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The development of Kondratieff's theory of long waves: the place of the AI economy humanization in the 'competencies-innovations-markets' model

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The motivation to conduct this study is related to the uncertainty of the impact of the AI economy on the economic cycle and the need to unlock the potential of Industry 4.0 in stabilizing the global economic system amid a series of crises. The article discusses the fundamental issues of the emergence of a new theory related to the evolution of Kondratieff waves in the context of modern drivers of long-term economic development (MANBRIC technologies), taking into account the acceleration of the development of innovations and competencies. The spiraling dynamics of the co-development of competencies and the expansion of new markets are shown, which makes it possible to transform the decline phase of the Kondratieff wave into a similar linear process of maintaining economic growth rates close to the existing ones. As a result, based on the authors' model "competencies-innovations-markets", it is proved that subject to humanization, the AI economy allows the reduction of the cyclical nature of the world economic system. The main idea of the article is to smooth out Kondratieff's long waves due to the humanization of the AI economy.

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Introduction

Although the phenomenon of long waves has long been discussed in the economic, social, and political sciences, there is still a very controversial debate about how to provide empirical evidence for fluctuations such as regular cycles in economic time series.

Since the first publications of N. Kondratieff and up to the present time, quite a lot of explanations for the observed long waves have been proposed (Modelski, 2001). However, in recent decades, the concept of technological innovation has become the most popular explanation for the dynamics of the Kondratieff waves. The first theses of this concept were laid by Kondratieff himself, mentioning that during the recession of long waves, important discoveries in technologies are made, which are actively introduced already at the stage of the next rise. This thesis was developed by J. Schumpeter, who studied the effect of the 'innovation cluster' on wave dynamics. Later, these studies were heavily criticized by S. Kuznets. In the 1980s, G. Mensch presented substantial empirical data on the approximately 50-year pace of introducing major innovations into the market. Van Duyin and A. Kleinknecht (Kleinknecht, 1990) added a significant amount of additional empirical data to support the Kondratieff–Schumpeter hypothesis.

The phenomena of significant acceleration of scientific and technological development due to the introduction of technologies of the sixth wave of innovation raise the question of changing the nature of Kondratieff's long waves, shaping new economic laws describing the relationship of competencies, technologies, innovations, and economic dynamics. The modern wave of the economic cycle takes place in the economics of artificial intelligence (AI) which raises a research question about the impact of the development of the AI economy on the economic cycle. The meaning of the question posed is whether it supports economic growth or increases the risks of an economic crisis.

Therefore, the article aims to develop the theoretical concept of Kondratieff–Schumpeter in terms of the role of innovation and structural technological changes in wave dynamics. The authors set themselves the task of aspiring to identify the relationships between economic laws to justify the change in the nature of long waves and medium and short-term business cycles. The main research hypothesis is related to the thesis that the traditional economic cycle 'growth of markets—reduction of markets' in the modern high-tech economy is transformed into a linear process of growth due to the accumulation of sufficient reserves of competencies (intellectual resources) to create prerequisites for new drivers of growth of markets and competencies.

The originality of this paper is due to the fact that it is for the first time that the methodology of the Theory of economic cycles in the model of Kondratieff's long waves is used to describe the prospects for humanization of the economy under the conditions of a new technological mode: Industry 4.0. The paper's novelty is due to the description of the social implications of the formation of the AI economy and to the formation of a humanistic approach to its development, which implies the gradual development of Industry 4.0 with a slow rate and step-by-step automatization, which will allow achieving advantages in the form of social adaptation to the technological progress.

Theory

To create the main approaches to the description of long-term economic growth, first of all, it is necessary to study certain patterns that occur in the process of economic activity. These patterns are expressed by *basic economic laws.*

The first group includes laws that have a direct impact on the formation of the competitiveness of products: the law of value, the law of demand, the law of supply, and the law of increasing marginal costs. *The second group* includes laws that do not directly affect the competitiveness of products but are interconnected with the production processes and consumer behavior, which are decisive factors in market competition. This includes laws that affect competitiveness through the laws of the first group: the law of decreasing productivity of factors of production, the law of decreasing returns, the law of diminishing marginal utility, the law of optimal consumer behavior, and the law of comparative advantage.

The listed laws can be represented in the form of a block diagram that reflects the influence of economic laws on the competitiveness of products and services, as well as the complex relationship and interaction of laws.

Existing economic laws need to be adapted to the current situation, which requires the search for new sources of economic growth. The block diagram of economic laws presented in Fig. 1 illustrates their impact and relationship with the management of economic growth and development, the preservation, maintenance, and improvement of which is the primary task of any organization, industry, and country.

The system of managing the growth and development of the economy should include new economic laws, tools, and mechanisms. Moreover, the existing laws for the most part rely on psychological and retrospective observations and do not take

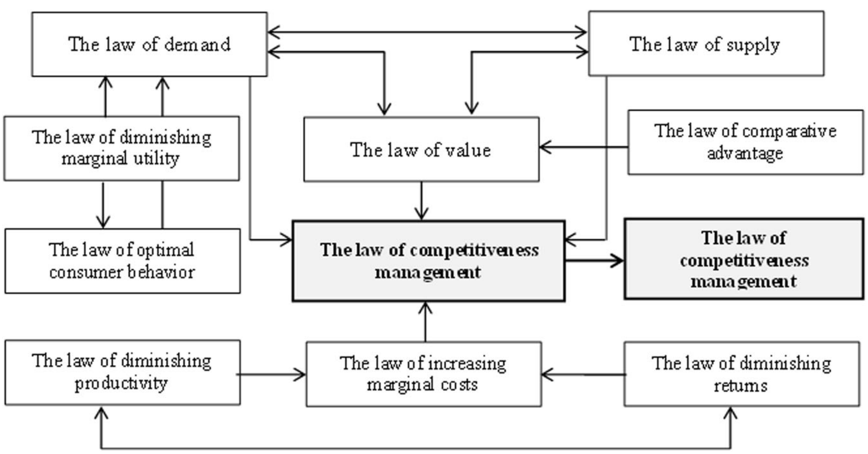

Fig. 1 The relationship of economic laws. The block diagram of economic laws.

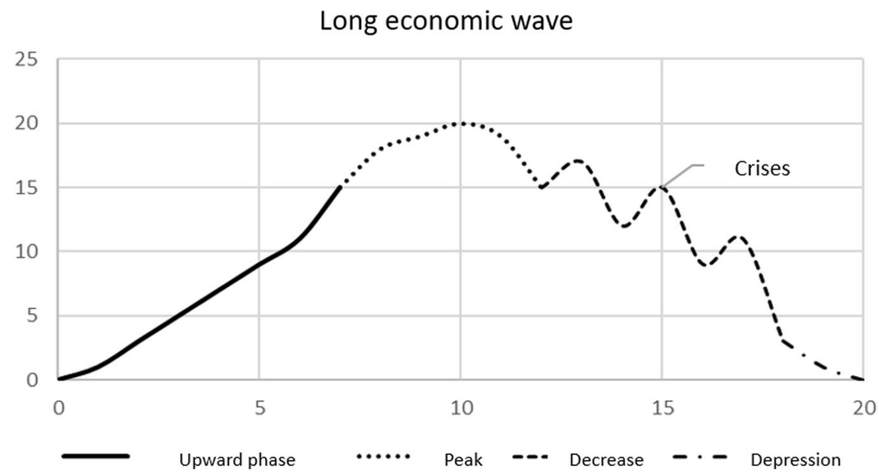

Fig. 2 Long economic wave of Kondratieff. Quite well-known structure on Kondratieff's waves.

into account the factors of negative impact, while *the new ones developed in the digital economy must be described and substantiated strictly mathematically* (Mandych and Bykova, 2021).

