TECHNOLOGICAL PERSPECTIVES

GLOBAL TECHNOLOGICAL PERSPECTIVES IN THE LIGHT OF CYBERNETIC REVOLUTION AND THEORY OF LONG CYCLES*

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In the present paper, on the basis of the theory of production principles and production revolutions, we reveal the interrelation between K-waves and major technological breakthroughs in history and make some predictions about features of the sixth Kondratieff wave in the light of the Cybernetic Revolution which, we think, started in the 1950s. We assume that the sixth K-wave in the 2030s and 2040s will merge with the final phase of the Cybernetic Revolution (which we call the phase of self-regulating systems). This period will be characterized by breakthroughs in medical technologies which will manage to combine many other technologies into a single complex of MBNRIC-technologies (med-bio-nano-robo-info-cognitive technologies). The article offers some predictions concerning the development of these technologies.

Keywords: *production revolutions, production principle, Industrial Revolution, Cybernetic Revolution, self-regulating systems, Kondratieff waves, fourth K-wave, fifth K-wave, sixth K-wave, World System, center, periphery, medicine, biotechnologies, nanotechnologies, robotics, cognitive technologies.*

Introduction. On the Methodological Base of the Study

The objective of the present article is to make some predictions in technology for the nearest half a century and also to justify the scientific and methodological basis for these predictions. To fulfil the task we employ two significant theories and show both their important cross-points and their mutual verification. The first theory is the theory of long waves (or cycles) whose founder is an outstanding Russian economist and sociologist Nikolay Kondratieff (Kondratieff 1935, 1984, 2002 [1926]). Josef Schumpeter (1939) called these waves the "Kondratieff waves". In the 1920s, Kondratieff pointed to a certain cyclical pattern in the long-term dynamics of some economic indices (at least starting from the late eighteenth century). This regularity consists in the alternation of the phases of accelerated growth of respective indices with their comparative slowdown or a less intensive development. The duration of such a wave was on average from 40 to 60 years. Thus, the Kondratieff waves (cycles) had demonstrated a rather strong regularity for at least two centuries. In what follows, we denote these waves as 'K-waves' each consisting of two phases of almost the same duration, that is every phase lasts for 20–30 years. One phase is an upward or take off phase (A-phase) characterized by a generally accelerated growth of certain important indices (*e.g*., prices, GDP *etc*.) during the whole period (although with fluctuations). The other phase is a downward or slowing down phase (further called a B-phase) with an opposite trend since the whole its period is characterized by a fall (slowdown) of the respective indices (*e.g*., drop in prices, decreasing GDP growth rates *etc*.)

Within the scope of the present paper we have no opportunity to dwell substantially on this theory, as well as on different views and approaches to it and the opportunities it provides (for details see Korotayev and Grinin 2012; Grinin and Korotayev 2014). But it is important to emphasize that a regular alternation of a more active economic phase with less active and depressive recessions allows making rather well-grounded predictions. Moreover, we can derive a method for the predictions from the idea introduced by Schumpeter (Schumpeter 1939) and actually Kondratiev himself (Kondratieff 2002 [1926]) and rather widespread among the economists that such an alternation is connected with technological innovations. The idea is that during the depressive and recessionary periods the voters and businessmen's activity increases since they try to overcome the crisis through a transition to innovative technologies. But still these technologies become widely implemented only at a subsequent phase of the long wave and trigger the economic acceleration (for details see Perez 2002; Grinin 2012a; Grinin and Korotayev 2014). We also employ the Long waves theory since at present only within this approach its followers seem to base their technology predictions on a solid methodological background and proceed from the assumption that every subsequent Kondratieff long wave is correlated to a respective new technological mode (see *e.g*., Akayev 2012; Glazyev 2009; Perez 2002; Lynch 2004; Dator 2006; Hirooka 2006; Nefiodow L. and Nefiodow S. 2014a, 2014b; Korotayev and Grinin 2012).

Another theory we employ is the theory of production revolutions and productive principles which is based on the account of considerable technological transformations in the world historical process. It is rather fruitful with respect to making certain predictions. We have elaborated this theory in our other works (see, *e.g*., Grinin 2006, 2007a, 2007b, 2012b; Grinin L. and Grinin A. 2013a, 2013b, 2014, 2015; Grinin A. and Grinin L. 2015a, 2015b; Grinin and Korotayev 2015a; for details on the tight connection with the theory of long waves and cycles see Grinin 2012a, 2013).

I. Production Principles, Production Revolutions and K-Waves

According to our theory (Grinin 2007a, 2007b, 2012b, 2013; Grinin and Grinin 2013a, 2013b; Grinin A. and Grinin L. 2015a, 2015b), the whole historical process can be most appropriately divided into four large periods, on the basis of the change of major developmental stages of the world productive forces, which we call production principles. *The production principle is a concept which designates very large qualitative stages of development of the world productive forces in the historical process. It is a system of the unknown before forms of production and technologies surpassing the previous ones fundamentally (in opportunities, scales, productivity, efficiency, product nomenclature, etc.).*

We single out four **production principles**:

1. Hunter-Gatherer.

2. Craft-Agrarian.

3. Trade-Industrial.

4. Scientific-Cybernetic.

Among all various technological and production changes that took place in history the following three production revolutions had the most comprehensive and far-reaching consequences for society:

1. **Agrarian** or Agricultural Revolution. Its result is the transition to systematic production of food and, on this base, to the complex social division of labor. This revolution is also connected with the use of new power sources (animal power) and materials.

2. Industrial, or Production Revolution as a result of which the main production concentrated in the industry and began to be carried out by means of machines and mechanisms, and at that not only the replacement of manual labor by machines occurred, but also biological energy was replaced by water and steam energy.

3. Cybernetic Revolution which have led to the emergence of powerful information technologies, and in future will stimulate transition to wide use of self-regulating systems.

Structural model of production revolutions. Within the proposed theory we suggest a fundamentally new idea that each production revolution has an internal cycle of the same type and, in our opinion, includes three phases: two *innovative* (initial and final) and one *modernization* phase (Grinin L. and Grinin A. 2013a, 2013b; Grinin A. and Grinin L. 2015a, 2015b; see Fig. 1). At the initial *innovative* phase new advanced technologies emerge which spread in other societies and territories after a while. As a result of the final *innovative* phase of a production revolution the new production principle reaches its peak.

