as follows from the survey, consists in a rigid separation of the internal and external environment of the enterprise. The managers and owners of enterprises believe that innovative activity can take place within the enterprise based solely on internal resources, primarily intellectual ones. The study made it possible to draw a conclusion about the applicability of the theory of endogenous development to describe the processes of development of the entrepreneurial ecosystem of rural areas. Indeed, the potential for the development of an entrepreneurial ecosystem is largely determined by the internal conditions of rural areas, and therefore, support for rural entrepreneurs should be aimed not so much towards creating external favorable factors as towards the formation of institutional, economic and social attributes of the entrepreneurial ecosystem.

It could be shown that the modern ecosystems are mainly founded on the basis of informational flows being generated as a result of intellectual labor. The paper [5] researched the new society of metadata and considered a contribution of various Italian scientists from the point of view of the paradigms of mass intellectuality, immaterial labor and cognitive capitalism, which have been developed by Lazzarato, Marazzi, Negri, Vercellone and Virno since the 1990s. A pioneering work by Romano Alquati [6,7] was published in Quaderni Rossi (the first journal of Italian operaismo) and introduced the notion of valorizing information as a conceptual bridge between the definition of information in cybernetics and the notion of living labor. During a 'militant inquiry' at the Olivetti computer factory in Ivrea, Alquati mapped and described the conditions of labor in front of new cybernetic apparatuses. Alquati noted that at the beginning of the industrial age capitalism started to exploit human bodies for their mechanical energy, but soon the most important value was determined by the series of creative acts, measurements and decisions that workers constantly had to perform. Alquati refers to information as all the innovative micro-decisions that workers have to make throughout the production process. Marazzi while considering digital capitalism [8] notes that in large scale software corporations, the fixed capital is presented under the form of a so-called "cognitive machine". Scientific contributions should be taken into account during the theoretical development of economic ecosystems that subsequently give way to digital ecosystems.

In connection with the spread of digital ecosystems in various areas of the economy (such as banks, business and production areas), it is necessary to clarify the modern conceptual apparatus, which was created on the basis of a wide range of works by scientists engaged in various fields of knowledge, such as biology, philosophy, sociology and economics.

The widespread interest of researchers in the term "ecosystem" is due to the variety of approaches available for examining and modeling it. The definition of ecosystem has been used to describe biological systems [9] and economical systems [9–11]. Recently, the use of this term has grown in frequency, and it has entered into the lexicon of technological [8,11] and commercial companies and business areas [12]. This paper synthesizes existing research in order to identify the key mechanisms underlying the occurrence, dynamics and structure of ecosystems. Our goal is to identify what ecosystems represent, find how they differ from other associations of organizations like clusters, incubators [13], platforms [14] and networks as well as to determine the properties of ecosystems and the unique mechanisms of how they are created. The concept of an "ecosystem" can include any of the above subsystems as its elements; therefore, the principles of managing clusters, incubators and networks are similar. A classification of ecosystems is given, and economical ecosystems are compared to biological ecosystems [15–18], thereby identifying the common characteristics of both types of ecosystems, such as the structure of the participants, the mechanisms of creation and the principles of operation. The similarity of the characteristics of biological and digital ecosystems, as well as their management without any human participation (forces of nature in the first case or using artificial intelligence in the second), makes it possible to use the same approaches for describing and modeling them. The correctness of the various approaches to describing ecosystems was studied in regards to affiliation to it and regarding its structure [19]. It was then concluded that study of ecosystems should begin by looking at the members belonging to them.

The widespread adoption of digital technologies has changed the economy and society. One of the directions for the development of modern ecosystems is the use of a single digital environment. Digital platforms are widespread in various sectors of the economy, such as banking, trade and logistics. Based on an analysis of scientific literature on digital ecosystems [20–24], this paper offers a definition of a digital ecosystem which operates on the basis of digital platforms used for interaction between the members of ecosystems. Based on the conducted comparative analysis of the characteristics of digital and biological ecosystems, it was concluded that the structure of the members, the creation mechanisms and operation principles as well as the conditions for the ecosystem to interact with the outside are all similar. The main feature distinguishing digital ecosystems from traditional ones is identified as the automated management decision making. The existing approaches to typing digital ecosystems are studied. Processes of cooperation and mutual assistance play an important role in the functioning of ecosystems, regardless of the status and capabilities of their participants. The authors believe that the emergence of a trend in the transformation of ecosystems in the direction of expanding the collaboration of economic agents is reasonable. At the same time, digitalization helps to replace competition between the actors of the digital ecosystem with collaboration.

2. Methods

2.1. Research Theory and Methodology

The term "ecosystem" is borrowed from biology and was first brought into circulation in 1930 by Arthur Tansley to define any group of cohabiting organisms and their environment [9]. His limited (reductionist) view of the ecosystem as a semblance of an ecological system was further expanded in studies [15,16]. Application of the concept of biological systems to social systems [15] is based on the proposal to adapt the principles of nature for the development of social systems. Knowledge acquired by humans should not be used to conquer nature, but instead to build sustainable communities, designed by using an analogy with wildlife. By developing knowledge that gives man power over nature, it is possible to adapt the economy to the principles copied from natural communities. The use of these principles in the design of an ecological-economic system can improve life at the individual, social and ecological levels.

