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Forthcoming Kondratieff wave, Cybernetic Revolution, and global ageing☆

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ABSTRACT

In the present article we analyze the relationships between K-waves and major technological breakthroughs in history and offer forecasts about features of the sixth Kondratieff wave. We use for our analysis the basic ideas of long cycles' theory and related theories (theories of the leading sector, technological styles *etc.*) as well as the ideas of our own theory of production principles and production revolutions. The latest of production revolution is the Cybernetic Revolution that, from our point of view, started in the 1950s. We assume that in the 2030s and 2040s the sixth K-wave will merge with the final phase of the Cybernetic Revolution (which we call a phase of self-regulating systems). This period will be characterized by the breakthrough in medical technologies which will be capable to combine many other technologies into a single system of MANBRIC-technologies (medico-additive-nano-bio-roboto-info-cognitive technologies). The article also presents a forecast of the process of global ageing and argues why the technological breakthrough will occur in health care sector and connected spheres.

1. Introduction. Long wave theory and forecasts of future technological breakthroughs and transformations

Karl Popper believed that the real and practically important task of social science is not "the prophecy of the future course of history", but, "rather, the discovery and explanation of the less obvious dependences within the social sphere. It is the discovery of the difficulties which stand in the way of social action—the study, as it were, of the unwieldiness, the resilience or the brittleness of thesocial stuff, of its resistance to our attempts to mold it and to work with it" (Popper, 1966: 295–296). He was largely right in regard to criticism of attempts of historical predictions, as past trends cannot be fully used to predict the future. And in general, due to a variety of accidents and coincidences, our future is not predetermined (*e.g.*, Aron, 1967). Nevertheless, it is clear that the future grows out of the past and present, that certain patterns have a wide range of application (*e.g.* cyclic ones especially if they have a long duration – for example, 50–60 years (Kondratieff (1926, 1935, 1984), about 100 years (Groot and Frances, 2008: 301) or even more (Goldstein, 1988; Thompson, 1988; Modelski and Thompson, 1996)). Hence it is possible, firstly, to use our knowledge of the rhythms and trends of important processes in the past and in the present, in order to try to forecast their future development, and secondly, to use the predictive capacity of some theories that describe relatively recurrent patterns at specific time intervals (one of those theories is the theory of long cycles, which we will discuss below).

Currently, there is little doubt that the development of technology is one of the most important factors in the development of society. The success of economic strategies for the forthcoming decades and the position of any country in the balance of forces in the world will largely depend on the success of forecasts of development of various innovative technologies (this is one of important causes of the race among several states in the field of nano-, bio- and other technologies).

As a result of increasing attention to technology, we observe the publication of numerous articles devoted to forecast of development of certain areas ("Technological Forecasting and Social Change" being the most important venue for the publication of such articles (Phillips and Linstone, 2016)). Most of the research is related to forecasts of the development of some large areas, such as the development of bio-, nano- and information technologies (*e.g.*, Venkatesh et al., 2003; Phillips and Yu-Shan, 2009; Islam and Miyazaki, 2009),

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or new areas such as nanomedicine (Moghimi, 2005), cloning (Gurdon and Colman, 1999), or nanorobots (Mallouk and Sen, 2009). However, it should be noted that, unfortunately, the majority of studies that forecast the future development of nano- and biotechnologies, robotics, and so on, are not based on major theoretical concept, as it was common among futurologists of the previous generations (*e.g.*, Bell, 1974; Toffler, 1981, 1991; Fukuyama, 2002 [with some reservations]).

In our opinion this is one of the reasons (along with inherent difficulties and uncertainties in making such forecasts), why some people are so enthusiastic with researchers, suffering from excessive technological optimism, who rely on the idea of the exponential (or even hyperexponential) growth of human technological power that will make us immortal in the foreseeable future; a brilliant representative here is, for example, Raymond Kurzweil (2005), see also, *e.g.*, Pride and Korotayev, 2008; Grinin and Grinin, 2015d for more detail).

It is worth noting that, along with the technological optimism, there is also certain technological pessimism – see, for example, Huebner (2005), Modis (2002, 2005), Maddison (2007), or Teulings and Baldwin (2014) who believe that at present we are dealing with a slowdown of scientific progress (see Korotayev and Bogevolnov, 2010 for more detail). In this article we try to explain and give argument to the above statement about what has caused a slowdown in technological progress at the moment, and why and when it should be replaced by some technological acceleration.

Thus, it seems that, despite the large amount of works associated with the forecasting of the future scientific and technological progress, there is an evident lack of general theories, which could provide a methodology for such forecasts. Against this background, it is important to note the prognostic possibilities of the theory of long cycles, especially in terms of their relationship with technological paradigms (although, of course, it also has significant shortcomings, of which we have already written elsewhere [see, *e.g.*, Korotayev and Grinin, 2012; Grinin and Korotayev, 2014]).

As is well known, the theory of long (lasting for 50–60 years) cycles of economic dynamics was formulated in the early 1920s by Nikolay Kondratieff (1925a, 1926, 1928, 1935, 1984, 1998, 2004 [1922]). Kondratieff himself (in his seminal article "Long Cycles of Conjuncture" (Kondratieff, 1925b)) mentioned the following scientists who prior to him had managed to detect to some degree these long waves of economic dynamics: Moore (1914, 1923), Lescure (1912), Aftalion (1913), Spiethoff (1925), Layton (1922), Motylev (1923) and Trotsky (1923); however, Trotsky was not sure that those waves could be regarded as a regular phenomenon (see Kondratieff, 1993: 27–29). He also mentioned a number of economists who refused to identify long waves as a regular phenomenon, but actively discussed them, such as Cassel (1918), Kautsky (1918), Osinsky, 1923a, 1923b) (Kondratieff, 1993: 29). In his study "Dynamics of prices of manufactured and agricultural commodities" published in 1928 (Kondratieff, 2002: 450–451) Kondratieff provided an even more extended list of economists who noticed the long wave phenomenon. In any case, it is clear that long waves started to be mentioned quite frequently in the 1900s, but starting from the 1920s they began to be discussed especially actively. One of Kondratieff's teachers, Mikhail Tugan-Baranovsky also described them, in particular in his study "Paper Money and Metal" (Tugan-Baranovsky, 1998 [1917]). However, none of the above-mentioned economists studied the long waves systematically, and none of them offered a systematic theory of the long cycles. Thus, Kondratieff's actual contribution was not the discovery of the long wave phenomenon as is frequently believed, but the systematic study of this phenomenon and the development of a long wave theory on this basis (about the history of investigation of the long waves see also de Groot and Frances, 2012: 59–60).[1]

Although Kondratieff's explanations were not entirely satisfactory, however, they give an opportunity of using the theory of long waves in terms of forecasting on a fundamentally new basis. In particular, the idea that such cycles are not random and/or exogenous, but inherently endogenous allowed to use the theory of long waves for economic projections for long enough periods. In the 1920s Kondratieff himself successfully forecasted on this basis the coming Great Depression (Kondratieff, 2004 [1922]).

Of special interest is the "first empirical regularity" discovered by Kondratieff: "during the recession of the long waves, an especially large number of important discoveries and inventions in the technique of production and communication are made, which, however, are usually applied on a large scale only at the beginning of the next long upswing" (Kondratieff, 1935: 111), as it connected causes of the economic growth acceleration/deceleration with the innovation rhythms, which served as a basis for the development of the "clusters-of-innovations" version of the Kondratieff wave (K-wave) theory proposed by Joseph Schumpeter (1939). This further developed into theory suggesting that every new Kondratieff wave corresponds to a new technological paradigm (see, *e.g.*, Volland, 1987; Modelski and Thompson, 1996; Berry, 2000; Modelski, 2001, 2006; Freeman and Louçã, 2001; Perez, 2002; Wymbs, 2004; Devezas et al., 2005; Ayres, 2006; Kleinknecht and van der Panne, 2006; Dator, 2006; Hirooka, 2006; Papenhausen, 2008; Korotayev et al., 2011; Linstone and Devezas, 2012; Nefiodow, 1996; Nefiodow and Nefiodow, 2014a, 2014b; Wilenius and Casti, 2014). On this basis, many K-wave students forecast that the unfolding of the new (sixth) Kondratieff wave will be accompanied by the formation of the new (sixth) technological paradigm. However, there are different approaches as regards the possible characteristics of this technological paradigm. As is known, with respect to the sixth technological paradigm (known also as the sixth technological system or style) there is a widely spread idea connected with the notion of NBIC[2]-technologies (or NBIC-convergence) (see Akayev, 2012; Bainbridge and Roco, 2005; Dator, 2006; Kovalchuk, 2011; Lynch, 2004). Our own research suggests that the new technological system could be wider and it could have a different structure.