Between these phases there is the *modernization* phase – a long and very important period of distribution, enrichment, diversification of the production principle's new technologies (which appeared in the initial innovative phase) when conditions for a final innovative breakthrough are created.[1]

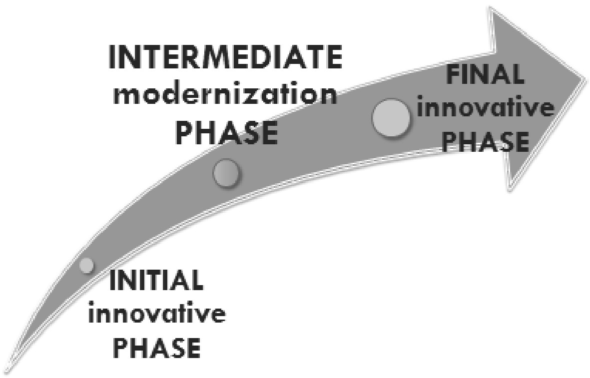

Fig. 1. Phases of production revolutions

Thus, the cycle of each production revolution looks 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 looks as follows (modernization phases are omitted).

Agrarian Revolution: **the initial** 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) (this began approximately 5.5 thousand years ago).

Industrial Revolution: **the initial** phase starts in the fifteenth 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 eighteenth and the first third of the nineteenth centuries, connected with the introduction of various machines and steam energy.

Cybernetic Revolution: **the initial (scientific and information)** phase dated back to the 1950–1990s. The breakthrough occurred in automation, energy production, synthetic materials, space technologies, exploration of space and sea, and agriculture. But especially in 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 of production revolutions means the transition to a fundamentally new production system; the beginning of each production revolution marks the borders between corresponding production principles.

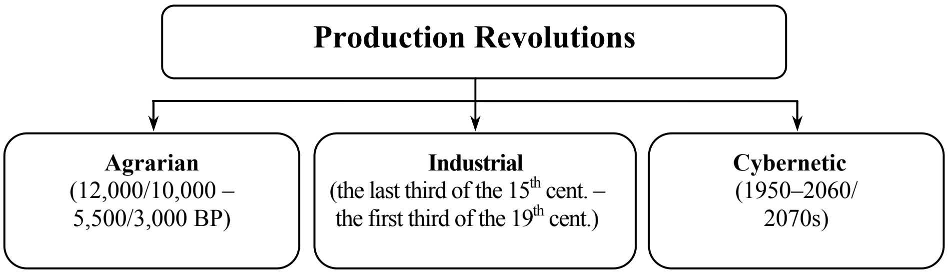

Fig. 2. Production revolutions in history

The Structure of a Production Principle

Development of the production principle is a period of genesis, growth and maturity of new forms, systems and paradigms of organization of economic management, which surpass many times the former ones in major parameters.

The principle of production is a six-phase cycle. Its first three stages correspond to three phases of the production revolution. The subsequent three (post-revolutionary) stages are a period of the maximization of the potentials of the new forms of production in structural, systemic, and spatial sense:

1. *The phase of the production revolution's beginning*. A new, not yet developed principle of production emerges.

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

3. *The phase of completion of the production revolution*. The production principle acquires advanced characteristics.

The first three phases of the production principle still present an incomplete production principle.

4. *The phase of maturity and expansion of the production principle*. The wide geographic and sectoral diffusion of new technologies brings the production principle to mature forms, as well as transformations in social and economic spheres.

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

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

The last three phases of the production principle characterize its mature features.

Table 1

Chronology of the production principle's phases

No	Production Principle	1st phase	2nd phase	3rd phase	4th phase	5th phase	6th phase	Total Production Principle
1.	Hunter-Gatherer	40,000–30,000 (38,000–28,000 BC) **10**	30,000–22,000 (28,000–20,000 BC) **8**	22,000–17,000 (20,000–15,000 BC) **5**	17,000–14,000 (15,000–12,000 BC) **3**	14,000–11,500 (12,000–9,500 BC) **2.5**	11,500–10,000 (9,500–8,000 BC) **1.5**	40,000–10,000 (38,000–8,000 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 (3,000–1,500 BC) **1.5**	3,500–2,200 (1,500–200 BC) **1.3**	2,200–1,200 (200 BC – 800 AD) **1.0**	800–1430 AD **0.6**	10,000–570 (8,000 BC – 1430) **9.4**
3.	Trade-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 (a more detailed chronology see in Grinin 2006; Grinin and Korotayev 2013). The duration of phases (in thousand years) is marked by the bold-face type. Duration of phases of the scientific-cybernetic production principle is hypothetical. The duration of the scientific-cybernetic production principle is also given in Fig. 3.

As is clear, the scientific-cybernetic production principle is at the beginning of its development. Only its first phase finished, and in the mid-1990s the second started. The second phase is proceeding now and will last till the early 2030s. The third phase is likely to begin approximately in the 2030s or the 2040s. At this particular time the final phase of the Cybernetic Revolution should start. The end of the scientific-cybernetic production principle will fall on the early twenty-second century (for more details see Grinin 2006).

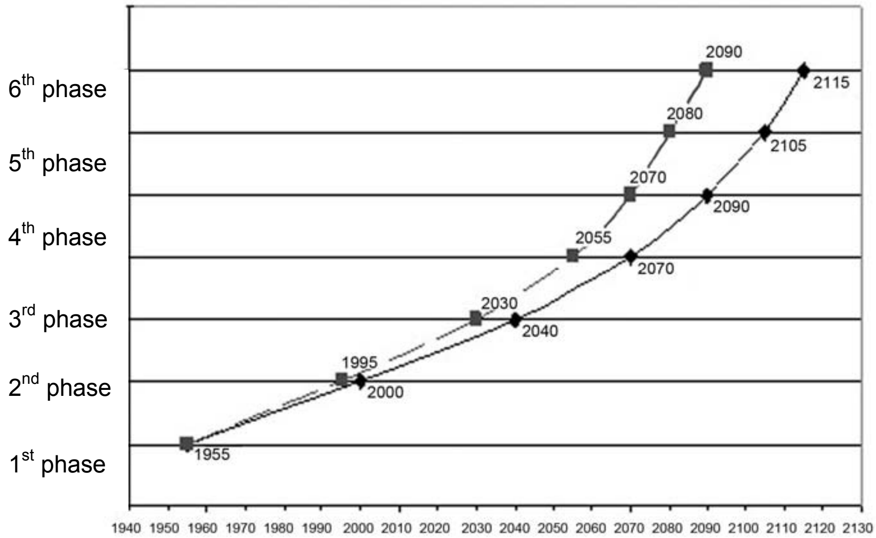

Fig. 3. The development of the scientific-cybernetic production principle

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 bottom row in Table 1.