The usefulness of applying the term "ecosystem" to biological as well as any socio-economic systems is based on the similarity of structure, functions, operational principles and conditions for interactions and resource exchange with the outside. At the same time, the interrelation between the elements of economic ecosystems is characterized by a large "mobility" and flexibility in comparison to biological ecosystems. The term "ecosystem" was used by [11] in 1993 for the theory of business ecosystems, after which it started to be widely used in the scientific and business world.

James Moore defined a business ecosystem as "an economic community supported by a foundation of interacting organizations and individuals—the organisms of the business world." [25,26]. In later publications, Moore specified the term "economic ecosystem" in terms of its constituent elements and included in its make-up the business community made up of the firm itself, its consumers, suppliers, market facilitators, channels for movements of goods, owners and other stakeholders, government and non-government organizations as well as competitors [17]. Using the example of biological systems which consume natural resources such as water, air and sunlight, Moore asserted that business ecosystems are born and operate due to the interest of consumers, capital and investment growth.

We can agree with the researchers of this vast topic on the general methodological approach applied to solving the problem of systematizing the conceptual apparatus of digital ecosystems [18,19].

The logic of scientific research used in this study can be represented in the form of a diagram (Figure 1). At the first stage, the study of concepts is carried out, which includes the choice of the object of research (in the specific case—Ecosystems), the systematization of the conceptual apparatus (in the specific case—Digital Ecosystem) and the definition of the purpose of the scientific review. Scientific research is based on the selection of articles matching keywords and main characteristics. Classification of research objects according to their basic properties allows them to be grouped according to different attributes. The scientific search ends with the analysis of scientific articles related to the object of research and the choice of research directions that go beyond the scope of this. In general, this logic of scientific research can be taken as the basis for further research in the field of a broader object of research—the transformation of economic relations in the context of the new technological order of Industry 4.0.

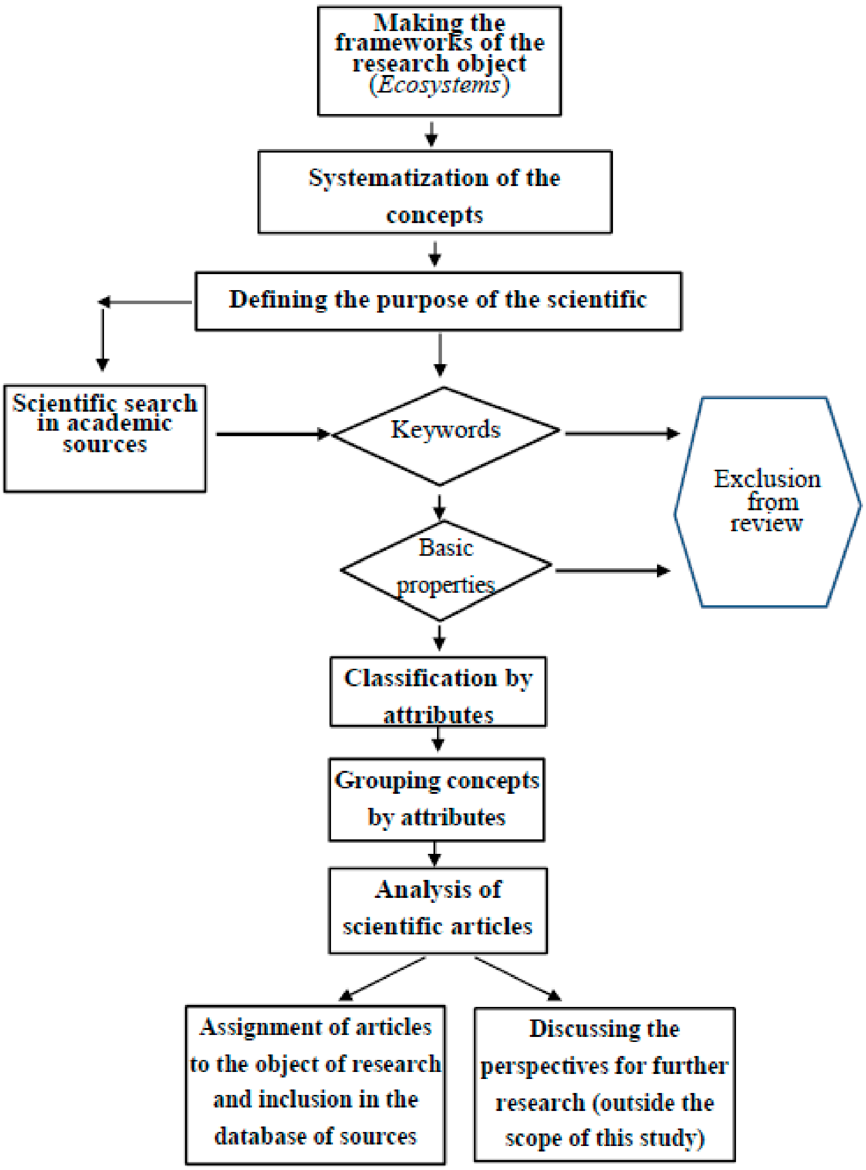

Figure 1. The logic of scientific research in order to systematize the conceptual apparatus.