Thus, the theory of long waves allows us to identify tentatively the period of the beginning of a new long wave. It can start, according to several researchers in the 2020s or 2030s. The formation of the new technological system will not happen until this wave starts; it will emerge during the sixth long cycle. Thus, we have a period of the

[1] On the other hand, it should be noticed that majority of mainstream economists still deny the presence of Kondratieff waves (as well as any other regular economic cycles). For example, the title of the respective section in a classical *Principles of Economics* textbook by *N. Gregory* Mankiw – "Economic Fluctuations are Irregular and Unpredictable" (Mankiw, 2008: 740) is rather telling in this respect; see also, *e.g.*, Zarnowitz (1985): 544–568, or Solomou (1990), who denies specifically the existence of K-cycles. Note also a number of empirical tests that failed to support the hypothesis of the K-waves' presence in world production dynamics (see, *e.g.*, van der Zwan (1980): 192–197; Chase-Dunn and Grimes (1995): 407–409, reporting the results of Peter Grimes' research). A few scientists using spectral analysis have also failed to detect K-waves in production series on the national levels of quite a few countries (*e.g.*, Diebolt, 2012; Diebolt and Doliger, 2006; Metz, 1998, 2006; van Ewijk, 1982). Against this background we (together with Sergey Tsirel) have found it appropriate to check the presence of K-waves in the world GDP dynamics using the most recent datasets on these variable dynamics covering the period between 1870 and 2007 and applying an upgraded methodology for the estimation of statistical significance of detected waves (see, *e.g.*, Korotayev and Tsirel, 2010a, 2010b, 2010c; Grinin et al., 2011); it is worth stressing that for the first time our analysis made it possible to estimate the statistical significance of Kondratieff waves in the world GDP dynamics; we have demonstrated the presence of K-waves in the world GDP dynamics at a generally quite acceptable 5% level. Of special interest are the works by Marchetti and his coworkers at the International Institute for Advanced System Analysis who have shown extensively the evidence of K-waves using physical indicators, as for instance energy consumption, transportation systems dynamics, *etc.* (Marchetti, 1980, 1983, 1986, 1988, 2006; Grübler, 1990, 1991; Grübler and Nakićenović, 1991; Modis, 1992, 1998; Stewart, 1989a, 1989b, *etc.*).

[2] Nano-Bio-Info-Cogno.

2030s (possibly a decade later), which is considered very important for our projections. Therefore, the theory of long waves gives us certain timing. However, despite all its advantages, this theory, in our opinion, is still lacking a due connection to long-term processes. We believe that the most convenient for this purpose would be the rhythms associated with major technological revolutions in the historical process (the production revolutions).[3] We identify three largest revolutions: the Neolithic (or more precisely, Agrarian) Revolution; the Industrial Revolution; and the modern production revolution (that has been realized as an information revolution, but we assume, will get new features in the future).

By now many studies exploring these major technological revolutions in history have been published (though most of them have been devoted to the study of partucular production revolutions, and not to the study of production revolutions as a recurring phenomenon) (see, *e.g.*, Reed, 1977; Harris and Hillman, 1989; Cohen, 1977; Rindos, 1984; Bellwood, 2004; Shnirelman, 1989, 2012a, 2012b; Smith, 1976; Miller, 1992; Ingold, 1980; Cauvin, 2000; Knowles, 1937; Dietz, 1927; Henderson, 1961; Phyllys, 1965; Cipolla, 1976; North, 1981; Stearns, 1993, 1998; Lieberman, 1972; Mokyr, 1985, 1990, 1993, 1999, 2010; Mokyr and Foth, 2010; Allen, 2009, 2011, Clark, 2007, Pomeranz, 2000; Huang, 2002; Goldstone, 2009; More, 2000; Bernal, 1965; Philipson, 1962; Benson and Lloyd, 1983; Sylvester and Klotz, 1983). Having taken into account all the major technological revolutions in the world historical process, we have developed a model of production revolution that allows us to make some forecasts (see, *e.g.*, Grinin, 2007a, 2012a; Grinin and Korotayev, 2013, 2015; Grinin and Grinin, 2015a, b, c; Grinin et al., 2016c).

2. Materials and methods

In this article, on the basis of the synthesis of the theory of long cycles and the theory of production revolutions, we provide an analysis of the modern production revolution whose initial phase (often referred to as the scientific and information revolution) began in the 1950s. We expect that in the coming decades, we should expect the final phase of this revolution. The final phase of this revolution will begin in the 2030s–2040s and will last until the 2060s–2070s. We denote this revolution as **"Cybernetic"**, basing on the fact that the leading type of its technology has been firmly linked to information and management, this relationship in the future will further increase and, accordingly, future technologies will be largely based on the principles that are formulated in the scientific discipline of Cybernetics.

We expect that the final phase of the Cybernetic Revolution will result in a widespread use of self-regulating systems (*i.e., of the systems that can regulate themselves, responding in a pre-programmed and intelligent way to the feedback from the environment; systems that operate either with a small input from humans or completely without human intervention; see below for detail*).

Respectively, the theoretical foundations of this article also include the main principles of Cybernetics (as is well-known, it is a science of regulatory systems) which are quite suitable for the description of self-regulating systems (see, *e.g.*, Wiener, 1948; Ashby, 1956; Beer, 1959, 1994; Foerster and Zopf, 1962; Heffron, 1995; Luhmann, 1995; Umpleby and Dent, 1999; Tesler, 2004; McClelland and Fararo, 2006; Dupuy, 2009; Wieser and Slunecko, 2014).

It is essential that Cybernetics deals with a very wide range of different (and, especially, self-regulating) systems. The more a different regularity observed in various areas of reality, the more reliable the use of these regularities in scientific analysis.[4] Therefore, it is interesting to note that the self-regulation is observed in nature at different levels from nanoscale (Makino et al., 1990) to populations of animals (Wynne-Edwards, 1965), and society (Bandura, 1991; Cummings, 1978). We also believe that the development of self-managing systems in the abiotic and biological world, in society and technology can be further analyzed *via* interdisciplinary and evolutionary paradigms.

Thus, when developing our forecasts we proceed from the following assumptions:

First. *Identifying the moment of the beginning of a new technological breakthrough*. Around the 2030s, one can expect the beginning of a major technological transformation. The validity of this forecast is based *(a)* on the theory of long waves (many of its proponents suggest that the sixth Kondratieff long cycle will be accompanied by the emergence of the new sixth technological paradigm; respectively, its formation will become noticeable around the 2030s) and *(b)* on the theory of production revolutions, which suggests that in this period the technological pause will be fully completed (which will bring closer together the levels of development of developed and developing countries, which is a necessary condition to start a technological breakthrough) and during this period the final phase of the Cybernetic Revolution will begin.

Second. *Determining the direction of the leading technological breakthrough*. Here we rely on the idea of above-stated theories that proceed from the assumption that the formation of a new technological paradigm should be realized through the emergence of a system of leading technological directions. It is also obvious that this system should include such spheres as nanotechnology, biotechnology, and information technology. However, basing on an analysis of the latest innovations, we expect that the system will be wider.

At the same time, when identifying the leading areas for future technological breakthrough, we especially rely on demographic projections that with all the clarity indicate that the global ageing, together with simultaneous increase in life expectancy and reduction in working-age population will be one of the major challenges for many countries. In our opinion, this may trigger a breakthrough in medicine and related innovative fields. That is why we expect the formation of a new system of technologies, with the new medicine (with new approaches, methods, system of organization *etc.*) as its central part.