So, in our opinion, the management of economic growth at the level of organizations and industries should be synchronized with the development of competencies. In this regard, the management of economic growth and development is closely related to *the economic law of interaction between the development of competencies and consumer markets*, which states that mutual development occurs along a spiral trajectory.

Analysis of economic development demonstrates the cyclical nature of its development at the macro and micro levels, and therefore it is advisable to determine the range of active management of competitiveness at two levels, directly related and have some features that should consider several economic laws and factors such as the cyclical development of innovation, product, organizations, economies of scale, etc.

Currently, there are short-, medium- and long-term economic cycles (Devezas and Corredine, 2002; Isaic et al., 2019), among which the most well-known are:

- J. Kitchin's cycles, cycles of movement of inventory with a period of 2–4 years (Matheus and Nguyen-Huu, 2018);
- the 7–12-year industrial cycles of K. Jouglard, who analyzed the fluctuations in interest rates and prices in France, Great Britain, and the United States, found their coincidence with the investment cycles, which in turn initiate changes in GNP, inflation, and employment (Grinin et al.. 2010);
- Kuznets's cycles, or long swings, have the largest amplitude of 20 years (Bosserelle, 2017);
- N. Kondratieff's waves (40–60 years). N. D. Kondratieff created the economic theory of long waves, large cycles of conjuncture (Grable, 2019). In our opinion, N. Kondratieff's cycles are of the greatest interest and relevance. In addition, as will be described below, it is these cycles that can be best interconnected with the development of scientific and technological progress and the cyclical nature of innovations.

The structure of N. Kondratieff's waves is quite well-known (Fig. 2) and includes a growth stage (recovery and expansion phases) lasting about 20–30 years, and a downward stage (recession and depression phases)—a period of long-term predominance of low economic conditions, lasting about 20 years, when, despite temporary upswings, low business activity dominates, as a result of which the world ecxonomy develops unstably, temporarily falling into deep crises (Fig. 3).

The latest iterations of the crisis have shown that the 'technological method' that worked for many decades to overcome the recession no longer gives the desired effect, and fundamentally new mechanisms are needed to overcome crises in order to avoid military scenarios of restarting economic systems, since the tools that currently exist and are actively used in world practice (stimulating demand and creating new jobs, supporting small businesses, improving the institutional environment, improving the system of technical regulation in order to strengthen incentives for enterprises to improve the technological level of their products; modernizing the system of regulation in financial markets, which will ensure the reliability of the financial services sector, etc.) are becoming less effective.

In this regard, new tools and measures should be put on the agenda: financial measures and tools that encourage economic actors to create radical innovations, and tools that contribute to the accumulation of human capital in various fields, building competencies in various fields and building radical competencies that will lead to a breakthrough in science, new discoveries, and achievements, establishing a technology platform for the development and manufacture of radically new products and services to meet the future needs of the market capable of putting the economy on the path of advanced development.

Our research shows (Chursin and Vlasov, 2016; Chursin and Tyulin, 2018) that the relationship between the level of unique competencies and the emergence of new needs and markets leads to a spiral cycle that provides innovative economic growth. Let us consider how modern interconnected processes of accelerated development of competencies, the introduction of radical innovations and the creation of new consumer markets are reflected in the development of the economy, described by Kondratieff's long economic waves.

Despite the fact that AI economy has received a lot of attention in the existing literature, there is no unambiguous interpretation of AI economy as a factor of cyclical economic systems in the academic community. Fleischer et al. (2021), Matilda Bez and Chesbrough (2020), and Prahl and Goh (2021) indicate that the AI economy amplifies the risks of socio-economic crises, as (1) automation increases unemployment and intensifies competition in the labor market and (2) the spread of Industry 4.0 technologies increases social tension due to the digital divide: the uneven distribution of technology, infrastructure and digital technologies in society.

In contrast, Bobanović (2021), De Nicola et al. (2020), Merola (2022), and Pan and Yang (2021) note the significant contribution

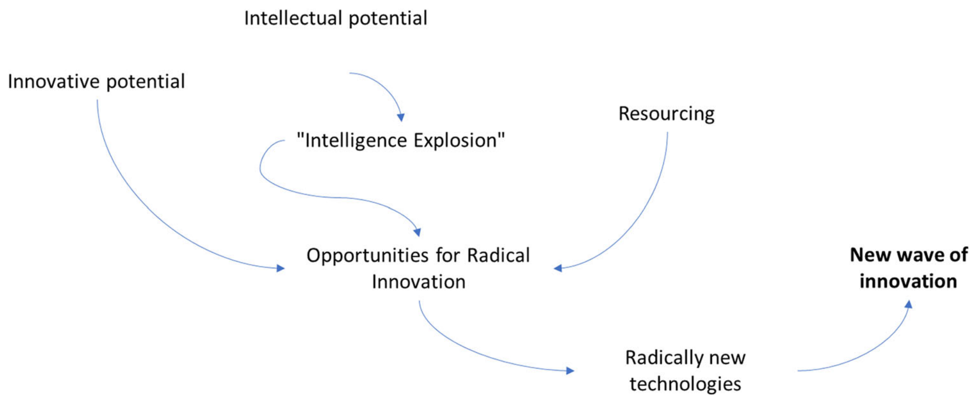

Fig. 3 The relationship between the growth of the intellectual and innovative capacity of the world community with a change in waves of innovation. Scheme of innovation formation.

of AI economy to the acceleration of economic growth. Humanization as an ethical and socially oriented development of the AI economy is addressed in the publications of DeFilippis et al. (2022), Ivey (2022), Morimoto (2022), and Seufert et al. (2022).

The performed in-depth context analysis of the existing literature has shown that large attention is paid to the issue of the social consequence of the transition to the AI economy. Liu-Thompkins et al. (2022) substantiate the existence of artificial empathy in marketing interactions and the need to bridge the human–AI gap in affective and social customer experience. Lew and Walther (2022) assess the international practice of communication between humans or chatbots and AI and determine social scripts and expectancy violations.

Kim et al. (2022) present a critical view of the set problem in the form "man vs. machine", substantiating the negative response of human to an AI newscaster and the role of social presence. Hong (2022) proposes the treatment of the set problem from the aspect of "with great power comes great responsibility", proving the necessity to study social roles and the power dynamics in human–AI interactions. Formosa (2021) describes the Robot Autonomy vs. Human Autonomy antagonism, rethinking the essence of social robots, AI, and the nature of autonomy. Bankins and Formosa (2020) formulate a view of the considered problem from the aspect of "when AI meets PC", substantiating the negative implications of workplace social robots and a human–robot psychological contract.

The uncertainty (inconsistency) of the interpretation of AI economy as a factor of the cyclical nature of economic systems is a research gap, to fill which this article defines the place of AI economy in the "competence-innovation-markets" model. The place of this paper in the literature is at the intersection of the technocratic approach to the development of the economy and the concept of the social market economy. This paper is to bridge the gap between them through the development of a humanistic approach to the development of the AI economy.

Methods and models

With the increase in the unique competencies of high-tech enterprises, new innovative technologies are formed in the economy. The laws of development of high-tech enterprises contribute to the fact that the achievements of fundamental science give rise to applied developments that form the basis of innovative technologies. Emerging innovative technologies are embodied in the creation of new products or services.