2.2. Theoretical Fundamentals

The definition of ecosystems given by [11] was correct for the 1990s and was subsequently improved by Ron Adner [20]. His refinement of the term highlighted the special role of certain conditions under which an ecosystem transforms into an economic ecosystem (as can be seen in Figure 2). Such conditions are the economic interrelations, competition between organizations and the presence of stakeholders who are directly or indirectly interested in the development of the economic ecosystem.

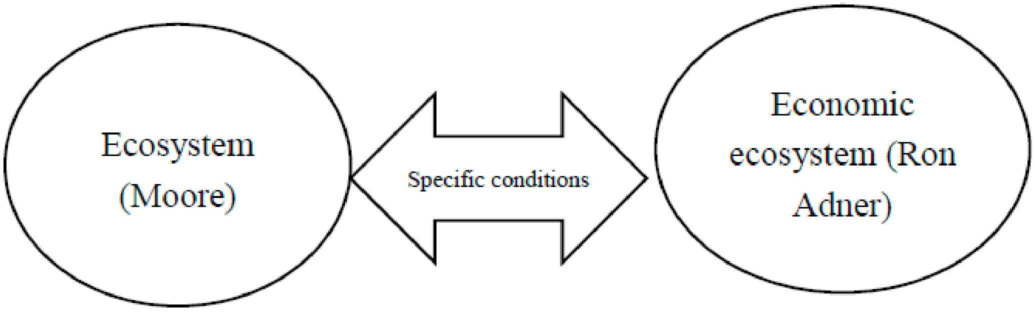

Figure 2. Interrelation of definitions for an ecosystem developed by Moore and Ron Adner.

Nowadays, the term "ecosystem" is widely used in publications relating to environmental sciences. This term can be found mentioned in IT publications [21]. However, an interpretation of the definition of "ecosystem" is not given in any philosophical dictionary. This gives reason to conclude that this term is not currently used to characterize the general principles of being and cognition or the general laws of movement and development in nature, society and human thought.

An analysis of multiple publications by domestic and foreign researchers showed that there is no single approach to defining the term "ecosystem".

Some researchers define an ecosystem as a number of interconnected organizations [10,22,23]. Other researchers, such as [24,27], consider business ecosystems to be networks or coalitions of weakly linked organizations, corporations or small and medium businesses, all of which could be developing around a common technological base or platform.

G.B Kleiner [28] believes that an ecosystem performs the function of a natural covering for clusters, platforms, networks and business incubators to interact, similar to the main role of an enterprise in the operation of divisions, departments and business processes. According to Kleiner, an ecosystem is an expansion of a business as a new form of organization of real economic activity. At the same time, despite the several differences in the approaches, the majority of researchers are in agreement that a business ecosystem (entrepreneurial ecosystem) is a "network population" of organizations interacting with each other and the outside world, adapting to changes, and competing among each other [29,30].

Depending on how strong a relationship is and the level of competition between the organizations making up an ecosystem, Ron Adner [20] differentiates between two kinds of ecosystems: an ecosystem as affiliation, or an ecosystem as structure. An ecosystem as affiliation is presented as a number of enterprises joined by network and platform connections. An ecosystem as structure is an ecosystem as a configuration of activity and is determined by the value proposition. In our view however, it is not entirely correct to talk about two kinds of ecosystems in this way. There are instead two approaches to viewing ecosystems. In the first case, an ecosystem is looked at in terms of the affiliation of interconnected organizations with it. The collaboration between the members of an ecosystem from various economic sectors, as well as their cooperation, is based on breaking traditional industry borders. This ecosystem contributes to the organization of mutually beneficial activities, the emergence of competitive advantages and the growth of potential to create "product value" and "company value" (the potential for symbiotic relationships in productive ecosystems). The increased number of members of an ecosystem leads to a growth in the likelihood of chance interactions between partners, which can open new interactions and combinations, in turn, increasing the overall system value creation.

The second approach is based on studying the structure of an ecosystem, and member interaction is based on the selection of members of the ecosystem necessary for interactions when obtaining the value proposition, and planning the actions of its materialization. The possibility of conflicts occurring in an ecosystem as a structure can arise when members are not satisfied with their positions. Furthermore, different members can have differing views on the value proposition, or the analysis for the value proposition can be conducted in various ways. An ecosystem should take into account not only diverging interests, but also diverging prospects (expected value creation and determining the cost of third parties).

In parallel with the emergence of the definition of "ecosystem", such economic objects as clusters, platforms, networks, innovation incubators and so on, drew the attention of the researchers. The versatility of the concept "ecosystem" helps with the claim that the concept of an ecosystem can include any of the subsystems listed above as its elements. Definitions are given and the key features of the above mentioned economic objects are identified below in order to prove our claim.

The main feature of a cluster is the close functional relationship and the geographical proximity of the enterprises of the cluster. The cluster can develop both in time and in space. To a large extent, clusters are formed from industrial enterprises and to a lesser extent from the service industry. It could be considered that this depends on the level of competition in each respective industry. In industrial clusters, the interaction of enterprises is based on their future, mutually beneficial partnership. Meanwhile, in clusters relating to the service industry, for example, in a tourism cluster, there is strong competition, and the formation of such a cluster can be explained by the temporary benefits of the partnerships [31].