2.1. The structure of the article

The structure of the article in its entirety stems from its methodology and intent: to justify the possibility of forecasting the forthcoming technological breakthrough and to identify its possible consequences. The next (third) section explains the basic ideas of the theory of production revolutions in their relationship with the theory of long cycles. The fourth section presents the main results of this study. It demonstrates that the Cybernetic Revolution began in the mid-twentieth century and will finish in the 2060s and 2070s. Accordingly, this period includes

[3] For a detailed analysis of the methodological connections between the two theories see Grinin, 2012b, 2013; Grinin and Grinin, 2015a, b, d; Grinin et al., 2016c.

[4] Note, *e.g.*, that the term "**cyborg**" (short for "cybernetic organism") was introduced by Clynes and Kline in connection with their theory of the expansion of human capabilities to survive in the space. They wrote in their article introducing the notion of "cyborgs": "Altering man's bodily functions to meet the requirements of extraterrestrial environments would be more logical than providing an earthly environment for him in space … Artifact-organism systems which would extend man's unconscious, self-regulatory controls are one possibility" (Clynes and Kline, 1960: 26). At present the term cyborg is often applied to an organism that has restored function or enhanced abilities due to the integration of some artificial component or technology that relies on some sort of feedback. Respectively, the development of medical technologies (the main direction of the Cybernetic revolution in our understanding) is moving in the direction of cyborgization of the human organism, which implies both great opportunities, and great risks (see Grinin and Grinin, 2015b, d for more detail).

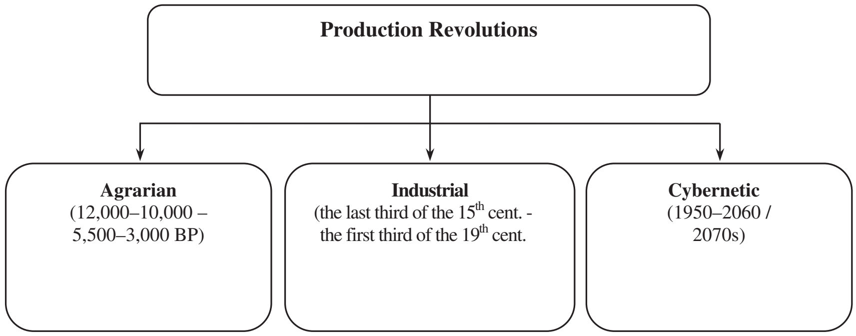

Fig. 1. Production revolutions in history.

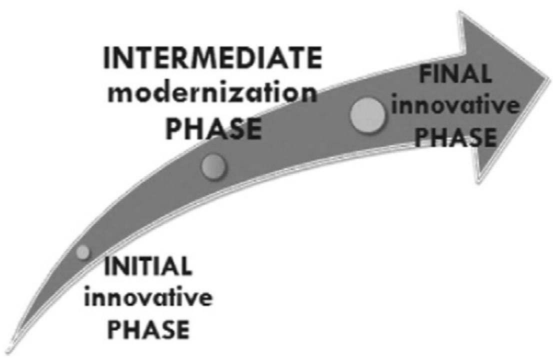

Fig. 2. Phases of production revolutions.

three Kondratieff waves – the fourth K-wave that lasted till the early 1980s, the current fifth long cycle and the forthcoming sixth Kondratieff wave. This section shows the close relationship between the processes of the Cybernetic Revolution and Kondratieff waves, the authors try to explain the characteristics of each wave, using the theory of production revolutions. It also focuses on the characteristics of the Cybernetic Revolution and justification of the idea that the first sphere where its final phase will start will be medicine, which will be an integral element of a large innovation complex. The fifth section discusses demographic projections and shows how and why the demographic trends create the preconditions for the start of the final phase of the Cybernetic Revolution in the field of medicine and related technologies. In conclusion, we return to the problem of the relation between the Cybernetic Revolution and sixth Kondratieff wave, and show that the completion of the Cybernetic Revolution may result in the disappearance of the K-waves, or their radical transformation.

3. Theory

3.1. Production principles, production revolutions and K-waves

According to our theory (Grinin, 2006b, 2007a, 2007b, 2012b, 2013; Grinin and Grinin, 2013a, b, 2014, 2015a, b, d; Grinin and Korotayev, 2013), the whole historical process can be most adequately divided into four large periods, on the basis of the change of major developmental stages of the world productive forces, which we call production principles. The production principle is a concept which designates very large qualitative stages of development of the world productive forces in the historical process, whereas every new production principle surpasses the previous one in a fundamental way (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 Neolithic Revolution. Its result was the transition to systematic production of food and, on this base, to the complex social division of labor. This revolution was also connected with the use of new power sources (animal power) and materials.
2. **Industrial**, or the Production Revolution, which resulted in the main production being concentrated in industry and production being carried out by means of machines and division of labor mechanisms. Not only was manual labor replaced by machines, but also biological energy was replaced by water and steam energy.
3. **Cybernetic** Revolution which has already led to the emergence of powerful information technologies, and in the future will stimulate transition to the wide use of self-regulating systems.

Each production revolution means the transition to a fundamentally new production system; the beginning of each production revolution marks the borders between corresponding production principles. (See Fig. 1.)

3.2. 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, 2006a, 2007a, 2012a; Grinin and Grinin, 2013a, b, 2015a, b, d; see Fig. 2). In the initial *innovative* phase, new advanced technologies emerge which eventually spread to other societies and territories. As a result of the final *innovative* phase

Table 1
Phases of agrarian revolution.

Phases	Type	Name	Dates	Changes
Initial	Innovative	Manual agriculture	12,000–9000 BP	Transition to primitive manual (hoe) agriculture and cattle-breeding
Middle	Modernization	Diffusion of agriculture	9000–5500 BP	Emergence of new domesticated plants and animals, development of complex agriculture, emergence of a complete set of agricultural instruments
Final	Innovative	Irrigated and plow agriculture	5500–3500 BP	Transition to irrigated agriculture or plow agriculture without irrigation

Table 2
Phases of Industrial Revolution.

Phases	Type	Name of the phase	Dates	Changes
Initial	Innovative	Manufacturing	15th–16th centuries	Development of shipping, technology and mechanization on the basis of water engine, development of manufacture based on the division of labor and mechanization
Middle	Modernization	Diffusion of industrial enterprises	17th–early 18th centuries	Formation of complex industrial sector and capitalist economy, increase in mechanization and division of labor
Final	Innovative	Machinery	1730–1830s	Formation of sectors with the machine cycle of production using steam energy

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.[5]

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 Agrarian Revolution was a great breakthrough from hunter-gatherer production principle to farming (about its phases see Table 1).

The Industrial Revolution was a great breakthrough from craft-agrarian production principle to machine industry, marked by intentional search for and use of scientific and technological innovations in the production process[6] (about it phases see Table 2). (See also Table 3 for the chronology of phases of all the production principles.)

The Cybernetic Revolution is a great breakthrough from industrial production to the production and services based on the operation of self-regulating systems.

Its **initial** phase dates back to the 1950–1990s. The breakthroughs occurred in the spheres of automation, energy production, synthetic materials production, space technologies, exploration of space and sea, agriculture, and especially in the development of electronic control facilities, communication and information. We assume that the **final** phase will begin in the nearest decades, that is in the 2030s or a bit later, and will last until the 2070s.

We denote the initial phase of the Cybernetic Revolution as **a scientific-information** one, and the final – as **a phase of self-regulating systems**. So now we are in its modernization phase which will probably last until the 2030s. This intermediate phase is a period of rapid distribution and improvement of the innovations made at the previous phase (*e.g.*, computers, internet, cell phone, *etc.*). The technological and social conditions are also prepared for the future breakthrough. *We suppose that the final phase of the Cybernetic Revolution will lead to the emergence of many various self-regulating systems.*[7]

The scheme of the Cybernetic Revolution is presented in Fig. 3. (See also Fig. 10.)

3.3. The structure of the production principle

Development of the production principle consists of a period of genesis, growth and maturity in the new forms, systems and paradigms related to the organization of economic management, which far surpass former modes of management in terms of their major parameters.

