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The Dynamics of Kondratieff Waves in the Light of the Theory of Production Revolutions*

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Abstract

This article attempts to clarify and develop some important aspects of the theory of long cycles (K-waves). For this purpose, the Kondratieff waves theory is correlated with the theory of production revolutions which analyzes the regularities of major technological breakthroughs in history. Both theories analyze the processes of cyclic nature related to the innovative technological development of the World-System. The authors have identified a significant correlation between the duration of the Kondratieff waves and their phases, on the one hand, and the phases of the production principles, on the other. The article consistently describes the features of each Kondratieff wave (and its phases) as stages of the world economic and technological process. At the same time, a number of features of certain Kondratieff waves and their phases, which are insufficiently explained by the theory of long cycles, become more comprehensible if one applies the conclusions of the theory of production principles. Based on the comparison of both theories, the authors make some predictions concerning the development of the fifth and sixth K-waves for the next 40–50 years.

Keywords: *production revolutions, production principle, Industrial revolution, Scientific and Information revolution, Cybernetic revolution, Kondratieff waves, Juglar cycles, World-System, core, periphery, waves of innovation.*

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* This research has been supported by the Russian Science Foundation (Project № 20-61-46004).

This article is a continuation of the article 'Kondratieff Waves, Technological Modes, and the Theory of Production Revolutions' published in the Yearbook *Kondratieff Waves: The Spectrum of Opinions* / Ed. by L. E. Grinin, and A. V. Korotayev, pp. 95–144. Volgograd: Uchitel, 2019.

Introductory Remarks

This paper is the second of two interrelated papers that attempt at clarifying and developing some important aspects of the theory of long cycles, or Kondratieff waves (hereinafter K-waves). 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 major technological revolutions in history. The 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 article (Grinin 2019) the main ideas of the theory of production principles and production revolutions were presented (in this article, for the reader's convenience these main ideas are briefly outlined). Its main part was devoted to the aspects and restrictions of the *theory of technological modes* which is used by many researchers to explain the reasons of long-wave dynamics, and to the comparison of the findings with the findings of the theory of production principles and production revolutions. The established correlation between technological modes, macrosectors and production principles is presented in Tables 1 and 2.[1]

Table 1. K-waves, technological modes and leading macrosectors

Kondratieff Wave	Date	A New Mode	Leading Macrosector	Production Principle and Number of Its Phase
1	2	3	4	5
First	1780–the 1840s	The textile industry	Factory (consumer) industry	Industrial, 3
Second	1840–the 1890s	Railway lines, coal, steel	Mining industry and primary heavy industry and transport	Industrial, 4

[1] About technological modes and their corresponding K-waves see Mensch 1979; Kleinknecht 1981, 1987; Dickson 1983; Dosi 1984; Freeman 1987; Tylecote 1992; Glazyev 1993, 2009; 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 Polterovich 2009; Perez 2011; Akaev *et al.* 2012; Akaev *et al.* 2011.

Continuation of the Table

1	2	3	4	5
Third	1890–the 1940s	Electricity, chemical industry and heavy engineering	Secondary heavy industry and mechanic engineering	Industrial, 5/6
Fourth	The 1940s – the early 1980s	Automobile manufacturing, manmade materials, electronics	General services	Industrial, 6, Scientific-Cybernetic, 1
Fifth	The 1980s – 2020	Micro-electronics, personal computers	Highly-qualified services	Scientific-Cybernetic, 1/2

Table 2. The sixth K-wave: assumed technological mode and leading macrosector

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

In the present paper, the features of each of the K-waves (and of their every phase) are consistently analyzed as stages of the world economic and technological process in the light of the theory of production revolutions and production principles. It is shown that a number of features of certain K-waves and their phases, which cannot be explained by the theory of long cycles, can be logically clarified by using the conclusions of the theory of production principles which is significantly supplemented by the ideas of K-wave theory and the analysis of each of them. We will demonstrate that there is a meaningful correlation between the duration of K-waves and their phases, on the one hand, and the phases of the production principles, on the other. Based on the comparison of both theories, there have been made some forecasts concerning the development of the fifth and the sixth K-waves for the next 40–50 years.

The Concept of Production Principles and Production Revolutions

We have been elaborating the theory of production principles and production revolutions for over thirty years. It is presented in the most complete form in a number of our monographs and articles to which we do not refer here (*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 2017a, 2017b, 2020) but we recommend these works to our readers for a more detailed understanding of the theory of production principles. We suppose that the main ideas of the theory of production revolutions and production principles should be presented again in this paper. According to our theory, the whole historical process can be most adequately divided into four large periods. As the basis for periodization, the concept of production principle was proposed by which the major developmental stages of the world productive forces are described. We single out four production principles:

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

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 made the main production become concentrated on industry and was 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-Information** (see below) and resulted in the emergence of efficient information technologies, new materials and types of energy, and spreading of automation.

The Structural Model of Production Revolutions

Within the proposed theory framework we suggest a fundamentally new idea that each production revolution has a common internal cycle consisting of

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[2] Hereinafter Industrial.

[3] Previously we denoted this production principle as Scientific-Information, which is quite proper for its initial stages (corresponding to the initial phase of the Cybernetic revolution, namely: the scientific-information phase). In our interpretation, the attribute 'cybernetic' quite reflects the essence of the term 'information' (see below). In this article we will sometimes use the both concepts Scientific-Cybernetic and Scientific-Information as synonyms.

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 innovative phases there is a *modernization* phase – a very important long period when new technologies of production principle (which appeared during the initial innovative phase) are distributed, enriched, and diversified, thus creating prerequisites for a final innovative breakthrough.[4]

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).

The 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).

The Industrial Revolution: **the initial** innovative phase starts in the 15th century with the development of navigation, water-powered equipment and 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.

The 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. Therefore these revolutions can be chosen as the basis for periodization of the world historical process. The beginning of each production

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[4] *E.g.*, during the modernization phase of the Agrarian Revolution local varieties of plants and breeds of animals (borrowed from other places) were created. This process is similar to the process of adaptive radiation within biological macroevolution.

revolution marks the thresholds between the corresponding production principles (see Table 3 below).

The Structure of a Production Principle

The production (or technological) revolutions are fundamental technological breakthroughs which mark the emergence and development of new production principles which gradually change social and economic relations. It is a long-running process. 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 part 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). The production revolution, which takes up at least a half of the period of production principle (in fact more than a half, see Table 3) 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 production principle is a six-phase cycle.

1. *The phase of the starting production revolution.* A new and yet underdeveloped 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.* During 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 phase of non-system phenomena or a preparatory phase.* The intensification leads to the emergence of non-system elements which prepare the rise 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 3. 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. 2015a, 2016). The duration of phases (in thousand year intervals) is marked by the bold-face type. The duration of phases of the Scientific-Cybernetic production principle is hypothetical.

Section 1. The Industrial Production Principle and the First, Second, and Third K-Waves

Thus, *the production principle is a concept which designates the major development stages of the world productive forces in the historical process. It is a system of previously unknown forms of production and technologies significantly surpassing the previous ones (in opportunities, scale, productivity, efficiency, product nomenclature, etc.). The development of the production princi-*

ple is a period of the formation, development and transformation of new forms, systems and paradigms of economy, far surpassing the previous ones by the most important parameters.

1.1. The Industrial Production Principle as a Cycle Consisting of K-Waves

Taking into account that K-waves arise only with the emergence of a certain level of economic development, one can consider *K-waves as a specific mechanism connected with the emergence and development of the Industrial production principle and the way of expanded reproduction of industrial economy*. Given that each new K-wave does not just repeat the wave motion, but is based on a new technological mode, *K-waves can be treated, to a certain extent, as developmental phases of the Industrial production principle and the first phases of development of the Scientific-Cybernetic production principle.*[5] This situational definition is important for the purpose of this article because it reflects an important aspect of K-waves, but may not be fully adequate as a definition of K-waves in another aspect.

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 a new system of technologies and production, the maturity phase, the phase of emergence of the new non-system elements and its transitional crisis, culminating in the replacement by a new production principle*. Thus, both concepts (the K-waves and production principles) deal with a cyclical pattern and development of production technologies and production system as a whole, with the scale surpassing the limits of a single society, as well as with driving forces associated with innovations. No doubt, this evidences the non-accidental similarity between the two analyzed notions and provides great opportunities for their comparison.

Since there were no evident K-waves in the economy until the end of the 18th century, within the framework of this study we consider the last two production principles: Industrial and Scientific-Cybernetic. Each of them, however, significantly exceeds the duration of one K-wave and in fact comprises at least three waves (see Tables 5 and 8).[6] Thus, while the Industrial and Scientific-Cybernetic production principles can be represented as cycles of the formation and development of a special system of technologies and forms of production organization, then K-waves are one of the most important forms of the unfolding cycles of production principles. In other words, there are two types of

[5] 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.

[6] One should note that K-waves overlap only part of the two production principles. We will return to this issue below.

cycles structurally connected with each other. *It follows that the peculiarities of each phase of a larger cycle (of production principle) should affect to some extent the peculiarities of a smaller cycle (of K-wave and its phases).* The development and change of technologies (and subsequent transformation of society resulting from their introduction and diffusion) at each phase of the production principle have their own specific characteristics, which help to clarify the features of each K-wave (and their phases), and some features of long-wave dynamics in general.

1.2. The Zero and First K-Waves

1.2.1. Why did Long K-Waves and Medium-Term J-Cycles Appear? Their Connection with the Industrial Production Principle

The first K-wave, which was singled out by Nikolai D. Kondratieff and many other researchers, began around the end of the 1780s. It is no coincidence that the first clear manifestations of the long-wave processes of economic dynamics coincided with the Industrial revolution. One can assume that the final phase of the Industrial revolution created the phenomenon of Kondratieff waves in the economy (or at least allowed distinguishing them clearly). The fact is that during this period the productive forces began to acquire a new fundamental characteristic – an 'aspiration' for steady and continuous expansion (which had previously been realized occasionally). Together with this property there emerged 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 smooth and must obey different rhythms whose common property was the alteration of acceleration and deceleration phases caused by the exhaustion of available resources for growth, market saturation, reduced profit margins, *etc.*

Those rhythms were already present in the development of trade in the 18th century. The rise of the first K-wave (there are some reasons to suppose that it was preceded by a zero wave; see below) at the final phase of the Industrial Revolution meant the emergence of a new form of cyclical dynamics that was specific for the Industrial production principle. The completion of the Industrial Revolution and consolidation of the extended production pattern were marked by the emergence of a new and more explicit form of cyclical pattern – the medium-term cycle (ending with cyclical crises). The first cycle of such kind can be dated to 1818–1825.[7] It is rather symptomatic that this cycle[8] occurred after

[7] The year 1825 witnessed a typical cyclical crisis of the Juglar type that involved for the first time the entire British economy and to some extent economies of many other countries. It was preceded by the rise, which in 1824 and early 1825 grew into a real investment and speculation boom (for more details see Grinin and Korotayev 2010). The crises in industry that occurred prior to 1825 were not universal; they were connected with particular problems in trade caused by different factors (inflation, wars and others).

the completion of the upswing phase of the first K-wave. There is every reason to believe that K-waves may be fully realized only through the medium-term cycles, as aggregated depressions of medium-term cycles determine the overall downswing trend at the B-phases of K-waves, whereas aggregated booms of medium-term cycles determine the upswing dynamics of K-wave A-phases (see Grinin 2010; Grinin and Korotayev 2012; Korotayev and Grinin 2012).[9]

Thus, both the Kondratieff long waves and medium-term Juglar cycles are associated with the same fundamental change – the transition to a new developmental pattern of production, *i.e.*, extended reproduction based not only on the involvement of new resources (this happened already within complex premodern agrarian systems), but on the economic growth through regular investments, innovations and improvements. In other words, *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 are associated with a longer (and deeper) cyclic change of the productive forces – production revolutions that lead to the movement from one production principle to another. At the same time, the cycle of the production principle includes several generations of technologies and technological paradigms.