A platform is an integration of, as a rule, technological or other infrastructural environments, on the foundation of which businesses operate and interact, and such a platform is naturally supportive. A platform can develop in time but not in space. As an example, widely popular digital platforms as intermediaries have provided for direct interactions between companies, thanks to which costs have been reduced [14] and the act of tracking goods and services has been simplified and accelerated [32]. According to K. Schwab, when using digital platforms, the marginal cost of production for each additional product, good or service tends to zero, providing transformative results for business and society [33].

A network is understood as the geographic distribution of a business. Thanks to the economies of scale and centralized management, the performance of networks is improving. Cost reductions are achieved in networks due to their high level of specialization and labor cooperation. Networks have been most popular in the area of goods circulation due to their creation of successful model industries. Network development occurs in time and space. Notably, the geographic expansion of the retail network reached its peak at the start of the 21st century [34]. Thanks to the distributed structure and the independence of its member businesses from each other, the closure of one or several of the businesses has virtually no effect on the operation of the overall industry. The mobility and changeability of a network business enables it to adapt to any changing conditions outside of the business.

Incubators, including innovation incubators and business incubators [13], are created to solve specific problems or to achieve the realization of certain projects. Their structure, which can be temporarily created, joins structured entities and businesses in order to get the greatest result when pursuing a set goal. The businesses interact in a mutually beneficial partnership and not against one another. Such an alliance does not imply development in time and space.

The identified key features of the economic objects listed above allows us to conclude that such business alliances like clusters, networks and incubators are not outside the definition of an ecosystem, with the exception of platforms, which are the basis for the operation and interaction of the businesses included in the ecosystem.

In order to create a classification which most fully reflects the essence of an ecosystem, it is necessary to look at its properties:

Properties of an ecosystem:

1. localized in space and continued (unlimited) existence in time [35]. An ecosystem functions within a limited area, whose borders do not change significantly with time. This localized existence can continue for an unlimited time and depends on a number of factors including economic factors, technological factors, social factors, informational factors and so on.
2. internal consistency, geographic proximity and close ties between the components and members of the ecosystem lead to a high level of integrity and to an internal balance in an ecosystem that is capable of suppressing internal turbulent processes [20];
3. adaptability, including the structural isomorphism of the ecosystem [35] and its ability to change and adjust to the conditions of the outside environment in order to preserve the system as a whole. An ecosystem is capable of including new members, whose roles can change with time in order to support its sustainability. The structure of the ecosystem is susceptible to flexible changes thanks to the constant interaction between all members cooperating with each other. An ecosystem can take multiple forms depending on the number of members, whose interaction is often based on the complementarity of goods, technologies and services. The significant number of the existing members of an ecosystem and attraction of new members increases the dynamism of the system, whose success improves the performance for all of the members of the system without exception [10];
4. systematic non-hierarchical coordination of members; the institutional approach is used when forming an ecosystem [25]. However, there is no clearly defined algorithm for this, and the hierarchy of the ecosystem members is not regulated. The fact that there is a clear leader who initiated the formation of the ecosystem does not imply their monitoring role in the future. The coordination and cooperation of the members of the ecosystem are necessary conditions for its proper function;
5. versatility—there is not only a multiplicity of partners in an ecosystem but also a selection of complex partner relationships which cannot be broken down into the bilateral interaction of both parties 34]. Each member of the ecosystem can influence the direction of the latter's growth, although the influence of larger members is stronger than that of the smaller members. The formation of alliances between the members can change the balance of power in an ecosystem regarding key strategic issues;
6. homeostasis—in an ecosystem as with any open socio-economic system, resources are exchanged between members as well as between its subsystems in order to maintain internal balance [35]. Likewise, the ecosystem actively exchanges its resources with its environment and, thus, maintains balance with it.

Classification of ecosystems:

1. by territorial feature (regional, city and municipal socio-economic ecosystems),
2. by scale (micro ecosystem, meso ecosystem, macro ecosystem, global ecosystem),
3. by industry feature (industry, interindustry);
4. by platform used (digital, technological).
5. by type [35] (objects (enterprise, region, government), environments (infrastructure, federal law, investment climate), processes (business processes of the enterprise, spread of information, logistics), projects (start-ups, release of new products, reorganization of an enterprise)).

The pervasive spread of digital technologies has affected the trajectory of development for the economy and society and has caused drastic changes to people's lives. One of the possible development paths for business ecosystems and a main condition for their development is the use of a single digital environment, which has brought about a transformation of the traditional economic sectors and a creation of new goods and services markets. The level of digital technology embodied (applied) in Russia varies according to the economic sector. The most widespread digital platforms on the markets which characterize the close interaction of suppliers and consumers are in the area of commodities circulation, including retail and logistics, where high-speed machining of big data takes place, since transactions occur in real time. The formation of digital ecosystems (DES) was largely to do with the popularity and stability of digital platforms.