The production principle 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 maximizing the potentials of the new forms of production in a structural, systemic, and spatial sense:

1. *The starting phase of the production revolution*. 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 last three phases of the production principle characterize its mature features.

4. *The phase of maturity and expansion of the production principle*. In this phase there occurs a wide geographical and sectoral diffusion of new technologies, bringing the production principle to mature forms. A consequence of this phase is vast transformations in the social and economic spheres.
5. *The phase of absolute domination of the production principle*. The final victory of the production principle in the world yields an intensification of technologies, bringing opportunities to the limit of their 'reach,' beyond which crisis features appear.
6. *The stage of non-system phenomena, or a preparatory phase*. The intensification leads to emergence of non-system elements which prepare the birth of a new production principle. Under favorable conditions these elements form a system and in some societies the transition to a new production principle will begin and the cycle will repeat at a new level.

As is clear, the scientific-cybernetic production principle is at the beginning of its development. Only its first phase has been completed, and in the mid-1990s the second phase started up. 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 in the early 22nd century (for more details see Grinin, 2006a).

3.4. The industrial production principle is 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; Grinin and Grinin, 2015b, d). Taking into account that K-waves arose only with the emergence of a certain level of economic development, we can consider *K-waves as a specific mechanism connected with the emergence and development of the industrial-trade production principle*. 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 phases of the development of the industrial production principle and the first phases of development of the scientific-cybernetic production principle.*

It has been shown that the first three K-waves are connected with the industrial production principle (Grinin, 2012a, 2013; Grinin and

[5] For example, in the modernization phase of the Agrarian Revolution local varieties of plants and breeds of animals (borrowed from other places) were created.
[6] For a detailed application of Production Revolution Theory to the analysis of the Industrial Revolution see Grinin and Korotayev, 2015: 17–84.
[7] For more detail see Grinin, 2006a, 2007a, 2007b, 2012a, 2013; Grinin and Grinin, 2013a, b, 2014, 2015a, b, c, d, e, f.

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 dates and duration
1.	Hunter-gatherer	40,000–30,000 (38,000–28,000 BCE) **10**	30,000–22,000 (28,000–20,000 BCE) **8**	22,000–17,000 (20,000–15,000 BCE) **5**	17,000–14,000 (15,000–12,000 BCE) **3**	14,000–11,500 (12,000–9500 BCE) **2,5**	11,500–10,000 (9500–8000 BCE) **1,5**	40,000–10,000 (38,000–8000 BCE) **30**
2.	Craft-agrarian	10,000–7300 (8000–5300 BCE) **2,7**	7300–5000 (5300–3000 BCE) **2,3**	5000–3500 (3000–1500 BCE) **1,5**	3500–2200 (1500–200 BCE) **1,3**	2200–1200 (200 BCE – 800 CE) **1,0**	800–1430 CE **0,6**	10,000–570 (8000 BCE – 1430 CE) **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 (for a more detailed chronology see Grinin, 2006a, 2009, 2012a; Grinin and Korotayev, 2013). The duration of phases (in thousand year intervals) is marked by the bold-face type. Duration of phases of the scientific-cybernetic production principle is hypothetical. The duration of the scientific-cybernetic production principle is also given in Fig. 4.

Grinin, 2015b). 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 the production's cycle its phases differ in duration, but their duration proportions remain the same in each production principle. We have also found a more complex ratio according to which on average, one K-wave corresponds to one phase of the industrial production principle. In general, we found 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 4. 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.

4. Results

4.1. 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 proceeding, has led to a 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 to 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 improvements and the diffusion of innovations made at the initial phase in particular by a wide proliferation of easy-to-handle computers, means of communication, and the formation of a macro-sector of services among which information and financial services take center stage. At the same time the innovations necessary to start the final phase of the Cybernetic Revolution are being prepared.

Table 5 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). The correlation here is 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.[8]

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; Grinin and Grinin, 2015b).[9]

[8] The reason for the shorter duration is the general acceleration of historical development.

[9] While compiling Table 6 we have taken into account ideas and works cohering with the theories which explain the nature and pulsation of K-waves by changing of technological systems and/or *techno-economic paradigms:* 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 Lazurenko (1992), Polterovich (2009), Perez (2002).

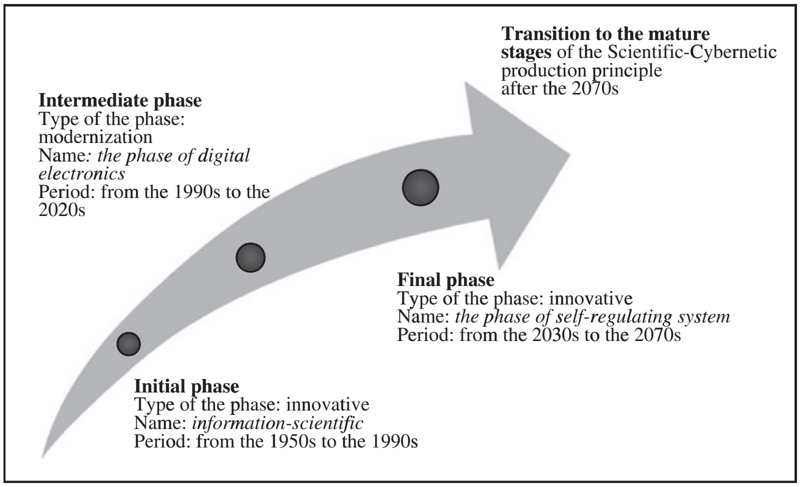

Fig. 3. The phases of the Cybernetic Revolution.

4.1.1. Peculiarities of the fourth K-wave in connection with the beginning of the Cybernetic Revolution

The fourth K-wave (from the second half of the 1940s to the early 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*.[10] That was the feature of the upswing phase of the fourth K-wave (from the second half of the 1940s to the early 1970s) 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 the A-phases of the third and fifth K-waves. The downswing phase of the fourth K-wave (from the early 1970s to the early 1980s1980s) 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.

4.1.2. 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 computer technologies, and therefore capable of developing a new technological mode. Those directions which had already appeared and those which are supposed to become the basis for the sixth K-wave were considered in position to make a breakthrough. However, it was the development and diversification of already existing digital electronic technologies and rapid development of financial technologies that became the basis for the fifth K-wave. Those innovations which were really created during the fifth K-wave as, for example, low carbon energy technologies, still have a small share in the general energy, and, as we suppose, they might be able to become a real and substantial energy sector (similar to nuclear power industry), but they will not be able to replace completely fossil fuels… Some researchers believe that from the 1970s up to the present is the time for the decelerating scientific and technological progress (see a discussion on this topic in Brener, 2006; see also Huebner, 2005, Modis, 2002, 2005; Maddison, 2007). Polterovich (2009) also offers the notion of a technological pause. But, in general, the mentioned technological delay is, in our opinion, insufficiently explained. We believe that taking the features of the intermediate modernization phase of a production revolution (*i.e.*, the second phase of the production principle) into account can help explain this. Functionally it is less innovative; rather during this phase earlier innovations become more widely spread and are 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 requires there to be changes in the structure of societies and global relations (see Grinin and Korotayev, 2010a, b, 2015). 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 cannot increase all the time (Korotayev et al., 2015). Secondly, the 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 socio-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 (or, perhaps, first of all) within the international economic institutions. The latter can change only as a result of 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 them to reorganize and dismantle conventional institutions that are unlikely to be changed under ordinary conditions due to a lack of courage and opportunities (for our vision of the future of the world order see Grinin and Korotayev, 2010b, 2015; Grinin et al., 2016a; Grinin, 2016).