We believe that as a result of the spiral cycle, the traditional economic cycle 'growth of markets—reduction of market' in the modern high-tech economy is transformed into a linear process of growth due to the accumulation of sufficient reserves of competencies (intellectual resources) to create prerequisites for new drivers of growth of markets and competencies.

Let us consider the issues of constructing methods and models for revealing the impact of modern changes connected with the acceleration of the development of competencies and the change in basic technologies on economic growth, the dynamics of which are described by Kondratieff's long economic waves. To do this, consider the formalization of the proposed logic.

This economic model can be described using several dynamic parameters that will change over time. The most important condition for the development of these parameters is their constant dependence*:* We will consider the following parameters:

– the level of technological competence;
– the level of innovative technologies;
– the level of consumer potential of products;
– the level of market development.

The development of innovative technologies by high-tech industries is based on the currently available average level of technological competencies.

The level of competencies strongly affects another parameter of the model- the level of innovative technologies, the essence of which, in the economic sense, is to describe the intensity of the introduction of innovative technologies by high-tech industries.

This feedback is the key point of the model describing the mutual relationship between competencies and new consumer markets. The positivity of this feedback creates the basis for the spiral development of all indicators of the levels. This reflects the fact that there is permanent (continuous in time) economic growth based on unique competencies and innovative technologies. The observed synergistic effect of the development of competencies, the emergence of radical innovations, and the emergence of new markets neutralizes the growing crisis phenomena observed at the phase of decline in the long economic wave and allows maintaining the level of economic growth rates, thereby reversing the phase of decline in the Kondratieff wave into a process close to a linearly increasing process, the fluctuations of which do not change the trend of economic growth to negative. This proves that Kondratieff's theory of long economic waves does not have the necessary accuracy in the conditions of intensive economic development under the influence of a spiral process of co-development of innovations and competencies.

For a mathematical description of this pattern, let us consider the balance equations describing the cyclical relationship between the level of competence and the growth of consumer markets. Let us use $IC(t)$ to indicate the level of funding for increasing key technological competencies for creating innovative technologies at time t. We will consider both continuous time and discrete

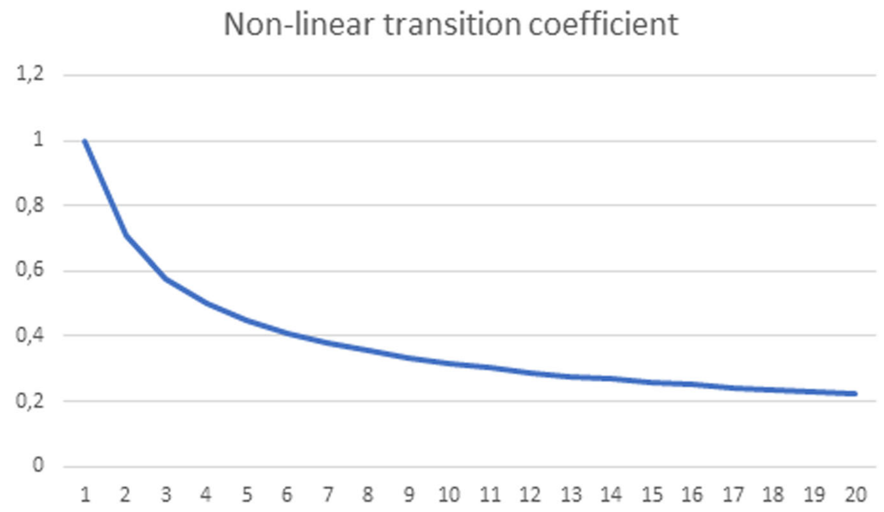

Fig. 4 Dynamics of the non-linear growth rate of the consumer market. Model (3) demo.

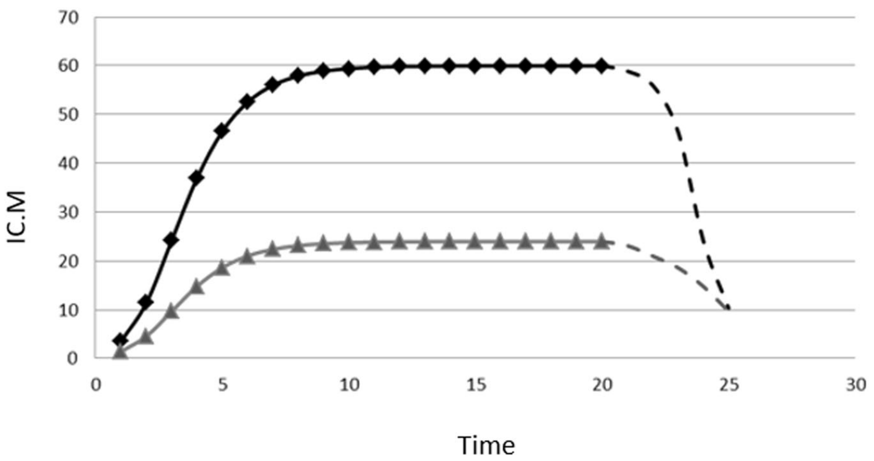

Fig. 5 Dynamics of balance variables. Joint solution of models (1)-(3).

change in time depending on the formulation of the problem. By $M(t)$ we denote the generalized indicator of the consumer market, created as a result of the release of new products. The first balance equation can be written as follows:

$$M(t) = K(t)\mathrm{IC}(t-h) \tag{1}$$

Here $K(t)$ is the transition coefficient, the economic meaning of which is that it shows the growth of the consumer market depending on the management, which consists in increasing the financing of the creation of key technological competencies, $h > 0$ is a time lag, which reflects the time lag of the impact of the financing of key competencies on the growth of the consumer market.

It is more convenient to write this equation as

$$IC(t) = L(t)K(t)IC(t-h) \tag{2}$$

This is the basic linear balance equation for managing the development of key competencies. This is a difference equation, therefore, to determine the function IC(t), it is necessary to recursively solve this equation.

By adding non-linear components to the model, it explains the cyclical development of consumer markets for new products created through the introduction of innovative technologies. We will consider non-linear models that will reflect the extreme saturation of consumer markets. Indeed, any market has a certain capacity, so its expansion must have limitations, which will be expressed in a non-linear dependence of the coefficient $K(t)$. In particular, the following formula for this coefficient can be used:

$$K(t,\ M(t)) = k_0(t)\left(\frac{1}{1+M(t)}\right)^{\alpha} \tag{3}$$

It is assumed here that the exponent satisfies the condition $0 < a < 1$. In this formula for the transition coefficient, we see that with limited values of $k0(t)$ and with increasing values of $M(t)$, this coefficient decreases, which reflects the marginal utility of the product. A typical view of this coefficient is shown in the following graph (Fig. 4)

In this case, the model signals the need for measures to update existing products or develop new competitive products that become the main ones in the market or are able to create a completely new market. In the absence of such processes, Kondratieff waves are in a classical state, characterized by an increase in crisis phenomena in the phase of decline.

Let us consider a numerical simulation of the dynamics of balance variables using a non-linear coefficient. We will use the following initial conditions: $\mathrm{IC}(0) = 1$; $M(0) = 1$; $L(t) = 2.5$; $k_0 = 2$; $a = 0.5$.

These values correspond to the stage of the rapid growth of funding for key competencies and, accordingly, the rapid growth of consumer markets (Fig. 5).