Scientific literature gives various definitions of a digital ecosystem, defining it as a convergence of three networks: IT networks, social networks and knowledge networks [26], as a domain of a cluster environment that includes biological, economic and digital types [36]. Another definition mentions the features of DES such as its self-organization, scalability and sustainability [37]. Separate researchers [38] point out the static part of DES represented by digital technologies and people, as well as the dynamic component of interactions which shape the conduct. DES consist of interacting organizations which are digitally connected to each other, attached as modules (blocks) and are not managed by any vertical hierarchy of power [39]. Digital ecosystems, represented by multiple enterprises that are joined by network and platform connections, fit better under the description "ecosystem as affiliation" rather than "ecosystem as structure" [20].

The usefulness of applying the term "ecosystem" to biological as well as any socio-economic systems is based on the similarity of structure, functions, operational principles and conditions for interactions and resource exchange with the outside.

3. Results

It could be shown that a digital ecosystem is a self-organizing, sustainable system with digital platforms at the base, which form a single information environment where the members of the ecosystem can interact when no hard functional ties between them exist.

The definition put forward distinguishes the leading role of modern digital technologies in forming a digital ecosystem. The base of a digital ecosystem is the diverse platform technologies which form a single information environment for all members: society, business and government. The development of platform technologies contributes to the scaling up of digital ecosystems, which are beyond the business environment and B2B and B2C relationships. The digital environment is used to connect members, exchange information and resources, organize processes and coordinate objectives.

One of the most important features of a DES is its ability to self-organize and the lack of a managing or supervising member of the ecosystem. Thus, all members are autonomous, with management decisions being based on their collective interaction. The partnership and distributed efforts of the members are aimed at the success of the DES. The large number of diverse goals and objectives which motivate the members of the DES and the complex connections between them, which are based on the use of digital technologies to give information, exchange resources and coordinate activities are what give the ecosystem its typical features as a collective intelligence system [37] capable of innovations, entrepreneurship and collective decision making, which often turns out better than decision making by a single member. The specific features of digital platforms are studied by [40] while describing the nature of Google and Facebook.

Sustainability is the ability of a DES to change and adapt to the conditions of the outside environment as a whole as well as to continue operating during changes to the members or their respective roles. The sustainability of a DES is based on the possibility of flexible changes to the structure of the ecosystem, the continuous interaction of members and their collaboration and cooperation [41]. The cooperation is considered by [42] in terms of the willingness of citizens to collaborate.

The properties of digital ecosystems listed above allow us to assert that they display the same properties as biological ecosystems. The characteristics of biological and digital ecosystems are compared below (Table 1).

Table 1. Comparison of characteristics of biological and digital ecosystems [15,25,43–45].

Characteristic	Biological Ecosystem	Digital Ecosystem
External environment	Natural habitat	Human society, digital environment
Members of ecosystem	Biological organisms, objects of non-living nature	Enterprises, organizations, clients
Relationship between system members	Exchange of nutrients and energy, symbiosis	Exchange of information and resources, cooperation, collaboration
Vertical hierarchy relationship	none	none
Internal mechanism for development of ecosystem	Natural selection	Cooperation, collaboration
Limiting effect	Natural conditions, resources	Social norms, the law, resources
Roles and interactions of members	Clearly defined	Clearly defined
Rate of change	Low	High

It can be concluded that the ecosystems examined are "communities" of living and non-living subjects interacting with one another. The overwhelming majority of the characteristics of biological and digital ecosystems are similar to each other, which is evidence of the similarity of the structure of members, creation mechanisms and principles of operation and conditions for interacting with the outside environment. However, the relationship between elements in a digital ecosystem is distinguished by its wide diversity in comparison to biological ecosystems.

The main difference between digital ecosystems and traditional ecosystems is that the organization of business in the latter is based on management decision making by a human. Meanwhile, management decision making in digital ecosystems is for the most part automated and carried out without human participation, thanks to the diverse tools which exist such as artificial intelligence, computer vision and so on. The complex structure of digital ecosystems, the large number of their members, the diverse external influences and internal fluctuations are only some of the factors which a person cannot fully take into account, thus leading to a possibly suboptimal or faulty decision. For this reason, automated decision making is a distinctive feature of digital ecosystems.

Digital ecosystems can be classified according to various reasons: by scale, functionality, evolution, level of centralization, and so on. Using the approach for the functional classification of ecosystems put forth by [37], three main types of digital ecosystems can be distinguished:

- Process-oriented digital ecosystems, whose main goal is to support the creation processes of innovations and venture capital enterprises using special services and specific tools;
- Resource-oriented ecosystems, which have a predominant focus on searching for material or non-material resources necessary for carrying out the activities of companies or for the realization of business projects;
- Product-oriented ecosystems, which are predominantly focused on releasing new products or services onto the market.

It could be proved, that this kind of classification is legitimate; however, it is more suitable for defining the subsystems of a digital ecosystem characterized by a high level of integration and with strong links between the object (organizational), environment, process and project (innovation) subsystems of a digital ecosystem [46].