The above explains as well the reasons of different rates of development between the center and periphery of the World System during the

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

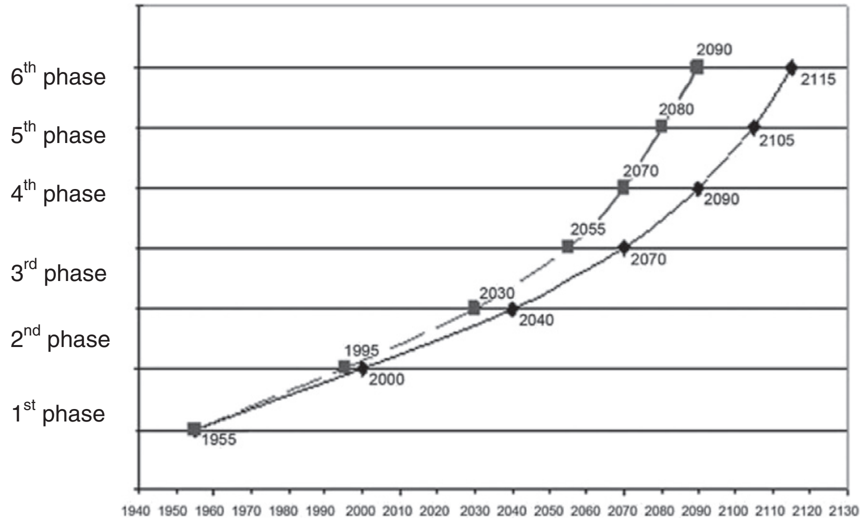

Fig. 4. Development of the scientific-cybernetic production principle. *Note:* the dashed line depicts one of the scenarios for the expected development of the scientific-cybernetic production principle and corresponds to the dates before the slash in the fifth column of Table 1.

fifth K-wave (for more details see Grinin, 2013; see also Grinin and Korotayev, 2010a, 2015). 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 a 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 and can stimulate structural changes in the peripheral countries, thus also increasing international tension. The world order has already begun to change, and it will continue to change over the next ten to twenty years and some visible results of this change may appear by the start of the new K-wave. We have called this change "the World System reconfiguration" (see Grinin and Korotayev, 2010b, 2015: 159–166; Grinin et al., 2016b). Thus, we suppose that in the next 10–15 years the world will face serious and painful changes. The World System reconfiguration processes further explain the reasons for the very turbulent processes observed in the recent years, as well as increased tensions in the last two-three years in the world.

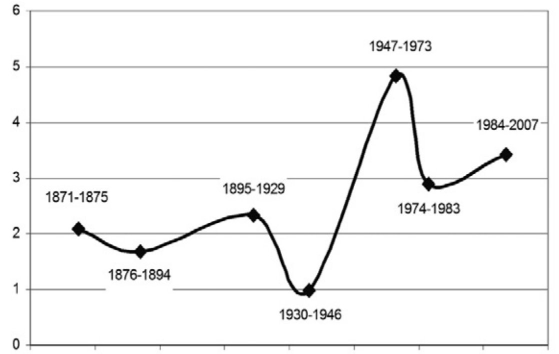

Fig. 5. Average annual World GDP growth rates (%) during phases A and B of Kondratieff waves, 1871–2007, inflation adjusted (data sources: Maddison, 2010; World Bank, 2016).

4.2. Characteristics of the Cybernetic Revolution

4.2.1. 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 either with a small input from human or completely without human intervention.[11] Today there are many self-regulating systems, for example, the artificial Earth satellites, pilotless planes, navigation systems laying the route for a driver. Another good example is life-support 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. Recently there appeared various models of self-driving cars which give us an excellent example of self-regulating technical system. There are also special programs that determine the value of stocks and other securities, react to price changes, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems have been created but they are mostly technical and informational systems (as robots or computer programs). During the final phase of the Cybernetic Revolution there will be a lot of self-regulating systems

[11] Note that the notion of "self-regulating systems" correlates rather closely with the one of artificial intelligence. Artificial intelligence has been a subject of intensive research in the recent decades (see, *e.g.*, Poole et al., 1998; Hutter, 2005; Luger, 2005; Russell and Norvig, 2009; Neapolitan and Jiang, 2012; Keller and von der Gracht, 2014; Hengstler et al., 2016). "Intelligent" machine is often defined as the one that takes actions that maximize its chance of success at some goal (*e.g.*, Russell and Norvig, 2009) and such a machine can of course be also regarded as a self-regulating system. The notion of artificial intelligence is usually connected with machines, IT-technologies and sometimes equated with technical intelligence (*e.g.*, Yi Zhang et al., 2016). Thus, the notion "self-regulating systems" is wider than the notion "artificial intelligence" (AI), because it includes various self-regulating systems that can function independently, but can hardly be regarded as Artificial Intelligence – for example, biotechnological systems designed to neutralize pollution, or connected with human physiology (*e.g.* artificial immunity on the basis of artificial antibodies, or systems based on the use of various other proteins or viruses, or genetic engineering technologies that are able to control certain physiological processes and so on). In addition we expect the emergence of self-regulating systems of mixed nature – for example, biochemiotechnical. Note that they can function within more complex systems, such as the human organism. As examples of such self-regulating systems one may mention artificial organs created from tissues grown in laboratories and incorporating a number of biosensors and other technical elements. Thus, any AI can be regarded as a self-regulating systems, but not all the self-regulating systems can be identified with AI. Hence, the notion of "self-regulating systems" turn outs out to be much wider than the one of the AI.

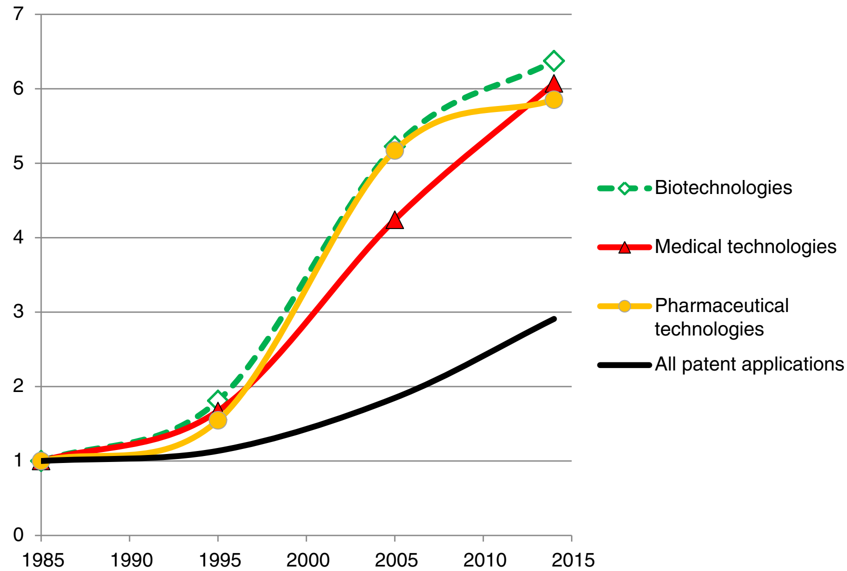

Fig. 6. Relative global dynamics of patent applications for various technologies, 1985–2014, 1 = 1985 level. Data source: WIPO, 2016.

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 (for details see Grinin and Grinin, 2015a, c). These systems will also significantly reduce energy and resource consumption. Human life will become organized to a greater extent by such self-regulating systems (for example, by monitoring health, daily regimens, regulating or recommending levels of personal exertion, having 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; Beer, 1959, 1994; 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. In 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 (see Grinin, 2006a for more detail).

Below we single out the most important characteristics of the Cybernetic Revolution. One can observe them today, but they will be realized in their mature and mass forms only in the future. These features are closely interconnected and corroborating each other (see Grinin and Grinin, 2013a, 2015a, b, c, d, e, f for more detail).