The resulting graph shows that at the simulated stage, there is a rapid mutual growth of balance variables (responsible for

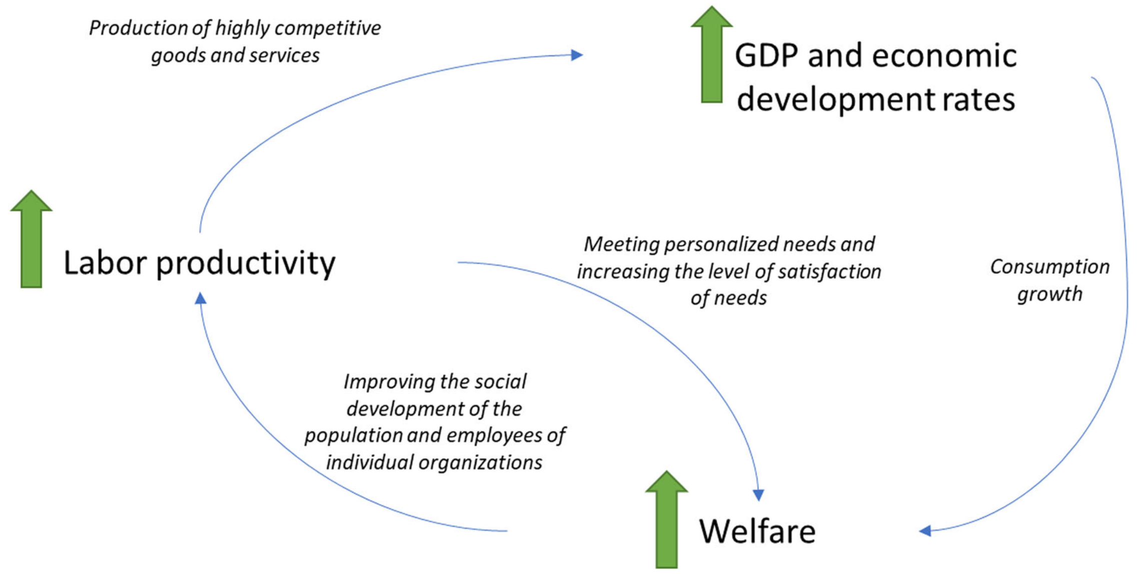

Fig. 6 The relationship between economic growth, labor productivity, GDP, and the well-being of the population. Several interrelated effects that are interconnected in a single network for ensuring economic growth.

managing the development of competencies and market growth), which moves to stationary values after reaching the saturation state. The results of this simulation show that when using non-stationary balance coefficients, it is possible to obtain a spiral behavior of the dynamics of balance variables, which will correspond to the modeled pattern of mutual development of competencies and the expansion of new markets, which makes it possible to transform the phase of the decline of the Kondratieff wave into a linear process of maintaining economic growth rates close to the existing ones.

The proposed model shows the need for continuous implementation of measures (managerial actions) for the development of competencies in order to form products that have high consumer properties. This is due to the fact that in the absence of control, any wavelike processes damp, and the indicators characterizing the processes do not have positive dynamics. At the same time, the classical theory of long economic waves connects control actions with the manifestation of the 'invisible hand of the market', which usually means competition. In the modern conditions of the hybrid economy, the main driver of overcoming the crisis conditions is the development of existing and the creation of new technology platforms (Chursin et al., 2021) [1] that enable the creation of unique products using radical competencies that can form new markets or be dominant in existing ones. Each time, a crisis is avoided and the Kondratieff wave is transited to the decline phase due to the creation of more advanced products (using new materials, technologies, equipment, new production methods, etc.) based on radical competencies.

The development and accumulation of competencies lead to an intellectual explosion, resulting in the development of technologies that provide the creation of radically new products. Thus, a technological singularity is achieved—an extremely rapid technological progress, in which human labor is completely replaced by machine labor, and the existing machine labor is replaced by more productive, automated, and intellectualized machines. This makes it possible to exclude the consumer value chain a number of capital costs related to pre-production (the concept of pre-production as such disappears, since all operations are performed by intelligent systems in automatic or automated mode).

Thus, due to the continuous development of competencies and periodically emerging intellectual explosions, there is a gradual reduction in the number and complexity of work currently being carried out at various stages of product design, which reduces the costs of its development and production and, consequently, the cost of finished products and reduces the risks of going beyond the set cost of a future product created on the basis of new technologies. So, new products with high consumer properties are becoming more accessible to a wide range of consumers, which determines the growth of the consumer market and, consequently, the economic growth of the manufacturer.

In addition, high labor productivity is also ensured by a high level of social development, provided by the growth of the well-being of the population, conditioned by economic growth in general. Thus, there are several interrelated effects that are interconnected in a single network for ensuring economic growth (Fig. 6).

Data

The simulation modeling presented below is theoretical experiments carried out by the authors according to the developed algorithm. Their results are supported by empirical evidence:

World Bank on indicators of global economic development[2];
World Intellectual Property Organization on scientific and technological priorities of countries in terms of patents[3];
U.S. National Bureau of Economic Research on Business Cycles[4];
U.S. Department of Commerce on U.S. Economic Development Indicators[5].

Results of theoretical experiments and empirical evidence

Let us review the results of simulation modeling of economic growth in the case of continuous development of competencies in conditions of sufficient resourcing of these processes. The considered balance model of co-dependence of the level of management (financing) of the development of key competencies and the growth of consumer markets confirms that there is an objective pattern that describes the spiral growth of consumer markets for high-tech products. The growth of these markets encourages the development of technological competencies, which is reflected in the balance equations, and the growth of competencies results in the development of new products, that is, the creation and development of new consumer markets. As a result of simulation modeling with the level of competence in the stationary state, we get the following graph describing the growth of the consumer market (Fig. 7).

The graph of the dynamics of the consumer market has a conical shape, which indicates that there is a limit to growth due to the development of competencies in a particular direction. Early identification of such situations allows for a timely launch of the development of new competencies and technologies, which will become the basis for the development of radically new products that meet future needs and a regulator of new economic growth. Thus, it is possible to avoid serious crises of technology development and prevent a significant economic downturn corresponding to the stage of the Kondratieff wave decline (Fig. 8).

Theoretical experiments confirm the validity of our theses described above. Next, we will prove empirically that the features of scientific, technological, and structural changes in recent decades significantly change the nature of Kondratieff's long-wave dynamics. Let us denote several theses that we have identified.

First, we noted above that effective processes of introducing new competencies and, accordingly, innovations are able to smooth out fluctuations in economic dynamics on the downward trend of the Kondratieff wave and avoid serious crises and economic recession. Figure 9 shows the GDP dynamics of the key

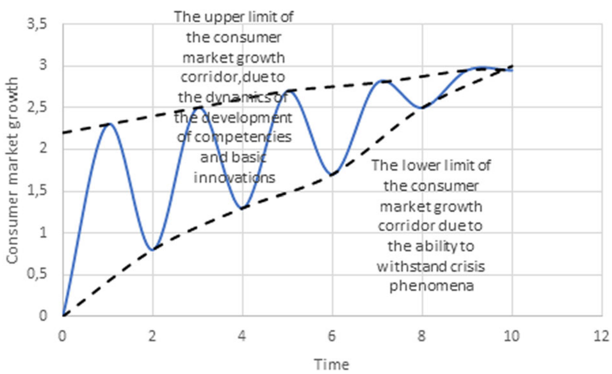

Fig. 7 Permanent growth of consumer markets under the influence of competence development (no transition to the Kondratieff wave decline stage). Demonstration of a linear trend in economic growth.

spatial clusters of countries with a significant impact on the scientific, technological and innovative development of the world economy-Europe, Southeast Asia, and the United States.