Harbingers of Medium-Term Cycles

The researchers of medium-term cycles and crises of the 19th century often paid much attention to the 18th-century crises finding them very instructive, and most importantly considered them as similar to those that occurred during the 19th century. Indeed, the similarities (excessive lending, unexpected bankruptcies, credit crunch, panic and bust) are obvious. And it is no coincidence, a number of necessary elements for modern economic cycles (with the exception, of course, of the system of machine industrial production, which dramatically increased the market good supply) had already emerged by that time. As mentioned above, the imperative of the continuous expansion of economic turnover emerged. Therefore, cyclical pattern (inherent in the Industrial production principle) became obvious. The role of credit also increased. And since the mid-term cycles and crises are associated with fluctuations in credit (at some phases of the cycle there is a rapid spread of credit but when the situation worsens, it shrinks sharply, which contributes to a rapid collapse), a certain prototype of medium-term cycles with a characteristic period of about 10 years can be traced in the 18th century, especially in its second half (see Braudel 1973;

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8 Joseph Schumpeter called cycles of this kind the Juglar cycles (J-cycles) (after the French economist Clement Juglar).

9 One should note that Arthur Spiethoff proposed to consider the sequence of several Juglar cycles as a single period with an upward or downward impulse (see Kondratieff 1989 [1925]: 28). But he did not single out long cycles (*Ibid*.).

Hansen 1951).[10] In 1763, the crisis began in Hamburg against the background of the depreciation of currency during the Seven Years' War, but then as a result of the huge bankruptcy of the Neufville brothers in Amsterdam this crisis acquired a pan-European character (Braudel 1973; Wirth 1877). Then there was the crisis of 1772–1773, which took place against the background of severe crop failures in 1771–1772 and, like the previous crisis, included a large bankruptcy (the Cliffords bankruptcy of December 1772 which became the detonator of collapse). Finally, the crisis of 1780–1783 reinforced by the military events of that period (including the military blockade of the Dutch coast by England) also achieved a large scale as a result of another major bankruptcy in 1780 (see Braudel 1973).[11]

Crises could grow to European scale largely because trade and economic relations in the Western (or rather, Atlantic) part of the World-System significantly increased and became more intense. Against this background it is hardly surprising that any market fluctuations in one place would also influence other places. According to the German researcher of the 19th-century crises Max Wirth (1877: 65), 'The trade and financial crises of the 18th century, no matter where they unfolded, had a more or less permanent effect on the rest of the trading centers of northern Europe'. It is no coincidence, that the crises in the 19th century were called trade-industrial, as they particularly and quickly hit trade (which tends to depend heavily on the credit). Still, we note that there was a significant difference between the 18th and 19th centuries. In the 18th century, crises were mainly trade-related and based on a 'disorder of the credit'; that is a violation of trust in the credit sector which resulted in failures in the function-

[10] According to Murray N. Rothbard (2005 [1969]), during this period, the clue to the repeated cycles of expansion and contraction, booms and crashes, puzzling the observers since the mid-18th century was found by David Hume and David Riccardo in the activities of commercial banks, which first unrestrainedly extended credit and then began to sharply reduce it. However, it should be noted that Rothbard is a representative of the so-called Austrian school, which believed that the main cause of crises was excessive lending, so credits should not exceed cash. As for the crises of the 16th and the first half of the 18th century, they were mainly of a financial nature, linked first to the insecurity of large public loans, especially with regard to Spain, and then to the major financial pyramids in England (shares of the South Seas Company) and France (John Law's system) in the 1710s. Nevertheless, one can also observe certain regularity in them, at least in the 16th and 17th centuries. Giovanni Arrighi (2006: 179) writes, 'The Genoese financiers who created, managed, and profited from this systemic link between Iberian power and Italian money, were themselves affected by a whole series of crises in 1575, 1596, 1607, 1627 and 1647, all of which had Spanish origins'. If we also recall the famous default of Philip II in 1557, which resulted in devastation of the famous Fuggers and the decay of Antwerpen, reinforced by the bankruptcy of the French King Henry II, one can witness crises with intervals of about 20 years. Of course, one should mention the so-called Tulip mania of 1637 in Amsterdam, which somewhat breaks this periodicity.

[11] Then, however, crises became more frequent and started to occur every three-four years. For example, one can mention the crises of 1787–1788, 1793, 1797, 1803. But, as mentioned above, they had a transitional nature: from trade-financial to trade-industrial, and mostly they were already on the general upswing A-phase of the first K-wave.

ing of the financial system. Until 1825, industrial crises (of overproduction) were observed in the cotton-textile industry (Mendelson 1959–1964, vol. 1), but they are more likely to be considered local, and the normal cycle period had not yet emerged.

1.2.2. On the So-called Zero K-wave.

The formation of the medium-term cycles could not but affect the longer-term trends that occurred earlier (see, *e.g.,* Braudel 1992). It can be assumed that as a result of the general acceleration of development and the formation of medium-term cycles, the long-wave dynamics began to form as well, perhaps transforming from the longer and more irregular price trends of the past. Of course, there were irregular fluctuations in innovation and long-term investment (*e.g.*, government loans, large commercial-industrial enterprises, and increasing of land fertility) even before the end of the Industrial Revolution. Due to the acquisition by the Juglar medium-term cycles of relative temporal regularity, the K-waves could further receive stability in terms of duration (on the relationship between medium-term and long cycles see Grinin 2010; Grinin and Korotayev 2012).

Thus, there was a certain preparatory period, during which the mechanism of K-waves and J-cycles were formed. That is why the idea of singling out the so-called zero K-wave by some researchers has serious reasons. This approach is useful to show that K-waves did not come out of nowhere, but had a latent period. We date the beginning of the third period of the Industrial production principle very conventionally to the 1730s.[12] Therefore, the full-scale zero

[12] We had reason to date the beginning of the final phase of the Industrial revolution in this way (see Grinin 2006a: 141–142). Although, in general, we could have chosen the late 1760s, when James Hargreaves invented Spinning Jenny and Richard Arkwright – the first powered textile machine. But in fact, the most important period of the final phase of the Industrial Revolution began precisely in the 1730s. In 1733, there was patented John Kay's flying shuttle for weaving cloth (see Tseitlin 1940), which launched the era of rapid weaving operations compared to spinning. As stated in the text of the 1733 patent, it was 'a shuttle, recently invented for better and more accurate weaving of wide cloth, twill, sail cloth and wide fabrics in general' (*Ibid*.). It was not yet a machine in the full sense of the word, but a certain mechanization of labor, which doubled productivity. Characteristically, the new invention was met with strong resistance from weavers, and in 1753 the inventor's house was even ransacked. The machine was introduced by entrepreneurs, but Kay himself did not get a penny for it. By the 1760s, however, the spread of the loom had created the optimal conditions for finding an adequate method of acceleration of the spinning process. During this thirty-year period there were made several interesting but generally unimpressive attempts to mechanize the spinning process (in particular the inventions of John Wyatt, Lewis Paul, James Taylor which led to mechanization of drawing out operations). But in the end the mechanical Spinning Jenny and the above mentioned Arkwright's spinning machine were invented (although the actual inventor is considered to be Thomas Highs). Arkwright also created the first spinning mill. Subsequently Arkwright's machine was named a water frame or a water machine. At early stages both machines complemented each other. It should also be noted that Hargreaves was subjected to harassment for his invention by fellow craftsmen, and Arkwright had to defend his rights in court. The positive decision in his favor opened a wide path for the Industrial Revolution.

K-wave falls within the period between the 1730s and the 1780s (according to Kondratieff, the last date is the beginning of the first K-wave). Still, the analysis of this period does not allow doing this to the full extent. Therefore, within the framework of our research, it would be more appropriate to confine ourselves to the downswing phase of the zero K-wave.

First, its beginning (around the 1760s) nearly coincides with the generally accepted dating of the beginning of the Industrial Revolution.

Second, one can assume that fundamental innovations are made at the downswing phases which then become the basis of rapid implementation. The period from the 1760s to 1780s was precisely of this kind because it was the period of formation of a fundamentally new branch of industry (implementation of radical innovations in a limited volume).

Third, in this period one can already observe trade and economic medium-term cycles, ending with cyclical crises.

Finally, the zero K-wave was quite depressive. The overall economic situation during this period was not particularly favorable in general, and negative phenomena, such as decline in the volume of international trade, deflationary processes, rising unemployment in some places, *etc.* were observed for quite long periods.[13] During that period the final decline of Amsterdam and the weakening of Holland took place (see Braudel 1992: 268–269). All this was supplemented by or was the result of rather intense and dramatic political phenomena, among which the Seven Years' War, the American War of Independence, the war between England and Holland, plague epidemics, catastrophic crop failures and food riots.

Thus, in this study when comparing the Industrial production principle and K-waves we will consider the downswing phase of the zero K-wave (conditionally 1760–1787).

1.3. Industrial Production Principle: The Transition to Maturity (B-phase of the First K-wave and the Second K-wave)

As the title of the section indicates, the transition of the Industrial production principle to maturity (*i.e.*, its fourth phase) took one and a half K-wave. One may conventionally consider that the Industrial revolution in England was completed by 1830.[14] What does this mean? This statement should by no means

[13] *E.g.*, according to Wirth, 'The period of 1763–1788 was commercially one of the most unfavorable that Hamburg had ever experienced. Even the North American War which caused such damage to English trade mainly on the part of France did not bring Hamburg the profits which one should have expected. The decline in prosperity was particularly evident in the fall in house prices and rents…' (Wirth 1877: 52).

[14] One may conventionally consider as the completion of the revolution the creation by the engineer Richard Roberts, first in 1822 of a highly perfect mechanical weaving loom (a machine which was already completely subject to the laws of mechanics) and then between 1825 and 1830 of a perfect spinning mule which removed the remaining manual operations in spinning. One can, however, define as a finishing point the invention by James Smith in 1934 of the so-called self-

be interpreted in such a way that the main innovations had already been introduced by that time. On the contrary, the introduction of innovations into production had only just begun. This can be seen from the fact that, as early as in 1831 in England, the hand weavers accounted for more than 80 % and factory weavers – less than 20 % (225,000 and 50,000 people respectively [Tseytlin 1940]). The completion of the Industrial revolution means that by that time the industries which emerged due to this revolution had already established themselves, having created the primary model of the mature industrial (machine) production principle which was spreading to new industries. There were tens of thousands of new machines, thousands of steam engines were running in England, and there was constructed the first public railway (1825). At the same time, according to the theory of production principles, during the upsurge of the new principle, the economy is in fact a hybrid, organically incorporating the new and old production principles. By the beginning of the fourth decade of the 19th century English manufacturing was such a hybrid.

At the fourth phase (the phase of maturity and expansion of the production principle) the old sectors were replaced by new ones. Speaking of economy as a whole, this replacement was carried out gradually, but in some sectors it occurred very quickly. Therefore, in general the modernization of the economy was quite painful for society, especially for weavers in the 1830s and 1840s. In England, displacement of craftsmen by machines lasted for two decades. A sharp turning point in the situation of English weavers came at the end of the 1830s and beginning of the 1840s (their number decreased by more than three times in almost 15 years – from 225,000 to 60,000). In other European countries the situation of weavers was also difficult, where even riots broke out (in particular, in Silesia in 1844). But the situation of artisans in India, where the process unfolded rapidly, was particularly difficult. As early as in 1834, the Governor-General of the East Indies William Bentinck reported, 'The misery hardly finds a parallel in the history of commerce. The bones of the cotton weavers are bleaching the plains of India'. The phrase, which became popular after it was used by Karl Marx (1960 [1867]), has since been repeated many times.[15]

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acting mule in which all operations, except for some supplementary ones, were already fully automatic. No radical improvements were subsequently made to these machines. As early as in 1834, self-acting mules with 200,000 spindles were installed in 60 spinning mills in England (Tseitlin 1940), which well illustrates the rapid speed of changes in industrial production.

