Kondratieff Waves, Technological Modes, and the Theory of Production Revolutions

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Leonid E. Grinin

Abstract

In the present article Kondratieff waves theory is considered in comparison with the theory of production revolutions which analyzes the regularities of the major technological breakthroughs in history. Both theories analyze the processes of cyclic nature related to the innovative technological development of the World-System. The mutual comparison of both theories allows the author to make important clarifications in understanding of the long-wave dynamics as a whole, as well as to give relevant explanations of the peculiarities of the unfolding of each of the five waves and their phases, to make forecasts about the sixth wave and the development of technologies of the sixth technological mode. The special attention is paid to the analysis of aspects and limitations of the theory of technological modes, as it is used by many researchers to explain the causes of the long-wave dynamics.

Keywords: *production revolution, Agrarian Revolution, Industrial Revolution, Cybernetic Revolution, production principle, Kondratieff waves, long waves, phases of long waves, technological innovations, technological mode, World-System, service sector, complex service sector.*

Preliminary Remarks on the Intent and the Structure of the Article

The movement towards qualitatively new (including innovative) forms cannot continue endlessly and in a linear and smooth manner. It always proceeds with limitations, accompanied by the emerging imbalances, increasing resistance to environmental constraints, and competition for resources, *etc*. These endless attempts to overcome the resistance of the environment created conditions for a more or less noticeable advancement in particular societies and in the World-

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System as a whole. However, relatively short periods of rapid growth (which could be expressed as a linear, exponential or hyperbolic trend) tended to be followed by stagnation, different types of crises and setbacks which led to the creation of complex patterns of historical dynamics, within which trend and cyclical components were usually interwoven in intricate ways (see, *e.g.*, Grinin and Korotayev 2010; Grinin, Korotayev, and Malkov 2010; Korotayev and Grinin 2012; Grinin and Korotayev 2014; Grinin, Korotayev, and Tausch 2016; Grinin L. and Grinin A. 2016). Hence, in history we see a constant interaction between cyclical dynamics and dynamics of trends, including some long-term trends. This was one of the main causes that led to the formation of cyclical components and with respect to the pre-industrial epoch one can speak of the cycles with different duration, including millennial ones.

The cyclical dynamics was noticed a long time ago. Already ancient historians (see, *e.g.*, the second Chapter of Book VI of *Polybius' Histories*) described the cyclical component of historical dynamics, whereas new interesting analyses of such dynamics also appeared in Medieval and Early Modern periods (see, *e.g.*, Ibn Khaldūn 1958 [1377], or Machiavelli 1996 [1531]). This is not surprising as the cyclical dynamics was dominant in the agrarian social systems. With modernization, the trend dynamics became much more pronounced and, naturally, the students of modern societies pay more attention to these trends.

In the industrial period when a 'desire' for a steady and continuous expansion had become a major characteristic of the productive forces, cyclicality in some respects became even more evident. Th economic cycles with a characteristic period of 7–11 years that manifest themselves in energetic booms and crises that suddenly engulf social systems have become an integral part of progressive development. However, the cycles with different duration were less obvious at the background of these sometimes very vivid cyclical fluctuations. The long cycles of 50–60 years, called Kondratieff waves, are one of the most intriguing and fascinating intellectual mysteries.

The analysis of long economic cycles allows us to understand the long-term world-system dynamics, to develop forecasts, to explain crises of the past, as well as the current global economic crisis. At the same time, the long cycles are more difficult to understand beyond the ultra-long cycles of technological development, which we call production principles, and which start with technological or production revolutions. The long Kondratieff cycles (and the technological modes formed within them) can be represented as integral components of ultra-long cycles of technological development. The comparison of these two types of cycles is the subject of this article.

This paper is the first of two interrelated papers that attempt to clarify and develop some important aspects of the theory of long cycles, or Kondratieff waves (hereinafter K-waves).[1] In order to clarify and verify a number of its important provisions, the comparative method has been applied which in this case consists in sequential comparison of the main provisions of the K-wave theory with the conclusions and basic provisions of another theory that investigates the same processes. This refers to the theory of *production principles and production revolutions* which reveals the laws and major developmental stages of the world productive forces, including the causes and cyclical sequence of the largest technological revolutions in the historical process.

The fact that both theories analyze the processes of cyclical nature related to the innovative technological development of the World-System makes justified and relevant the comparison of the two theories for the purposes of obtaining of the previously unknown knowledge. Interrelated verification of two independent theories increases the value of the findings and to some extent may even be considered as a verification procedure.

In the first section of this article we will briefly describe the main ideas of the theory of production principles and production revolutions. The second part of the article will be devoted to the aspects and restrictions of the theory of technological modes. It is often believed that Kondratieff waves are generated by changing technological modes or paradigms and, in turn, create conditions for their development and change. However, this system possesses a number of aspects that should be clarified and extended. At the same time, we will compare the assumptions of both theories since they are all closely related to innovations. We propose some additional ideas to the theory of technological modes which should be combined with the ideas about the change of economic macro-sectors associated with the change of K-waves. We show that the multifunctional character of the world economy is an important factor for the origin of innovation waves.

Since the K-waves are associated only with the last two production principles – Industrial and Scientific-Cybernetic ones, within the framework of this study we consider the periods from the final phase of the Industrial revolution, *i.e.* from about 1730 to the present, and offer some forecasts concerning the development of the sixth technological mode for the next 40–50 years.

Section 1. THE MAIN IDEAS OF THE THEORY OF PRODUCTION PRINCIPLES AND PRODUCTION REVOLUTIONS

1.1. The Concept of Production Principles and Production Revolutions

We have been elaborating the theory of ultra-long cycles of technological development (production principles and production revolutions) for over thirty

[1] The second article will be published in the next issue of the *Kondratieff Waves* Yearbook. There is the announcement of the second article at the end of this paper.

years. It is presented in the most complete form in a number of our monographs and articles which we do not refer to (*e.g.*, Grinin 2007a, 2007b, 2012b, 2013; Grinin L. and Grinin A. 2013a, 2013b, 2015a, 2015b, 2016, 2020a, 2020b; Grinin A. and Grinin L. 2015; Grinin and Korotayev 2015; Grinin, Grinin, and Korotayev 2017, 2020) but we recommend these works to our readers for a more detailed understanding of the theory of production principles.[2] According to our theory, the whole historical process can be most adequately divided into four large periods, on the basis of the change of major developmental stages of the world productive forces, which we call production principles. Each production principle means the transition within the framework of the world-historical process (World-System) to completely new, more productive production systems, which eventually restructure the whole range of economic activities and respective relations. In other words, we speak not only about new technologies and economic management, but also about a (fundamentally) complete and worldwide change of modes of activity.

We single out four production principles:

1. Hunter-Gatherer;
2. Craft-Agrarian;
3. Trade-Industrial;
4. Scientific-Cybernetic.

Each production principle can be presented as a specific development cycle consisting of six phases (for more details see below). Table 1 provides some insight into the chronology of the production principle's phases, and Figs 1 and 2 show the development of Industrial and Scientific-Cybernetic production principles.

Among all various technological and production changes in history the following three production revolutions had the most comprehensive and far-reaching consequences for society: 1. **Agrarian** or **Agricultural** Revolution which launched the transition to systemic production of food and, on this basis, to the complex social division of labor. This revolution is also associated with the use of new energy sources (animal power) and materials. 2. **Industrial** Revolution, which led to the main production concentrated on industry and carried out by machines and mechanisms. The significance of this revolution consists not only in the replacement of manual labor with machines, and biological energy – with water and steam energy but also in the fact that it initiated the introduction of labor saving in a broad sense (not only in physical labor, but also in accounting, control, management, exchange, credit, and information transfer). 3. **Cybernetic** Revolution which originated as a scientific-informa

[2] These ideas were briefly discussed in our contribution to the preceding volume of this Yearbook (Grinin L. and Grinin A. 2014: 354–377). Since they are crucial to this article, we apologize in advance for the inevitable repetitions that may occur.

tion (see below) and resulted in the emergence of efficient information technologies, new materials and types of energy, and spreading of automation.

The Cybernetic Revolution was a great transition from the Industrial production principle to the production and service sector based on the implementation of self-regulating systems.

The defined revolutions are often referred to as production (technological) revolutions. Each production revolution is the result of a long accumulation of quantitative and qualitative changes that eventually bring a great evolutionary breakthrough. Each one provokes an increasing complexity of the social division of labour and the integration of humanity.

The above-mentioned technological thresholds in the history of societies have been long attracting the attention of academic community. The Industrial Revolution became the object of an extensive research in the nineteenth and early twentieth centuries both within Marxist framework and within non-Marxist theory (see, *e.g*., Engels 1955 [1845]; Marx 1960 [1867]; Plekhanov 1956 [1895]; Labriola 1986 [1896]; Toynbee 1927 [1884]; 1956 [1884]; Mantoux 1929). The first ideas on the Agrarian (Neolithic) revolution were introduced by Gordon Childe in the 1930s, and between the 1940s and 1950s he developed the theory of the Neolithic revolution (Childe 1934, 1944, 1948). From the 1940s there was observed an increasing interest in the analysis of the impact of production on the historical development and historical process in general; meanwhile, the originating technological society received both optimistic and pessimistic assessments. The interest became even more acute after it was perceived that the world had entered the Cybernetic Revolution (which in the 1950s and 1980s was denoted by different terms; thus, within some approach it was called the scientific and technological revolution following John Bernal [1965]). It is not surprising then that in the 1960s and 1980s the increasing interest in production revolutions found its expression in numerous works including the publications of such postindustrial economists as Daniel Bell (1973, 1978, 1990), Alvin Toffler (1980, 1985, 1990; Toffler A. and Toffler H. 1995), Tom Stonier (1983), Alain Touraine (1974, 1983), Herman Kahn (1983), and to a lesser extent in other scholars' works (Drucker 1995, 1996; Thurow 1996; see also Dizard 1982; Martin 1981; Castells 1996), not to mention the philosophers of technology (Ellul 1964, 1975, 1982, 1984; Mumford 1966; *etc*.; see also Inozemtsev 1999).

Much has been written about each of the three production revolutions (see, *e.g.*, Allen 2009, 2011; Bellwood 2004; Benson and Lloyd 1983; Bernal 1965; Cauvin 2000; Cipolla 1976; Clark 2007; Cohen 1977; Cowan and Watson 1992; Dietz 1927; Goldstone 2009; Harris and Hillman 1989; Henderson 1961; Huang 2002; Ingold 1980; Knowles 1937; Lieberman 1972; Miller 1992; Mokyr 1985, 1990, 1993, 1999, 2010; Mokyr and Foth 2010; More 2000; North 1981; Philipson 1962; Phyllys 1965; Pomeranz 2000; Reed 1977; Rindos

1984; Sabo 1979; Shnirelman 1989, 2012a, 2012b; Smith 1976; Stearns 1993, 1998; Sylvester and Klotz 1983). However, there is a surprisingly small number of studies concerning these revolutions as recurrent phenomena, each representing an extremely important landmark in the history of humankind. Meanwhile, the repeatability of the most important model characteristics of production revolutions and especially some phases of their cycle provides a good tool for forecasting. We have developed a theory of production revolutions within the framework of the general theory of the world historical process (Grinin 2007a, 2007b, 2012a; Grinin L. and Grinin A. 2013b, 2015a, 2015b; see also Grinin and Korotayev 2015).