The mathematical description of the laws for the interaction of members of a digital ecosystem are highly controversial. This is primarily due to the properties of a digital ecosystem, specifically the systematic non-hierarchical coordination of members and multilateralism. Within market interactions, three main groups of members can be distinguished which are differentiated according to the nature of their interests and advantages:

Producers of the final good and its constituent elements. This group represents enterprises and organizations which produce goods and provide services to other members of the digital ecosystem, and also produce goods and provide services necessary for the final good. The quantitative expression for the interests of the representatives of this group can be differentiated; however, the most universal quantitative attribute can be considered to be profit;

Consumers of the final good. This group represents consumers and clients of the producers of the final good. It should be noted that the representatives of this group within a digital ecosystem can also take on the role of final good producers. The quantitative expression of the interests of this group's representatives can be expressed by the relative satisfaction coefficients. The number of coefficients for consumer satisfaction is very high in marketing. In this case, for universalization, this indicator can be presented as a rank variable reflecting the degree to which consumer expectations from the consumption of some product or service are met by its actual performance;

Administrator of a digital ecosystem. Despite the fact that a digital ecosystem can be formed for the interaction of the groups of members described above, it is formed in a legal framework. This determines the laws and rules of the interaction. Furthermore, the infrastructure of a digital ecosystem can be formed forcibly, and the role of "architect" and, subsequently, administrator can be taken by the government or large corporate members of the ecosystem, for which the infrastructure itself and the act of managing it is the generated good. This group does not have a distinct vector of interests; therefore, it is advisable to reflect the influence of the variable impact parameters of the representatives of this group of members of the digital ecosystem on the interests of the other groups of members. This influence can be quantitatively expressed by the control level indicator, which reflects the degree of controllability of the digital ecosystem by its administrators.

Thus, for the quantitative indicators whose interaction reflects the mathematical laws of operation for the digital ecosystem, we can distinguish the profits of enterprises and producers of the final good (X), satisfaction coefficient of consumers of the final good (Y), and control level indicator of the system by the administrator (Z). In order to model this, it is supposed that these indicators are standardized and are measured in relative units of measurement.

First off, the dialectic nature of the interaction between the administrator of a digital ecosystem and the consumers of the final good should be noted. The increment for the control parameter constantly reduces the level of adaptability of the digital ecosystem, reduces the rate of decision making, while also increasing the use of resources connected to supporting the activities of the administrator. These processes lead to a reduced assortment, lower adaptability of interaction and increase the cost of the final good. In this way, a change in the level of control the administrator has on the system can be determined inversely to the satisfaction coefficient of the consumers of the final good and is expressed by the following differential equation:

$$\frac{dz_t}{dt} = -\beta * y_t \quad (1)$$

where:

z_t—is the standardized control level indicator of the system by the administrator for period t;
y_t—is the standardized satisfaction coefficient of consumers of the final good for period t;
β—elasticity coefficient of the administrative control over satisfaction of consumers of the final good. This coefficient reflects the degree of sensitivity of the administration system towards consumer satisfaction.

The interaction of producers and consumers of the final good is dynamically non-linear. On the one hand, the increased level of consumer satisfaction mediates profit growth in a relatively subsequent period due to the demand increment provided by the spread of information regarding satisfaction fluctuations. However, since the satisfaction level is based on the expectations of consumers, this indicator is overestimated in the subsequent period, which in turn can reduce the level of satisfaction. This interaction can be expressed through the integration of trigonometric functions in the differential equation described below:

$$\frac{dx_t}{dt} = \alpha * \left(y_t + b * \sin\left(\frac{\pi x_t}{2a}\right)\right) \quad (2)$$

where:

x_t—is the standardized profit of the producers of the final good in period t;
α—is the profit elasticity coefficient of the producers of the final good for consumer satisfaction. This coefficient reflects the sensitivity of the market towards consumer satisfaction;
b—is the coefficient of consumer satisfaction elasticity to retrospective fluctuations of satisfaction. This indicator reflects the degree of transformation of consumer expectations under the influence of their current satisfaction level;
a—is the indicator for the rate of transformation of consumer expectations. This indicator reflects how frequently consumer expectations transform in a period of time. The comparatively small values of this indicator reflect the low level of consumer loyalty, while high values of this indicator show the relative maturity of the consumers and their readiness to develop a digital ecosystem together with the producers of the final good.

The change of satisfaction of consumers of the final good in turn can be linearly dependent on all three of the highlighted indicators. The increment of the standardized profit is directly related to changes of the standardized satisfaction coefficient of consumers of the final good. At the same time, the increment of the standardized system control level by the administrator also contributes to increased satisfaction since the level of consumer expectations decreases, which significantly increases the conversion of changes. Thus, this dependence can be expressed through the following differential equation:

$$\frac{dy_t}{dt} = x_t - y_t + z_t. \quad (3)$$

The formulated system of differential equations allows us to form multiple unstable trajectories, which are chaotic in nature. Small-scale disturbances of this system can be transformed exponentially. In this way, this system has a dynamic chaos, and a strange attractor is formed. The architecture of the formed attractor is identical to the architecture of the modified Chua chaotic attractor [33]. The solution to the system of equations presented for various combinations of coefficient values forms multiple unstable trajectories. A few particular examples for the linear changes of values of t from 0 to 100 are given, forming 40,000 observations. The base values of indicators x_t, y_t and z_t equal 1, 1 and 0, respectively. The base values of coefficients β, α, b and t are equal to 14.286, 10.82, 0.11 and 1.3, respectively.