[15] The dramatic situation of Indian artisans in the above quotation is probably still exaggerated. However, objectively, their situation was considerably worse than that of the English weavers. One should give some facts. In the 1830s–1850s the export of English textiles to India increased 60(!) times (Bobrovnikov 2004: 423). In contrast, in the 18th century and in the first decades of the 19th century India exported its textiles on a large scale to England, which affected the growth of Indian textile artisans. It led to the disappearance of Indian handicrafts. The population of Dhaka, the major industrial center of Bengal, *e.g.*, fell from 150,000 to 30,000 people (*Ibid*.).

The fourth phase dates back to the 1830s–1890s and comprises two B-phases of the second and third K-waves and one A-phase of the third K-wave (but without full coincidence in time). This is understandable since the spread of the new production principle is not easy and takes quite a long time, especially within the framework of the World-System.

First, as mentioned above, the B-phase of the first K-wave was accompanied by a profound restructuring of the economy and social structure of Great Britain due to the elimination of handicrafts and involvement of a large number of people in industry.

Second, the new production principle had to be established and distributed not only in the core, but also in the World-System semi-periphery (in particular, in the European countries, for which the period of 1850 – the 1870s, that is, A-phase of the second K-wave, was in a sense equivalent to the period of 1800–1830 for England).

Third, since European countries borrowed ready-made technologies, significant socio-political transformations were taking place there as well.

1.4. The Features of the Phases and Waves in the Light of the Theory of Production Principles

During the period of rapid formation of the industrial economy there is a sort of adding the layers to it due to the formation of new large sectors (see Table 1). The macro-sector of primary heavy industry, including industrial modes of transport and communication, rapidly grew and became the leading one. Only the breakthrough in this field could result in the expansion of economic space and formation of a mature Industrial production principle. It was absolutely impossible to cope with the ever-growing volume of freight and information using old methods. On the other hand, railways, water transport, and communication technologies were repeatedly modernized due to the spread of improved pig iron grades, steel and other materials, and more powerful mechanisms. Throughout this period, but especially at the B-phase of the second wave, a macro-sector of heavy recycling industry was formed (see Table 1). Only with its sufficiently widespread distribution one may speak about the maturity of the Industrial production principle.

It was a period of mass distribution of innovations in the World-System. Therefore, the high-priority problem for England was to expand exports of goods and by the end of the period one could observe the rapid development of the export of English capital.

1.4.1. The B-phase of the First K-wave, Very Similar in Type to A-phases

It should be noted that the downswing phase of the first K-wave has significant peculiarities compared to the downswing phases of subsequent K-waves.

1) The contradiction between a very rapid increase of labor productivity in industry and depressive spirit of the period. At that period one could observe a large share of innovations and very rapid increase of labor efficiency. Thus, according to Kondratieff, from 1820 to the 1850s, the productivity almost doubled even in the extractive industry, which developed more slowly than manufacturing industry (Kondratieff 2002: 476, Fig. 16). We also provided the examples of speed and strength of introduction of innovations. The speed at which roads and factories were built is sometimes astounding. The increase of labor productivity is usually higher at A-phases than at B-phases.[16] As regards the first wave, the situation in the economy as a whole was the opposite due to the peculiarities of the fourth phase ('expansion') of the Industrial production principle which is characterized by exceptionally high development potentials.

2) Another peculiarity is the short-term nature of the crisis phases of medium-term cycles. Usually at the B-phase, as Kondratieff (2002: 379–380) noted, the upswings are not so strong and the downswings are longer than at the A-phase. However, at the B-phase of the first K-wave, the upswings and downswings in the medium-term cycles are typical of the A-phases.[17] In our opinion, this can be explained by the fact that this phase coincides with the end of the third and beginning of the fourth phases of Industrial production principle, *i.e.* the end of the Industrial revolution and its primary outcomes. And these are very significant periods in terms of innovations, because the reserves of potential innovations are still so large that they allow shortening crisis periods and make economic upswings stronger. Moreover, the fourth phase of the Industrial production principle is a period of dissemination of the results of Industrial revolution in the World-System, which offered additional opportunities in a variety of ways: from the synthesis of inventions made in different countries into a single stream to the struggle for duty-free trade, which spread the latest technologies all over the world.

3) At this phase, the rigidity of change in patterns and paradigms was higher than at other B-phases of the K-wave. As has been shown (Grinin 2012a), the nature of this shift at B-phases is less additive and more substitutive than at A-phases due to the fact that entrepreneurs have to fight negative trends towards lower prices and profit rate. However, the rigidity of sectoral displacement at B-phase of the first K-wave was perhaps the highest (see above on the situation of the weavers). This was due firstly to the peculiarity of the stage of the production principle (a more revolutionary change of technologies than usual), and secondly to the lack of the necessary social tools. After all, England

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[16] Under the conditions of a more severe recession, enterprises stand idle or remain underutilized for a longer time, which reduces labor productivity despite higher unemployment. But for the first wave, taking into account that the industrial sector was still developing, the underutilization factor was less relevant.

[17] On medium-term cycles and other phases of K-waves see Grinin and Korotayev 2010; Ch. 1, 2.

was 'ahead of the whole world', and this limited the conditions for economic development and social experience. As a result the phenomenon of collision of technical and technological progress with the old relations at the same time made this period difficult, requiring major restructuring, and therefore full of social struggle.

1.4.2. The Strange Dynamics of the Second K-wave: The Comparison of the Dynamics of GDP Growth at Its A- and B-phases

The uprise of the A-phase (1850 – the 1870s) of the second wave was quite powerful (in contrast to the A-phase of the first wave, see Table 4), because there was a synergetic effect of the superposition of two technological waves. As a result, there occurred an acceleration of development compared to the preceding first wave due to the combination of two technological waves: the new primary (heavy) industry and transport in England and the old (textile) industry combined with the new one in Europe and the US. An even more significant rise can be observed in the development of Western countries, whose GDP growth rates reached very considerable annual values of around 2.5 % during the A-phase of the second wave (see Fig. 1).

Fig. 1. Average annual world GDP growth rates (%) of the West during A-and B-phases of Kondratieff waves, 1820–1913

Source: Korotayev and Grinin 2012: 85; Fig. 18).

The Peculiarity of the Second K-Wave: the West vs. the World-System. Concerning the world GDP growth rate, one can hardly disregard the fact that contrary to the theory of K-waves, it is lower during the A-phase of the second K-wave than during its B-phase (see Table 4). Whereas it should be the other way round (A-phases are called the upswing phases because the growth rates at this phase are higher than at downswing phases). However, taking into account only Western countries, the situation with GDP growth rates there evolves according to the theory: at A-phase of the second K-wave (1849–1873) they are higher than at its B-phase (1873–1895) (see Fig. 1).

There arises the question: why the dynamics of the West do not coincide with global dynamics? We have given some explanations for this phenomenon; in particular in 1852–1870 it could have happened due to the catastrophic economic decline in China, whose economy in the mid-19th century was still the largest in the world[18] (see Grinin and Korotayev 2012; Korotayev and Grinin 2012; Grinin, Korotayev, and Tsirel 2011). At the same time, we made the following conclusion: there are some reasons to doubt that K-waves can be traced in the dynamics of world GDP in the period before 1870, although in this period they can be traced in the economic macrodynamics of the West. It is worth recalling that Kondratieff also established K-wave dynamics only for the West, where long-term price fluctuations correlated with GDP growth dynamics. Based on these indicators (which show the K-wave dynamics), this is quite true. In terms of the theory of production principles and production revolutions everything is explained even more logically. The K-waves, as we have seen above, arise when productive forces acquire new characteristics, namely as a result of the aspiration for constant expansion. It is quite obvious that as long as these characteristics are not realized in some form in certain regions of the world, the long-wave and medium-wave dynamics cannot really manifest themselves there.[19] The spread of the innovations of the Industrial revolution was gradual and most active precisely during the second K-wave, *as it coincided with the fourth phase of the Industrial production principle (the stage of its maturity and expansion).* However, at the A-phase of the second wave, this diffusion covered mainly the USA, Europe and associated semi-peripheral countries (Russia, Egypt, Turkey, *etc.*). At the same time, the Far East and a number of other regions with a huge part of the world's population were either in complete isolation or were only slightly open due to military force.

Accordingly, the development of different parts of the world proceeded asynchronously as they coexisted within different production principles. Quite logically, the scope of the Kondratieff waves expanded first at the expense of the Western countries, where at the A-phase of the second wave one can observe GDP growth significantly surpassing the previous periods. And only in the next period, at the B-phase of the second K-wave (1873–1895), the spread of the achievements of the Industrial revolution involved the most populous peripheral countries in the general economic system. Such asynchrony, on the

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[18] Due to the political and demographic collapse caused by the Taiping Rebellion and other political upheavals, famine, epidemics, *etc.*

[19] Involvement of production in the global division of labor and world trade, whose fluctuating needs will be reflected in the dynamics of local production, even if it is not mechanized would be suffice.

one hand, led to a slowdown in the development of the core (see Fig. 1), which at the same time allowed the semi-periphery to catch up,[20] and on the other hand, the overall growth rates at this B-phase, contrary to the theory of K-waves, were higher than at the preceding A-phase of the second K-wave (see Table 4). The latter occurred due to the rapid involvement in the general economic system (trade, division of labor) of a number of regions which previously had not actively or not at all participated in it.[21] Thus, within the framework of the theory of production principles there is no anomaly in the faster growth rates of the global GDP at the B-phase of the second K-wave compared to its A-phase, everything looks logical.

Table 4. Average annual world GDP growth rates (%) during the A- and B-phases of Kondratieff waves, 1820–1894

Kondratieff wave number	*Phase*	*Years*	*Average annual world GDP growth rates (%) during respective phase*
I	B	1820–1850	0.88
II	A	1851–1875	1.26
II	B	1876–1894	1.68

Source: Korotayev and Grinin 2012: 83; Table 5.

1.5. The Third Wave: A Rapid Takeoff and Catastrophic Downfall

The unusual nature of the third wave (1895–1947), especially the intensity of the production decline during the Great Depression as well as military and social cataclysms that dominated this period, has always attracted greater attention of researchers. One should note, however, that the *B-phase of the third K-wave is richer in sociopolitical upheavals than its A-phase.* However, the K-waves theory fails to explain this. On the contrary, according to Kondratieff and his so-called 'second regularity' (Kondratieff 2002: 74ff.), there must occur more important socio-political events during A-phase than during B-phase. Although the A-phase of the third wave with numerous wars and revolutions was also very turbulent, the B-phase surpassed it.[22] However, as we will see

[20] This was also facilitated by the active export of capital indicating the distribution of the Industrial production principle.

[21] Only the involvement of the western territories of the USA, Russia, India and some other countries in the world trade in grains and other agricultural products had a significant effect, but more importantly, one could observe economic growth in China, Japan and other countries; modernization in Turkey, Russia, India, Argentina, *etc.* also contributed enormously to the overall growth.

[22] Especially if one considers it from 1914. But even if we consider it from 1920 (the last digit of Kondratieff periodization [1914–1920]) or from 1929, as we suggest, this phase includes the Great Depression, tremendous changes in the USSR, wars in China (civil war; the war with Japan), the establishment of the Nazi dictatorship, preparations for World War II, World War II, the fall of a number of regimes, the establishment of socialist regimes in Europe and Asia, the Partition of India, the establishment of American hegemony in economy, politics, *etc.*

below, within the framework of the theory of production principles the upheavals of the period of the third K-wave should be taken as a whole without opposing A-phase to B-phase. On the whole, within the framework of the theory of production principles many features characteristic of the third K-wave become more distinct, the logics of the process becomes more comprehensible, within which diverse and apparently dissimilar events fit together. The rapid distribution of the Industrial production principle, and at the same time the spread of the influence of the new production principle over the entire World-System do indeed lead to divergent tendencies.