1.2. The Structural Model of Production Revolutions

It is obvious that each production revolution is unique and has absolutely peculiar characteristics. But at the same time, there are similarities in their development that allow creating a model of production revolution as a global and recurrent phenomenon.

Within the proposed theory we suggest a fundamentally new idea that each production revolution has a common internal cycle consisting of three phases: two innovative (initial and final) and one modernization phase. During the initial innovative phase, there emerge new advanced technologies which eventually spread to other societies and territories. As a result of the final innovative phase of a production revolution the new production principle reaches its peak.

Between these phases there is a modernization phase – a long and very important period when the new technologies of production principle (which appeared in the initial innovative phase) are distributed, enriched, and diversified, thus creating prerequisites for a final innovative breakthrough.[3]

Thus, the cycle of each production revolution can be described as follows: the initial innovative phase (emergence of a new revolutionizing production sector) – the modernization phase (diffusion, synthesis and improvement of new technologies) – the final innovative phase (when new technologies acquire their mature characteristics).

The scheme of innovative phases of production revolutions in our theory is as follows (modernization phases are omitted).

Agrarian Revolution: **the initial innovative** phase – the transition to primitive manual (hoe) agriculture and animal husbandry (started about 12,000–9,000 BP); the **final** – transition to irrigation agriculture (or plow agriculture without irrigation) (which began approximately 5.5 thousand years ago).

Industrial Revolution: **the initial** innovative phase starts in the fifteenth century with the development of navigation, water-powered equipment and

[3] *E.g.,* in the modernization phase of the Agrarian Revolution local varieties of plants and breeds of animals (borrowed from other places) were created.

mechanization, with qualitative growth of labor division in the manufacturing, and also other processes; **the final** phase – the industrial revolution of the 18th – the first third of the 19th century, connected with the introduction of various machines and steam energy.

Cybernetic Revolution: **the initial (scientific and information)** phase dated back to the 1950–1990s. The breakthrough occurred in automation, energy production, synthetic materials, space technologies, exploration of space and sea, agriculture, but especially – in the creation of electronic control facilities, communication and information. **The final** innovative phase **(of self-regulating systems**) will begin in the 2030s or 2040s and will last till the 2060s or 2070s.

Each production revolution implies a transition to a fundamentally new production system; the beginning of each production revolution marks the borders between corresponding production principles.

1.3. The Structure of a Production Principle

A production revolution is a long-running process which is an integral part of a production principle. The production revolution is a fundamental technological breakthrough which is realized in discovery of absolutely new principles of creating food and other valuable mass products. These new ways of manufacturing (methods) mark the emergence and development of a new production principle which gradually changes social and economic relations. In our concept we define the following large-scale (two-part) division of a production principle: the first part is the production revolution, the second period is maximization of the structural, systemic, and spatial potentials of the new forms of production (hereafter we can sometimes use the terms 'production principle' and 'production revolution' as synonyms). However, such a large-scale division is clearly insufficient for a full-fledged analysis. As mentioned above, the production revolution, which takes up at least a half of the period of production principle (in fact more than a half, see Table 1) consists of three phases each corresponding to the first three stages of the production principle. Thus, together with the three subsequent (post-revolutionary) phases the principle of production is a six-phase cycle.

1. The phase of the starting production revolution. A new and not yet developed principle of production emerges.

2. *The phase of primary modernization* – diffusion and strengthening of the production principle.

3. The phase of completing production revolution. The production principle acquires advanced characteristics.

4. The phase of maturity and expansion of the production principle. In this phase there occurs a wide geographical and sectoral diffusion of new technologies, bringing the production principle to mature forms. A consequence of this phase is vast transformations in the social and economic spheres.

5. *The phase of absolute domination of the production principle*. The final victory of the production principle in the world yields an intensification of technologies, bringing opportunities to the limit of their 'reach,' beyond which crisis features appear.

6. *The stage of non-system phenomena, or a preparatory phase*. The intensification leads to the emergence of non-system elements which prepare the birth of a new production principle. Under favorable conditions these elements form a system and in some societies the transition to a new production principle will begin and the cycle will repeat at a new level.

Table 1. Chronology of the production principle's phases

No	Production Principle	1st phase	2nd phase	3rd phase	4th phase	5th phase	6th phase	Total Production Principle
1.	Hunter-Gatherer	40,000–30,000 (38,000–28,000 BC) **10**	30,000–22,000 (28,000–20,000 BC) **8**	22,000–17,000 (20,000–15,000 BC) **5**	17,000–14,000 (15,000–12,000 BC) **3**	14,000–11,500 (12,000–9,500 BC) **2.5**	11,500–10,000 (9,500–8,000 BC) **1.5**	40,000–10,000 (38,000–8000 BC) **30**
2.	Craft-Agrarian	10,000–7,300 (8,000–5,300 BC) **2.7**	7,300–5,000 (5,300–3,000 BC) **2.3**	5,000–3,500 (3,000–1500 BC) **1.5**	3500–2200 (1500–200 BC) **1.3**	2200–1200 (200 BC – 800 AD) **1.0**	800–1430 AD **0.6**	10,000–570 (8,000 BC – 1430 AD) **9.4**
3.	Industrial	1430–1600 **0.17**	1600–1730 **0.13**	1730–1830 **0.1**	1830–1890 **0.06**	1890–1929 **0.04**	1929–1955 **0.025**	1430–1955 **0.525**
4.	Scientific-Cybernetic	1955–1995/2000 **0.04–0.045**	1995–2030/40 **0.035–0.04**	2030/40–2055/70 **0.025–0.03**	2055/70–2070/90 **0.015–0.02**	2070/90–2080/105 **0.01–0.015**	2080/2105–2090/2115 **0.01**	1955–2090/2115 **0.135–0.160**

Note: Figures before the brackets – absolute scale (BP), figures in the brackets – BCE. Chronology in the table is simplified (for a more detailed chronology see Grinin 2006b, 2009; Grinin and Korotayev 2013, 2015; Grinin L. and Grinin A. 2015, 2016). The duration of phases (in thousand year intervals) is marked by the bold-face type. Duration of phases of the scientific-cybernetic production principle is hypothetical.

1.4. A Brief Chronology of Industrial and Scientific-Cybernetic Production Principles

Since in the context of this paper we are primarily interested in the last two production principles – industrial and scientific-cybernetic, we will briefly present their chronology and two diagrams (Figs 1 and 2).

The **beginning** of the initial phase of the Industrial Revolution may be dated to the period from the second third of the 15th century to the late 16th century. At first there were major changes in agriculture, cloth manufacturing, and navigation. Then came to the forefront those types of activities that were both more open to innovation and capable of accumulating more surplus product: long-distance trade and colonial activities, which had become more and more interwoven since the 16th century. Besides, at that time, primitive industries (yet particularly industries) developed in certain fields. It is during that period when according to Wallerstein (1974) the capitalist world-economy was formed.

From the end of the 16th century to the first third of the 18th century there was the **second** (primary modernization) phase of the industrial production principle accompanied with the development of labor division and mechanization; it was the period of growth and development of new sectors (centralized and especially distributed manufacturing, shipbuilding, long-distance trade) until they became leading in some societies. It was also the period of great success in agricultural production which made it possible for the first time in human history to create an economic system in which the growth of food production would eventually outpace population growth. It was the beginning of the escape from the Malthusian trap (see Grinin, Korotayev, and Malkov 2008; Grinin and Korotayev 2012, 2015).

The **third** phase of the Industrial production principle together with the final phase of the Industrial Revolution began in the 1730s in England and was accompanied by the creation of sectors with the machine cycle of production and the use of steam power. The manual labor was replaced by machine labor in cotton textile industry that was only emerging in England (Mantoux 1929; Berlanstein 1992; Mokyr 1993, 1999; Allen 2009, 2011; Griffin 2010; Grinin and Korotayev 2015). There appeared tens of thousands of mechanical weaving and spinning machines as well as machines that perform other operations in the textile industry. Already in the 1880s, James Watt's steam engine was introduced, and the number of steam engines in the first decades of the 19th century amounted about several thousands. There emerged a fundamentally new branch of industry – mechanical engineering. The British Industrial Revolution was mainly completed in the 1830s. One could already observe successful industrialization in a number of countries. There started major demographic changes connected with the entrance of a huge number of human populations into the first phase of the demographic transition (Armengaud 1976; Minghinton 1976: 85–89; Chesnais 1992; Vishnevsky 1976, 2005).

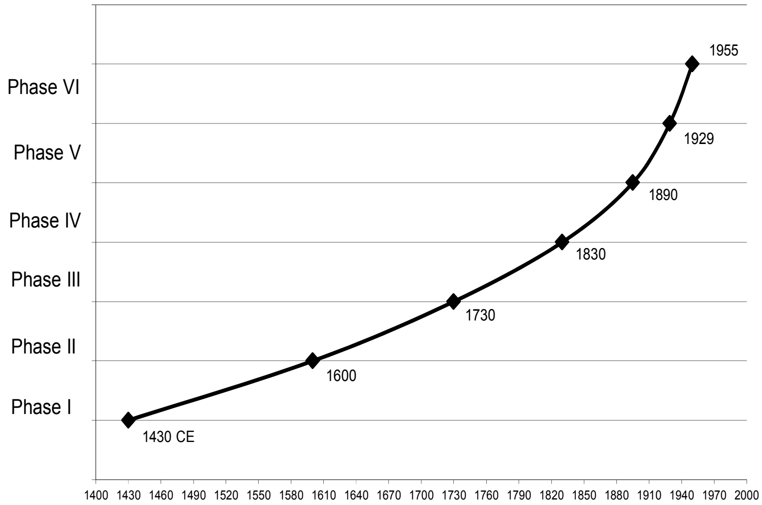

Fig. 1. The development of the Industrial production principle

The **fourth** phase (1830 – the 1890s) is the period of development of heavy industry, emergence of new methods of iron and steel smelting, chemical industry, rapid railway construction, and most significantly it is the period of final replacement of manual labor by machines production and its intensive diffusion not only in the field of production but also in transport and communication system. Unlike previous periods, mechanical engineering matured and the accuracy of machine and component manufacturing significantly improved (up to a fraction of millimeters, sometimes up to a hundredth or even a thousandth of a millimetre), which is clearly visible in weapons manufacture. It is a period of unbelievable number of innovations (see Bunch and Hellemans 2004; Korotayev and Grinin 2017).