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

We have established a close correlation between production principle cycles and Kondratieff cycles (for more details see Grinin 2012a, 2013). Taking into account that K-waves arose only at a certain level of economic development of societies, we can consider *K-waves as a specific mechanism connected with the emergence and development of the industrial-trade 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 in a certain aspect can be treated as phases of the development of the industrial production principle and the first phases of development of the scientific-cybernetic production principle.*

In the mentioned articles (Grinin 2012a, 2013) it has been shown that the first three K-waves are connected with the industrial production principle. The special attention is paid to the correlation between the duration of the industrial production principle phases and the duration of K-wave phases. Certainly, there can be no direct duration equivalence of both K-waves and their phases, on the one hand, and the industrial production principle phases, on the other, due to the different duration of the industrial production principle phases (that is within the principle of production's cycle its phases differ in duration, but their duration proportions remain the same in each production principle [Grinin 2006]). However, we have succeeded in establishing a more complex ratio according to which *at the average one K-wave corresponds to one phase of the industrial production principle.* In general, we found out that three and a half waves coincide with three and a half phases of the industrial principle of production! It is clearly seen in Table 2. 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 2

Periods of the industrial production principle and Kondratieff waves

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 Upward Phase, 1895–1928 – more than **35 years**	Third wave, The Downward Phase, 1929–1947 – **about 20 years**	About **190 years**
The Phase of K-wave	B-Phase of the Zero Wave,[2] 1760–1787	The Second half of the Downward Phase, 1817–1849	The Upward Phase, 1895–1928	The Downward Phase, 1929–1947	
The Phase of K-wave	The Upward Phase, 1787–1817	The Upward Phase, 1849–1873			
The Phase of K-wave		The Downward Phase, 1873–1895			

Note: 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.

II. The Cybernetic Revolution, Scientific-Cybernetic Production Principle, the Fourth, Fifth and Sixth K-Waves

The production revolution which began in the 1950s and is still in process and it 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 referred to as a **scientific-informational** as it was characterized by the transition to scientific methods of planning, forecasting, marketing, logistics, production managements, distribution and circulation of resources, and communication. The most radical changes took place in the sphere of informatics and information technologies. The final phase will begin approximately in the 2030s or the 2040s and will last until the 2070s. We called this phase a 'phase of self-regulating systems' (see below). Now we are in the intermediate (modernization) phase which will last until the

2030s. It is characterized by powerful improvement and diffusion of innovations made at the initial phase in particular 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. At the same time the innovations necessary to start the final phase of the Cybernetic Revolution are being prepared.

The Cybernetic Revolution *is a great technological breakthrough from the industrial production principle towards production and services based on the operation of self-regulating systems*. In general, it will become the revolution of *self-regulating* systems (see Grinin 2006a, 2007b, 2012b, 2013; Grinin and Grinin 2013a, 2013b).

Table 3 demonstrates the connection between three phases of the scientific-cybernetic production principle (which coincide with three phases of the Cybernetic Revolution) and three Kondratieff waves (the fourth, fifth and sixth). Correlation is here even stronger than between the first three K-waves and the industrial production principle phases, due to the shorter duration of the scientific-cybernetic production principle phases in comparison with those of the industrial production principle.[3]

Table 3

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

Taking the theory of production principles into account, we have also revised the sequence of change of the major (leading) production sectors during the change of K-waves (Grinin 2012a).[4]

Table 4

K-waves, technological modes and leading macrosectors

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

Peculiarities of the fourth K-wave in connection with the beginning of the Cybernetic Revolution. The fourth K-wave (the second half of the 1940s – 1980s) fell on the initial phase of the Cybernetic Revolution. The beginning of a new production revolution is a special period which is connected with the fast transition to a more advanced technological component of economy. 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 *an upward phase of the K-wave coinciding with the beginning of a production revolution can appear more powerful than A-phases of other K-waves*.[5] That was the feature of 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. All this also explains why in the 1950s and 1960s the economic growth rates of the World System were higher, than in A-phases of the third and fifth K-waves. The downward phase of the fourth K-wave (the 1970s – 1980s) in its turn also fell on the last period of the initial phase of the Cybernetic Revolution. This explains in many respects why this downswing phase was shorter than those of the other K-waves.

The fifth K-wave and the delay of the new wave of innovations. It was expected that the 1990s and the 2000s would bring a radically new wave of innovations, comparable in their revolutionary character with the computer technologies, capable to create a new technological mode. Those directions which had already appeared and those ones, which are now supposed to become a basis for the sixth K-wave were considered to be a breakthrough. However, it was the development and diversification of already existing digital electronic technologies and rapid development of financial technologies that became a basis for the fifth K-wave. Those innovations which were really created during the fifth K-wave as, for example, energy technologies, still have a small share in the general energy, and, above all, they do not grow properly. Some researchers believe that from 1970s up to the present is the time of the decelerating scientific and technological progress (see discussion about it in Brener 2006; see also Maddison 2007). Polterovich (2009) also suggests a notion of a technological pause. But, in general, the mentioned technological delay is, in our opinion, insufficiently explained. We believe that taking features of the intermediate modernization phase of a production revolution (that is the second phase of the production principle) into account can help explain this. Functionally it is less innovative; rather during this phase earlier innovations are widely spread and improved. As regards the 1990s – 2020s (the intermediate phase of the Cybernetic Revolution) the question is that the launch of a new innovative breakthrough demands that the developing countries reach the level of the developed ones, and the political component of the world catches up with the economic one; all this needs changes of the structure of societies and global relations (see about some aspects Grinin and Korotayev 2010b). Thus, the delayed *introduction of innovations of the new generation* is explained, first, by the fact that the center cannot endlessly surpass the periphery in development, that is the gap between developed and developing countries could not increase all the time. Secondly, economy cannot constantly surpass the political and other components, as this causes very strong disproportions and deformations. And the appearance of new general-purpose technologies, certainly, would accelerate economic development and increase disparities. Thirdly, introduction and distribution of the new basic technologies do not occur naturally, but only within the appropriate social political environment (see Grinin 2012a, 2013; see also Perez 2002). In order for basic innovations to be suitable for business, structural changes in political and social spheres are necessary, eventually promoting their synergy and wide implementation in the world of business.

Thus, the delay is caused by difficulties of changing political and social institutions on the regional and even global scale, and also (and, perhaps, first of all) within the international economic institutions. The latter can change only thanks to the strong political will of the main players, which is difficult to execute in the framework of the modern political institutions. These institutions rather can change under the conditions of depressive development (and probable aggravation of the foreign relations) compelling to reorganization and breakage of the conventional institutions that could hardly be changed due to the lack of courage and opportunities under ordinary conditions.