One can identify a number of features which are related to the position of this period in the Industrial production principle.

1. *The changing proportions between the duration of the K-wave and the phases of the Industrial production principle.* Unlike the more or less constant duration of K-waves (which is their most important characteristic), the duration of the phases of the production principle is different.[23] The general trend is that each subsequent phase of the production principle cycle is shorter than the previous one (this is due to the peculiarities of the production principle cycle and the general acceleration of historical process). As a result, *the third wave comprises two phases of the Industrial production principle.* If the fourth phase had one and a half waves, then in this case it is vice versa: one wave comprised two phases of the production principle. Thus, *the frequency and quantity of changes increase*. This leads to various results, including firstly a slight acceleration of economic development as compared to the A-phase of the second K-wave (see Fig. 1 above and Fig. 3 below), and then a very strong deceleration.[24]

2. *The absolute victory of the Industrial production principle both within the production system and the structure of the World-System leads to the emergence of qualitatively new phenomena, preparing the world for another transformation.* The fifth phase of the production principle also means its absolute victory in agriculture (which is pre-industrial in its origin), which is mechanized and in general leads to its depression. The relationship between industry and agriculture becomes for a long time one of the most important within the national and world economies as well as one of the main sources of deflationary-inflationary fluctuations of conjuncture. It is not without reason that the proportions of industrial and agricultural development were the central focus of leading economists, including Kondratieff. A complete victory of the Industrial

[23] At the same time, the proportions of phase duration in the cycle of the production principle are quite strongly correlated. In other words, the correlation of, *e.g.,* the first and second phases in all four production principles is quite close. It is about 1.2:1 (for more details see Grinin and Korotayev 2009: 124).

[24] It should also be taken into account that now three waves of technological changes of the Industrial production principle (textile, primary heavy industry and mechanic engineering) are unfolding within the framework of the World-System. Therefore, within this framework the rate of economic growth at the A-phase of the third K-wave was higher than at the A-phase of the second K-wave.

production principle means an acceleration of technological shift. On the one hand, these new technologies[25] are already less revolutionizing the society, which is now quite ready for continuous technological changes, but on the other hand, there emerge sophisticated technologies which begin to prepare the world for a transition to a new Scientific-Cybernetic (Scientific-Information) production principle, a transition that is associated with severe crisis phenomena.

3. *The systemic crisis at the end of the Industrial production principle.* The transition to a new production principle is a difficult process. In fact, it is a systemic *transitional* crisis caused by deep disproportions in a number of areas (see Grinin 2006a: 172–173). In this period, they were manifested primarily in the structure of the World-System (in its reconfiguration, painful catching-up of the semi-periphery, forced modernization of the periphery, *etc.*). Particular attention should be paid to the changing leader of the World-System, which significantly contributed to the escalation of the military-political struggle for leadership (between Germany and Britain). The disproportions were particularly acute within production organization of society as in this period the level of socialization of production far surpassed the system of state control over it. The old competitive market system was no longer able to self-regulate, its 'invisible hand' was clearly lacking. Ultimately, a system of state control together with a new system of redistribution through the state budget and forms of social security had to emerge (see Grinin 2006a, 2009).

However, the necessary changes do not happen automatically; they are associated with deep socio-political (or military-political) conflicts, equally with other serious cataclysms, which lead to a search for new answers. When searching for these answers, new modes of production and new technologies emerge (as one of the means of easing the tensions), leading ultimately to a new industrial revolution. The closer the World-System core countries come to the technological opportunity of making the transition to a new production principle, the more acute are the contradictions and problems arising from the nonconformity of social and international relations to the increased level of technologies. However, these contradictions are not yet recognized in such a global context. Rather, they are a 'bouquet' of various tensions and contradictions whose natural-historical role is to perk up the already established system, to break its certain elements (and not necessarily the most leading ones, usually the weakest ones), to induce societies and elites to make absolutely extraordinary and beyond the logic of the existing system decisions and experiments.[26] Indeed, government regulation seems to be totally illogical under the system of free competition, social insurance is an inappropriate waste of taxpayers' mon-

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[25] In particular, the transition to new fuel and engine types – electric and internal combustion engines. It is worth recalling the Scientific Revolution of the early 20th century.

[26] A more meaningful struggle for reformation in terms of the logic of the new production principle takes place in its early stages (for more details see Grinin 2006a: 72–73, 181–184).

ey; minimum wage regulation is unacceptable under the system of free contracts between employers and employees, prohibition on gold transactions (Franklin Roosevelt's policy) is a mockery of the monetary system of gold standard, *etc.*

It is not surprising, therefore, that precisely at the end of the production principle cycle, which is associated with the search for ways to make the transition to a new production principle as well as with powerful cataclysms (see Grinin 2006a, 2009),[27] there are not many people who think of profound reform in the truly right direction, because the system is already so refined that it is remarkable for its completeness and rationality. But suddenly societies and social classes face the phenomena that seem uncontrollable, unexpected, illogical, and inconsistent with previous experience. The end of the fifth and sixth phases of the Industrial production principle vividly demonstrated this. It is no coincidence that two world wars, powerful social revolutions (including those in Russia and China) and the deepest crisis of the 1920s and 1930s[28] occurred during this period. It is quite obvious that K-waves, being primarily an economic phenomenon, could not continue to unfold in the changed conditions. At the same time, as has been mentioned above, the K-wave theory does not explain such a deep economic decline during the Great Depression which is unprecedented (not to mention wars and revolutions).

5. *A particularly strong cluster of innovations in the B-phase of the third K-wave.* According to a number of researchers, during the downswing B-phase of the K-wave there emerges a cluster of innovations which at A-phase results in a rise in production. However, their theories do not explain why during the period of the 1920s and the 1930s an unprecedented number of inventions emerged, which became the basis for innovations in the fourth K-wave.[29] But

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[27] The plague epidemics ('black death'), protracted wars and economic decline in the first half of the 15th century were such cataclysms in Europe, in particular before the beginning of the Industrial revolution at the end of the 15th century. At first sight, the plague epidemic is a purely external (exogenous) fact. Indeed, the outgrowth of the normal for the Craft-Agrarian production principle proportions between the rural and urban population, the increasing role of long-distance trade, *etc.* led to plague epidemic which was a terrible disaster, never seen before on such a large scale. The catastrophe led to a drastic decline in population, which initiated the transformation of relations in the agricultural sector, opening the way for new (capitalist) phenomena in agriculture and industry (in particular, an increasing interest in mechanization of labor). Protracted wars led to the emergence of a new type of state (the developed state), while depression in agriculture and shortages of precious metals increased the desire for long-distance trade, which eventually led to a rapid expansion of the known space and the formation of the World-System. Thus, the degree of influence of one or another factor depends heavily on the state of societies and the World-System as a whole.

[28] It becomes clear why both phases of the third wave must have been very rich in major social and political upheavals.

[29] *E.g.*, Vilenin G. Klinov, on the basis of the data given in the monographs by Gerhard Mensch, Ch. Freeman, J. J. van Duijn and a number of other researchers, argues that in the depression decade of the 1930s the total number of basic innovations was one and a half times larger than in the 1940s – the 1960s (31 basic innovations in the 1930s and 20 innovations on average in the 1940s – the 1960s respectively) (Klinov 1992: 183).

this can be explained by the peculiarity of this period in relation to the Industrial production principle. The sixth (transitional) phase of the production principle is particularly rich in innovations, whose implementation requires deep structural changes in society. At this period there appear some prerequisites for the start of a new industrial revolution.

1.6. The Correlation between the Phases of the Industrial Production Principle and K-waves

We have considered three K-waves associated with the Industrial production principle. At the same time, a sufficiently strong correlation between K-waves and the phases of the Industrial production principle is obvious in a number of aspects. Special attention should be paid to the correlation between the duration of the phases of the Industrial production principle and the duration oftheK-wave phases. Certainly, there can be no direct duration equivalence of K-waves and their phases, on the one hand, and the Industrial production prin-ciple phases, on the other, due to the different duration of the Industrial produc-tion principle phases. However, we have succeeded in establishing a more complex correlation according to which on average one K-wave corresponds to *one phase of the Industrial production principle.* Taking into account that the beginning of the B-phase of the zero K-wave was not at the beginning of the third phase of the Industrial production principle (but in the period that is much closer to its middle, in other words not in the 1730s, but in the 1760s), one can assume that three and a half waves coincide with three and a half phases of the Industrial principle of production! This is clearly seen in Table 5.

Such a correlation is not coincidental, as innovative development of the Industrial production principle is realized through long Kondratieff cycles which are largely defined by large-scale innovations.

Table 5. The phases of the Industrial production principle and Kondratieff waves[30]

Phases of 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 Upswing Phase, 1895–1928 – more than **35 years**	Third wave, The Down-swing Phase, 1929–1947 – about **20 years**	About **190 years**

[30] For simplicity, we take concrete years for the beginning and the end of the periods, though such a transition obviously lasts for a certain period of time.

Continuation of the Table

1	2	3	4	5	6
The Phase of K-wave	B-Phase of the Zero Wave,[31] 1760–1787	The Second half of the Downswing Phase, 1817–1849	The Upswing Phase, 1895–1928	The Downswing Phase, 1929–1947	
The Phase of K-wave	The Upswing Phase, 1787–1817	The Upswing Phase, 1849–1873			
The Phase of K-wave		The Downswing Phase, 1873–1895			

Section 2. The Scientific-Cybernetic (Scientific-Information) Production Principle, the Fourth, Fifth and Sixth K-Waves

The production revolution which began in the 1950s and is still going on causes powerful acceleration of scientific and technological progress. Taking into account expected changes in the next 50 years, this revolution deserves to be called **'Cybernetic'** (see our explanation below). The initial phase of this revolution (the 1950s – the 1990s) can be denoted as a **scientific-information** as it was characterized by the transition to scientific methods of planning, forecasting, marketing, logistics, production management, distribution and circulation of resources, and communication.[32] The most radical changes took place in the sphere of informatics and information technologies. In addition, the scientific-information phase of the revolution had a number of other directions: in energy production, in the creation of synthetic materials, automation, exploration of space and sea, and in agriculture.

The Scientific-Cybernetic production principle is at the beginning of its development. Only its first phase has completed, and in the mid-1990s the second one started. It is characterized by a wide proliferation of easy-to-handle computers, means of communication, and formation of macrosector of services among which information and financial services took the major place.[33] The second phase is currently unfolding (the duration of future phases is presented in Table 3 and Fig. 2).

[31] The Industrial Revolution is usually dated from the 1760s, so numbering of K-waves from this date is fully justified.

[32] At the same time, it is important to take into account that the concept of 'scientific' does not imply only a positive assessment, it is only about the technology of influence. And the results and objectives of the 'scientific' impact may vary.

[33] Within this macrosector, there emerged new financial technologies which have widely spread and multiplied the monetary instruments of the second, third and further levels (including the so-called derivatives). At the same time, financial and economic globalization has intensified, followed by other vectors of globalization.

The third phase is likely to start approximately in the 2030s or 2040s. At this period the final phase of the Cybernetic Revolution should start. After its completion this phase together with the Scientific-Cybernetic production principle will fully reveal its characteristics. 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 2006a, 2007a; Grinin and Korotayev 2009). Below we will give an explanation to this concept. Hereafter, we will sometimes refer to the final phase as the 'revolution of self-regulating systems' and use it as a synonym for the Cybernetic revolution. 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 manufacture – 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.