Let us examine the data starting from 1980 since this very moment is dated as the time of the turning point from the IV Kondratieff wave to the V wave as a fait accompli. Glazyev believes that this change occurred in the late 1980s–early 1990s (Glazyev et al., 1992). J. Kayane considers 1970 to be the year of the turning point to the upward phase, based on data on the explosion of microprocessor technology at that time. Meanwhile, according to his own calculations in 1973–1985 (recovery stage according to his concept), economic growth rates are 1.5 times lower than in the period 1953–1973 and two times lower than in 1937–1953 (Kogane, 1988). Nevertheless, we can rather agree with the opinion of B. Berry, who considers 1981 to be the maximum point of the IV long wave (Berry, 1991).

Figure 9 shows that the countries of Southeast Asia are successfully overcoming the downward stage of Kondratieff's long wave, demonstrating super-high rates of economic growth. A similar situation, but without sharp growth spurts, is observed in the US economy. However, Europe, being a global player in the technology market, is demonstrating stagnation, which is not yet turning into a downward trend.

As stated earlier, this is largely determined by the effectiveness of the introduction of new competencies in the national economy, which can be quantified through patents registered by the country. Table 1 shows data on the number of patents in priority areas of scientific and technological development. Thus, the most obvious technological leaders in all key areas are the countries of Southeast Asia-China, Japan, and South Korea. Thanks to technological leadership, building up competencies and the rapid introduction of innovations, they can avoid a downturn in the economic environment caused by the downward stage of the Kondratieff wave predicted in the theory. The United States of America ranks second or third in the list of countries in the most priority areas of scientific and technological development.

Second, According to the data of the time series of the US economy, the dynamics of the IC(t) parameter proposed above are observed—funding the development of key technological competencies, which plays a significant role in assessing the innovative dynamics of markets. But first, we would like to focus on the identification of two main stages in the long Kondratieff wave, which, alternately, form its upward and downward trends.

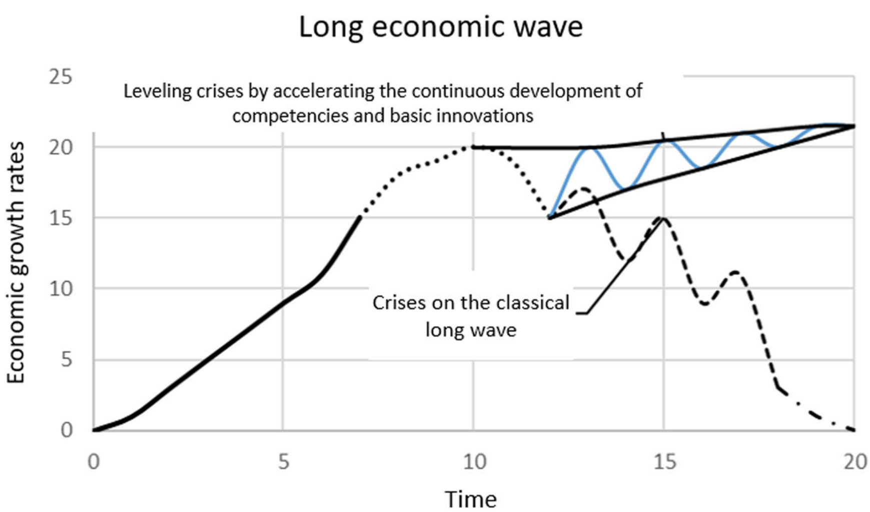

Fig. 8 Leveling the Kondratieff wave crises by accelerating the development of competencies and basic innovations. Transformation of the downward phase of the wave into a process of economic growth close to linear.

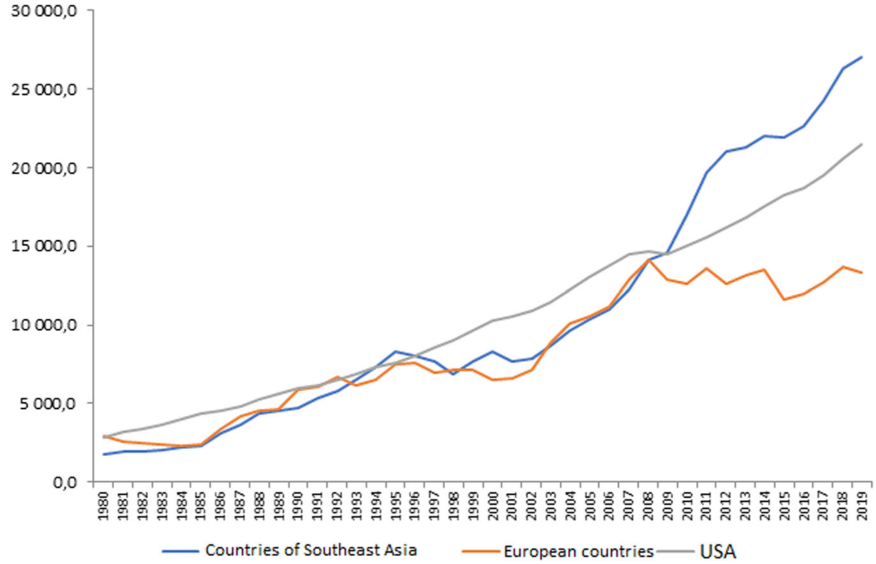

Fig. 9 Dynamics of GDP of spatial clusters-technological leaders for the period 1980–2019, trillion USD. Source: World Bank data on global economic development indicators.

Table 1 Rankings of countries by the number of patents by priority of scientific and technological development, 2018.

End-to-end digital technologies and new materials			Environmentally friendly and resource-saving energy			Personalized medicine and high-tech healthcare			Sustainable agriculture and aquaculture, safe food			Countering security threats			Connectivity of the territory and development of transport and telecommunications systems		
	Country	Units		Country	ед.		Country	ед.		Country	ед.		Country	ед.		Country	ед.
1	China	764,712	1	China	140,503	1	China	79,870	1	China	131,012	1	China	120,382	1	China	67,296
2	Japan	205,253	2	Japan	41,465	2	USA	55,768	2	USA	36,179	2	USA	21,344	2	Japan	32,168
3	USA	203,359	3	USA	21,150	3	Japan	17,908	3	Japan	19,466	3	Japan	19,819	3	USA	27,245
4	South Korea	97,025	4	South Korea	18,984	4	South Korea	10,312	4	South Korea	14,830	4	South Korea	9337	4	Germany	14,898
5	Germany	59,710	5	Germany	12,291	5	Germany	8191	5	Germany	8632	5	Germany	7735	5	South Korea	13,885
6	France	20,688	6	France	3659	6	Switzerland	4924	6	France	4861	6	France	2596	6	France	6121
7	Switzerland	11,113	7	Switzerland	2017	7	Great Britain	3924	7	Switzerland	4788	7	Russia	1831	7	Sweden	1813
8	Great Britain	10,322	8	Great Britain	1798	8	France	3861	8	Great Britain	3358	8	Italy	1412	8	Russia	1644
9	Russia	10,002	9	Netherlands	1664	9	...		9	Russia	Russia	9	Netherlands		9	Italy	
10	Netherlands	9672	10	Russia	1649	11	Russia	2857	10	Netherlands	2815	10	Switzerland	1178	10	Great Britain	1457

World Intellectual Property Organization data on scientific and technological priorities of countries on patents.

We are speaking of the convergent and divergent stages of the long wave, within which the processes of funding research and shaping competencies are of a different nature.