The above said explains as well the reasons of different rates of development of the center and periphery of the World System during the fifth K-wave (for more details see Grinin 2013; see also Grinin and Korotayev 2010a). The periphery was expected to catch up with the center due to the faster rates of its development and slowdown of the center development. However, one should not expect continuous crisis-free development of the periphery – a crisis will come later and probably in other forms. Without slow-down of the development of the periphery and serious changes full harmonization of the economic and political component will not happen.

Consequently, it might be supposed that in the next decade (approximately by 2020–2025) the growth rates of the peripheral economies can also slow down, and internal problems will aggravate that, as said above, can stimulate structural changes in the peripheral countries and strengthen international tension. Thus, we suppose that in the next 10–15 years the world will face serious and painful changes.

As is known, among researchers there is no agreement about periodization of the Kondratieff waves (about this see Korotayev and Grinin 2012). We believe that at present we witness the downward phase of the fifth K-wave which will last till the early or the mid-2020s. However, for example, Leo Nefiodow in his works (Nefiodow 1996; Nefiodow and Nefiodow 2014) argues that the sixth K-wave began in the late 1990s. Thus, according to Nefiodow's logic, now we observe an upward phase (however, the crisis of 2008–2014 and prospects for the next years contradict this), and in the 2020s the downward phase should come.

III. Characteristics of the Cybernetic Revolution

What are self-regulating systems and why are they so important? Self-regulating systems are systems that can regulate themselves, responding in a pre-programmed and intelligent way to the feedback from the environment. These are the systems that operate with a small or completely without human intervention. Today there are many self-regulating systems around us, for example, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Another good example is life-supporting systems (such as medical ventilation apparatus or artificial hearts). They can regulate a number of parameters, choose the most suitable mode of operation and detect critical situations. There are also special programs that determine the value of stocks and other securities, react to the change of their prices, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems has been created. But they are mostly technical and informational systems (as robots or computer programs). During the final phase of the Cybernetic Revolution there will be 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 their autonomy will dramatically increase. Besides, they will essentially reduce energy and resource consumption. The very human life will become organized to a greater extent by such self-regulating systems (for example, by monitoring of health, regimen, regulation of or recommendation concerning the exertions, control over the patients' condition, prevention of illegal actions, *etc.*).

Thus, we designate the modern revolution 'Cybernetic', because its main sense is the wide creation and distribution of self-regulating autonomous systems. Cybernetics, as is well-known, is a science of regulatory systems. Its main principles are quite suitable for the description of self-regulating systems (see, *e.g.*, Wiener 1948; Ashby 1956; Foerster and Zopf 1962; Umpleby and Dent 1999; Tesler 2004).

As a result, the opportunity to control various natural, social and production processes without direct human intervention (that is impossible or extremely limited now) will increase. At the fourth phase (*of maturity and expansion*) of the scientific cybernetic production principle (the 2070s and 2080s) the achievements of the Cybernetic Revolution will become quite systemic and wide-scale in its final phase.

Below we single out the most important characteristics of the Cybernetic Revolution. One can observe them today, but they will realize in mature and mass forms only in the future. These features are closely interconnected and corroborating each other (for more details see Grinin L. and Grinin A. 2013a, 2013b; Grinin A. and Grinin L. 2015a, 2015b).

The most important characteristics and trends of the Cybernetic Revolution:

1. The increasing amounts of information and complication of the systems of its analysis (including the ability of the systems for independent communication and interaction);

2. Sustainable development of the 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 subatomic and using tiny particles as building blocks);

5. Miniaturization and microtization[7] as a trend of the constantly decreasing size of particles, mechanisms, electronic devices, implants, *etc.*;

6. Resource and energy saving in every sphere;

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

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

9. Control over human behaviour and activity to eliminate the negative influence of the so-called human factor.[8]

The characteristics of the technologies of the Cybernetic Revolution:

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

2. The increasing connection between the technological systems and environment;

3. A trend towards autonomation and automation of control is observed together with the increasing level of 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 capabilities for *choosing optimal regimes in the context of certain goals and tasks*;

5. A large-scale synthesis of the 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;[9]

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

Various directions of development should generate a system cluster of innovations.[10]

Medicine as a sphere of the initial technological breakthrough and the emergence of MBNRIC-technology complex. It is worth remembering that the Industrial Revolution began in a rather narrow area of cotton textile manufactory and was connected with the solution of quite concrete problems – at first, liquidation of the gap between spinning and weaving, and then, after increasing weavers' productivity, searching of the ways to mechanize spinning. However, the solution of these narrow tasks caused 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 impulse to the development of the Industrial Revolution. In a similar way, 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 (of self-regulating systems) of this revolution will begin somewhere at the intersection of medicine and many other technologies. Certainly, it is almost impossible to predict the concrete course of innovations. 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*. In other words, it will be possible to extend our opportunities to alter a human body, perhaps, to some extent, its genome; to widen 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 the life and improve its biological quality.* It will be the technologies intended for common use in the form of a mass market service. 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 drivers of the final phase of the Cybernetic Revolution will be medicine, bio- and nanotechnologies, robotics, IT, cognitive sciences, which will together form a sophisticated system of self-regulating production. We can denote this complex as **MBNRIC-technologies**. As is known, there is the widely used abbreviation of NBIC-technology (or convergence), that is nano-, bio-, information and cognitive technologies (see Lynch 2004; Dator 2006; Akayev 2012). However, we believe that this complex will be larger.

It should be noted that Leo Nefiodow has been writing about medicine as the leading technology of the sixth Kondratieff wave for a long time (Nefiodow 1996; Nefiodow and Nefiodow 2014c). In general, we support his approaches (including the ideas about a new type of medicine), but it is important to point out that Nefiodow believes that it is biotechnologies that will become an integrated core of a new mode. However, we suppose that the leading role of biotechnologies will be, first of all, in their possibility to solve the major medical problems.[11] That is why, it makes sense to speak about medicine as the core of a new technological paradigm. Besides, Nefiodow practically does not mention nanotechnology that will be of great importance in terms of the development of biotechnologies and medicine (they are supposed to play a crucial role in the fight against cancer; at the same time nanotechnologies will play a crucial role in other spheres too, in particular in energy and resources saving). It is difficult to agree with his opinion that psychosocial health, which, in his opinion, cover not only psychotherapeutic, psychological and psychiatric services, but also numerous measures of people's health improvement that is capable to reduce, in his terms, social entropy, will be the second leading mode. The problems of this social entropy which he points out (corruption, growth of small and large crime, drug addiction, loss of moral guide, divorces, growth of violence, *etc.*) have always existed in society; many of them even had a greater share than today. Social changes can be really extremely important for creation of starting conditions for a long-term upswing and its keeping (for more details see Grinin and Korotayev 2014). However, it is production and/or commercial technologies that represent the driving force of the K-Waves upward phases.