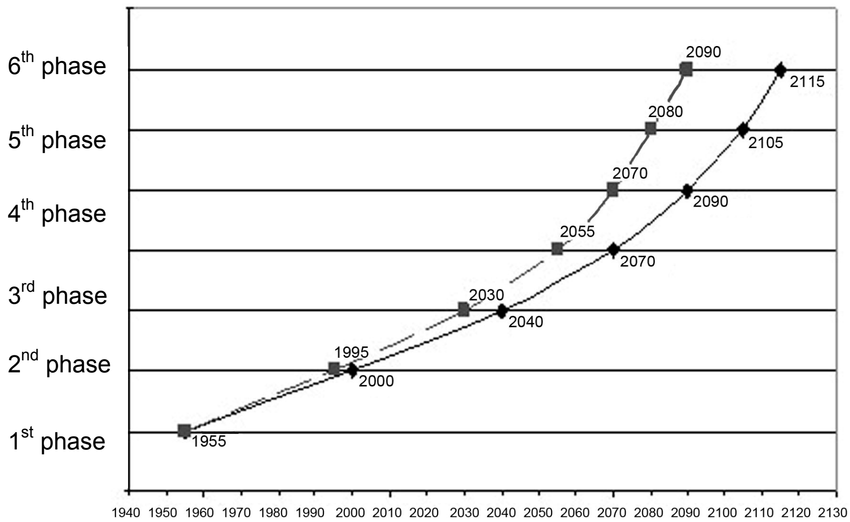

Fig. 2. Development of the Scientific-Cybernetic production principle

Note: The dashed line depicts one of the scenarios of expected development of the Scientific-Cybernetic production principle and corresponds to the dates before the slash in the fifth column of Table 3.

We assume that the Cybernetic Revolution will start first in a certain 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 predict that the final phase (the one of self-regulating systems) of this revolution will begin at intersection of medicine, biotechnologies and genetic 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.*[34] 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 specific characteristics (see Table 2). 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.*), one can assume that the future revolution will have 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).

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

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.

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

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

9. Control over human behavior and activity to eliminate the negative influence of the so-called human factor.[35]

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.[36]

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).

The analysis of these characteristics fully explains the terms chosen for the innovative phases of the Cybernetic production revolution, which began as a scientific-information revolution and will end as a revolution of self-regulating systems.

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

[35] *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).

[36] 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 fulfills the managing function. And this facilitates the transition to the epoch of self-regulating systems.

autonomous systems or through affecting the key parameters and elements that are capable to launch a necessary process, *etc*. As is known, Cybernetics is the science of control. The second reason is that 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 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. The 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 aging 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 2017a, 2017b).

Now let us consider the formation of the Scientific-Cybernetic production principle within the framework of the fourth K-wave.

2.1. The Fourth K-wave

2.1.1. The Fourth Wave and the Beginning of the Cybernetic Revolution: A Synergetic Effect

The beginning of a new production revolution is a peculiar period which is associated with a rapid transition to more advanced technologies. All accumulated innovations and a large number of new innovations generate a new system that has a real synergetic effect. It would appear reasonable that the *upswing phase of the K-wave, coinciding with the beginning of the production revolution can appear more powerful than the A-phases of other K-waves*.[37] That was the case with the upswing A-phase of the fourth K-wave (1947–1974) which coincided with the scientific-information phase of the Cybernetic Revolution. As a result a denser than usual cluster of innovations (in comparison with the second, third and fifth waves) was formed during that period. The share of new products in the economy of core countries of the World-System was very high. Thus, according to McGraw-Hill, the share of new products that appeared on the market after 1952 reached 85 % in the US industry in 1970 in the general engineering industry sector, 97 % in the electrical engineering sector, and 77 % in the automobile industry (Klinov 2006: 87). In general, the share of mechanical engineering and chemical industry products in the US manufacturing industry exceeded 56 % by the end of the 1960s (*Idem* 1992: 177, 179–180).

In addition, this phase brought together: a) mass technologies created at the end of the third K-wave (auto and aircraft construction, electrical engineering and non-computer electronics), which before the World War II just began to develop, and now they have reached maturity (especially in the semi-periphery and periphery countries, *e.g.*, in Japan); b) the scientific-information revolution as a result of the synergy of innovations in chemistry, mechanical engineering (artificial materials, automation), optics, electrical industry, progress in agriculture, *etc.*; c) primary generation of computer technology and electronics.[38] This also explains why in the 1950s and 1960s the economic growth rates of the

[37] Therefore, it appears reasonable that A-phase of the sixth K-wave can also make a great progress, as it will coincide with the beginning of the final phase of Cybernetic Revolution. Thus, the sixth wave is likely to have a stronger manifestation than the fifth one. We will return to this point below.

[38] Not to mention the development of the second and third wave technologies (metallurgy, mining industry, electrical energy industry, *etc.*). In a number of industrializing countries such as China, India, Pakistan, South Korea, *etc.*, the fact that the preparation for war and the war itself created a severe deficit of almost all ordinary peace-time products at first. However, by comparison with the similar situation after the World War I, it becomes clear that this was a temporary, not decisive factor of the rapid growth.

World-System were higher than during the A-phases of the third and fifth K-waves. It is clearly illustrated below in Fig. 3 and Table 6.[39]

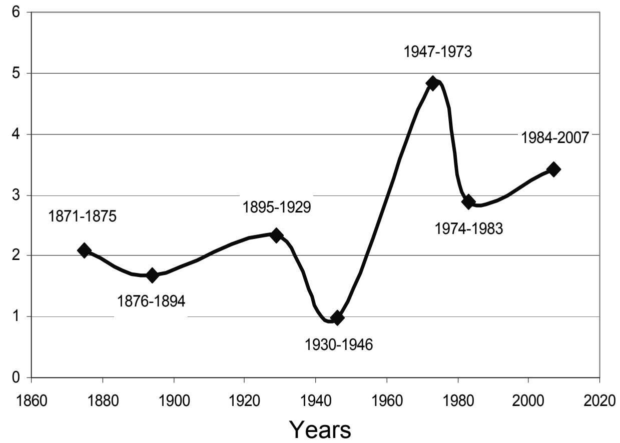

Fig. 3. Average annual World GDP growth rates (%) during A- and B-phases of Kondratieff waves, 1871–2007 (version 2, see the explanation in footnote 41)

Table 6. Average annual World GDP growth rates (%) during A- and B-phases of Kondratieff waves, 1871–2007 (version 2, see the explanation in footnote 41)

Kondratieff wave number	Phase	Years	Average annual World GDP growth rates (%%) during respective phase
II	The end of upswing phase A	1871–1875	2.09
II	Downswing phase (B)	1876–1894	1.68
III	Upswing phase (A)	1895–1929	2.34
III	Downswing phase (B)	1930–1946	0.98
IV	Upswing phase (A)	1947–1973	4.84
IV	Downswing phase (B)	1974–1983	2.88
V	Upswing phase (A)	1984–2007	3.42

[39] Fig. 3 and Table 6 are taken from: Korotayev and Grinin 2012: 71, 83, where they are marked as version 2, so in this paper we will follow this numbering, that is why version 2 comes before the first one. Version 1 is shown in Table 7 and Fig. 4. These versions demonstrate different periodization of the A-phase of the third wave, the B-phase of the fourth and the fifth wave (for more details see Korotayev and Grinin 2012). One should mention that both versions are identical as regards GDP growth rates for the period of 1947–1973.

2.1.2. The Downswing Phase of the Fourth K-Wave and the Dynamics of the Scientific-Information Phase of the Cybernetic Revolution

The exceptionally rapid economic growth ('economic miracles') in a number of European countries and Japan, as well as quite rapid growth rates in other countries (in particular, in the USSR and a number of socialist countries) and in the world in general, lasting about 20 years (from early/mid-1950 to the end of 1960) could not continue indefinitely. As usual, there was a common cause for the slowdown, which is the basis of cyclicity in the economy.[40] The stagnation observed since the late 1960s which turned into a deep and severe crisis of the 1970s was largely due to the transition from the A-phase of the fourth K-wave to the B-phase. And such critical crises are always particularly severe, especially since the A-phase of the fourth K-wave was extremely violent. One should note that the leading economists' disregard of the long-wave dynamics prevents them from revealing the causes underlying important phenomena in economy, in particular those caused by the alternation of upswing and downswing trends of K-waves. For example, the Nobel Prize winner Paul Krugman in his 2009 monograph argues that 'the reasons for the growth slowdown throughout the advanced world in the early 1970s are still somewhat mysterious' (Krugman 2009: 57), whereas for the long-wave dynamics researchers the reasons are fundamentally obvious. And the theory of the production revolution can also help us to clarify them.

Of course, the specific causes of the crisis are well known. In addition to sharp increase in fuel and raw material prices in the 1970s and 1980s and the impact of US foreign policy on the position of the dollar, major demographic changes in the world played a significant role. While developing countries had an excess of working-age population for which most governments could not provide work, the demographic resources of the USSR and other European socialist countries, as well as of the major capitalist countries had been exhausted by that time. And this had a significant impact on the growth rates both in the socialist (for which it was fatal) and in the capitalist states (which nevertheless managed to overcome the crisis).

The depletion of demographic resources was the first warning to the West that its position as the centre of the World-System had become vulnerable. On the whole, the beginning of a new industrial – Cybernetic – revolution meant that the economic (and eventually political) structure of the World-System would have to change fundamentally. But this change would take quite a long period of time, so the final transformation will occur only after the completion of the sixth K-wave (the transition of the Scientific-Cybernetic production principle to its maturity and major socio-political changes).

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[40] For that reason, accelerated booms inevitably lead to depletion of resources and investment-price distortions, resulting in a slowdown or decline in production as a way of redressing imbalances and distortions.

In addition to the depletion of demographic resources by that time, one can also mention a kind of innovation depletion (not without reason there is an opinion about the slowdown in scientific-technological progress since the 1970s). With rapid pace of development, it takes more effort to promote and introduce already-proven innovations, which are capable of rapid growth than to approve new ones. Thus, the number of innovations that could be implemented in the subsequent decades decreased slightly. In addition, many countries – the drivers of economic growth like Japan (and to a large extent the USSR and other socialist countries) were pure recipients of innovations preferring to buy (or otherwise obtain) patents or fully introduce new technologies. Thus, only a relatively small number of Western countries focused on the development of innovations which limited their growth.

This dynamics seems to fit perfectly the idea of the development of the initial phase of the Industrial revolution. This phase took about 40 years (from the mid-1950s to the mid-1990s). However, its structure is not linear, of course, but to a certain extent resembles the general model of the production revolution: it also makes sense to distinguish two waves. Firstly, a great deal of previously unrealized innovations is realized (and the region of such a burst of innovations is concentrated to the very core of the World-System). One should recall that in the 1950s and 1960s, the key sectors were new chemistry, automatics and non-computer/non-interactive electronics (radio, TV, transistors, *etc.*), which merged with automatics. This innovation wave to a certain extent continues old trends and simultaneously generates new ones (but the latter still play a subordinate role in the economy).[41]

However, the depletion of the innovation resources created in the 1930s and 1950s was inevitable. The formation of the next innovation wave, however, requires some time, when the scope of the new production principle is expanded and simultaneously the pace of innovation is somewhat weakened. During this period, new generations of innovations are created and introduced, which are to become widespread later. One should also note that the sharp rise in energy prices significantly changed search direction for innovations (*e.g.,* towards alternative energy sources), and the eventual abandonment of the Gold Standard, which had plunged Western economies into prolonged inflation and contributed to the growth of innovation in the financial sector. All these processes took place during the downswing B-phase of the fourth K-wave (1970 – the 1980s). As a result, a new innovation wave came into production in the following period – innovations in the sphere of information and computer technologies as well as communication.[42] In contrast to the previous one, this rise allows

[41] Thus, the beginning of the scientific-information revolution was marked by the qualitatively new innovations (computers and new forms of information – binary code, *etc.*), whose diffusion became widespread enough, but not so much as to become the basis of the economy.