The **fifth** phase covered the period from the end of the 19th century to the beginning of the Great Depression of the 1930s. During that period significant changes took place (for more details see Grinin L. and Grinin A. 2015b, 2016). The chemical industry (including artificial fertilizers, organics and the first artificial materials) experienced vigorous development, a breakthrough was observed in steel production, the extensive use of electricity (together with oil) would gradually replace coal. The introduction of electric engines fundamentally changed the functioning of factories and everyday life. There appeared machines with the internal combustion engine which were able to act autonomously and this led to revolution in agriculture. Due to the introduction of assembly line, automobile manufacturing rose vigorously. It was a period of the first electronics innovations. With the advent of aviation we managed to subdue the air element, and with the invention of radio one could observe the breakthrough in the field of communication and control.

The **sixth** phase lasted until the middle of the 20th century. The period of the 1930s gave a great number of basic innovations, many of which were implemented in 1940 – the 1970s. There were developing the advanced branches of mechanical engineering (including electric, automotive, aeronautical engineering, heavy, agricultural machinery, *etc.*), which took the lead in heavy industry. This phase was marked by a powerful intensification of production, introduction of scientific methods, development of standardization and the enlargement of production units. A vigorous intensification of production and the introduction of scientific methods of its organization took place during this period. There was an unprecedented development of standardization and the enlargement of production units. At that period the precursors of the Cybernetic revolution became more and more evident in the field of television, rocket and missile engineering, atomic energy.

The production revolution which began in the 1950s and is still proceeding, has led to a powerful acceleration of scientific and technological progress. Taking into account the two innovative phases of this revolution and expected changes in the next five decades, it is relevant to denote this revolution as 'Cybernetic' (see our explanation below). The initial phase of this revolution (the 1950s – the 1990s) can be referred to as a scientific-information phase since it was characterized by the transition to scientific methods of planning, forecasting, marketing, logistics, production management, distribution and circulation of resources, and communication.[4] The most radical changes took place in the sphere of computer science and information technologies. Besides, the Cybernetic revolution occurred in energy production, synthetic materials, automation, space technologies, exploration of space and sea, and agriculture.

The Scientific-Cybernetic production principle is in the early stages of its development. Its first phase has finished, and in the mid-1990s the second phase started. This principle is marked by a wide diffusion of user-friendly computers, communication technologies as well as new financial technologies which widely promote and exponentially increase the financial instruments of the second, third and subsequent orders (including so-called derivatives). At the same time, financial and economic globalization has intensified, followed by other vectors of globalization. The second phase is in progress now. Table 1 and Fig. 2 present the calculated duration of the future phases.

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[4] At the same time, it is important to note that the concept 'scientific' does not imply only a positive assessment; it refers only to the technology of influence. And the results and objectives of 'scientific' impact may be very different.

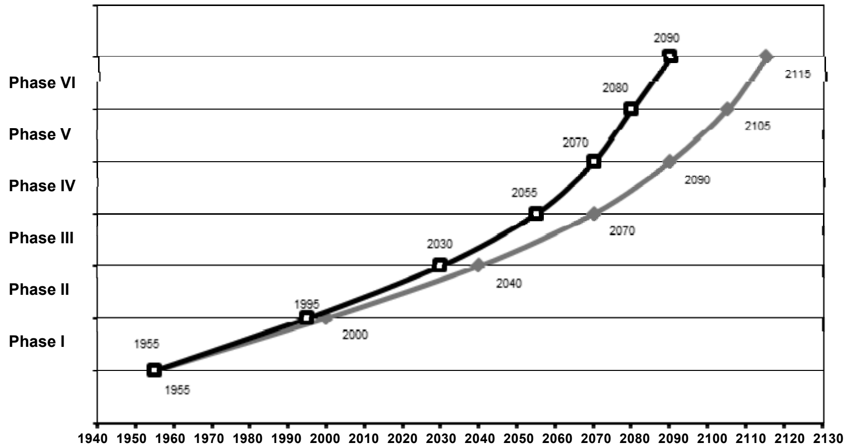

Fig. 2. Development of the Scientific-Cybernetic production principle

Note: The dashed line represents one of the scenarios of predicted development of the Scientific-Cybernetic production principle and corresponds to the dates before the slash in the fifth column of Table 1.

The third phase is likely to start approximately in the 2030s – the 2040s. At this particular period the final phase of the Cybernetic Revolution should start. We assume that the 'essence' of this revolution will coincide with the name which was given to its final phase, *i.e.* it will become the revolution of self-regulating systems (see Grinin 2003, 2006a, 2007a; Grinin A. and Grinin L. 2015; Grinin L. and Grinin A. 2015a, 2015b, 2016; Grinin and Korotayev 2009; Grinin *et al.* 2017; Grinin, Korotayev, and Tausch 2016). Below we will give an explanation to this concept. This phase may be launched as a result of some specific transformations. Let us recall that the Industrial revolution began in a peculiar area of the textile manufactory – cotton production – with the solution of quite specific problems: liquidation of the gap between spinning and weaving, and then, after increasing weavers' productivity, searching for the ways to mechanize spinning. However, the solution of these narrow tasks caused an explosion of innovations conditioned by the existence of a large number of the major elements of machine production (including abundant mechanisms, primitive steam engines, quite a high volume of coal production, *etc.*) which gave an impetus to the development of the Industrial Revolution.

We assume that the Cybernetic Revolution will first start in some specific area. Given the general vector of scientific achievements and technological development and taking into account that a future breakthrough area should be highly commercially attractive and have a wide market, we forecast that the final phase of this revolution will begin somewhere at the intersection of medical technologies, biotechnologies and gene engineering (perhaps, with the involvement of nanotechnologies). Certainly, it is almost impossible to predict how innovations will develop in future. However, the general vector of breakthrough can be defined as a rapid growth of opportunities for correction or even modification of the human biological nature.[5] In other words, it will become possible to extend our opportunities to alter human body, perhaps, to some extent, its genome; to extend sharply our opportunities of minimally invasive influence and operations instead of the modern surgical ones; to use extensively means of cultivating separate biological materials, bodies or their parts and elements for regeneration and rehabilitation of an organism, and also artificial analogues of biological material (bodies, receptors), *etc.* This will make it possible to *radically expand the opportunities to prolong life and improve its biological quality*. These will be technologies intended for common use. Certainly, it will take a rather long period (about two or three decades) from the first steps in that direction (in the 2030–2040s) to their common use.

The first steps of the new revolution should produce a synergetic effect in a number of other directions, resulting in a new level (and a new large sector) of production with special characteristics. Based on the trends that have already developed during the Cybernetic revolution, as well as on advanced discoveries and innovations in various fields (genetics, medicine, biotechnology, nanotechnology, programming, AI, manufacture of customized goods, *etc.*), we assume that the future revolution will be the following most important characteristics which have already become evident today but which will be realized in their mature and mass forms only in the future.

The most important characteristics and trends of the Cybernetic Revolution are:

1. The increasing amounts of information and complication of information processing (including the capacity of the systems for independent communication and interaction).

2. Sustainably developing system of regulation and self-regulation.

3. Mass use of artificial materials with previously lacking properties.

4. Qualitatively growing controllability: a) of systems and processes of various nature (including living material); and b) of new levels of organization of matter (up to sub-atomic level and usage of tiny particles as building blocks).

5. Miniaturization and microtization as a trend of a constantly decreasing size of particles, mechanisms, electronic devices, implants, *etc.*

6. Resource and energy saving in every sphere.

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[5] To a large extent this can take place on the basis of the qualitative growth of the possibilities of modification of any living organism from bacteria to mammals. Modified elements of such organisms can even serve as a material for use in the human body, *e.g.*, antibodies (in medicine animals have long been used to obtain blood serum, necessary for the vaccine manufacture).

7. Individualization/personalization as one of the most important technological trends.

8. Implementation of smart technologies and the humanization of their functions (use of common language, voice, *etc.*).

9. Control over human behaviour and activity to eliminate the negative influence of the so-called human factor.[6]

The characteristics of technologies of the Cybernetic Revolution:

1. The transformation and analysis of information as an essential part of technologies.

2. The increasing connection between technological systems and environment.

3. A trend towards autonomation and automation of control along with an increasing controllability and self-regulation of systems.

4. The capabilities of materials and technologies to adjust to different objectives and tasks (smart materials and technologies) as well as ability to choose optimal regimes for certain goals and tasks.

5. A large-scale synthesis of materials and characteristics of the systems of different nature (*e.g.*, of animate and inanimate nature).

6. The integration of machinery, equipment and hardware with technology (know-how and knowledge of the process) into a unified technical and technological system.[7]

7. The self-regulating systems (see below) will become the major part of technological process. That is the reason why the final (forthcoming) phase of the Cybernetic Revolution can be called *the epoch of self-regulating systems* (see below).

Various directions of development should generate a systemic cluster of innovations.[8]

It would be more appropriate to denote the forthcoming revolution as *cybernetic* one first of all since its main changes will imply rapidly increasing opportunities to control various processes by means of creating self-regulating autonomous systems or through affecting the key parameters and elements that

[6] *E.g.*, to control human attention to prevent accidents (*e.g.*, in transport) as well as to prevent human beings from using means of high-risk in unlawful or disease state (*e.g.*, not allow driving a motor vehicle while under the influence of alcohol or drugs).

[7] During the Industrial Epoch these elements existed separately: technologies were preserved on paper or in engineers' minds. At present, thanks to informational and other technologies the technological constituent fulfils the managing function. And this facilitates the transition to the epoch of self-regulating systems.

[8] Thus, *e.g.*, the resource and energy saving can be carried out via choosing optimal modes by the autonomous systems that fulfil specific goals and tasks and *vice versa*, the choice of an optimum mode will depend on the level of energy and materials consumption, and a consumer's budget. Or, the opportunities of self-regulation will allow choosing a particular decision for the variety of individual tasks, orders and requests (*e.g.*, with 3D printers and choosing of an individual program as the optimal one).

are capable to launch a necessary process, *etc.* As is known, Cybernetics is the science of control. Secondly, as the most important vector of this revolution will be related to the synthesis of principles typical of all types of systems covered by Cybernetics: biological, social and technical. These principles will be combined in various controlled systems (including human body).

The forthcoming phase of the Cybernetic Revolution will be connected with self-regulating systems which can regulate themselves, responding in pre-programmed and intelligent way to the feedback from the environment. Today there are many self-regulating systems around us, for example, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Moreover, there emerge self-driving electric vehicles. Another good example is life-supporting systems (such as medical ventilation apparatus or artificial heart). They can regulate a number of parameters, choose the most suitable mode and detect critical situations. There are also special programs that determine the value of stocks and other securities, react to the change of their prices, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems have been created. But they are mostly technical and informational systems (like robots or computer programs). During the final phase of the Cybernetic Revolution there will emerge a lot of self-regulating systems connected with biology and bionics, physiology and medicine, agriculture and environment. The number of such systems as well as their complexity and autonomous character will dramatically increase. Besides, they will essentially reduce energy and resources consumption. Human life will become organized to a greater extent by such self-regulating systems (*e.g.*, via health monitoring, regulation or recommendations concerning physical exertion, diet, and other controls over the patients' condition and behaviors; prevention of illegal actions, *etc*.). As a result, the opportunity to control various natural, social, and industrial production processes without direct human intervention (which is impossible or extremely limited at present) will increase.