4.2.2. The most important characteristics and trends of the Cybernetic Revolution

1. Increases in the amount of information and complications in the analysis of the systems (including the ability of systems for independent communication and interaction);
2. Sustainable development of the system of regulation and self-regulation;
3. Mass use of artificial materials which previously lacked the appropriate architectural properties;
4. Qualitatively increasing the controllability a) of systems and processes that vary in their constitution (including living material); and b) of new levels of managing the organization of matter (up to sub-atomic and using tiny particles as building blocks);
5. Miniaturization and microtization[12] 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.[13]

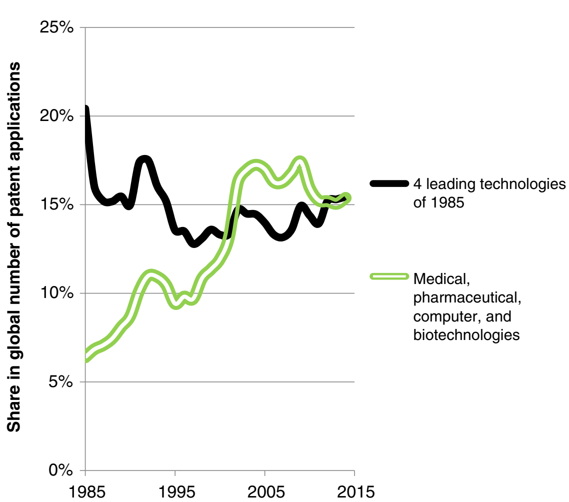

Fig. 7. Dynamics of the global combined share of patent applications in medical, pharmaceutical, computer, and biotechnologies in comparison with the dynamics of the global combined share of four technologies with the highest share of patent applications in 1985 (×1: electrical machinery; ×10: measurement; ×26: machine tools; ×29: other special machines), 1985–2014. Data source: WIPO, 2016.

[12] See: http://www.igi-global.com/dictionary/microtization/18587.

[13] 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 when they are in an unlawful or incompetent state (*e.g.*, not allowing a person to drive a motor vehicle while under the influence of alcohol or drugs).

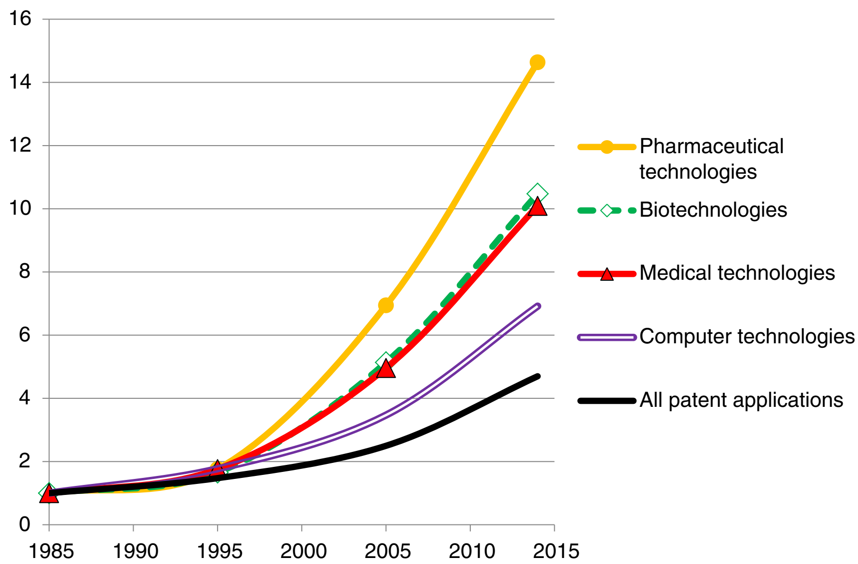

Fig. 8. Relative dynamics of patent applications for various technologies in East Asia, 1985–2014, 1 = 1985 level. Data source: WIPO, 2016.

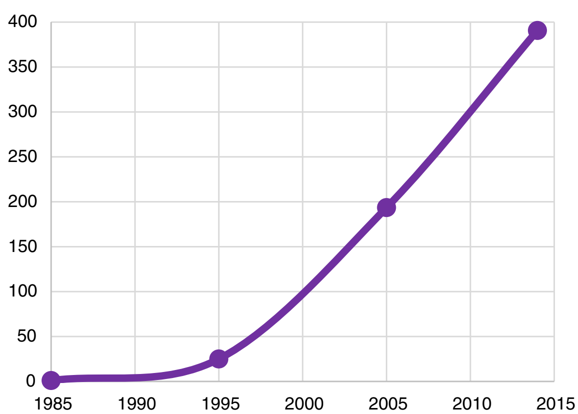

Fig. 9. Relative global dynamics of patent applications in nanotechnology, 1985–2014, 1 = 1985 level. Data source: WIPO, 2016.

4.2.3. 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[14];
7. Self-regulating systems (see below) will become the major component of technological processes. That is the reason why the final (forthcoming) phase of the Cybernetic Revolution is (or should) be called **the epoch of self-regulating systems** (see below).

Various directions of development should generate a system cluster of innovations.[15]

4.2.4. Medicine as a sphere of the initial technological breakthrough and the emergence of MANBRIC-technology complex

It is worth remembering that the Industrial Revolution began in a rather narrow area of cotton textile manufacturing 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 for ways to mechanize spinning (see Allen, 2009; Grinin and Korotayev, 2015). 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 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 this revolution will begin somewhere at the intersection of medicine and a number of other technologies (we will provide reasons for this statement below).

However, the initial breakthrough will not necessarily occur in all spheres of medicine but in its one or two innovative fields (similar, the final phase of Industrial Revolution occurred not in all branches of textile industry but in its innovative sector, namely in cotton industry). As for other branches of medicine, the revolutionary transformations will begin there later. Moreover, some branches of medicine would be unable to transform due to their conservatism. Thus, more radical reforms will occur in these fields in the future. So when speaking about

[14] During the Industrial Epoch these elements existed separately: technologies were preserved on paper or in the engineer's minds. At present, thanks to informational and other technologies the technological constituent fulfils the managing function facilitating the path to the epoch of self-regulating systems.

[15] For example, 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).

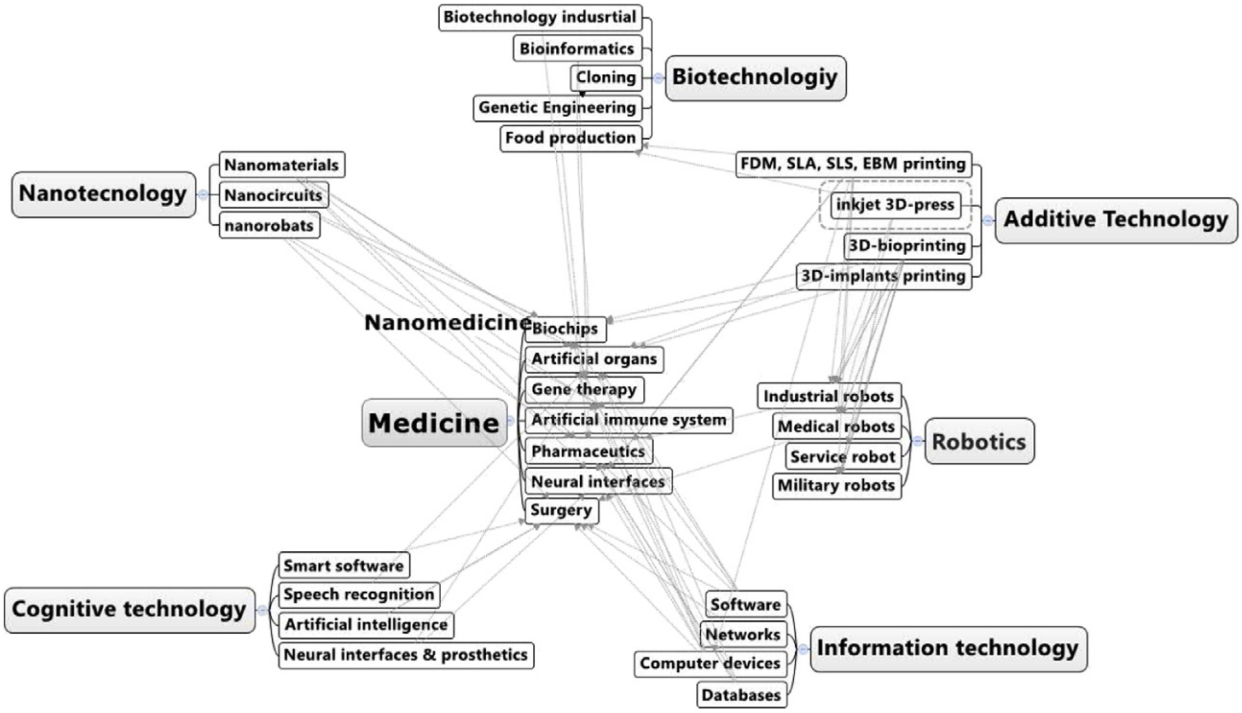

Fig. 10. Interconnections between various MANBRIC technologies. The scheme shows the main directions of the Cybernetic Revolution with respect to medicine. A large number of connections are found between medicine and information technology, which has provided the first phase of the Cybernetic Revolution. A large share of connections is between medicine, biotechnology and nanotechnology, that is in the area where the second phase of the Cybernetic Revolution can originate.

medicine, one should keep in mind that with respect to potential revolutionary transformations medicine is a very heterogeneous sphere.