[42] Including those based on space technologies, which emerged as a result of the scientific-information revolution.

implementing its own innovations of a new production principle which gradually become widespread and occupy justly their niche.[43] In this and partly in the preceding period, the service sector (typical of the new production principle) was actively developing, employing more and more of working-age population in Europe and Japan (in the US this process had started much earlier).

Thus, the dynamics of the phase transition during the fourth K-wave coincided with the dynamics of unfolding initial phase of the scientific-information revolution.

Why was the B-phase of the Fourth K-wave Short? Now let us point out the peculiarities of the downswing phase of the fourth K-wave. The most important one is its short duration (at least within the framework of our periodization of K-waves). There are many different views on the chronology of the fourth K-wave; for example some scholars believe that this wave completed only before the modern crisis. This view is based on the calculation according to the normal duration of K-waves (up to 60 years). However, with the account of the peculiarities of the technological and economic paradigm, the world-systemic changes, GDP growth rates, *etc.,* the period of the 1990s should be at least attributed to the A-phase of the fifth K-wave. If we analyze Figs 3 and 4 and compare Tables 6 and 7, it is easy to notice that the period from 1982 to 1991 is a turning point. Fig. 3 clearly shows that the decline in the world GDP growth stopped at that period, but there is no clear rise either. The rise is rather weak, while the growth rate itself is higher than in the preceding decade. At present it is difficult to say for sure to which phase (B-phase of the fourth K-wave or A-phase of the fifth K-wave) this decade belongs. In our works (see Grinin, Korotayev, and Tsirel 2011; Grinin and Korotayev 2012; Korotayev and Grinin 2012) we gave two versions of periodization. However, we are more inclined to the version of the short (up to 10–15 years from 1968/1974 to 1984) B-phase of the fourth K-wave (the chronology is given in Table 6, an alternative version is given in Table 7).[44]

In this case, B-phase is shortened to one or two Juglar cycles. We gave our explanations for the shorter duration of the B-phase of the fourth K-wave, indi-

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[43] Although interactive and digital ICTs became a reality already in the 1970s and 1980s, these inventions became truly widespread only in the late 1980s and 1990s, when the A-phase of the fifth K-wave began as evidenced in particular by the dot-com boom in the US, the development of the so-called financial revolution associated with the possibility of instant capital transfer anywhere in the world together with the increase in borders openness for it (see Grinin and Korotayev 2012). This mode became the leading one during the fifth K-wave and to a large extent ensured the rise in the 2000s.

[44] Of course, in this case it is more correct, to calculate the beginning of the B-phase of the fourth K-wave from the late 1960s, when the economic difficulties became quite evident. In this case the A-phase of the fourth wave is about 20 years long and the B-phase is 16 years. If we calculate the A-phase of the fifth wave from 1991 (as shown in Table 7), its short duration of about 15–16 years should be explained additionally. Previously there was no such short A-phase of K-wave.

cating the reason for this in the success of anti-crisis strategies of governments, which began to fight depressions much more actively and intensively than before (see Grinin and Korotayev 2012). This explanation is quite relevant (*e.g.*, at this period the reforms of Reagan and Thatcher were conducted). Therefore, the B-phase of the fifth K-wave will also be relatively short. Undoubtedly this would be more appropriate for the world economy but according to numerous forecasts, the B-phase of the fifth K-wave may be longer than the fourth one, and it will last at least 15–18 years. In this case, the interpretation associated with the effectiveness of anti-crisis measures does not fully explain the shortened duration of the B-phase of the fourth K-wave. At the same time, the comparison of the peculiarities of the K-wave phases with the peculiarities of the first phase of the Scientific-Cybernetic production principle which coincides with them allows making additional justification for this shortening. The downswing phase of the fourth K-wave was interrupted by a new wave of innovation of the scientific-information phase of the revolution. This could not immediately contribute to the economic recovery but it lifted the economy out of depression. *Thus, a more powerful than usual wave of innovations inherent in the scientific-information phase of the revolution made the rise in the fourth K-wave stronger and shortened the duration of its downswing phase.*

In reality, the B-phase is reduced to one or two Juglar cycles in this case. We have explained the shortening of the B-phase of the fourth K-wave, seeing the reason for this in the success of anti-crisis strategies of governments, which became more active and intensified in fighting depressions than before (*Ibid.*). This explanation is quite relevant (Reagan's and Thatcher's reforms, in particular, were carried out in this period). But it follows that the B-phase of the fifth K-wave will also be relatively short. Undoubtedly, this would be a good option for the global economy. However, all forecasts so far indicate that the B-phase of the fifth K-wave may be longer than the fourth, and it will last at least 15–18 years. In this case, the interpretation, associated with the successful operation of anti-crisis measures, does not fully explain the reduction in the duration of the B-phase of the fourth Kondratieff wave. At the same time, a comparison of the features of the K-wave phases with the features of the first phase of the Scientific-Cybernetic production principle coinciding with them in time allows us to make additional justifications for this reduction. The downswing phase of the fourth K-wave was interrupted by a new step of innovations in the scientific-information phase of the revolution. This step could not immediately transfer the vector into a high rise but brought the economy out of a depressed state. Consequently, a more powerful than usual impulse of innovation, peculiar to the scientific-information phase of the revolution, made the rise in the fourth K-wave stronger and shortened the time of its downswing phase.

Table 7. Average annual World GDP growth rates (%) during A- and B-phases of Kondratieff waves, 1871–2007 (version 1, see the explanation in footnote 41)

Kon-dratieff wave number	Phase	Years	Average annual World GDP growth rates (%%) during respective phase
II	The end of upswing phase A	1871–1875	2.09
II	Downswing phase (B)	1876–1894	1.68
III	Upswing phase (A)	1895–1913	2.57
III	Downswing phase (B)	1914–1946	1.50
IV	Upswing phase (A)	1947–1973	4.84
IV	Downswing phase (B)	1974–1991	3.05
V	Upswing phase (A)	1992–2007	3.49

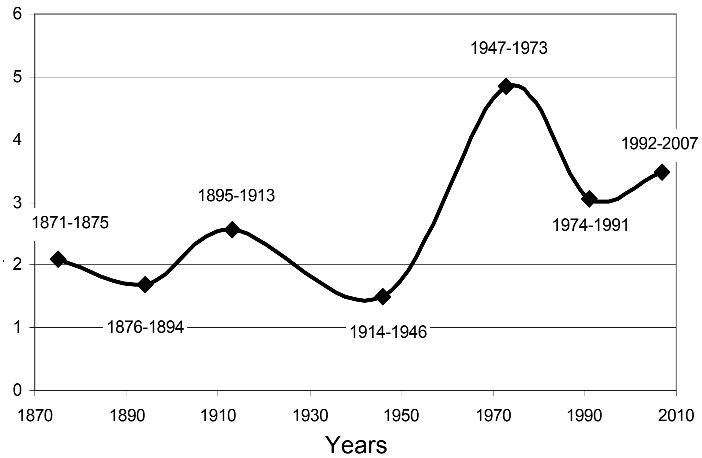

Fig. 4. Average annual World GDP growth rates (%) during A- and B-phases of Kondratieff waves, 1871–2007 (version 1, see the explanation in footnote 41)

Source: Korotayev and Grinin 2012: 81; Fig. 16.

The Change of the Deflationary and Inflationary Trend of K-waves. Another peculiarity was the change of the characteristics of K-waves proper. If previously their downswing phases (as well as the crisis-depression phases of medium-term cycles) were characterized by a deflationary trend, in the 1970s there appeared a new phenomenon called stagflation, *i.e.* increase in prices but not decrease against the background of recession. This further complicated the chronology of the fourth K-wave, as due to ongoing inflation one can consider the assignment of the period of the 1970s to the A-phase correct (see, *e.g.*, Berry and Dean 2012: Fig. 2). The reason why the recession did not lead to price stabilization or decline in prices was firstly the sharp increase in energy and commodity prices, which made deflation really difficult, and secondly the abandonment of the Gold Standard. However, from the point of view of the theory of the production principles, the reasons are deeper. The Scientific-Cybernetic (Scientific-Information) production principle, unlike the industrial principle, firstly, is increasingly based not on the free play of market forces, but on active regulation of the economy in general and of monetary aggregates, in particular. Of course, the Gold Standard remains an impediment to this process. Secondly, the Scientific-Cybernetic production principle is based on the fact that services, rather than goods, are mostly created, which is evidenced by the rapid growth of the service sector (see Table 1). The rapid growth of financial services as stated in the works by Colin Clark (1957), Allan Fisher (1939) and other researchers before World War II, meant nothing more than an opportunity to reduce cyclical processes in the economy, and to expand the capacity of demand. Indeed, what does the supply of financial services mean on a mass scale? First of all, it means large-scale expansion of credit, *i.e.* making credit instruments and products available for almost any individual. Then, already in the A-phase of the fifth K-wave, the development of financial services evolved into the so-called financial revolution, based on computer technologies and the free movement of capital. Thus, with the growth of the financial services sector, the monetary circulation began to follow different trajectories and laws than before. Therefore, deflation in its pure form became less frequent.

2.2. The Fifth K-wave

2.2.1. The Second Phase of the Scientific-Cybernetic Production Principle and the World-System Diffusion of Innovations

The research method used in this paper is based on the fact that the peculiarities of the K-wave development significantly depend on the peculiarities of the phases of the production principle corresponding to the period of its unfolding. In particular, we found that great cataclysms peculiar to the B-phase of the third K-wave (1914/29–1947) were associated with the difficulties characteristic of the transition to the new – Scientific-Cybernetic – production principle, and the higher GDP growth rates in the A-phase of the fourth K-wave (1947–1973) – with a denser overlap of innovation waves which was explained by the coincidence in time with the beginning of the scientific-information phase of the revolution. Many analysts believe that since the 1970s there has been an empirically observed slowdown in scientific and technological progress (see, *e.g.* Denison 1985; Eichegreen 2007; Maddison 2007; Chernov 2006; Abel and

Bernanke 2008: 282–289; Melyantsev 2009: 17–50; Korotayev *et al.* 2010: 51). If so, the beginning of this slowdown occurred during the downswing B-phase of the fourth K-wave (1968/1973–1983/91), and can be additionally explained by the peculiarities of the initial – scientific-information – phase of the cybernetic revolution within which we have established two innovation waves. However, the second one appears to have been less powerful than the first one. The second wave, as has been mentioned above, shortened the duration of the downswing phase of the fourth K-wave, and the impetus given by this innovation wave became the basis for the upswing phase of the fifth K-wave. But it was not so powerful to stimulate the same high growth rates as in the previous period of the 1950s and 1960s. This is understandable, since this initial phase of the Cybernetic revolution required a higher concentration of innovations accumulated since the 1920s than its intermediate phase. One should also note that the period of the 1990s, the time of the A-phase of the fifth K-wave, is not the first, but the second phase of the Scientific-Cybernetic production principle which is still going on. Due to the diffusion of innovations and the transition of previously advanced and now less innovative sectors to the periphery countries there is a growth at this phase. But the development towards the expansion of the innovation zone reduces the rate of creation of basic innovations (see below).

What are the features of the unfolding of the fifth K-wave? They are as follows:

1) lower recovery force, the GDP growth rates are also lower compared to the A-phase of the fourth wave but higher compared to the third wave (see Figs 3 and 4);

2) weak growth rates in the core of the World-System (lower than global) and their decreasing dynamics, and, on the contrary, high growth rates in the semi-periphery and periphery (higher than global) and their increasing dynamics.[45] It clearly shows that the restructuring of the World-System is inevitable (a similar situation was typical of the A-phase of the third K-wave which resulted in a world war, but in this case war should, of course, be excluded);

3) extremely important role of the financial component of growth (we have already considered it above in terms of the change of technological modes), such a situation has not been observed in K-waves before;

4) the turning point between the phases.