The fourth phase implies that in the next two decades the sector of self-regulating systems will rapidly improve and diffuse to various regions at an enormous speed. MANBRIC-technologies will be finally formed and will occupy a central place in the new production principle. At the same time, this will be a period of significant growth in life expectancy and, accordingly (against the background of low fertility), a period of rapid global ageing that will also involve still 'young' regions, including sub-Saharan Africa and South Asia (Grinin L. and Grinin A. 2015b, 2016; Grinin, Korotayev, and Tausch 2016; Grinin L., Grinin A., and Korotayev 2017, 2020).

We suppose that during the final phase of the Cybernetic Revolution different *developmental trends will produce a system cluster of innovations as is often the case with the innovative phases of production revolutions*. Thus, as for the forecasts for the final phase of the Cybernetic Revolution in our opinion *the* *general drivers of the final phase of the Cybernetic Revolution will be medicine,* additive (3D printers), *nano- and bio technologies, robotics, IT, cognitive sciences,* which together will form *a sophisticated system of self-regulating production.* We denote this complex as **MANBRIC-technologies.**

The fifth and sixth phases imply the beginning of the transition to a new economic system (see below) due to the increasing level of complexity of self-regulating systems and serious advances in medicine (see above). By this time, the process of global ageing will affect all countries. At the same time, more conservative older population may influence innovation and its direction. This will be accompanied by profound painful changes and confrontations in societies within the World System. Also, there will be a growing number of social self-regulating systems that will mostly operate autonomously, regulating the behavior of a large number of people in certain situations. They can be used to create positive or negative behavioral stimuli (carrot and stick method) to regulate human behavior.[9] This will have fundamental and contradictory consequences, which can both appeal to the conservatism of the older generation or cause a contradictory reaction.

Section 2. THE THEORY OF PRODUCTION REVOLUTIONS AND K-WAVES: COMPARATIVE APPROACH

2.1. The Correlation Between Two Theories

In this part of the article, in order to clarify some aspects of the K-waves theory we will consistently compare two theories with the help of the theory of production principles and production revolutions. In the latter theory we are especially interested in the periods from the final phase of the Industrial Revolution, *i.e.* from about 1730, to the present moment with making predictions for the coming decades. We assume that the comparison and application of two independent theories allows us to draw more reliable conclusions, as well as to understand some peculiarities in the unfolding of K-waves.

What makes us believe that the comparative approach can be useful for the analysis of the K-waves? First, both theories to a large extent investigate the same object and the same period of time and space. Second, the processes studied by both theories have very similar developmental models and produce similar effect on economy and society in general. Besides, the comparison of the theories allows making more grounded forecasts.

[9] Even today one can observe such regulating systems, *e.g.*, car insurance, when a more accurate driver pays less. The system of total regulation of social behavior is already announced in China (Chin and Wong 2016).

The unity of the object, space and time

Object. Both theories are related to major technological changes considered in terms of innovations and generational changes in technology that arise from society's aspiration to increasing production. **Space and spatial structure** are the World-System phenomena. The production principles and the Kondratieff cycles are a means of dissemination of technological and world economic innovations within the framework of the World-System. The latter is transformed under the influence of unfolding production revolutions and K-waves, while the changing characteristics transform the economic characteristics and, in turn, affect the rhythm of economic cycles. **Time**, as was mentioned, covers the period from the Industrial Revolution (when the manifestation of the Kondratieff waves in economy became more or less evident) to 2060–2070 after these years the long-wave economic dynamics may disappear or significantly transform.

Similarities in the types of processes

Both processes: a) are of cyclical nature, and the comparison of different cycles occurring in the same environment (reality) can be useful; b) are associated with fluctuations (changes) of economic and technological rhythms and characteristics. One can even trace the following patterns: a more rapid but less innovative development (the modernization phases of the production principle and A-phases of K-waves) and a more innovative but slower one (*e.g.*, the innovative phases of the production principle and B-phases of K-waves);[10] c) each new phase (wave) involves an increasingly larger part of the World-System, and at the same time they connect and integrate to more and more full extent; d) the development of production principles and long-wave dynamics are connected with overcoming of structural technological, economic and social contradictions in every society and within the framework of large parts of the World-System as well as in the World-System as a whole. At the same time the compared processes unfold in a different way in the core and periphery of the World System.

Similar impacts

Both processes: a) change the entire system of organization of production, world trade and world economic, including monetary and financial, relations; b) lead to the structuring of the World-System since with every new phase (wave) the World-System structure may significantly and sometimes fundamentally change.

[10] The theory of production principles is based on the fact that its six unfolding phases are pairs of innovative and modernization development. Thus, the first, third and fifth phases are innovative; and the second, fourth and sixth phases are modernization ones. The pauses in the rise (the slowdown in the speed of the rise) of K-waves, *i.e.* B-phases, are related with the expansion of World-System industrial core.

2.2. Differences Between Objects and Situational Definition of K-waves

As we have pointed, the concept *of the production principle is associated with the analysis of the system of the established (but previously unknown) forms of production, which far surpass the previously existing ones (in terms of their major parameters such as opportunities, scale, and productivity), and in many respects in terms of range of manufacture, etc.).*

K-waves arise only at a certain level of societal economic development, so we can consider them as ***a specific mechanism connected with the emergence and development of the Industrial production principle and the means of expanded reproduction of industrial economy.***[11] Given that each new K-wave does not simply repeat the wave motion, but is based on a new technological mode, ***K-waves in a certain sense can be treated as developmental phases of the Industrial production principle and the first phases of development of the Scientific-Cybernetic production principle.***[12]

One should realize that *the production principle is not just a process, but a cycle consisting of an initial phase, the phase of development and wide spread territorial diffusion of the new system of technologies, production, systems and paradigms related to economic management, the maturity phase, the phase of emergence of the new non-system elements and its transitional crisis, culminating in the replacement by a new principle of production.*

Thus, both concepts (the K-waves and production principles) deal with a cyclical pattern and the development of production technologies and production system as a whole; their scale surpasses the limits of a single society while their driving forces are associated with innovations. No doubt, this evidences the non-accidental similarity between the two analyzed notions and provides great opportunities for their comparison.

While emphasizing the similarities one should also mention the differences between theories:

- The production principle and production revolutions are the processes which are relevant to the whole historical human evolution, whereas K-waves, in our opinion, are only characteristic of the Industrial epoch.
- The production principle expresses the qualitative aspect of changes, whereas K-waves can be traced by quantitative indicators, which are created by various factors, including wars and inflation.

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[11] For more details see Grinin and Korotayev 2014; Grinin *et al.* 2014. Grinin, Korotayev, and Taush 2016.

[12] After the completion of the Cybernetic Revolution approximately in the 2050–2070s, the K-waves, as mechanisms of economic development are likely to disappear or change their nature and decrease their level of significance. See about it in the second article, which will be published in the next issue of the Yearbook 'Kondratieff Waves' (see also Grinin, Korotayev, and Tausch 2016).

- The innovative progress is only one aspect of K-waves along with others, whereas each stage of production revolutions marks the transition of society to a new state (attractor).
- Therefore, the unfolding of a production principle is determined by the development of the World System core, whereas the K-waves – by averaged values for the World System.
- The phases of the production principle (unlike the length of K-waves and their phases) are not equal, they are subject to a different dependence which can be expressed as follows: each subsequent phase of the production principle cycle is shorter than the previous one (and the total acceleration of the historical process shortens the duration of all phases of each subsequent production principle by several times as compared with the previous one).

Section 3. INNOVATIVE LOGICS OF ECONOMIC MODES

3.1. Technological Modes

Preliminary remarks. Below we will consider the theory of technological modes (or *techno-economic* paradigms; see the note 17 below) which is tightly connected with the theory of the long cycles. The scheme of six technological modes is presented below. Running ahead let us say about the connection between production principles and technological modes. Assuming that *the production principle is the development of a new system of technologies and production (see above), then such a cycle can also be shown as a process of the formation of new macro-sectors that are closely related to the long-wave dynamics.*

Schematically, this movement looks as follows. First, there appear new breakthrough technologies (*e.g.*, in the cotton industry) which create a large sector with new organizational forms of production (which, in particular, corresponds to the third phase of the industrial production principle, *i.e.* the completion of the production revolution). As these sectors evolve, they form a new technological mode, or a paradigm, of 'textile industry' (which at the same time means the transition of the production principle to a new phase – of maturity and expansion). Further, on the basis of the next wave of innovations the second technological mode – of 'railway lines, coal, and steel '– formed so that the Industrial production principle reaches its fifth phase – the phase of absolute dominance. Finally, while introducing the next-generation innovative technologies and forming the third technological mode ('of electricity, chemical industry and heavy engineering') the Industrial production principle moves to the sixth phase preparing the ground for the transition to a new (Scientific-Cybernetic) production principle. And then the technological modes are replaced along with the phases of this production principle. We will consider this process in detail.

3.1.1. The concept of technological modes/paradigms

N. D. Kondratieff also suggested the idea that the alternation of the downward trend with the upward trend in the long waves is characterized by an active implementation of innovations (the so-called first empirical regularity [Kondratieff 2002 [1926]: 370–374]). Joseph A. Schumpeter (1939) conceptually developed this idea and considered the uneven concentration of technological innovations as the main reason for long cycles (in his opinion, in the difficult conditions of depression, the innovative entrepreneurs more actively invest in the development and implementation of breakthrough innovations, which become the basis for the rise in the upward phase of the K-wave). Further, this innovative direction was transformed into theories, according to which the most important explanation of the nature and pulsation of K-waves is the change of *technological modes* and / or *techno-economic paradigms* (about the role of investments and the change of these modes and paradigms see the explanation of the long-wave dynamics: Mensch 1979; Kleinknecht 1981, 1987; Dickson 1983; Dosi 1984; Freeman 1987; Tylecote 1992; Glazyev 1993; Mayevsky 1997; Modelski and Thompson 1996; Modelski 2001, 2006; Yakovets 2001; Freeman and Louçã 2001; Ayres 2006; Kleinknecht and van der Panne 2006; Dator 2006; Hirooka 2006; Papenhausen 2008; see also Lazurenko 1992; Glazyev 2009; Polterovich 2009; Perez 2002).[13]

In the present article there is no point in describing the details of differences (sometimes quite significant) in the approaches of the above-mentioned researchers. When summarizing them, the main idea is as follows. Every subsequent K-wave is caused by the upsurge in the rate of basic technological innovations which arose during the downward phase of the preceding wave. Breakthrough innovations provide space for the expansion of production and cause an inflow of investments. The wave is uprising. As a result, new economic sectors are formed which create a new technological mode. The latter ultimately restructures the whole economy and eventually creates a new techno-economic paradigm.[14] Since it takes a long time for the innovations to spread,

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[13] Different researchers may give different attributes to the modes and paradigms (*e.g.*, *techno-economic* modes and *technological* paradigms), sometimes these concepts are used as synonyms, and sometimes as complementary definitions. In this article, the modes and paradigms are closely related, but not identical concepts (see the note below). The closest equivalent terms, such as a technological system and technological style can also be applied.