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 organs and tissues for it, *etc.*

This will make it possible to *radically expand the opportunities to prolong life and improve its biological quality*. 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 the common use of this new generation of medical technologies.

The drivers of the final phase of the Cybernetic Revolution will be medical technologies, additive manufacturing (3D printers), nano- and bio- technologies, robotics, IT, cognitive sciences, which will together form a sophisticated system of self-regulating production. We can denote this system as MANBRIC-technologies.[16] As it was mentioned above, with respect to the sixth technological paradigm there is a widely used idea connected with the notion of NBIC[17]-technology (or NBIC-convergence) (see Lynch, 2004; Bainbridge and Roco, 2005; Dator, 2006; Kovalchuk, 2011; Akayev, 2012). There are also some researchers (*e.g.*, Jotterand, 2008) who see in this role another set of technological directions – GRAIN (Genomics, Robotics, Artificial Intelligence, and Nano-technology). However, we believe that this set will be larger. And medical technologies will be its integrating part.

The clustering of a part of MANBRIC-technologies is quite clear by now. For example, it is manifested in the convergence of the patent application growth rates in medical, pharmaceutical, and biotechnologies[18] (see Fig. 6). This figure also illustrates rather well that key technologies of the forthcoming sixth Kondratieff cycle display much higher innovation rates in comparison with most other technologies registered by WIPO.

Fig. 7 indicates that by now the four leading technologies of the MANBRIC system has caught up with the four technologies that were leading as regards the number of patent applications in 1985.

Fig. 8 confirms the idea that within the MANBRIC-technologies medical and related technologies will play the integrating role. It demonstrates that in East Asia the growth rates of patent applications in medical, pharmaceutical and biotechnologies are higher than not only the overall patent application growth rate, but also the patent application growth rate in computer technology. It also suggests that the final phase of the Cybernetic Revolution may start in East Asia.

Returning to the issue of formation of the MANBRIC system, it appears necessary to note that the development of technologies within it will proceed unevenly, as this system combines younger and more mature technologies. For example, nanotechnologies develop very fast now (see Fig. 9); however, as regards absolute numbers of patents they still lag far behind medical, or biotechnologies (WIPO, 2016). Robotics and additive technologies also develop very fast; but, unfortunately, the WIPO database do not register them as separate spheres of technology yet.

Thus, we maintain 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,

[16] The order of the letters in the acronym does not reflect our understanding of the relative importance of areas of the complex. For example, biotechnologies will be more important than nanotechnologies, let alone additive manufacturing. The order is determined simply by the convenience of pronunciation.

[17] Nano-Bio-Info-Cogno.

[18] Some pharmaceutical technologies may be regarded as a variety of biotechnologies, but here we use the WIPO classification.

Table 4
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 to 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[a] 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 the sake of simplicity, we take specific years as dates for the beginning and the end of the periods.
[a] We took as the beginning a zero K-wave in which the 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).

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 above mentioned 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 (see the next section).

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

In the next section we will consider the future development of medical technologies in connection with the global ageing.[19]

[19] It should be noted that Leo Nefiodow has been writing about health as the leading technology of the sixth Kondratieff wave for a long time (Nefiodow, 1996; Nefiodow and Nefiodow, 2014a, 2014b). He explains that health is much more than medicine and includes mental, psychosocial, environmental and spiritual aspects. He believes that medicine covers only a small part of the health problems we face today. We agree that health is more than medicine. However, we regard medicine as the most important business sphere connected with health care (note that the overwhelming majority of researchers in the health area work with medical technology). We also agree with Nefiodow that business and profit far from always serve people. But we do not know any power beside medical business which has opportunities (in co-operation with such state agencies as the National Institutes of Health in the USA) to finance research and development in this area, to elaborate new ways to fight mortal diseases, to invest in prolongation of life expectancy. In Nefiodow's opinion, health area covers not only psychotherapeutic, psychological and psychiatric services, but also numerous measures of health improvement that, using his terms, will reduce social entropy. The problems with this argument, based on reducing social entropy (*e.g.*, corruption, small and large crime, drug addiction, lack of moral guide, divorces, violence, *etc.*), is that social entropy (as Nefiodow himself points out) has always existed in society. Social changes can be really extremely important for the creation of starting conditions for a long-term upswing in reducing social entropy (see Grinin and Grinin, 2014 for more detail). However, it is production and/or commercial technologies that represent the driving force of the K-Wave upswing phases. There is one more important point. The Nefiodows believe that it is biotechnologies that will become an integrating core of the new technological system. However, we suppose that the leading role of biotechnologies will be, first of all, in their possibility to solve the major medical problems. That is why it makes sense to speak about medical technologies as the core of a new technological paradigm. Besides, we forecast a more important role of nanotechnology than the Nefiodows do (Nefiodow and Nefiodow, 2014b: Chapter 2). Nanotechnologies will be of great importance in terms of the development of bio- and medical technologies (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 resource saving).

5. Discussion

5.1. Demographic trends and forthcoming demographic risks as preconditions for a technological breakthrough in medicine

Let us consider in detail why medicine is to become the breakthrough sector of the forthcoming K-wave.

a) Medicine is unique because it inspires constant activity in the field of new high technologies.
b) There are far fewer social, cultural or structural obstructions to the application of these technologies in medicine than in other fields (as well as the obstacles to adoption of innovations).
c) The commercial prospects of new technologies in this sphere are huge since people are always ready to pay for them.
d) In the nearest decades not only the developed but also developing countries will face problems of population ageing, shortage of labor resources and the necessity to support a growing number of elderly people. The progress in medicine can contribute to the extension of working age (as well as to the general increase of the average life expectancy [see Fig. 11]) of elderly people and to more actively involve disabled people into labor activities. *Thus, elderly people and people with disabilities could more and more subsist for themselves.*
e) A rapid growth of the world middle class and of population education level, especially in the developing countries (NIC, 2012) is anticipated in the nearest decades and these two factors mean that there will be a sharp growth in the demand for health services.
f) The medical sphere has unique opportunities to combine the abovementioned technologies into a single complex. Many spheres (including but not limiting to biotechnologies, nanotechnologies, robotics, use of the latest ICTs and various devices, cognitive technologies, synthesis of new material) will be integrated in this field.

Thus, given the general vector of scientific achievements and technological development and taking into account that a future breakthrough area is to be highly commercially attractive and have a wide market, we predict that the final phase of the Cybernetic Revolution will begin in medicine.

By the 2030s there can appear unique opportunities for a breakthrough in medicine.

– by that time we will face the problem of population ageing (by 2030 the number of people aged 65 and over will amount one billion – see Fig. 12a).

As shown above, an especially rapid global increase in the number of age persons above retirement-age is expected to come in the next 20 years – their number will actually double during a short historical

Table 5
The scientific-cybernetic production principle (initial phases) and Kondratieff waves.

Phases of the scientific cybernetic production principle	The first phase (initial phase of the Cybernetic Revolution) 1955–1995 ≈40 years	The second phase (middle phase of the Cybernetic Revolution) 1995 – the 2030s/40s. ≈35–50 years	The third phase (final phase of 'self-regulating systems' of the Cybernetic Revolution) the 2030s/40s–2055/70s ≈25–40 years	Total: ≈ 100–120 years
K-waves 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-waves and their phases	Upward phase, 1947–1969/1974s	Downward phase of the fifth wave, 2007–2020s		
K-waves and their phases	Downward phase, 1969/1974–1982/1991	Upward phase of the sixth wave, 2020–2050s		
K-waves and their phases	The fifth wave, 1982/1991 – 2020s, upward phase, 1982/1991–2007			

period, thus it will increase by almost 600 million and the total number will considerably exceed a billion.