These peculiarities can largely be explained by the specific character of the second phase of the Scientific-Cybernetic production principle (1995–2030/

[45] In the first decade of the 21st century the developed countries lagged behind the world average in terms of GDP growth rate. While in 1991–2000 the average annual GDP growth rate of advanced countries was 2.8 % against the global 3.1 %, *i.e.* the lag was 0.3 %, in 2001–2008 the rate of developed countries decreased to 2.1 %, and the global increased to 3.9 %. The difference grew to 1.8 % (World... 2009: 169).

2040). The second phase of the production principle makes the new production principle become the leading and wide-spread in the World-System, and certain sectors and trends of the new production principle are integrated into a much broader system, so innovations are actively improved and become widely applicable in practice, *etc.* Thus, significant changes in the structure of the World-System occur at this (modernization) phase. Respectively, innovations become widespread in the World-System and the range of new ones extremely expands. At the same time, the depth of innovations becomes smaller than in the previous period. Such a great difference between the development levels becomes an obstacle for a wide spread of innovations and the involvement of new regions in the Scientific-Information production principle. This is why at the second phase of the production principle there is some developmental levelling of previously significantly different economies. This is the reason for lower growth rates than in the preceding wave, since the extensiveness of innovations does not replace their density. At the same time, the extensiveness of innovations explains the higher growth rates of the periphery, as well as the shifting to the periphery of industries characteristic of the preceding K-wave modes.

As to the growth of the financial component of the economy, in addition to the overall growth of professional, including financial, services, one should also point out the increase in the volume and speed of financial flows in the world as an instrument of globalization and developmental levelling. Money is a great democratizer (and democracy is based on the equality in some respects). Let us recall that during this period when globalization was just taking shape (in the 15th – the 17th centuries, just at the junction of the first and second phases of the Industrial production principle), the monetary and trade relations created strong global relations and the prototype of the capitalist World-System.

The developmental levelling will continue to actively proceed during the second phase of the Scientific-Cybernetic production principle, expanding into new areas, and will continue at the third phase. In addition to economic levelling, political and cultural development is also required. The wide spread of innovations will eventually lead to a contradiction between the rapidly changing productive forces, on the one hand, and still largely unchanged political and social relations, on the other. This contradiction will manifest itself at two levels: at the country level (especially in the periphery)[46] and at the global level, where new instruments for joint solutions are required. Thus, the rapid spread of innovations and accordingly the rise caused by this is objectively followed by a slowdown in economic growth since it is necessary to improve other areas of life. The economy cannot always outrun them.[47]

[46] The events of the Arab Spring are a vivid example, but political changes are on the horizon in many other countries, including China.

[47] In the similar period of the 17th – the 18th centuries, there broke out revolutions of a new type (in fact, social revolutions as a form of solving the pressing contradictions emerged at that time);

The levelling of the economic and political development of different regions and countries of the world is a very complex and painful process, without which, however, the final phase of the Cybernetic revolution will be delayed (either its beginning will be postponed or it will be delayed in time). Therefore, assuming that this revolution is likely to begin in the 2030s and 2040s, we believe that by this time there will take place major changes in the socio-political landscape of the world.

As already mentioned, at the second phase of the scientific and information revolution, the growth is primarily driven by the expansion of innovations and the moving of the existing sectors to the periphery countries. This has supported the impulse of the A-phase of the fifth K-wave, especially in the periphery, for nearly two decades. But in relation to the above-mentioned objective necessity of restructuring the World-System and developmental levelling, this process is now unfolding at the downswing phase of the fifth K-wave. According to K-waves theory, the Juglar crises that occur at the turning point of the K-wave trend (*i.e.* between the upswing and downswing phases of the K-wave) are usually quite severe and prolonged. This explains the duration of the 2008–2012 crisis and allows us to assume that in the next 10–15 years the growth in the world as a whole will be significantly less than in the 2000s. The above-mentioned features of the second phase of the Scientific-Cybernetic production principle allows us to consider the explanation of the causes as more detailed and the forecast as more reliable, since a prolonged depression (B-phase of the fifth K-wave) will occur during the period of pulling up other spheres to the economy and *on the whole this will require significant changes in the structure of the World-System.* Hence during this period political and social problems may be more acute and possibly expand beyond individual countries, as manifested in the events of the Arab Spring.

2.2.2. The Fifth K-Wave and the Delay of a New Innovation Wave

It was expected that the 1990s and 2000s would bring a new radical innovation wave comparable in its revolutionary character to the advent of computer technologies and capable of creating a new technological mode. The breakthrough trends were precisely those trends that had already been identified and which are now expected to become the basis for a new – sixth K-wave (see Table 2). However, the basis for the fifth wave was the development and diversification of already existing digital electronic technologies and the rapid de-

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a new type of colonies appeared; on the contrary, the process of self-isolation started in the Far East, which was also a specific reaction to global economic changes. In the countries of Northern and North-Eastern Europe there was the rise of serfdom and (as throughout Europe), the formation of estates with well-defined rights. First, the type of developed state was formed in full form, and then of a mature state (see Grinin 2009). All of these are the ways to transform the political and social sphere, but political democratization turned out to be the main one.

velopment of financial technologies. The innovations that were formed during the fifth K-wave, such as energy technologies, still occupy a small share in the overall energy sector, and, most importantly, they do not develop at the necessary pace. Moreover, due to the discovery of the so-called shale gas technologies, it is possible that they will remain marginal. This delay in the emergence of the new technological paradigm and techno-economic paradigm in fact contradicts the theories of technological modes, which assume that each K-wave leads to a new paradigm.

This delay has been explained in various ways, but in general has not received a sufficient theoretical explanation.[48] However, the above-mentioned peculiarities of the second phase of the Scientific-Cybernetic production principle (in particular, the need of pulling the political component of the world to the economic one) may better explain the reasons for the delay in the introduction of a new generation of innovations. Let us recall again that the second phase of the production principle is less innovative in its functional nature, it can be considered as modernization one, when previously created innovations are widely disseminated and improved. Therefore, at this period the periphery catches up the core, and the necessary changes in the structure of society takes place. Therefore, there is nothing surprising in this delay. Firstly, the core cannot be infinitely ahead of the periphery in development, *i.e.* the gap between the developed and developing countries could hardly grow all the time. Secondly, the economy cannot constantly outpace the political and other components, otherwise there may occur very strong imbalances and distortions. And the emergence of new technologies of wide application would certainly accelerate the development of the economy and intensify the distortions. Thirdly, the introduction and diffusion of new basic technologies does not occur by itself, but only in an appropriate socio-political environment (see Grinin 2010; Grinin and Korotayev 2009, 2012). Carlota Perez devoted considerable attention to this aspect in her work (2011). By the way, she is one of the few Western economists, if not the only, who elaborates this important topic. For the emergence of basic innovations in appropriate forms for business, structural changes in the political and social spheres are needed among other things, which will ultimately provide impetus to their synergy and a broad-based 'launch' in business. Fourth, the arena of modern changes has become global and, accordingly, the political, social and other changes needed for catching-up are also of a regional and global nature. The downswing phases of the K-wave are always character-

[48] *E.g.*, academician Victor M. Polterovich when explaining his hypothesis of the innovation pause, which, in his opinion, was the main cause of the 2008 crisis, believes that the emergence of new technologies of broad applicability (a concept rather close to the concept of technological modes) has no regularities. He notes that the emergence of such technologies is random; if they emerge often enough, one can observe a steady growth; if the emergence of a new technology of broad applicability is delayed, a crisis may occur (Polterovich 2009).

ized by rather serious changes in different areas of life (see Grinin 2010; Grinin and Korotayev 2009, 2012; Korotayev and Grinin 2012). However, particularly serious changes should occur at the second phase of the Scientific-Cybernetic production principle. Therefore, more effort is needed.

Thus, the delay is caused by the difficulty with changing political and social institutions regionally and even globally, as well as (and perhaps first and foremost) with international economic institutions. The latter can be changed only via strong political will of the main players, which is difficult to achieve in terms of the present political institutions. And they are likely to change precisely in the context of crisis-depressive development which forces the reorganization and dismantling of the established institutions, which under normal conditions there is neither the courage nor the opportunity to change.

The delay of a new innovation wave is, in fact, the other side of the idea of a slowdown in scientific and technological progress.[49] As we have already mentioned, such a slowdown, first of all, is not actually a slowdown but only some kind of correction, because the 1950s and 1970s were the period of accelerated scientific and technological development, associated with the initial phase of the new production revolution. A similar pace will be probably observed during the final phase of the Cybernetic revolution (in the 2030s – the 2060s). Second, a slowdown is the reverse side of a wide spread. First, it was necessary to pull up the periphery to the core, which was achieved in the 1990s – the 2000s, and now it is necessary to transform regimes as well as various international institutions in developing and semi-peripheral countries (this will happen at the B-phase of the fifth K-wave and the A-phase of the sixth K-wave).

Thus, there is another point which can be better explained by the above-mentioned features of the current (second) phase of the Scientific-Cybernetic production principle. These are the reasons for the difference in the developmental rate between the World-System core and periphery during the fifth K-wave. The periphery had to catch up with the core, which is achieved by a faster rate of its development and a slowing down growth of the core. However, one should not expect a permanent crisis-free development of the periphery, the crisis will occur later and probably in different forms. Without a slowdown of the periphery and serious changes, there will not be a complete catching-up of the political component to the economic one. Hence, one can assume that in the nearest decade (approximately until 2025–2030) the growth rate of the periphery countries may also slow down while their domestic problems will intensify. To a certain extent, this may turn out to be a phenomenon that will activate Western countries, and it is possible that this will bring about some signifi-

[49] To be sure, however, the seeming slowdown is also caused by the transfer of very important innovations into areas other than pure technology: trade, financial, information and other applied technologies.

cant changes in international economic relations. It may also contribute to the increase (as a counter-measure against recession) of financial technologies in periphery countries and on the whole innovations in financial technologies due to a decrease of profitable areas for capital application. It is possible that Russia with the right policies will be able to benefit from these changes. One can also predict the development of technologies aimed at improving the fuel, raw materials and other materials efficiency, (and finding alternatives to them), both due to high prices for them and an increase in overall demand (due to industrial development in developing countries), and also because this is the main path of development in conditions of greater depression. In general, there may occur a return to some psychology of saving.

2.3. The Sixth K-wave

Since the emergence of the sixth K-wave is still only speculation, we give even more conventional dating to it compared to the fourth and fifth waves. It should be noted that all the datings should have a range of 5–10 or even more years. Thus, we currently assume that the B-phase of the fifth wave will be completed in the 2020s, but it may continue until the 2030s (25–30 years is an average length of a wave) especially given the above-mentioned need to pull up the political component. Political events are even less predictable than economic ones. One thing is clear: the longer lasts the depressive period that started with the current crisis, the more radical may be the changes needed to overcome it.

The depressive period from 2010 to the early 2020s does not mean that there will be a continuous depression without upswings. There will be some upswings but probably not as strong and long as in the 1990s and early 2000s, and the periods of depression will be longer than before. For example, in 1997–1998 the horrendous downturn in several countries, including Russia, which seemed to set them back, was suddenly followed by a rapid upswing. This is the effect of the upswing phase of the K-wave. At the downswing phase, the rise is more difficult to achieve.

2.3.1. The Scientific-Cybernetic Production Principle and K-waves

We have considered above the correlation between the fourth and fifth waves and the phases of the Scientific-Cybernetic (information) production principle. The sixth wave basically corresponds to its third phase. Thus, three K-waves (the fourth – the sixth) correspond to the three phases of the Scientific-Cybernetic production principle, which can also be clearly seen from Table 8. The correlation here is even more evident than that between the first three K-waves and the Industrial production principle due to shorter duration of the phases of the Scientific-Cybernetic production principle.