Thus, we suppose the following:

1. Medicine will be the first sphere to start the final phase of the Cybernetic Revolution, but, later on, self-regulating systems development will cover the most diverse areas of production, services and life.

2. We treat medicine in a broad sense, because it will include (and already actively includes) for its purposes a great number of other scientific branches (*e.g.*, the use of robots in surgery and care of patients, information technologies in remote medical treatment, neural interfaces for treatment of mental illness and brain research; gene therapy and engineering, nanotechnologies for creation of artificial immunity and biochips which monitor organisms; new materials for growing artificial organs and many other things to become a powerful sector of economy).

3. The medical sphere has unique opportunities to combine the abovementioned technologies into a single system.

4. There are also some demographic and economic reasons why the phase of self-regulating systems will start in medicine:

– increase in average life expectancy and population ageing will favor not only the growth of medical opportunities to maintain health, but also allow the extension of working age, as population ageing will be accompanied by the lack of working-age population (see Figs 4 and 5);[12]

− people, in general, are always ready to spend money on health and beauty. However, the growth of the world middle class and the cultural standard of people implies much greater willingness and solvency in this terms; and

− medical corporations usually do not impede technological progress, but, on the contrary, are interested in it.

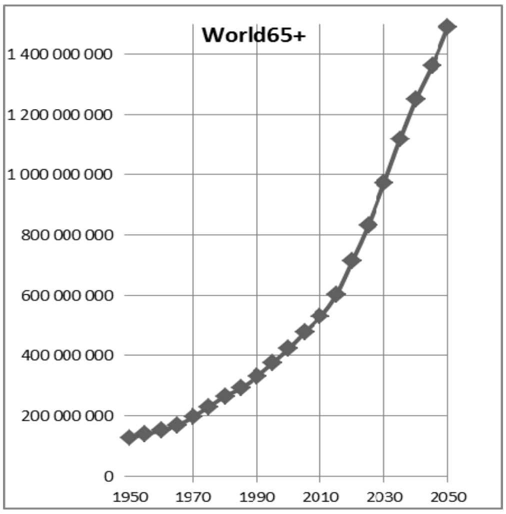

Fig. 4. Predictable increase in the number of people aged 65+, estimated for 1950–2015 and projected to 2050.

Source: UN Population Division 2015; calculated in Grinin and Korotayev 2015b.

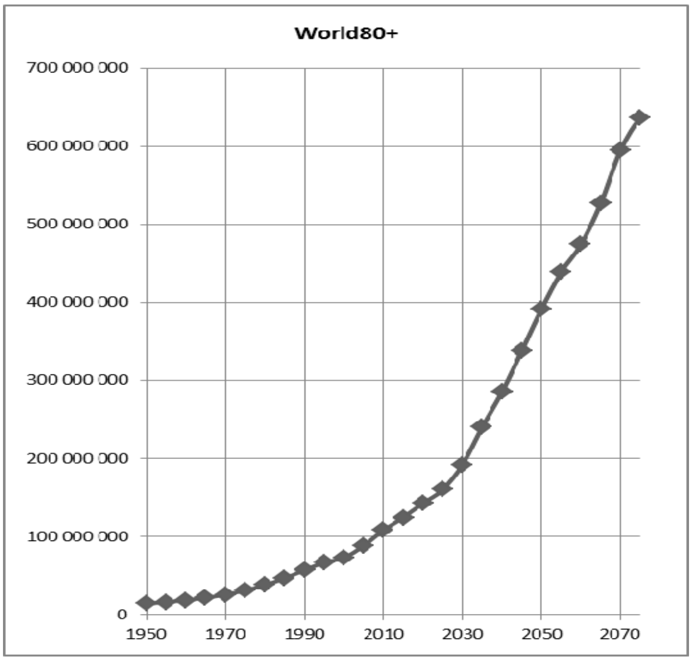

Fig. 5. Predictable increase in the number of people aged 80+, estimated for 1950–2015 and projected to 2075.

Source: UN Population Division 2015; calculated in Grinin and Korotayev 2015b.

Thus, today medicine is a very important sector of the economy, and tomorrow it will become even more powerful.

In the present article we confined ourselves to a short description of the spheres which represent a new, in a broad sense, medical system or realm of medicine, creating a complex of technologies and their application with other perspective directions.

Surgery. Robots have become widely used in surgeries (see Fig. 6). The da Vinci robot has become especially popular. In the future, an increasing number of surgical operations will be performed with less involvement of professionals. Many simple surgeries will need no human participation at all.

Robots can perform a wide range of surgeries because of:

- easy access to the zone of surgery;
- small scars;
- superhuman accuracy;
- no hand tremor;
- possibility to control a robot at a distance via Internet.

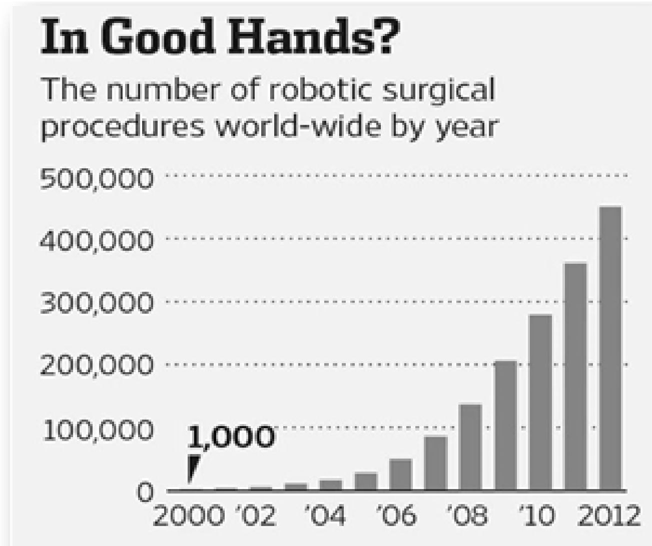

Fig. 6. Robots in surgery

Source: Pinkerton 2013.

Biochips represent a new trend of combining medical and nanobiotechnologies. Biochips are able to register a wide range of physiological changes and respond to them or perform specific actions. In the long term, biochips will permit a continuous control of a person's health. There are many biochips in medicine today. For example, cardio-chips which are connected to the heart cells, register all necessary indices, and transmit them to devices. Some biochips are so small in size that can be placed into a cell or tiny spheres of lipids, liposomes. They can be used for different purposes, for example, for targeted drug delivery.