[14] Developing the ideas of Carlotta Perez (2002) one should note that besides the new equipment and production technologies the techno-economic paradigm includes a new system of management and business strategies and technologies, which is rooted not only among practicing businessmen, but also among economists as well as in broader strata of society. Therefore, one can assume that the mode is formed earlier and serves as the basis for the development of a paradigm. And when the changes begin to affect a number of aspects, economic consciousness and a way of doing in society are fundamentally reshaped. According to Perez (*Ibid.*), this means the final paradigm shift. Sometimes one can also speak about *the general purpose technologies* (Bresnahan and Trajtenberg 1995; Helpman 1998; for a detailed analysis of this theory, see Pol-

and restructuring of economy needs time as well, this process takes up from 20 to 30 years. The downward phase is related to the fact that the efficiency of the previous cluster of basic innovations decreases and new breakthrough technologies and technologies of wide application lag behind. As a result, it takes another 20–30 years until the core of the new technological mode is formed and a new wave starts.

One can distinguish six modes (the sixth one is anticipated in the period from 2020 to the 2060/70s).[15] The summarised scheme of K-waves and corresponding technological modes is as follows:

– the first wave (1780 – the end of the 1840s): textile industry;
– the second wave (the end of 1840 – the 1890s): railway lines, coal, steel;
– the third wave (1890 – the end of the 1940s): electricity, chemical industry and heavy engineering;
– the fourth wave (the end of 1940s – the beginning of the 1980s): automobile manufacturing, manmade materials, electronics;
– the fifth wave (the beginning of the 1980s – ~ 2020): microelectronics, personal computers, biotechnologies;[16]
– the sixth wave (*c.* 2020 – the 2060/70s), according to some assumptions, will be mostly associated with nano- and biotechnologies, as well as alternative power sources and new information technologies (see, *e.g.,* Lynch 2004; Dator 2006). However, in our opinion, this mode will be much broader and particularly related to biomedical innovations (see above about MANBRIC-technologies and also see below).

3.1.2. The disadvantages of the concept. The theories of the leading sector and macrosectors

One should agree that the major systemic innovations which affect almost every economic sectors and the general change of technological modes are the

terovich 2009). The meaning of this concept is close to the technological mode, but the meaning of the former concept is still narrower than the latter one, since there can be several general purpose technologies within one mode.

[15] See, *e.g.*, Schumpeter 1939; Freeman 1987; Rumyantseva 2003: 12–14; Glazyev 1993: 95–111; Ivanova 2003: 210; Papenhausen 2008: 789; Akayev *et al*. 2012. In fact, as in any classification there are numerous differences in the main characteristics of some or other modes, *e.g.*, some researchers 'attribute' such transitionary areas of innovations like automobile to the third wave, the others – to the fourth K-wave, *etc*. (see also the note below).

[16] Alternatively, the following definitions are used: the third Kondratieff wave was the age of steel, electricity, and heavy engineering. 'The fourth wave takes in the age of oil, the automobile and mass production. Finally, the current fifth wave is described as the age of information and telecommunications' (Papenhausen 2008: 789). This is not surprising, since the life cycle of a new technological paradigm does not fit into one phase of the production principle (*e.g.*, heavy engineering developed since the 1830s and accompanied the whole Industrial production principle). The question, therefore, is at what phase this sector becomes an innovative leader.

most important factor setting the pace of development and change of K-waves.[17] The disadvantages of this theory are as follows:

a) only production technologies are taken into account, as a result the change of the whole macrostructure of production, in particular its macro-sector and their ratio are ignored (see below);

b) it hardly takes into account that a new mode does not just substitute the old one, but from the beginning also has an additive character, that is, new branches are added to the old ones. This significantly complicates the structure of production which in turn modifies the unfolding of both medium- and long-term economic cycles;

c) the theory insufficiently covers the multistructural character of economy both of individual countries and (especially) of the World-System where the technological waves first spread from the center to the nearest societies, then to semi-periphery, and then to the periphery, to the hinterland, *etc.*

Let us consider these factors. First, one should note that these unaccounted aspects are taken into consideration in the theory of production principles, according to which a new production system is first added to the previous one, complicates it and only later begins to supersede it, but while expanding it uses the periphery as a supplier of products insufficiently produced in the centers of the new production principle. This is especially evident at the stages following the final phase of the production revolution. The first expansion involves the periphery precisely because of its subordinate position. In addition, the substitution of one production principle with another (or of the technologies of its early stages with later ones) necessarily leads to the change of types of production and fundamental demographic changes.

The macrostructural change. Every new technological mode does not simply result in the emergence of new technologies (and respective branches), which at a certain stage begin to expel the old ones. It even ignores the fact that each wave and each structure either create a new macrosector, or transform the previous sector into the one, which acquires a fundamentally new significance. So, the period of the 1950–1970s is associated with an automobile, artificial materials, *etc*. And still this was the period marked by a most rapid growth of the service sector, which, for example, by 1980 provided employment to about two thirds of the American population including almost three quarters of wom-

[17] However, this explains only the mere fact of fluctuations, but not the stable temporal regularity of the upward and downward phases (20–30 years). The latter should have changed along with the acceleration of the scientific and technological progress. But this does not happen. The temporal regularity is explained by other factors, namely the connection between Kondratieff long and Juglar medium-term cycles, since three medium-term cycles which have similar characteristics (their total duration is from 20 to 30 years) form either an upward or downward phase of the wave (for more details see Grinin 2010b; Grinin, Korotayev, and Tsirel 2011; Grinin and Korotayev 2012, 2014; Grinin, Korotayev, and Tausch 2016).

en (World Bank 2019).[18] Based on these shifts there was formed the theory of post-industrial society (Bell 1973, 1990). Let us consider the period from 1990 to the 2000s, which is usually associated with computer technologies. However, on the whole the sector of complex (which includes not only programming) and financial services was growing most rapidly at that period.

At a first glance it seems that the theory of the leading sector may reverse the situation. Different aspects of this theory were developed by S. Kuznets, W. Rostow, J. van Duijn, J. van Golderen, G. Modelski, W. Thompson, J. Rennstich, *etc.* (Kuznets 1926, 1930; Rostow 1975; Duijn 1983; Modelski 1987; Modelski and Thompson 1996; Thompson 1990, 2000; Rasler and Thompson 1994; see also Modelski and Thompson 1992; Rennstich 2002). Sometimes one and the same author interprets the concept of the 'leading sector' differently in different contexts and aspects and far from always in a clear manner. In general, the leading sector appears as an advanced innovative sector of economy, which in fact constitutes the backbone of what is also called a technological mode.[19] Within the scope of this work we use the term 'sector' in a way similar to that used in the three-sector theory of C. Clark and A. Fisher (Clark 1957; Fisher 1939), industrial and post-industrial theory of J. Fourastie, R. Aron, and D. Bell (Fourastie 1958; Aron 1967; Bell 1973): the primary sector includes agriculture and forestry, the secondary sector – industry, the tertiary sector – a service sector, the quaternary sector (which was later introduced) includes the companies providing information, communication, education and some other services. There already exists the term 'quinary sector' which includes the companies that provide healthcare services, culture and research. As we will see below (Tables 2 and 3), the quaternary and quinary sectors correlate with the fifth and sixth K-waves.

3.1.3. The integration of macrosector theory and the theory of K-waves

But still, the sectoral division does not completely reflect the formation pattern of the modes. In particular, there are disputes how the mining industry should be classified – in the primary or the secondary sector? To answer this question one should consider it from a historical point of view (the same way as we consider K-waves).

In general the historical formation pattern of macrosectors looked as follows: during the 16th – 18th centuries there appeared a new industrial sector which significantly differed from the handicraft industry. However, it was still based on manual labor, although machinery was used in the supplementary and secondary directions. In general the primary (agricultural) sector continued to

[18] It is very difficult to single out the service sector especially from the historical perspective since there is a lot of disagreement about what types of activities could be included here (for more details see Hartwell 1976).

[19] For the analysis of ideas about the leading sector see Fomina 2005: 17–19, 28, 34 *etc*.; Rumyantseva 2009; Akayev *et al*. 2011, 2012; Gurieva 2005).

dominate, but the secondary sector was mainly growing at a higher rate. Nevertheless, the opportunities for its growth were limited.

From the beginning of the final phase of the Industrial revolution the secondary sector began its fundamental transformation: with every K-wave there was a simultaneous transition from manual to machine labor in a number of industries and a large macro-sector was formed until the Industrial production principle realized itself fully and spatially. First, there appeared an industrial factory sector (mainly light industry), then the branches of the first processing cycle (steelmaking and iron smelting) and transport, and then the second processing cycle (manufacturing, chemical industry, and heavy engineering) develop especially rapidly. Every such expansion respectively increased the number of workers. This trend was common both in England and in other industrialized countries yet with account that modernization was accelerated there.[20]

We consider the leading macrosector as a set of the fastest growing sectors of economy which produce a high profit and thus attract capital. This set has the ability to accumulate a very large part of labor force.

From the historical point of view we adhere to, there is a need to modify the macrosector division. Namely, to divide the industrial sector into three branches of industry (as they historically emerged): 1) factory (light) industry; 2) heavy industry of the first cycle: mining and primary processing (associated with metal smelting, *etc*.) and transport; 3) heavy industry of the second cycle: manufacturing industry and heavy engineering. The advantage of this approach is that its scheme clearly reflects the logic of K-waves, when each wave has its own macrosector:

the primary sector – agriculture and forestry;[21]

the secondary sector – light industry;

the tertiary sector – mining and heavy industry of the first processing cycle;

the quaternary sector – heavy industry of the second processing cycle (including heavy mechanical engineering).

With the formation of the Scientific-Cybernetic production principle one can observe a step-by-step establishment of the service sector and the increase in the number of employees in it, which reached almost 80 per cent in the US (World Bank 2019).[22] And this led to the emergence of:

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[20] In this case, we always ignore the coexisting and simultaneously developing sectors and focus on the fact that the leading sector develops most rapidly and becomes the most profitable thus, concentrating large amounts of capital.

[21] This sector was dominant, and thus, leading prior to the Industrial revolution.

[22] Thus, in the course of unfolding Industrial, and then Scientific-Cybernetic production principles, first the formation of a new macrosector takes place and then, as the production principle develops, this sector grows until new sectors evolve from it. It is necessary to take into consideration that the Scientific-Cybernetic production principle is now at its second phase, *i.e.*, still in an early stage, whereas the Industrial production principle in 1830 – the 1890s was already at the fourth (maturity) phase. In this context, the modern service sector typologically resembles the

the quinary sector – the sector of general services;[23]

the senary sector – the sector of complex (highly-qualified services) services;

the septenary sector – the sector of services of self-regulating systems (see below).