Table 8. 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–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 upswing phase of the sixth wave (2020 – the 2050s) **≈ 30–40 years**	The sixth wave, 2020–2060/70s. The end of the upswing phase and downswing phase (the latter ≈ 2050 – 2060/70s) **≈ 40–50 years**	About **110–120 years**
K-Wave and Their Phases	Upswing phase, 1947–1969/ 1974	Downswing phase of the fifth wave, 2007–2020s		
K-Wave and Their Phases	Downswing phase, 1969/1974 – 1982/1991	Upswing phase of the sixth wave, 2020 – 2050s		
K-Wave and Their Phases	The fifth wave, 1982/1991 – the 2020s, upswing phase, 1982/1991 – 2007			

2.3.2. Forecasts. The A-phase of the Sixth Wave: Acceleration to Enter the Final Phase of the Cybernetic Revolution

The sixth K-wave is likely to begin approximately in the 2020s. Meanwhile the final phase of the Cybernetic Revolution should begin later, at least, in 2030 – the 2040s. Thus, we suppose that a new technological mode will not develop in a necessary form even by the late 2020s (thus, the innovative pause will take longer than expected). However, one should note that the beginning of the K-wave upswing phase is never directly caused by new technologies. This beginning is synchronized with the start of the medium-term business cycle's upswing. And the upswing takes place as a result of the levelling of proportions in economy, the accumulation of resources and other impulses that improve demand and conjuncture. Here one may recall that the beginning of the second K-wave was connected with the discovery of gold deposits in California and Australia, the third wave – with the increasing prices for wheat, the fourth one – with the post-war reconstruction, the fifth one – with the economic reforms in the UK and the USA. And then, with the ongoing acceleration, a new technological mode (which could not completely – if at all – realize its potential) facilitates overcoming of cyclic crises and allows further growth.

Consequently, some conjunctural events will also stimulate an upward impulse for the sixth K-wave. And, for example, the rapid growth of the underdeveloped world regions (such as Tropical Africa, the Islamic East, and some Latin American countries) or new financial and organizational technologies can become a primary impulse. Of course, there will also appear some technical and technological innovations which, however, will not form a new mode yet. Besides, we suppose that financial technologies have not completed yet their expansion in the world. If they can be modified and secured in some way, they will be able to spread into various regions where they are underused now. One should keep in mind that a large-scale application of such technologies demands essential changes in the legal and other systems, which is absolutely necessary for developmental levelling in the world. Taking into account a delay of the new generation of technologies, the period of the 2020s may resemble the 1980s. In other words, it will be neither a growth recession, nor a rise, but rather an accelerated development (with stronger development in some regions and continuous depression in others).

Then, given the above mentioned favorable conditions, during this wave the final phase of the Cybernetic Revolution will begin. In such a situation it is possible to assume that the A-phase of the sixth K-wave (the 2020 – the 2050s) will have much stronger manifestation and last longer than that of the fifth one due to more dense combination of technological generations. And since the Cybernetic Revolution will evolve, the downswing phase of the sixth K-wave (2050 – the 2060/70s) is expected to be not so depressive, as those during the third or fifth waves. In general, during this K-wave (2020 – the 2060/70s) the Scientific-Information Revolution will come to an end, and the Scientific-Cybernetic production principle will acquire its mature shape.

2.3.3. A Different Scenario

The final phase of the Cybernetic Revolution may begin later – not in the 2030s, but in the 2040s (see Table 3). In this case the A-phase of the sixth wave will terminate before the beginning of the revolution of self-regulating systems; therefore, it will not be based on fundamentally new technologies and will not become so powerful as is supposed in the previous scenario. The final phase of the Cybernetic Revolution in this case will coincide with the B-phase of the sixth wave (as it was the case with the zero wave during the Industrial Revolution, 1760–1787) and the A-phase of the seventh wave. In this case the emergence of the seventh wave is highly possible. The B-phase of the sixth wave should be rather short due to the emergence of a new generation of technologies, and the A-phase of the seventh wave – rather long and powerful.

2.3.4. Predictions: The End of the Cybernetic Revolution and the Disappearance of K-waves

The sixth K-wave (about 2020 – the 2060/70s), like the first K-wave, will proceed generally during completion of the production revolution. However, there is an important difference. During the first K-wave the duration of a phase of the Industrial production principle significantly exceeded the duration of the whole K-wave. But now one phase of the K-wave will exceed the duration of one phase of production principle. This alone should essentially modify the course of the sixth K-wave; the seventh wave will be feebly expressed or will not start at all (on the possibility of the other variant see above). Such a forecast is based also on the fact that the end of the Cybernetic Revolution and distribution of its results will promote the integration of the World-System and considerably increasing influence of new universal regulation mechanisms. It is quite reasonable, considering the fact that the coming final phase of the revolution will be the revolution of self-regulating systems.[50] Thus, the management of the economy should achieve a new level. *So, the K-waves appear at a certain stage of social evolution and are likely to disappear at its other stage.*

Conclusion

Thus, the application of the comparative method of investigation allowed us to clarify some important aspects of the K-wave theory. We have defined a quite significant correlation between the phases of production principles and K-waves: on average, one wave corresponds to one phase of a production principle. In general, for the period of three hundred years from the 1760s to the 2060s, six and a half phases of the Industrial and Scientific-Cybernetic (information) production principle coincide with six and a half K-waves, although some phases coincide with one and a half wave and some only with half a wave.

The functional characteristics of the phases of production principle largely determine the duration of each of them. The nature of the production principle,

[50] Apparently, one can speak about the spread of the control-technology paradigm in the economy. For that reason the downswing phase of the sixth K-wave will be significantly different, not so much dramatic in economic terms but rather more controllable because of the innovations associated with the growth of management capabilities that are likely to emerge in the period between the 2030s and 2060s.

the functionality and duration of its certain phases significantly affect the characteristics of unfolding of K-waves and their phases. Thus, the application of the theory of the production principle and production revolution deepens our understanding of long-wave dynamics and allows us to predict the characteristics of the forthcoming K-waves and their phases.

The table presented below briefly shows the features of K-waves and gives their explanation which follows from the theory of production principles.

Table 9. Features of K-waves and their phases, which are better explained by the theory of production principles and production revolutions than by the theory of K-waves

K-wave number and phase	A feature that does not stem from the theory of K-waves	Explanation from the theory of production principles and production revolutions
Zero, B-phase (1760–1787)	During this phase the reason for the origin of K-waves is unclear [51]	It is the period of the final phase of the production revolution, as a result of which the industrial productive forces acquire a stable impulse to innovations and expanded reproduction, which leads to a new type of cyclicality
The first, A-phase (1787–1830)	It is not clear why long K-waves and medium-term J-cycles are so close in time of origin and why they are genetically linked	Various forms of cyclicality were associated with the constraints impeding the expansion of production and the desire to overcome them. A common feature of such development is the change in acceleration and deceleration caused by restrictions on economic expansion. K-waves may be fully realized only through the medium-term cycles
The first, B-phase (1817–1847)	1) The contradiction between a very rapid growth of labor productivity in industry and the depression of the period. 2) The short-term nature of cyclical crises, which usually does not correspond to the B-phases of K-waves. 3) Violent change of technological modes	The beginning of this phase coincided with the end of the third – beginning of the fourth phase of the Industrial production principle. In fact, the industrial revolution was still going on. This provided additional recovery force and a rapid increase in labor productivity. However, since the development of the Industrial production principle had not yet

[51] This also applies to the first wave.

Continuation of the Table

K-wave number and phase	A feature that does not stem from the theory of K-waves	Explanation from the theory of production principles and production revolutions
		created a broad technological and social base, the economic growth faced major obstacles. The technological shift was rapid but there were no social tools to mitigate the shift
The second K-wave (1847–1895). The comparison of A-phase (1847–1873) and B-phase (1873–1895)	The world GDP growth rates at the upswing A-phase were lower than at the downswing B-phase which contradicts the K-wave theory	This is the period of the fourth phase (maturity and expansion) of the Industrial production principle. However, at the A-phase of the second K-wave, the most important world areas were not covered by the sphere of the Industrial production principle, while the main expansion of the Industrial production principle occurred at the B-phase. Due to the volume growth of the regions involved in the new production principle, the world GDP rates became higher
The third K-wave, A-phase (1895–1929)	Acceleration of GDP growth (compared to the A-phase of the second wave) not only in the western countries but also in the world	The fifth phase of the Industrial production principle is shorter than the previous ones (the speed of changes increases), the area and depth of its spread significantly increased together with the complexity (level) of the economy
The third K-wave, B-phase (1929–1947)	1) The depth of depression and the intensity of cataclysms, which are not explained by the K-wave theory. According to this theory, a greater number of socio-political shocks should occur at the A-phase, but not at the B-phase. However, the A-phase was also intense. 2) There is a particularly powerful innovation cluster at this phase	Preparation for the transition to a new (Scientific-Cybernetic) production principle inevitably leads to a systemic crisis at the end of the current (Industrial) production principle (at the end of its fifth and sixth phases), since the transition requires deep structural changes of society. The period of transition to a new production principle is particularly rich in innovations, as some prerequisites are needed for the start of a new production revolution

Continuation of the Table

K-wave number and phase	A feature that does not stem from the theory of K-waves	Explanation from the theory of production principles and production revolutions
The fourth K-wave, A-phase (1947–1973)	Unusually high world GDP growth rates which had not been observed previously	The beginning of the scientific-information phase of the Cybernetic revolution resulted in an increased density of innovations, which provided higher growth rates
The fourth K-wave, B-phase (1973–1982)	1) Very short B-phase and neutral period of the 1980s (which can be attributed to the end of the fourth or beginning of the fifth wave) which is characterized by GDP growth rate stabilization. 2) The change in the deflationary-inflationary trend of the K-waves. At this B-phase the inflationary dynamics characteristic of the A-phases appeared instead of deflation during the depression	The strength of the impulse of the scientific-information phase of the revolution was so high that it drastically reduced the depressive phase, stabilizing growth rates in the 1980s. With the transition to the Scientific-Cybernetic production principle the economic characteristics changed: *e.g.*, there was an increase in the role of financial services, regulation of the monetary aggregates of the state, the role of credit for households which reduced deflationary processes (previously manifested on the basis of the gold standard)
The fifth K-wave, A-phase (1982–2007)	1) Lower GDP growth rates compared to the A-phase of the fourth wave. 2) Weak growth rates in the core of the World-System and, on the contrary, high growth rates in the periphery. 3) Delay of the new generation of basic technologies	During the second (expansion and modernization) phase of the Scientific-Cybernetic production principle, new generations of innovations are not created, since the main vectors of development are the improvement of already existing innovations, pulling the levels of the periphery up to the core and spreading innovations to the maximum number of territories. Therefore, the overall growth rates are slowing down and there is also some developmental levelling of previously very different regions in terms of economic indicators. Such levelling leads to higher growth rates of the periphery and lower growth rates of the core

Continuation of the Table

K-wave number and phase	A feature that does not stem from the theory of K-waves	Explanation from the theory of production principles and production revolutions
The fifth K-wave, B-phase (2007 – the 2020s)	The epoch-making crisis of 2008–2012 is very severe, but the development in the core is much more difficult than in the periphery	The need to pull the periphery up to the core at the second phase of the Scientific-Information production principle for development levelling; the need to pull the political component of development up to the economic one
The sixth K-wave (2020 – the 2060s)	The A-phase will be significantly more powerful than the A-phase of the fifth K-wave, and the B-phase will be less depressive and shorter. If the final phase of the Cybernetic revolution is delayed, the A-phase of the sixth wave will be less powerful but the seventh K-wave should manifest itself	During this wave, the final phase of the Cybernetic revolution will begin, the density of innovations will increase and will remain such for a long time. Hence, the A-phase will be more powerful and the B-phase (like the B-phase of the first wave) – less depressing

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