Artificial organs are the key to resolving the urgent lack of enough donor organs. In medicine scientists already use or work to design different artificial organs: skin, retina, trachea, vessels, heart, ear, eye, limbs, liver, lungs, pancreas, bladder, ovaries. This will definitely increase life expectancy and can have various consequences. The artificial womb, for example, can provide an opportunity to have children for people irrespective of age and, perhaps, even gender.

Artificial immune system is an autonomous intellectual system against diseases and pathogenic organisms. For example, a nanorobot can travel through the body and collect pathogenic organisms into a special module, where they are decomposed. Organic compounds are further used by human organism.

Gene therapy is an explosively developing sector. It is a powerful tool for correcting hereditary diseases as well as developing new abilities that an organism lacked before. In our view, the crucial breakthroughs in gene therapy will be made in the treatment of genetic disorders and sport medicine.

Neural interfaces are an interaction between brain and computer systems that can be realized via electrode contact with head skin or via electrodes implanted into the brain. The implementation of neural interfaces is already wide-spread. They have developed neural interfaces that allow prosthetic devices to be moved via brain signals. Today, scanning techniques have been developed that allow studying brain signals. This gives an opportunity to reproduce any brain response.

So the final phase of the Cybernetic Revolution:

− will create various self-regulating systems;

− will start in medicine, which in the conjuncture with other fields will create the revolutionizing system of MBNRIC (med-bio-nano-robo-info-cognitive) technologies;

− will improve the quality of life particularly of old people and disabled persons;

− will increase average life expectancy (up to 100 years);

− will lead to the emergence of opportunities to correct and modify human biology itself.

However, the final phase of the Cybernetic Revolution will have ambiguous consequences. On the one hand, vigorous growth of production volume will be expected. On the other hand, due to the diffusion of various self-regulating systems the number of specialists needed in different spheres will decrease. For instance, due to the development of self-regulation and remote medical care the number of doctors will significantly diminish.

The possibilities of medicine will hugely increase. At the same time the emergence of opportunities to radically change the human organism may bring about unprecedented ethical issues and seriously damage such vital aspects as family, gender, and morals. That is why it is very important to search for some optimal social, legal and other means beforehand. Then those changes will not be completely unexpected and their negative consequences could be minimized.

IV. The Phase of Self-Regulating Systems and the Sixth K-Wave

A-Phase of the sixth K-wave: acceleration to enter the final phase of the Cybernetic Revolution

The sixth K-wave will probably begin approximately in the 2020s. Meanwhile the final phase of the Cybernetic Revolution has to begin later, at least, in the 2030–2040s. Thus, we suppose, that a new technological mode will not develop in a necessary form even by the 2020s (thus, the innovative pause will take longer than expected). However, it should be kept in mind 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. One should remember, 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 increase in 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, given an upswing, 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 of 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. Naturally, 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 finished yet its expansion in the world. If we can modify and secure them somehow, they will be able to spread into various regions which underuse them now. One should not forget that 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 sixth K-wave's A-phase (the 2020–2050s) 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 sixth K-wave's downward B-phase (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 and Information Revolution will come to an end, and the scientific and cybernetic production principle will acquire its mature shape.

A different scenario. The final phase of the Cybernetic Revolution can begin later – not in the 2030s, but in the 2040s. In this case the A-phase of the sixth wave will terminate before the beginning of the regulating systems revolution; 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 at 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.

The End of the Cybernetic Revolution and 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 the one 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 occur 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 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 the regulating systems. Thus, the management of the economy should reach a new level. Thus, *the K-waves appear at a certain stage of social evolution and are likely to disappear at its certain stage.*

NOTES

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1 For example, in the modernization phase of the Agrarian Revolution local varieties of plants and breeds of animals borrowed from other places were created.

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

3 The reason for the shorter duration is the general acceleration of historical development.

4 During the table compiling we took into account ideas and works cohering with the theories which explain the nature and pulsation of K-waves by changing of technological ways and/or *techno-economic paradigms:* Mensch 1979; Kleinknecht 1981, 1987; Dickson 1983; Dosi 1984; Freeman 1987; Tylecote 1992; Glazyev 1993; Mayevsky 1997; Modelski and Thompson 1996; Modelski 2001, 2006; Yakovets 2001; Freeman and Louçã 2001; Ayres 2006; Kleinknecht and van der Panne 2006; Dator 2006; Hirooka 2006; Papenhausen 2008; see also Lazurenko 1992; Glazyev 2009; Polterovich 2009; Perez 2002.

5 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 Cybernetic Revolution final phase. Thus, the sixth wave is to have a stronger manifestation than the fifth one. We will return to this point below.

6 Even now this market is growing rapidly, and in the future it will run up to hundreds billion dollars.

7 See: http://www.igi-global.com/dictionary/microtization/18587.

8 For example, the control of human insufficient attention in order to prevent dangerous situations (*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).

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

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

11 We agree with Nefiodow that it is also necessary to include in this complex food, pharmaceutics and ecology (see Grinin and Grinin 2013a, 2013b).

[12] One should note that these forecasts are made basing on the ratchet-effect scenario from the UN, the dramatic changes in medical technologies can rather considerably increase the number of elderly and old people.

REFERENCES

Akayev, A. A. 2012. Mathematical Foundations of Schumpeter–Kondratieff' Theory of Innovative Cycles in Economic Development. In Akayev, A. A., Grinberg, R. S., Grinin, L. E., Korotayev, A. V., Malkov, S. Yu. (eds.), *Kondratieff Waves: Aspects and Perspectives* (pp. 110–135). Volgograd: Uchitel. *In Russian* (Акаев А. А. Математические основы инновационно-циклической теории экономического развития Шумпетера – Кондратьева. *Кондратьевские волны: аспекты и перспективы* / Ред. А. А. Акаев, Р. С. Гринберг, Л. Е. Гринин, А. В. Коротаев, С. Ю. Малков, с. 110–135. Волгоград: Учитель).

Ashby, R. 1956. *An Introduction to Cybernetics.* London: Chapman and Hall.

Ayres, R. U. 2006. Did the Fifth K-Wave Begin in 1990–92? Has it been Aborted by Globalization? In Devezas, T. C. (ed.), *Kondratieff Waves, Warfare and World Security* (pp. 57–71). Amsterdam: IOS Press.