The scheme of correspondence of the leading sector and K-waves:

the first K-wave: *the sector of factory (light) industry*;

the second K-wave: *the sector of mining and primary (first processing cycle) heavy industry and transport* (coal and iron ore mining, iron smelting, railway services, *etc*.);

the third K-wave: *the sector* of secondary *heavy industry* (including chemical, electrical, *etc*.) and *mechanical engineering* (including heavy, transport, electrical, automobile manufacturing);[24]

the fourth K-wave: the *sector of services* (with a predominance of less-qualified services);

the fifth K-wave: the sector of highly-qualified services (financial, informational, scientific, educational, and medical ones; these services were separated from a single service sector of the fourth K-wave).

However, one should take into account that every new macro-sector creates new layers of economy within whose structure one can observe not a mere change of one mode by another but a complex restructuring, redistribution of capital flows and resources, including labor force. As a result all the macro-sectors remain in the structure; however, some of them may thrive and develop dynamically whereas others would stagnate. Thus, the formation, development and change of macro-sectors allow clarifying the logic of development of the production principle. New macro-sectors mostly emerge and develop as supplementary ones, aimed at serving the leading sector. It is generally accepted that the technological mode of 'railway lines, coal and steel' refers to the second K-wave. However, the rapid formation of this mode began in England (as well as in a number of European countries) at the B-phase of the first wave since it was impossible to provide growth without sharp increase in shipment and fuel supply. Mechanical engineering was developing during the transition to the industrial (*i.e.*, machine) technologies of certain – the most promising, fast growing and profitable – branches of industry without affecting other

secondary (industrial) sector before the Industrial revolution (which is described above). Apparently, after the completion of the Cybernetic revolution it will be transformed as radically as the working class in the 19th century if compared with the 18th century.

[23] The sector of services appeared a very long time ago, starting with the emergence of institutionalized inequality and a stratified (class) society. But during the Industrial period, this sector underwent significant changes which in the post-war period led to dramatic changes in the employment structure (for more details see Hartwell 1976).

[24] In this context there is no contradiction that a motor vehicle can be included either in the third or in the fourth wave.

branches of industry. Primary heavy industry (coal and iron ore mining, iron, steel and non-ferrous metals smelting) increased due to the necessity to provide materials for the rapidly growing industry, and respectively, construction and transport needs (as well as military needs). It is very important that within the macro-sector the industrial branches were mutually supporting: metallurgy needed coal, and in turn coal mining needed metal. But as primary heavy industry grew, it turned out that, first, the development of technology for obtaining cheaper (high-quality) materials opened up new opportunities for their export, and secondly, there were discovered new huge niches of their application. The development vector made the previously subsidiary sector to become the leading macrosector, and simultaneously formed the forthcoming leading macrosector, the latter remaining a subsidiary one for a while. It is worth mentioning that the fifth sector of complex services will be actively developing in the next two decades not so much in the World-System center but in its periphery. Not without reason, the analysts predict a rapid growth of the middle class in the developing countries and in the world as a whole up to two billion people by 2030 (NIC 2012).

Table 2. K-waves, technological modes and leading macro-sectors

Kondratieff Wave	Date	A New Mode	Leading Macrosector	Production Principle and Number of Its Phase
The First	1780–the 1840s	The textile industry	Factory (consumer) industry	Industrial, 3
The Second	1840–the 1890s	Railway lines, coal, steel	Mining industry and primary heavy industry and transport	Industrial, 4
The Third	1890–the 1940s	Electricity, chemical industry and heavy engineering	Secondary heavy industry and mechanic engineering	Industrial, 5/6
The Fourth	1940-e – the early 1980s	Automobile manufacturing, manmade materials, electronics	General services	Industrial, 6, Scientific-Cybernetic, 1
The Fifth	the 1980s –~2020	Micro-electronics, personal computers	Highly-qualified services	Scientific-Cybernetic, 1/2
The Sixth	the 2020/30s – the 2050/60s	**MANBRIC-technologies** (med-bio-nano-robo-info-cognitive)	Medical human services	Scientific-Cybernetic, 2/3

3.1.4. The leading sector, the change of production principles and the sixth K-wave

It is important to note that while the first three K-waves have technological modes and leading sectors significantly correlating in their names, the situation is different with respect to the last two K-waves: new modes lead to the creation of sectors that significantly differ from the typical industrial ones. This is no coincidence at all since it marks the transition from the Industrial to the Scientific-Cybernetic production principle. That is the reason why the explanation of the significant changes in the vector of the leading sectors starting from the post-war period needs the theory of the production principles. The latter emphasizes the changing activities as a part of total changes which occur in two cases: 1) as a result of the initial phase of the Industrial revolution, when a fundamentally different (and much more productive) type of economic activity arises which has a large economic niche; 2) when this type of economic activity acquires mature features as a result of the completion of the Industrial revolution. Since the final phase of the Cybernetic revolution may start during the sixth wave one can assume that the core of the new leading sector will be formed by the self-regulating systems services (with medical and biological, humanitarian services at its core).[25] This sector will become especially important at the downward phase of the sixth K-wave (2060 – the 2070s) and will continue to develop beyond this wave.

Table 3. The sixth K-wave: expected technological mode and leading sector

Kondratieff Wave	Date	A New Mode	Leading Macrosector	Production Principle and Number of Its Phase
The Sixth	the 2020/ 30s – the 2050/ 60s	**MANBRIC-technologies** (medical-additive-nano-bio-robo-info-cognitive)	Medical human services	Scientific-Cybernetic, 2/3

During the unfolding revolution of 'self-regulating systems', as mentioned above, there should take place the transition to various technologies which will be aimed at creating different (in size and complexity) self-controlled, self-

[25] Humanitarian services in a broad sense aimed not only at intellectual services but also at maintaining the physical and mental human existence by organizing various conditions, influencing social and recreational systems as well as increasing control capabilities of previously uncontrolled physiological processes, which also refer to medical services (*e.g.,* associated with the population ageing, with the adaptation of people with disabilities due to the creation of artificial organs or receptors of new cognitive systems to control health, *etc.*). But these services will be provided within the whole complex of MANBRIC technologies.

regulating and self-adjusting systems. Accordingly, they will be used to control and regulate all kinds of industrial, household, medical, natural and biological processes and various needs of people, including producers and consumers. Thus, a whole cluster of general-purpose technologies can emerge here (GPTs). In particular, the technologies used for individual production services (on a by-order basis) may become very popular. These technologies allow the implementation of a variety of individual plans and projects (so-called 3D printing can appear a prototype of such technologies in some ways). There will be also created various individual programs by order to ensure the most optimal mode (physiological, physical load, *etc.*) taking into account the individual characteristics of a customer, local territory, *etc*. It should be emphasized that providing biomedical humanitarian services will increasingly be implemented by self-regulating systems including robots. Besides, under completion of the fifth K-wave in the 2020s and in the process of growth of the sector of complex services there may start a noticeable process of replacing simple and less complex services due to new technologies associated with 'smart' technologies.

By the end of the 21st century one will probably talk about the technologies for creating individual genetic programmes.

In other words, the focus of the leading sectors of economy will be shifted from the sphere of industrial occupation that we got used to and will be directed towards the fields that were not previously economic at all or were slightly related to the economy. This will eventually lead to the disappearance of K-waves as one of the forms of unfolding technologies.

3.1.5. On the peculiarities of the change of the leading sector and economic paradigm

Thus, during the first three K-waves, in accordance with the logic of development of the Industrial production principle, there occurred the transition from the agrarian and manufacturing and handicraft macrosectors to the industrial macrosector which gradually expanded. First, there appears the sector of the factory industry (light industry), then – the sector of mining and primary heavy industry (with a new transport subsector), and finally the sector of the secondary heavy industry, including mechanical engineering. This logic manifested in the so-called Kondratieff's 'third regularity' (2002 [1926]: 376–379), according to which the downward phases of (the first three) K-waves are followed by the long depression of agriculture.[26] The depression was expressed in a rather sharp drop in prices for agricultural products. Why did it happen just at the downward B-phases? N. D. Kondratieff explains this by the fact that agriculture is less flexible to falling prices and more difficult to adjust (Kondratieff 1928). More-

[26] S. Kuznets in his works (1926, 1930) also pays considerable attention to the relationship between two sectors: agricultural and industrial. During the period when the prices on agricultural production dropped significantly, a lot of people were concerned with these problems.

over, it is clear that in the conditions of industrial growth the demand for agricultural products (food and raw materials) increases, and respectively one can observe the rise in prices, whereas during the depression the demand decreases (because it is the city that determines the market capacity).[27] At the same time, due to the inflexible agricultural supply, the decline rate may be even larger than in industry. After all, the reduction in cultivated areas and decline in production proceed much more difficult than in industry, besides many producers are the owners or tenants and they cannot reduce the labor force participation, as in case with the employees in factories. It is interesting to note that agriculture of that period was less subjected to fluctuations of the medium-term Juglar cycles (which is confirmed by the purely industrial nature of the latter), but it is more susceptible to long depressive periods (expelling small-scale production) fitting the duration of the downward phases of K-waves. In addition in the last decades of the 19th century the development of transport triggered a rapid growth of the world agricultural market (especially corn market) which strengthened the deflationary trend.

The B-phases of K-waves are the periods of more active expansion of the center to the periphery and more active involvement of the periphery into the economic relations of the center. The involvement of the (primarily agricultural) resources of the periphery could increase the supply and, accordingly strengthened the deflationary trend. For example, the considerable decline in wool prices especially after 1825 (see Kondratieff 2002 [1926]: 377, Table 2), is explained largely by the tremendous increase in wool imports from Australia to England, which increased from 1.8 million pounds to almost 30 million pounds in the period from 1829 to 1848 and exceeded by two times the indicators of the previously leading import of wool from Germany (Malakhovsky 1971: 46).

Let us mention some important provisions related to the paradigm shifts. First, it should be noted that the leading sector of the next wave is formed within the current one, and the leading sector of the preceding wave by the volume produced in the current wave can take the leading position. Thus, one can observe several generations of innovations at the same time. For example, during the fourth K-wave (1939–1984) the following technologies were actively developed:

• automobile and electrical engineering, including household appliances, which reached their peak during the third wave;

• production of artificial materials, automation, non-computer electronics (leading sectors of the fourth wave);

• computer technologies (the main technologies in the future fifth wave);

[27] Nevertheless, it is less clear with respect to the B-phase of the first wave (in particular, between 1816 and the 1840s). Although, one should certainly take into account that prices were decreasing from a sufficiently high level of the military (Napoleonic) period.

• the technology of the third wave (heavy engineering) and even of the second (mining, metal smelting, *etc.*).