As can be seen (Figure 3), through insignificant fluctuations of the coefficients in the described system of differential equations, the trajectory change of indicators is significantly transformed. At the same time, in accordance with the transformation vectors, the following laws of operation for the described system can be mentioned:

- The profit of the producers of the final good is inversely related to the system level control indicator. Consequently, in order for profit to grow within a digital ecosystem, it is necessary to liberalize it through a systematic decrease of the control level of the administrator;
- The satisfaction level of consumers of the final good has well-balanced fluctuations, which determines the possibility of obtaining a different level of satisfaction at identical profit values. In turn, this is due to the dynamics of consumer expectations which are universalized in a digital ecosystem due to the saturation of the information environment and the accessibility of communication channels.

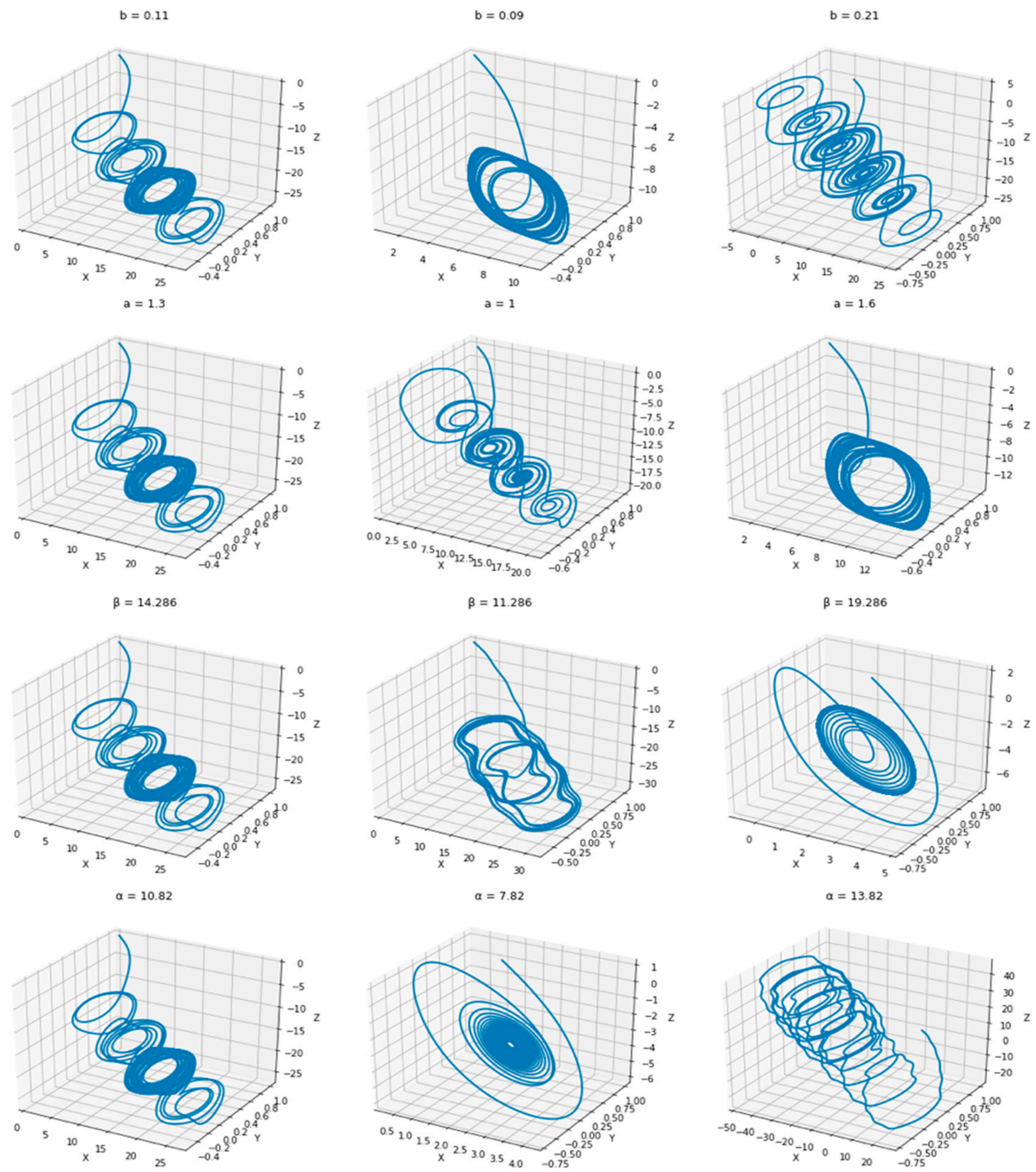

Figure 3. Graphic interpretation of changes to the parameters of an attractor.

Thus, using the system of differential equations formed, the economic laws of a digital ecosystem were mathematically formalized.