Brener, R. 2006. *The Economics of Global Turbulence. The Advanced Capitalist Economies from Long Boom to Long Downturn, 1945–2005*. London – New York: Verso.

Dator, J. 2006. Alternative Futures for K-Waves. In Devezas, T. C. (ed.), *Kondratieff Waves, Warfare and World Security* (pp. 311–317). Amsterdam: IOS Press.

Dickson, D. 1983. Technology and Cycles of Boom and Bust. *Science* 219(4587): 933–936.

Dosi, G. 1984. *Technical Change and Industrial Transformation.* New York: St. Martin's Press.

Foerster, H. von, and Zopf, G. (Eds.) 1962. *Principles of Self-organization*. New York: Pergamon Press.

Freeman, C. 1987. Technical Innovation, Diffusion, and Long Cycles of Economic Development. In Vasko, T. (ed.), *The Long-Wave Debate* (pp. 295–309). Berlin: Springer.

Freeman, C., and Louçã, F. 2001. *As Time Goes By: From the Industrial Revolutions to the Information Revolution.* Oxford: Oxford University Press.

Glazyev, S. Yu. 1993. *Theory of the Long-term Techno-Economic Development.* Moscow: VlaDar. *In Russian* (Глазьев С. Ю. *Теория долгосрочного технико-экономического развития*. М.: ВлаДар).

Glazyev, S. Yu. 2009. The World Economic Crisis as a Process of Changing Technological Modes. *Voprosy ekonomiki* 3: 26–32. *In Russian* (Глазьев С. Ю. Мировой экономический кризис как процесс смены технологических укладов. *Вопросы экономики* 3: 26–32).

Grinin, A. L., and Grinin, L. E. 2015a. Cybernetic Revolution and Forthcoming Technological Transformations (The Development of the Leading Technologies in the Light of the Theory of Production Revolutions). In Grinin L. E., and Korotayev A. V. (eds.), *Evolution: From Big Bang to Nanorobots* (pp. 251–330). Volgograd: 'Uchitel' Publishing House.

Grinin, A. L., and Grinin, L. E. 2015b. The Cybernetic Revolution and Historical Process. *Social Evolution & History* 14(1): 125–184.

Grinin, L. E. 2006. Periodization of History: A Theoretic-Mathematical Analysis. In Grinin, L. E., de Munck, V., and Korotayev, A. V. (eds.), *History & Mathematics: Analyzing and Modeling Global Development* (pp. 10–38). Moscow: KomKniga.

Grinin, L. E. 2007a. Production Revolutions and Periodization of History: A Comparative and Theoretic-Mathematical Approach. *Social Evolution & History* 6(2): 75–120.

Grinin, L. E. 2007b. Production Revolutions and the Periodization of History. *Herald of the Russian Academy of Sciences* 77(2): 150–156.

Grinin, L. E. 2012a. Kondratieff Waves, Technological Modes and the Theory of Production Revolutions. In Akayev, A. A., Grinberg, R. S., Grinin, L. E., Korotayev, A. V., and Malkov, S. Yu. (eds.), *Kondratieff Waves: Aspects and Perspectives* (pp. 222–262). Volgograd: Uchitel. *In Russian* (Гринин Л. Е. Кондратьевские волны, технологические уклады и теория производственных революций. *Кондратьевские волны: аспекты и перспективы* / Ред. А. А. Акаев, Р. С. Гринберг, Л. Е. Гринин, А. В. Коротаев, С. Ю. Малков, с. 222–262. Волгоград: Учитель).

Grinin, L. E. 2012b. *Macrohistory and Globalization*. Volgograd: Uchitel.

Grinin, L. E. 2013. The Dynamics of Kondratieff Waves in the Light of the Production Revolutions Theory. In Grinin, L. E., Korotayev, A. V., and Malkov, S. Yu. (eds.), *Kondratieff Waves: The Spectrum of Ideas* (pp. 31–83). Volgograd: Uchitel. *In Russian* (Гринин Л. Е. Динамика кондратьевских волн в свете теории производственных революций. *Кондратьевские волны: Палитра взглядов* / Отв. ред. Л. Е. Гринин, А. В. Коротаев, С. Ю. Малков, с. 31–83. Волгоград: Учитель).

Grinin, L. E., and Grinin, A. L. 2013a. Global Technological Transformations. In Grinin, L. E., Ilyin, I. V., and Korotayev, A. V. (eds.), *Globalistics and Globalization Studies: Theories, Research & Teaching* (pp. 98–128). Volgograd: Uchitel.

Grinin, L. E., and Grinin, A. L. 2013b. Macroevolution of Technology. In Grinin, L. E., Korotayev A. V. (eds.), *Evolution: Development within Big History, Evolutionary and World-System Paradigms* (pp. 143–178). Volgograd: Uchitel.

Grinin, L. E., and Grinin, A. L. 2014. The Sixth Kondratieff Wave and the Cybernetic Revolution. In Grinin, L.d E., Devezas, T. C., and Korotayev, A. V. (eds.), *Kondratieff Waves. Juglar – Kuznets – Kondratieff.* Yearbook (pp. 354–378). Volgograd: 'Uchitel' Publishing House.

Grinin L. E., and Grinin, A. L. 2015. The Cybernetic Revolution and the Sixth Kondratieff Wave. In Grinin L. E., Korotayev, A. V., and Bondarenko, V. M. (eds.), *Kondratieff Waves: Heritage and Modernity* (pp. 83–106). Volgograd: Uchitel. *In Russian* (Гринин Л. Е., Гринин А. Л. Кибернетическая революция и шестой технологический уклад. *Кондратьевские волны: наследие и современность:* ежегодник / Отв. ред. Л. Е. Гринин, А. В. Коротаев, В. М. Бондаренко, с. 83–106. Волгоград: Учитель).

Grinin, L. E., and Korotayev, A. V. 2010a. Will the Global Crisis Lead to Global Transformations? 1. The Global Financial System: Pros and Cons. *Journal of Globalization Studies* 1(1): 70–89.

Grinin, L. E., and Korotayev, A. V. 2010b. Will the Global Crisis Lead to Global Transformations? 2. The Coming Epoch of New Coalitions. *Journal of Globalization Studies* 1(2): 166–183.

Grinin, L. E., and Korotayev, A. V. 2013. *Social Macroevolution: The Genesis and Transformation of the World-System*. 2nd ed. Moscow: LIBROCOM. *In Russian* (Гринин Л. Е., Коротаев А. В. *Социальная макроэволюция: генезис и трансформация Мир-Системы.* 2-е изд. М.: Либроком).