The main difference between evolutionary stages from each other is as follows. At the divergent stage, a technology that is capable of developing a qualitatively different resource appears (Fig. 10). The result of the selection is the approval of a new technical and economic paradigm, which is the essence of the divergent stage of economic development at any level—from the sub-industry to the world economy as a whole.

Intermediate stationary stages provide a change of convergent and divergent stages (Fig. 10), which fit into fully developed techno-economic paradigms. Accordingly, the potential of these paradigms is proportional to the number of resources consumed. In an idealized scenario with almost unlimited resources and other constant environmental conditions, the stationary stage can last indefinitely. But in reality, when the dominant type of technology for some reason depletes the generalized resource, there is a transition to the divergent stage. Therefore, the exhaustion of the generalized resource leads to the fading of the old paradigm and to the transition to a new one. Economically, this transition can be described as the ripening of conditions for the growth of a new paradigm against the background of the exhaustion of the investment-profitable resources of the old one, when the previously working technological scheme ceases to be optimal and efficient.

In this regard, we will consider the empirical data of the United States over the past century and show the features of funding the development of competencies in the evolutionary stages of long waves. So, let us take the date of the change of technological patterns, defined by S. Glazyev—late 1980s–early 1990s. Accordingly, the late 1970s–early 1980s can be considered as the date of origin of the V wave of innovation. We will analyze the main indicators of innovation dynamics to identify divergent and convergent stages.

1. *Expenditure of economic agents on R&D*: The total expenditures of economic agents on R&D over the past century have progressive dynamics (Fig. 11). But, at the same time, on the border of the 1970s–1980s—at the time of the emergence of the V wave of innovation—there is a clear tendency of a sharp increase in research and development costs. The very change of waves, dating from the late 1980s–the early 1990s, is characterized by a jump in R&D costs. Dating the phase of the origin of the technological order is necessary to identify the beginning of the divergent stage of evolution, which lasts from the moment of origin to the technological stalemate, that is, a new wave is born during the heyday and gradual decay of the previous wave. Thus, we note that the beginning of the divergent stage is the interval at the border of the 1970–1980 s.

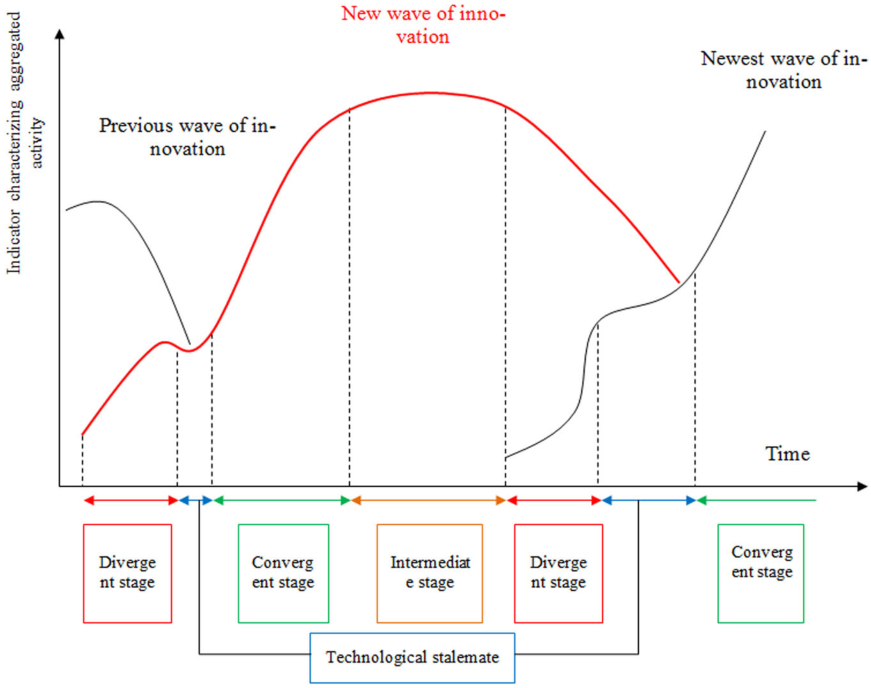

Fig. 10 The main stages of the evolution of economic and technological reality. The main differences of evolutionary stages from each other are demonstrated.

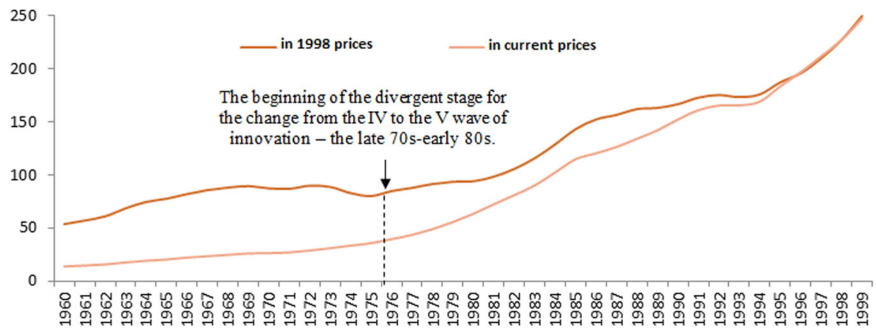

Fig. 11 Dynamics of R&D expenditures of all US economic agents for 1960–2000. Source: US Department of Commerce data.

2. *Ratio of R&D expenditures from the state budget and private business*: Figure 12 shows that at the divergent stage, the amount of R&D financed from the state budget exceeds the cost of R&D financed by private businesses. The State finances breakthrough technologies, mainly of a strategic nature. At the convergent stage, as a result of the diffusion of innovations, private investors begin to invest in innovation improvement and diffusion. In 1964 the federal budget expenditures on research and development were two times higher than the costs of private business, but at the stage of diffusion of innovations, the costs of private business begin to significantly exceed the maximum value by 2.6 times.
3. *Ratio of funds targeted at financing fundamental and applied research*: Fundamental and applied research itself is associated with divergent and convergent stages, i.e. with stages of development in which the behavior of economic agents is search and venture. The convergent stage is characterized by an emphasis on the role of imitators due to the contribution of funds to conducting applied research, and improving the quality of technologies and products of the previous stage of the innovation process (Fig. 13).
4. *R&D expenditure as a percentage of GDP*: Since the divergence stage marks the depletion of resources and a change in the life cycle, the share of R&D in GDP decreases. At the convergent stage, a new wave of innovation is maturing, and therefore the share of R&D in GDP in the form of expenditures of economic agents on applied research is increasing (Fig. 14).
5. *Dependence of GDP on indicators of innovation dynamics*: Our research allowed us to analyze the non-linear dependence of the US GDP on the indicators of innovation dynamics—R & D costs of all economic agents, investments in fixed assets, R & D costs of the federal budget, and private business. The three-dimensional image of these dependencies clearly demonstrates the phase transition in the period from the late 1980s to the early 1990s, which corresponds to the change of waves of innovation.