Second. It should be clearly understood that there is no single rhythm in the course of changing of one wave of innovation (technological mode) by another. Sometimes a new wave of innovation rushes when the previous one has not yet subsided, and this results in a higher rise in the upward phase of the Kondratieff cycle (this explains very high GDP growth rates in 1950 – the 1960s). And sometimes, just on the contrary, the new wave is delayed, and the previous one is already exhausting itself, then the rise in the upward phase of the Kondratieff cycle is weaker (this explains the weaker rise, especially in the center of the World-System in the 2000s). Thus, each shift has important features which are substantially determined by the rhythm of production revolutions and by the phase of the production principle of any given wave or phase (these details are analyzed below).

Third. It is necessary to mention the important features of the paradigm shift model which have remained unnoticed.[28] In fact, we should talk about different types of 'behavior' of the paradigm at its initial and mature phases. To be more precise, as long as a new paradigm is formed and developed, the result for the old paradigm will not be fatal, but rather positive. But when a mode transforms into the paradigm, its 'behavior' towards its predecessor becomes aggressive and intolerable. By the way, one should understand this when taking into account the development of the sixth technological mode which will start to form on the basis of the technologies related to self-regulating systems (first of all, as we have already mentioned, in the field of bio-medical, humanitarian services). Though until now these new technologies do not face any serious opponents, but subsequently this may cause strong resistance. We can easily imagine this in respect to the electric and self-driving cars. Taking a secondary position, a small niche, they serve a kind of advertising to automotive and other concerns, distract attention from the problems of ordinary cars, and open a new niche for investment. But just imagine the widespread introduction of self-driving cars and the replacement of not only taxi drivers, but also truck drivers, the actual depreciation of the cost of a huge car fleet and eventually the displacement of the old auto giants. Probably, it will cause massive protests and the increase of real and imaginary fears, split in society, *etc.*

Let us consider in more detail different 'behavior' of a new mode at different phases. During the first half of the way the formation and strengthening of a new mode leads not so much to the replacement of the old paradigm, but rather to strengthening it by means of expanding and including those branches which need to be developed. Therefore, there is a loyal attitude to innovations. This is also

[28] Despite the fact that C. Perez (2002) paid much attention to the analysis of the paradigm shift in her monograph, she did not take into account the fact that the new paradigm behaves differently in different periods of its expansion which leads to different consequences.

explained by the fact that new technologies appear not simply 'out of the blue', but as a need for certain services and goods (*e.g.,* in case of inefficient technologies or low capacity technologies or their high cost, *etc*.). Thus, during the initial phase new technologies replace the old ones to a lesser extent, but to a greater extent supplement them. For quite a long time, new technologies threaten only a relatively small part of the economy. Herewith, this creates a kind of symbiosis between old and new technologies. For example, for more than two decades the cotton spinning factories coexisted with numerous craftsmen.[29] And the number of hand weavers during the first period of the Industrial revolution even significantly increased and their economic situation was quite satisfactory (see, *e.g.,* Mendelson 1959; Tugan-Baranovsky 2008 [1913]). As early as in 1831 (*i.e.,* many years after the invention of the power loom by William Horrocks), in England, hand weavers accounted for more than 80 %, and factory weavers – less than 20 % (Tseytlin 1940). C. Perez gives an illustrative example of such a temporary expansion of the old sector due to the growth of the new one, taking this situation as an inexplicable 'strangeness' rather than a regularity. She notes, 'Strange as it may appear, the number of horses increased over the next fifty years (after the start of the construction of railways. – L. G.) due to the increased need for transport from railways and ships to homes' (Perez 2011: 66, note 1). But there is nothing strange about it. Just on the contrary, this is how the situation develops in many cases. With the introduction of oil coal mining increased. With the introduction of plastic metal smelting increased. Today, with the increase in the number of computers, paper production is still growing, but the time will come, and it will slow down with the reduction in the production of paper books, newspapers and paper products.[30]

A new mode which transforms into a new techno-economic paradigm at the peak of its development begins to manifest itself much more aggressively. Growth opportunities, *i.e.* supplements to the old paradigm have already been exhausted, so the replacement of the old technologies takes place. Additive characteristics are increasingly giving way to substitutive ones. Thus, by the mid-1840s there were 60,000 hand weavers for 150,000 machine weavers, and fifteen years later hand weaving in England almost completely disappeared (Tseytlin 1940). But a complete paradigm shift can only be achieved through the restructuring of society. Restructuring occurs primarily due to the fact that

[29] The famous spinning 'Jenny' (by James Hargreaves) with the invention of which the beginning of the Industrial revolution in the late 1760s is associated did not destroy the home system of spinning at all. On the contrary, due to the lack of a mechanical engine it spread mainly in small-scale handicraft production, thus, at first even strengthening it. In 1788 there were about 20,000 'Jennies' in England scattered throughout the small spinning workshops and the houses of village spinners (see Tseytlin 1940).

[30] The paper print production, by the way, was also growing for a long time along with the increase in the amount of electronic information, and for two decades newspapers have been presented in two formats. Only in recent years there is a crisis in the book publishing industry.

the old industries, without leaving physically together with the old paradigm start decaying. Their profitability decreases, as a result of which capital assets move to the branches of the new paradigm. After that, sometimes gradually and imperceptibly, and sometimes dramatically and revolutionarily, the process of changing views, institutions, preferences, *etc.* takes place.

The change of technological modes and techno-economic paradigms is a long process which takes place both at the upward and downward phases, but due to the characteristics of the phases themselves and their medium-term cycles the nature of this change is somewhat different. Due to the general rise and inflationary trend, figuratively speaking, there is more space at the upward phases, so it is easier for the old sectors to hold the position in such general upward movement. The higher demand makes even products created in the old way cost-effective. Thus, *at the upward A-phases of K-waves, the effect of changing modes and sectors is more additive and less substitutive than at the downward phases.* The deflationary trend, while significantly reducing the rate of return, is more severe with respect to outdated technologies. Therefore, at the downward B-phases, the effect of changing modes, sectors and paradigms usually appears to be more noticeable and more severe. Lower demand, lower prices and lower rates of return, given that many costs cannot be reduced, even in the conditions of depression, are forcing entrepreneurs to search for ways to increase efficiency and productivity. The change of equipment and technologies as a whole is the most important in this situation. *Therefore, at the downward B-phases of K-waves, the effect of changing modes and sectors is more substitutive and less additive than at the upward A-phases.*[31]

3.1.6. The change of technological modes as their increasing diversity

The economy of every country is known to comprise different sectors, starting with agriculture (but the level of technological development of the sectors depends on the general level of the economy: the higher it is, the more equal is the technological level of the sectors). The increasing diversity of modes in the economy of each country (*i.e.,* the coexistence of three or four paradigms within one economy) was not taken into consideration while analyzing the development of K-waves).

However, if in a particular sector of the economy a sector that is no longer a leading sector very rarely becomes a leading one,[32] then within the global economy, due to the international division of labor, the situation is different. The reason is that the former technologically leading sectors, when leaving the

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[31] Weaker deflation due to the complete abandonment of the gold standard in the last 40 years, however, has not eliminated the problems of decreasing demand and profit. But during the last three or four years' deflation has returned, as well as all the problems inherent in the period of falling prices.

[32] This may happen, *e.g.* if a country specializes in agricultural production as in case with New Zealand or in mining industry as in oil-producing countries.

World System Core, move to other parts of the World System, not as leaders with the prefix 'ex-' but as actual leaders.[33] First, this occurs in underdeveloped countries via the development of their own production in the ex-leading sectors by means of adopted (imported) technologies. Second, this happens due to the actual transfer of old sectors to the less-developed countries (as has already been mentioned, this process has been going on during the last two or three decades within the process of the deindustrialization of the West). Thus, the structure of the international division of labor which is generally the World System's most important axis reflects the historical succession of leading sectors to a certain extent and makes it possible for a new mode of production to emerge in the World System core. The last aspect is taken into consideration insufficiently.

But the new wave of technologies requires not only an innovation cluster but also a 'free space' in the leading countries in order to re-orient the work force. While capital and labor are being reoriented, the old basic commodities should be produced elsewhere in sufficient quantity so that the economy with an emerging new leading sector could have more opportunities. This means that it should get rid of the less-innovative commodities. Otherwise, in the situation of basic commodities shortage, it would be more difficult to concentrate on innovative ones which, despite their importance, becomes less connected with people's basic needs (compare food, clothes, and even metals, on the one hand, with Internet and specific services, on the other). Such a release becomes possible due to the import of goods whose production becomes unprofitable. Far from everything is logical here; the process of transformation proceeds with difficulty, but the logic of the process contributes to the World System's economic growth and provides opportunities for innovative breakthroughs in different regions of the World System. In fact, this is a way to introduce new economies into the operating arena of a new production principle. Even if a number of societies do not fit the principle yet (as at present many countries of the world do not really achieve the appropriate level for the Scientific-Cybernetic production principle), anyway to a certain extent they are getting involved in it (at least in large cities where there already exist some advanced technology centers). Moreover, they become a part of the international division of labor which is formed under the influence of a new production principle.
Therefore, the adaptation of new waves of innovations should be supported by technology and capital transfer to the less developed parts of the World System

[33] This is true even with regard to agriculture if considering, *e.g.* the way it was developing during the last decades of the 19th century and the first decades of the 20th century in the colonized territories of the West: USA, Canada, Australia, New Zealand, and also Argentina, Russia and India to a certain extent. In other words the primary sector began to develop in the territories where it already existed, but transformed from non-commodity to commodity, or in the areas where a 'zero' sector used to be (we mean hunting, gathering), or even in uninhabited areas.

in order to compensate for the volume and range of commodities not produced anymore in the core. It should be noted that such restructuring in the form of intensively growing sectors of economy is observed not only at the upward phases of K-waves. We can also notice that in the downward phases of K-waves there are also economies or their groups that grow faster than the center. This can be explained by the increased export of technology and capital in such periods. Such economies either present the periphery of the World-System, which is transforming into its semi-periphery, or countries and regions competing with the center.[34] As we have already mentioned, the most active expansion of the center to the periphery is accounted for the downward phases of K-waves (see also Korotayev and Grinin 2012; Grinin, Korotayev, and Tausch 2016). New economic strategies can also be formed during the downward phases of K-waves, which make it possible to provide a definite breakthrough for lagging countries. The development model through state planning which was implemented by different countries, starting with Germany of Bismarck's time and Japan after the Meiji Restoration Era to the USSR can be considered one of such strategies; and the other strategy is the East Asian model, originally created in Japan during the A-phase of the fourth wave (1950–1970), but which transformed during the downward phase of that wave since the late 1960s in South Korea, in Taiwan, Singapore and Hong Kong. Now this model is being successfully implemented into other societies.

Note that the complete cycle of such transfers in the world has a duration substantially exceeding the length of one K-wave. So, the transition of the textile industry (the oldest of the industrial ones) has not yet been completed: China passes the baton to Bangladesh, Vietnam and some other countries, and then somewhere else (*e.g.,* a few decades later to the countries of tropical Africa, unless technological development makes ineffective the use of cheap labor in it). Thus, in some cases this process is taking place occurs throughout three or four K-waves, basically coinciding with the duration of the production principle.