Grinin, L. E., and Korotayev, A. V. 2014. Interaction between Kondratieff Waves and Juglar Cycles. In Grinin, L. E., Devezas, T. C., and Korotayev, A. V. (eds.), *Kondratieff Waves. Juglar – Kuznets – Kondratieff.* Yearbook (pp. 25–95). Volgograd: 'Uchitel' Publishing House.

Grinin, L. E., and Korotayev, A. V. 2015a. *Great Divergence and Great Convergence. A Global Perspective*. Springer International Publishing.

Grinin, L. E., and Korotayev, A. V. 2015b. Global Population Ageing, the Sixth Kondratieff Wave, and the Global Financial System. In Goldstone, J., Grinin, L., and Korotayev, A. V. (eds.), *History & Mathematics: Political Demography & Global Ageing*. Yearbook. Volgograd: Uchitel Publishing House. In press.

Hirooka, M. 2006. *Innovation Dynamism and Economic Growth. A Nonlinear Perspective*. Cheltenham – Northampton: Edward Elgar.

Kleinknecht, A. 1981. Innovation, Accumulation, and Crisis: Waves in Economic Development? *Review* 4(4): 683–711.

Kleinknecht, A. 1987. *Innovation Patterns in Crisis and Prosperity: Schumpeter's Long Cycle Reconsidered.* London: Macmillan.

Kleinknecht, A., and van der Panne, G. 2006. Who Was Right? Kuznets in 1930 or Schumpeter in 1939? In T. C. Devezas (ed.), *Kondratieff Waves, Warfare and World Security* (pp. 118–127). Amsterdam: IOS Press.

Kondratieff N. D. 1935. The Long Wave in Economic Life. *Review of Economics and Statistics*. November 17(7): 105–115.

Kondratieff N. D. 1984. *The Long Wave Cycle*. New York: Richardson & Snyder.

Kondratieff N. D. 2002 [1926]. The Long Cycles of Economic Conjubcture. In Kondratieff, N. D., *The Long Cycles of Conjubcture and the Theory of Prediction* (pp. 341–400). Moscow; Ekonomika. *In Russian* (Кондратьев, Н. Д. Большие циклы экономической конъюнктуры. В: Кондратьев Н. Д. *Большие циклы конъюнктуры и теория предвидения*. Избранные труды (с. 341–400). М.: Экономика).

Korotayev A. V., and Grinin, L. E. 2012. Kondratieff Waves in the World System Perspective. In Grinin, L. E., Devezas, T. C. and Korotayev, A. V. (eds.), *Kondratieff Waves. Dimensions and Prospects at the Dawn of the 21st Century. Yearbook* (pp. 23–64). Volgograd: Uchitel.

Lazurenko, S. 1992. The Problems of Long-Term Oscillations of Economic Dynamics. *Voprosy ekonomiki* 10: 69–75. *In Russian* (Лазуренко С. Проблемы долговременных колебаний экономической динамики. *Вопросы экономики* 10: 69–75).

Lynch, Z. 2004. Neurotechnology and Society 2010–2060. *Annals of the New York Academy of Sciences* 1031: 229–233.

Maddison, A. 2007. *Contours of the World Economy, 1–2030.* Oxford: Oxford University Press.

Mayevsky, V. I. 1997. *Basics of Evolutionary Macroeconomics.* Moscow: Yaponiya segodnya. *In Russian* (Маевский В. И. *Введение в эволюционную макроэкономику*. М.: Япония сегодня).

Mensch, G. 1979. *Stalemate in Technology – Innovations Overcome the Depression*. New York: Ballinger.

Modelski, G. 2001. What Causes K-waves? *Technological Forecasting and Social Change* 68: 75–80.

Modelski, G. 2006. Global Political Evolution, Long Cycles, and K-Waves. In Devezas, T. C. (ed.), *Kondratieff Waves, Warfare and World Security* (pp. 293–302). Amsterdam: IOS Press.

Modelski, G., and Thompson, W. R. 1996. *Leading Sectors and World Politics: The Coevolution of Global Politics and Economics*. Columbia, SC: University of South Carolina Press.

Nefiodow, L. 1996. *Der sechste Kondratieff. Wege zur Produktivität und Vollbeschäftigung im Zeitalter der Information*. 1 Auflage/Edition. Rhein-Sieg-Verlag: Sankt Augustin.

Nefiodow, L., and Nefiodow, S. 2014a. *The Sixth Kondratieff. The New Long Wave of the World Economy.* Rhein-Sieg-Verlag: Sankt Augustin.

Nefiodow, L., and Nefiodow, S. 2014b. *Criteria to Identify and Predict a Kondratieff Cycle* (in print).

Nefiodow, L., and Nefiodow, S. 2014c. The Sixth Kondratieff. The Growth Engine of the 21st Century. In Grinin, L. E., Devezas, T., and Korotayev, A. V. (eds.), *Kondratieff Waves: Juglar – Kuznets – Kondratieff* (pp. 326–353). Volgograd: Uchitel.

Papenhausen, Ch. 2008. Causal Mechanisms of Long Waves. *Futures* 40: 788–794.

Perez, C. 2002. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages.* Cheltenham: Elgar.

Pinkerton, S. 2013. The Pros and Cons of Robotic Surgery. *The Wall Street Journal* November, 17. URL: http://www.wsj.com/articles/SB10001424052702304655104579163430371597334.

Polterovich, V. 2009. Hypothesis about Innovative Pause and the Strategy of Modernization. *Voprosy ekonomiki* 6: 4–23. *In Russian* (Полтерович В. Гипотеза об инновационной паузе и стратегия модернизации. *Вопросы экономики* 6: 4–23).

Schumpeter, J. A. 1939. *Business Cycles*. New York, NY: McGraw-Hill.

Tesler, G. S. 2004. *New Cybernetics.* Kiev: Logos. *In Russian* (Теслер Г. С. *Новая кибернетика*. Киев: Логос).

Tylecote, A. 1992. *The Long Wave in the World Economy*. London: Routledge.

Umpleby, S. A., and Dent, E. B. 1999. The Origins and Purposes of Several Traditions in Systems Theory and Cybernetics. *Cybernetics and Systems: An International Journal* 30: 79–103.

Wiener, N. 1948. *Cybernetics, or Control and Communication in the Animal and the Machine.* Cambridge: MIT Press.

Yakovets, Yu. V. 2001. *Heritage of N. D. Kondratieff: A View from the 21st Century.* Moscow: MFK. *In Russian* (Яковец Ю. В. *Наследие Н. Д. Кондратьева: взгляд из XXI века.* М.: МФК).