We have seen, therefore, that the stages we have identified exist and can be given a certain quantitative characteristic. Based on the characteristics of the main indicators of innovation dynamics, we can date the convergent and divergent stages of the last century. These periods coincide with the traditionally accepted

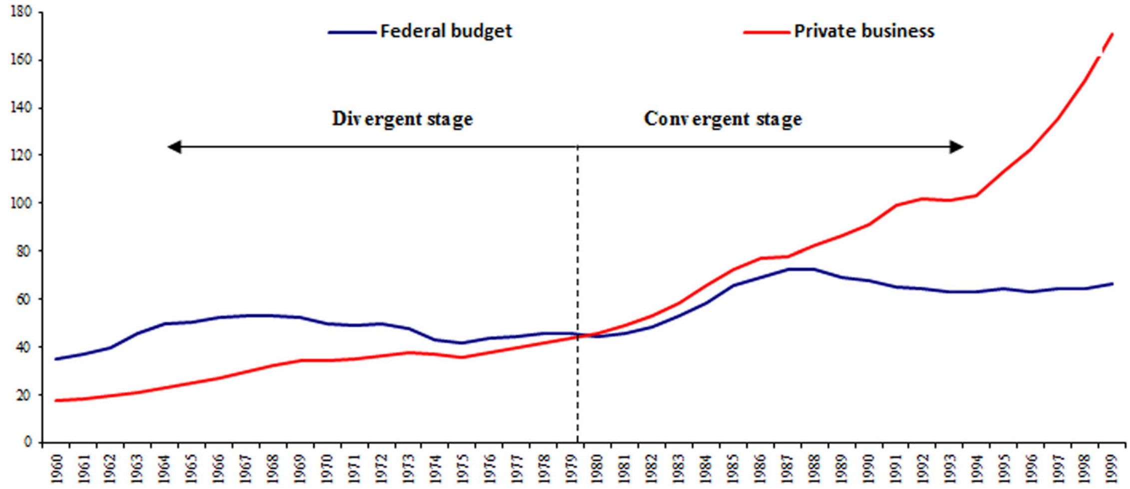

Fig. 12 Expenditures on R&D of the federal budget and private business in the United States for 1960–2000. Source: 'US Department of Commerce data'.

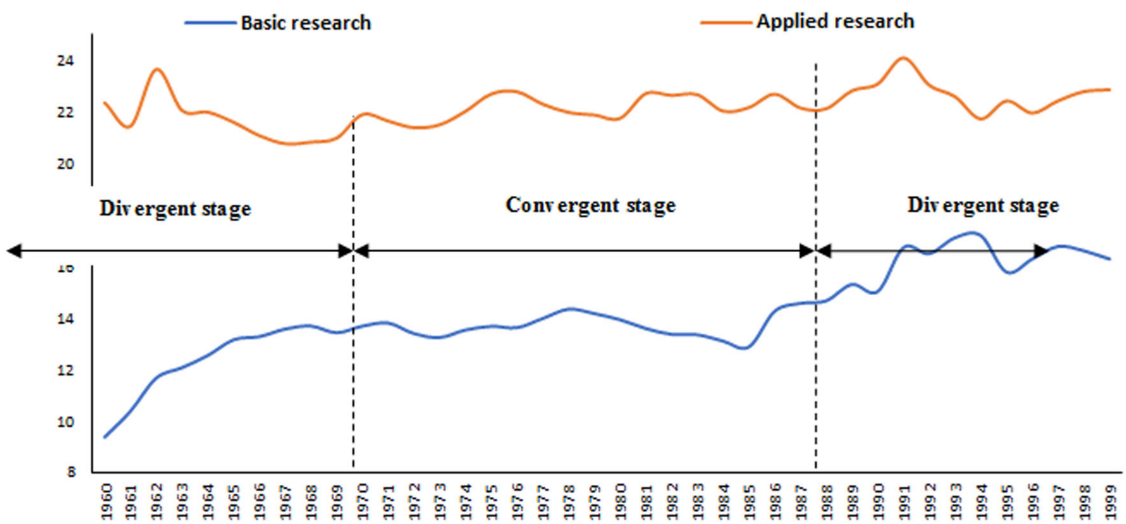

Fig. 13 Shares of expenditures on basic and applied research in the United States for 1960–2000. Source: 'US Department of Commerce data'.

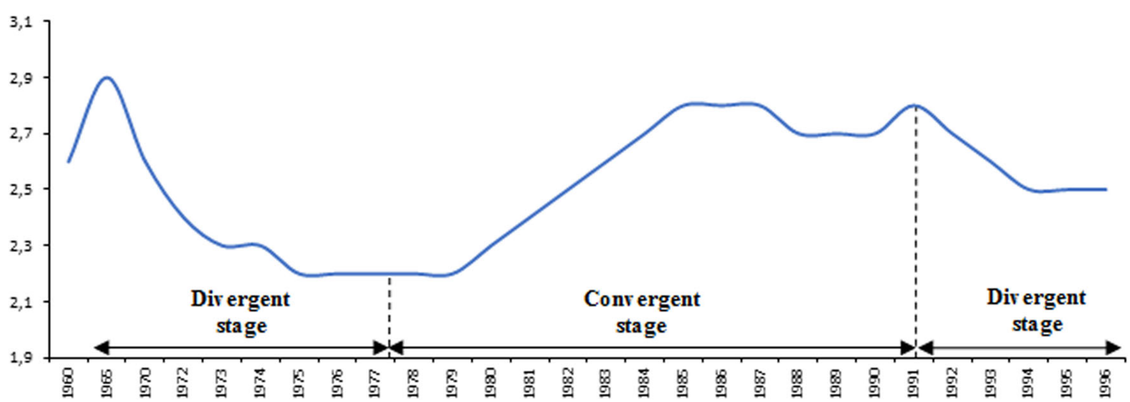

Fig. 14 R&D expenditures as a percentage of US GDP for 1960–2000. Source: 'US Department of Commerce data'.

periodization of changing the IV wave of innovation to the V, which indicates the adequacy of the proposed approach.

Third, in Figs. 7, 8, we present the results of theoretical experiments on leveling the crises of the Kondratieff waves based on accelerating the development of competencies and basic innovations and, in fact, on the absence of a transition to the stage of decline of the Kondratieff wave. Data on the duration of long waves and business cycles of the US economy for the period 1854–2020 provide a clear confirmation of the obtained theoretical results.

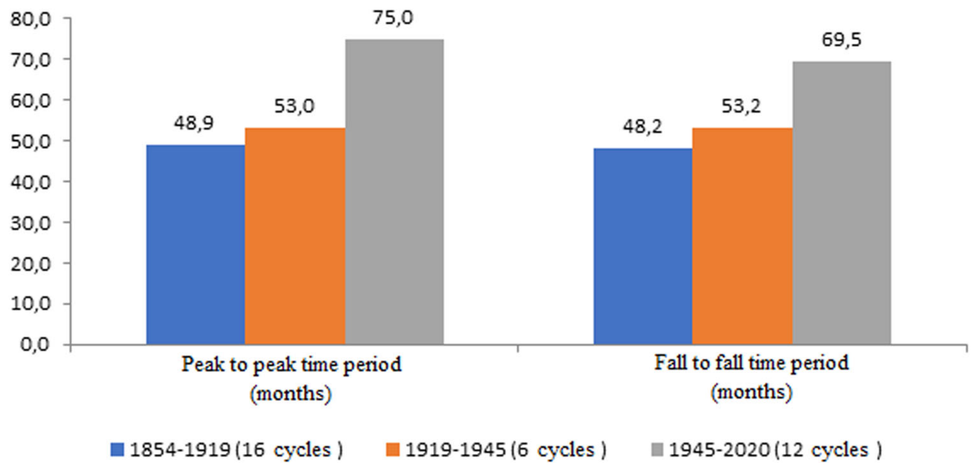

Fig. 15 Duration of business cycles of the US economy for the period 1854–2020 from fall to peak and from peak to fall. For over a 160-year time interval, including 34 business cycles, the average time period from the moment of the economy's decline to the next peak increased by 2.4 times, and the average period between the peak and the next economic decline decreased by 1.9 times. Source: Radin (2021).