Taking into consideration the abovementioned, the delay in the deployment of a new innovation cluster may be related to the fact that the structure of the World-System itself is not absolutely prepared for this. The degree of its readiness largely depends on the characteristics of the phase of the production principle at which it is now being developed.

[34] Thus, during the downward phase of the second K-wave (1873–1895) England experienced a severe economic depression, whereas the economy of such countries as the United States and Germany beginning to claim the role of a new center in Europe, and also the 'white' British colonies continued to grow. Countries with a totalitarian economic system developed rather quickly at the downward phase of the third K-wave (in the 1930s). The so-called 'Asian tigers' and then China appeared at the downward phase of the fourth K-wave (1970 – the 1980s). And the economy of many developing countries successfully grows at the downward phase of the fifth K-wave.

Instead of Conclusion. The Industrial Revolution and the Formation of the System of Industrial Cycles

We have compared some aspects of the theory of the production principles and K-waves. Typically, the idea of changing macro-sectors rather successfully may complete both theories. *If it is assumed that the production principle is a cycle consisting of the initial phase, development of the new system of technologies and production, its maturity, and then the emergence of the new non-system elements indicating the possibility of transition to a new production principle, then such a cycle can also be shown as a process of the formation of new macro-sectors, which are closely related to the long-wave dynamics.* First, there appear new revolutionary technologies that lead to the formation of the important sectors with a new approach to economic management. These sectors, as we have seen, for quite a long period of time become 'surplus', supplement to the old ones. Then the new generations of technologies of the young production principle are introduced, which bring its characteristics to maturity, extend them to new branches until it becomes absolutely dominant. Further there emerge the generations of technologies, providing the possibility of transition to a new production principle.

The application of a comparative method also allowed understanding the nature and driving forces of K-waves on a global scale. In particular, *we have seen that the Kondratieff cycles are one of the most important forms of implementing the Industrial production principle (which is implemented in the form of waves of innovative development of the economy)*. This indicates that K-waves (at least in economics) cannot be considered as independent phenomena that can be applied absolutely to any period and process. The fact that their appearance was caused by the emergence of a new type of productive forces makes it possible to see their similarity with other economic cycles.

It is no coincidence that the first clear manifestations of the long-wave processes of economic dynamics coincided with the Industrial revolution, namely the 1780s (see, *e.g.,* Grinin 2007a; Grinin and Korotayev 2015a). We can assume that the transition to machine industry created the phenomenon of Kondratieff waves (or K-waves) in the economy (or allowed at least the ability to see them clearly).

During the completion of the Industrial revolution (*i.e.*, during the last third of the 18th century), the productive forces began to acquire a new fundamental characteristics – 'a desire' for a steady and annual expansion (on this characteristics see, *e.g.,* Kuznets 1966; Gellner 1983; Abramovitz 1961; Grinin 2007a, 2006a, 2010, 2012b, 2013a; Grinin and Korotayev 2010, 2012). The emergence of this property led to the emergence of various forms of cyclical dynamics connected with various limitations (that hinder such an expansion) and attempts to overcome them. This forward movement, of course, could not be uniform, and must obey different rhythms; their common property was the alteration of acceleration and deceleration phases caused by the exhaustion of available resources for growth, market saturation, reduced profit margins and so on.

Innovations have become the most important way to overcome different obstacles. Herewith, various forms of cyclicity appeared, whereas the long-wave cyclic dynamics (with each cycle more and more clearly associated with innovations) became the first such cyclic form of development. Another form, more visible and more recognized by economists was the medium-term Juglar cycles, ending with a more or less severe cyclical crisis. The first cycle of such kind can be dated to 1818–1825. It is rather symptomatic that this cycle occurred after the completion of the upswing phase of the first K-wave. Thus, both the Kondratieff long waves and medium-term Juglar cycles are associated with the same fundamental change – the transition to a new pattern of development of production, *i.e.* extended production based not only the involvement of new resources but also on new technologies. The above mentioned further strengthens the idea that K-waves may be fully realized only through the medium-term cycles.[35] We will continue to develop this subject in the second article.

One can also note that *the relationship between the long and medium-term cycles, on the one hand, and the tendency of the modern productive forces toward their continued expansion, on the other, has a common denominator, which includes innovation as an important component*. Hence it is evident that both types of the economic cycle associated with a longer (and deeper) cyclic change of the productive forces – production revolutions that are leading to the movement from one principle of production to another. Kondratieff called the long waves the cycles of conjuncture, since these fluctuations were clearly traced in the dynamics of prices (prices are determined by supply and demand, *i.e.,* the conjuncture). However, medium-term cycles are subject to the influence of short-term economic changes to a much greater extent than the long ones (at the same time, they are significantly shorter than the short Kitchin cycles of 3 and 4 years).

One of the main reasons for changing the trend of Kondratieff waves, as it is shown in various studies (see above), is the development and implementation of large clusters of basic innovations (the pace of the emergence and the spread of which also resemble waves), leading to the change in the economic and technological paradigm. The medium-term cycles and cyclical crises are to a large extent associated with fluctuations in amount of investment and benefits from them, some of which are beneficial, and others are not. At the same time,

[35] Since the depression years of medium-term cycles altogether determine the overall downward trend at the downward phases of K-waves, whereas aggregated booms of medium-term cycles determine the upward dynamics (for more details see Grinin 2010; Grinin and Korotaev 2012).

major innovations are being introduced very unevenly in economy, first in certain enterprises, then in certain branches, *etc*. Investment flows in the process of going through medium-term cycles undergo selection: less successful are eliminated and more successful continue to develop. Therefore, the medium-term cycles are associated with the involvement and exhaustion of resources for development on the one hand, as well as price and speculative bubbles (and their connection with K-waves is already shown in aggregates of price changes during a certain period), on the other hand – with long-term investments and benefits from them, in this respect they are structural units that create the K-wave (again in the context of innovations, *i.e*. long-term investments).

On the whole both medium and long cycles are the means of development since the latter is a cycle of replacing of one production organization model (agricultural model, based on manual labor and using animal power) by another one (industrial model, based on mechanized labor using water power and steam). At the same time the cycle of the industrial production principle beginning from its origin to completion included several techno-economic paradigms. In the course of any of these economic cycles, structural technological and social contradictions in certain societies and in the World System are overcome.

Our research into the connection between the theories of production principles and long cycles will be continued in the next issue of *Kondratieff Waves.*

Announcement of the Second Article

Correlation of the phases of the Industrial production principle and K-waves. In two tables (4 and 5) below we show a certain and quite significant correlation between K-waves and phases of the Industrial and Scientific-Cybernetic production principles. Certainly, there can be no direct duration equivalence of both K-waves and their phases, on the one hand, and the phases of production principles – on the other hand (see Table 4). However, we have succeeded in establishing a more complex ratio according to which *at the average one K-wave correlates with one phase of the Industrial or Scientific-Cybernetic production principles.* On the whole beginning from the 1760s and ending in the 2060s, six and a half K-waves coincide with six and a half phases of the Industrial and Scientific-Cybernetic production principles, although some phases coincide with one and a half wave, and some – only with half a wave. As should be clear to the reader, such a correlation is not coincidental, as innovative development of the Industrial and Scientific-Cybernetic production principle is realized through long Kondratieff cycles which are largely defined by large-scale innovations.

Table 4. The Phases of the Industrial production principle and Kondratieff waves[36]

Phases of the Industrial Production Principle	The Third Phase, 1730–1830 **≈ 100 years**	The Fourth Phase, 1830–1890 **≈ 60 years**	The Fifth Phase, 1890–1929 **≈ 40 years**	The Sixth Phase, 1929–1955 **≈ 25 years**	Total: ≈ 225 years, from 1760 – **195 years**
The Number of the K-wave	Zero (B-Phase) / The First Wave (A-Phase), 1760–1817 – about **60 years**	The End of the First Wave / The Second Wave, 1817–1895 – more than **75 years**	The Third Wave, The Upward Phase, 1895–1928 – more than **35 years**	Third wave, The Downward Phase, 1929–1947 – about **20 years**	About **190 years**
The Phase of K-wave	B-Phase of the Zero Wave,[37] 1760–1787	The Second half of the Downward Phase, 1817–1849	The Upward Phase, 1895–1928	The Downward Phase, 1929–1947	
The Phase of K-wave	The Upward Phase, 1787–1817	The Upward Phase, 1849–1873			
The Phase of K-wave		The Downward Phase, 1873–1895			

As regards the Industrial principle of production, it should be noted that the beginning of the B-phase of the zero K-wave did not coincide with the very beginning of the third phase of this production principle (but with the period closer to the middle of it), so it can be assumed that three and a half waves coincide with three and a half phases of the Industrial production principle!

The fourth, fifth and sixth K-wave coincide with the first three phases of the Scientific-Cybernetic production principle. The sixth wave mainly corresponds to its third phase. We assume that the sixth wave, which will begin in the 2020s, will then be reinforced by the final phase of the revolution of self-regulating systems and thus its A-phase will be as powerful as the A-phase of

[36] For simplicity, we take specific years for the beginning and end of the phases, although it is clear that such a transition takes place within a certain period.

[37] We took as the beginning a zero K-wave which downward phase coincided with the beginning of the Industrial Revolution, *i.e.* the 1760s (as we know, it is downward phases that are especially rich in innovations).

the fourth K-wave, and its B-phase will be less depressing and shorter due to unexpended innovations.

Thus, three phases of the Scientific-Cybernetic production principle coincide with three K-waves (the fourth and sixth). This correlation is even more significant due to reduction of duration of the phase of the Scientific-Cybernetic production principle.

Table 5. The Scientific-Cybernetic production principle (initial phases) and Kondratieff waves

Phases of the Scientific-Cybernetic Production Principle	The first phase (initial phase of the Cybernetic Revolution) 1955–1995 **≈ 40 years**	The second phase (middle phase of the Cybernetic Revolution) 1995 – the 2030s/40s. **≈ 35–50 years**	The third phase (final phase of 'self-regulating systems' of the Cybernetic Revolution) the 2030s/40s – the 2055/70s **≈ 25–40 years**	Total: **≈ 100–120 years**
K-Wave and Their Phases	The Fourth Wave, 1947 – 1982/1991 **≈ 35–45 years**	The Fifth Wave, 1982/1991 – the 2020s. The beginning of the upward phase of the sixth wave (2020– the 2050s) **≈ 30–40 years**	The sixth wave, 2020 – 2060/70s. The end of the upward phase and downward phase (the latter ≈ 2050 – 2060/70s) **≈ 40–50 years**	About **110–120 years**
K-Wave and Their Phases	Upward phase, 1947 – 1969/1974s	Downward phase of the fifth wave, 2007– the 2020s		
K-Wave and Their Phases	Downward phase, 1969/1974 – 1982/1991	Upward phase of the sixth wave, 2020– the 2050s.		
K-Wave and Their Phases	The fifth wave, 1982/1991 – the 2020s, upward phase, 1982/1991 – 2007			

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