From a theoretical point of view, although all the aforementioned multiscroll chaotic attractors could be confirmed via numerical simulation and/or circuit implementation, it is more desirable to theoretically prove the existence of these visible n-scroll chaotic attractors. The considered n-scroll chaotic attractor is generated from the unfolded Chua's circuit. The Chua multiscroll chaotic attractor could have many practical applications in such fields as digital and secure communications, synchronous prediction, random bit generation, information systems and so on. In general, multiscroll chaotic attractors are verified by numerical simulations [47] and could be implemented by simulating the communications between participants of the digital ecosystems.

Such an approach allows us to consider the correlation between various participants of the digital ecosystems (householders, governments and businesses). It is important to study correlation between digital ecosystems (economics of ecosystems), network and platform connections and human sustainable development, corporate social responsibility, corporate governance and business performance, since these are valuable targets for any business and any economy these days. It is important to take into account that both social responsibility and corporate social responsibility are considered to be major constituents of ethical (business) theories and important components in promoting a strong balance in the climate system as a whole, as they play key roles in sustainability maintenance [48].

According to [49] Digital Business Ecosystems (DBE), a known focus area in the currently matured e-commerce era is the use of (software) bots or agents to replace less efficient human interfaces. The definition DBE include the innovation component (science, technology and policy) and digital technology (digital ecosystem itself). However, an important feature such as the collaboration of all digital ecosystem participants should be taken into account. This paper contributes to the development of the theory of ecosystems from the position of researching approaches to defining the term "ecosystem". The conducted analysis proves that the universality of the "ecosystem" concept makes it possible to include within an ecosystem business incubators, networks, and clusters as its constituent elements with the exception of platforms, which are the basis for the operation and interaction of enterprises within the ecosystem.

A digital ecosystem with its affiliated numerous enterprises, joined by network and platform connections [50], is an ecosystem as affiliation thanks to the lack of hard functional links between the members. The collaboration and cooperation between the members of the ecosystem from various economic sectors is built by breaking traditional sector borders. This mutually beneficial activity leads to the emergence of competitive advantages and potential growth of the ecosystem so it can create "product value" and "company value".

The paper gives a new definition of digital ecosystem as a self-organizing stable system, which is based on digital platforms forming a single information environment for the interaction between members of the ecosystem without any hard linking. The definition presented distinguishes two characteristic features of digital ecosystems. The first is its ability to self-organize and the lack of a leading or managing member of the ecosystem; however, there is often a leading (main) actor in the ecosystem around which it is built. The second is its sustainability, which is understood as the ability of the digital ecosystem to change and adapt to conditions of the outside environment in order to preserve the system as a whole, as well as to continue operating should there be changes to the members or their respective roles.

The research conducted allows us to conclude that biological and digital ecosystems are "communities" of living and non-living subjects that have similar characteristics. The main difference between biological and digital ecosystems is the wide variety of interconnections between members of a digital ecosystem. The widespread use of digital platforms and tools such as artificial intelligence and computer vision distinguish digital ecosystems from traditional ecosystems thanks to the use of automated management decision making.

The developed mathematical model makes it possible to determine the dynamics of changes in the effectiveness of the interaction of the main participants in the digital ecosystem, provided there is no impact from the external environment. Thus, this model can be used within the framework of modeling digital ecosystems, as well as for the purpose of modeling the reactions of participants in digital ecosystems within the given conditions. Such tasks are the subject of study by anthropologists, sociologists and other specialists in the field of social engineering. The proposed model can serve as a basis for quantification of the results of modeling complex digital ecosystems, which determines its practical significance.

The results obtained can be useful in conceptualizing new approaches to studying and modeling digital ecosystems, which are similar to biological ecosystems. The practical value lies in the formation of the main reference point for building digital ecosystems, consisting of the organization of the interaction and cooperation of participants, which replaces the competitive struggle.

4. Discussion

The initial theoretical positions on ecosystems were laid out in 1930 by [9]. Later on, this concept gained wide use not only in biological systems but also in any kind of socio-economic system. Both of these types of systems have similar structures, functions, principles of operation, and conditions for interaction and exchange of resources with the outside environment. It could be considered that an ecosystem is a broader concept than networks, clusters and business incubators. Any of these unions of businesses, integration of infrastructure environments and design structures are in essence a special case of an ecosystem.

Further development of the theory on ecosystems took different directions, one of which was the formation of digital ecosystems related to the popularity of digital platforms. The leading role of modern digital technologies in forming a single information environment for all members has been highlighted: society, business and government, as well as for the development of digital ecosystems.

The paper presented a new view of comparing biological and digital ecosystems. It could be shown that the similarity of the characteristics of biological and digital ecosystems, as well as their management without any human participation (forces of nature in the first case or using artificial intelligence in the second), makes it possible to use the same approaches for describing and modeling them.

Further research of digital ecosystems can focus on logistics ecosystems, which are based on the use of digital platforms. In this case, according to K. Schwab [33] the marginal cost of services tends to zero, opening up big possibilities for the commodity circulation sphere.

In general, this logic of scientific research can be taken as the basis for further research in the field of a broader object of research—the transformation of economic relations in the context of the new technological order of Industry 4.0.

The prospects for examining the interaction of economic agents on the basis of collaboration remained outside the scope of this study.

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