An analysis of the US business cycles indicates a trend in the change in the structure of cycles when the wave process is transformed into a process tending to a linear process that maintains economic growth at a permanently high level by reducing the development and introduction time of innovations.

For example, Fig. 15 shows that for over a 160-year time interval, including 34 business cycles, the average time period from the moment of the economy's decline to the next peak increased by 2.4 times, and the average period between the peak and the next economic decline decreased by 1.9 times. This indicates the smoothing of the wave dynamics, its 'stretching' on a long-term scale in a trend close to linear.

This fact is also confirmed by Fig. 16, which shows the average values of the duration of business cycles from peak to peak and from fall to fall. Figure 16 shows the trend of increasing the duration of the cycles of the end of the Second World War to the present time, which was the transition from the IV to V Kondratieff wave, as well as the birth of the VI wave related to a whole cluster of—MANBRIC—technologies (medical-additive-nano-bio-robo-info-cognitive).

Thus, the effects of the introduction of a cluster of new convergent technologies create conditions under which the average cycles (Kitchin, Juglar, and Kuznets) that happen on the downward period of a large cycle are no longer characterized by the duration and depth of recessions with short and weak rises, but rather reduce the periods of recessions, lengthen the periods of rises, bringing the wave dynamics into a smoothed oscillatory process with an upward trend.

According to the results of the study, it can be concluded that under the influence of modern drivers of economic growth associated with the accelerated development of competencies, the changeability of basic technological innovations, the regulatory effects of a State, and the development of mechanisms for knowledge transfer through the mechanisms of the global information space, it is possible to avoid crises and the transition of the long economic wave of Kondratieff into the phase of decline due to its transformation into a close to the linear process shown in Fig. 8, which keeps economic growth at a permanently high level.

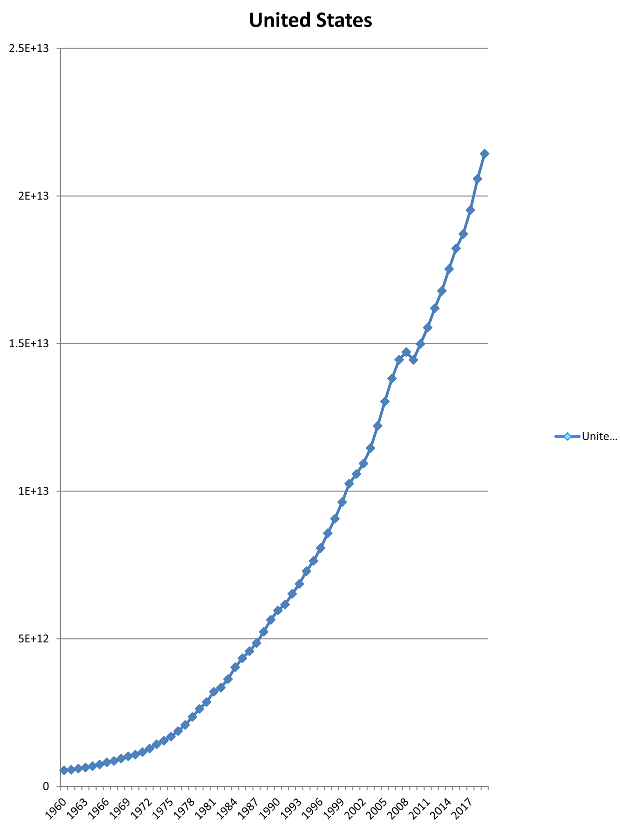

Fig. 16 Duration of business cycles of the US economy for the period 1854–2020 from peak to peak and from fall to fall. Source: Radin (2021).

Discussion

The article contributes to the literature through the development of Kondratieff's theory of long waves. The results obtained allow us to determine the place of the AI economy in the "competence-innovation-markets" model as a new technological paradigm—Industry 4.0, the impact of which on the economic cycle depends on humanization.

In contrast to Bessen et al. (2022), Bobanović (2021), De Nicola et al. (2020), Merola (2022), and Pan and Yang (2021), the results obtained in the article indicate that the technocratic approach to the development of the AI economy, which focuses on the development of advanced technologies for the growth of global digital competitiveness and accelerated automation for labor productivity growth, causes high social costs (unemployment, increased social inequality in the form of a digital divide) and therefore increases the risks of socio-economic crises.

Unlike Duke (2022), Fleischer et al. (2021), Goldsteen et al. (2022), Matilda Bez and Chesbrough (2020), and Prahl and Goh (2021) the authors' conclusions indicate that a humanistic approach involving the humanization of the AI economy is more preferable since it allows revealing its potential to support economic growth. The humanization of the AI economy involves the gradual development of Industry 4.0 at a slow pace and step-by-step automation, thereby avoiding a sharp change in the ratio of supply and demand in the labor market. Both employees and employers will have time to adapt to the ongoing changes and the labor market will be balanced.

Social inequality in the form of a digital divide has been reduced with the humanization of the AI economy. Unlike the fast pace of Industry 4.0 development, in which large cities are clearly in the lead, while small and peripheral, especially rural areas are lagging behind, a slow pace allows you to avoid this. Thus, the humanization of the AI economy makes it possible to mitigate the social consequences of the development of Industry 4.0 and thereby has a positive impact on economic cyclicity (reduces it).

Conclusion

In this paper, we examined the development of Kondratieff's theory of long waves and prove that the theory of Kondratieff waves is being replaced by a new theory, within the framework of which the prerequisites for the transformation of Kondratieff's long economic waves into a process of economic growth that is close to linear are formed.

As a result of the emergence of the described spiral cycle, the traditional economic cycle "growth of markets—reduction of markets" is transformed into a linear growth process in the AI economy due to the accumulation of sufficient competencies (intellectual resources) to create prerequisites for the emergence of new growth drivers of markets and digital competencies. That is, humanization allows reducing the cyclical nature of the AI economy in the "competence-innovation-markets" model: to reduce the risks of economic crises and accelerate the pace of economic growth.

The main idea of the article is to smooth out Kondratieff's long waves due to the humanization of the AI economy. The theoretical significance of the results obtained and the conclusions drawn is that they revealed the nature of the economic cycle in the conditions of the AI economy and demonstrated the patterns of changes in its cyclicity with the development of Industry 4.0. The practical significance of the results of the study is related to the fact that they substantiated the need for the humanization of the AI economy—they proposed humanization as a way to reduce cyclicality with the development of Industry 4.0.

However, the results obtained are limited by the generalized consideration and primarily theoretical elaboration of the humanistic approach to the development of the AI economy. Given serious differences in the socio-economic development of the modern economic systems and their involvement with the Fourth Industrial Revolution (which is manifested at the level of countries, in particular), as well as well-known and generally acknowledged institutional differences between countries, it is possible to assume that humanization of the AI economy should have certain national specifics. These specifics go beyond the scope of this research, which is its limitation. In future studies, it is recommended to pay attention to the national specifics of the humanization of the AI economy and the adaptation of the proposed approach to their context.

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Notes

1 A technology platform is a set of interrelated processes of creating value for the consumer in various sectors of the economy, based on radical concepts and key technologies of the product life cycle and the basic principles of cooperation of participants (the State, companies, the scientific community, etc.) in the conditions of intensive information exchange.
2 https://databank.worldbank.org/source/world-development-indicators
3 https://www.wipo.int/patentscope/en/.
4 https://www.nber.org/research/data/us-business-cycle-expansions-and-contractions.
5 https://www.commerce.gov/data-and-reports/economic-indicators.

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Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

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Additional information

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