However, an especially impressive acceleration will be observed as regards the growth of global population of people aged 80 years or more. While by 2050 the number of persons of retirement age will approximately double, the number of elderly people aged 80 years or more will practically quadruple, and in comparison with 1950 their number by 2075 will increase almost by 50 times – that is two orders of magnitude (see Fig. 12b):

Moreover, this problem will be typical not only of the developed countries, but also for a number of developing countries, in particular, China, Brazil, and India (see, *e.g.*, Grinin et al., 2015). Pension payments will become a pressing problem (as the number of retirees per an employee will increase) and at the same time the scarcity of labor resources will increase, which is already felt strongly in a number of countries, including Russia. *Thus, the problem of scarce labor and pension contributions will have to be solved in such a way that people physically could work for ten, fifteen and even more 15 years (certainly here we can also face a number of social problems).* This also implies the disabled people's adaptation for fuller involvement into labor processes made possible by new technical and technological means and achievements in medicine;

– simultaneously, by this time, the birth rate in many developing countries will significantly drop (for example, such developing countries as China, Iran, or Thailand already experience below-replacement fertility). Therefore, the respective governments will begin (and some of them have already started) worrying generally not about the restriction of population growth, but about promotion of population growth and the health of the population;
– by the 2030s great changes will occur in the opportunities of billions of citizens of the developing countries due to the catch-up of the developing countries to the developed countries, formation of a huge global middle class, and reductions in poverty and illiteracy. As a result, the focus will be shifted from elimination of the most unbearable conditions to the problems of raising the standards of living, healthcare, *etc.* So, there is a great potential for the development of medicine.

Along with many other medical innovations (e.g., minimizing invasive operations) it will be possible to dramatically increase life expectancy and improve physiological abilities of people as well as health-related quality of life (HRQoL).

Thus, by the 2030s, the number of middle-aged and elderly people will increase; economy will desperately need additional labor resources while the state will be interested in increasing the working ability of elderly people, whereas the population of wealthy and educated people will grow in a rather significant way. In other words, the unique conditions for the stimulation of business, science and the state to make a breakthrough in the field of medicine will emerge, and *just these unique conditions are necessary to start the innovative phase of revolution!*

It is extremely important to note that enormous financial resources will be accumulated for the technological breakthrough, such as: the pension money whose volume will increase at high rates; spending of governments on medical and social needs; growing expenses of the ageing population on health (related) services, and also on health services obtained by a growing world middle-class. All this can provide initial large investments, an appeal of high investment of respective venture projects and long-term high demand for innovative products, thus a full set of favorable conditions for a powerful technological breakthrough will become available.

6. Afterword. The phase of self-regulating systems and the sixth K-wave

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

Thus, 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 2030s or 2040s. Thus, we suppose, that a

Table 6
K-waves, technological modes and leading macrosectors.

Kondratieff wave	Date	A new mode	Leading macrosector	Production principle and number of Its phase
The first	1780–1840s	The textile industry	Factory (consumer) industry	Industrial, 3
The second	1840–1890s	Railway lines, coal, steel	Mining industry and primary heavy industry and transport	Industrial, 4
The third	1890–1940s	Electricity, chemical industry and heavy engineering	Secondary heavy industry and mechanic engineering	Industrial, 5/6
The fourth	1940-e – the early 1980s	Automobile manufacturing, manmade materials, electronics	General services	Industrial, 6, scientific-cybernetic, 1
The fifth	1980s – ~2020	Micro-electronics, personal computers	Highly-qualified services	Scientific-cybernetic, 1/2
The sixth	2020/30s–2050/60s	MANBRIC-technologies (med-addi-bio-nano-robo-info-cogno)	Medical human services	Scientific-cybernetic, 2/3

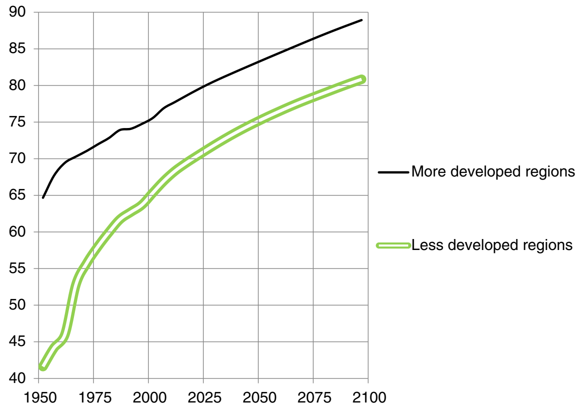

Fig. 11. Dynamics of the life expectancy at birth (years) in the World System core and global periphery, 1950–2015, the UN medium forecast to 2050.
Source: UN Population Division, 2016.

new technological paradigm will not develop in a necessary form even by the 2020s (thus, the innovative pause will take longer than expected – see *above*). 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, as well as oil price shocks. And then, given an upswing, a new technological paradigm (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 paradigm 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 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 recession, nor a real upswing, but rather somehow accelerated development (with stronger development in some regions and continuous depression in others – see Fig. 5 above).

Then, given the favorable conditions as they had been mentioned above, 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.

6.2. There is another 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 final phase of the Cybernetic 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 could be rather long and powerful.

6.3. The end of the Cybernetic Revolution and possible disappearance of K-waves

The sixth K-wave (about 2020 to the 2060/70s), like the first K-wave, will proceed generally during completion of the production revolution (see *above*). However, there is an important difference. During the first K-wave the duration of 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

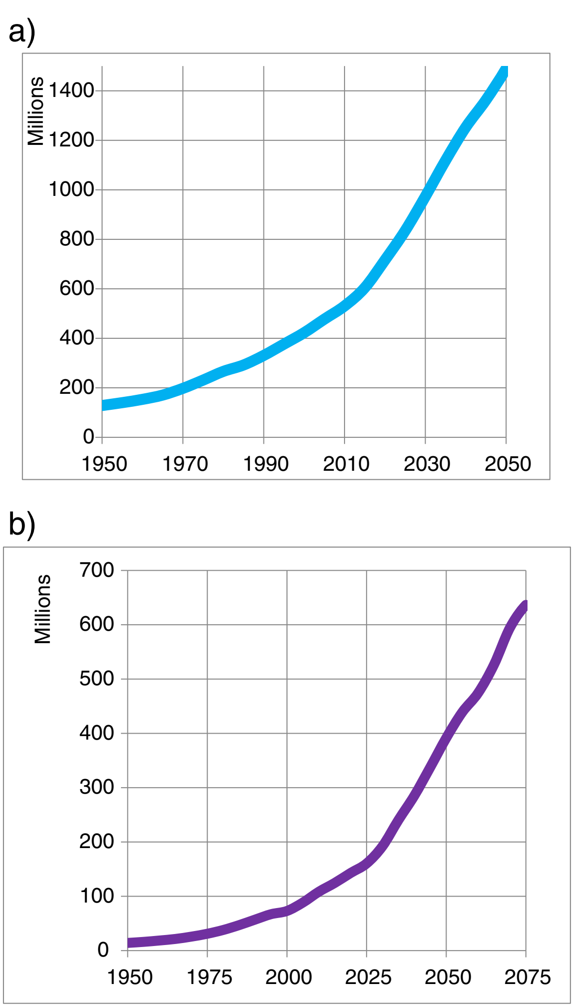

Fig. 12. a. Increasing number of persons of retirement age (over 65), 1950–2015, with the UN medium forecast till 2050. Source: UN Population Division, 2016. b. Increase of global number of elderly people (aged 80 years +), 1950–2015, with the UN medium forecast till 2075. Source: UN Population Division, 2016.

of the sixth K-wave; the seventh wave will be feebly expressed or will not occur at all (on the possibility of the other scenario 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 a considerable growth of influence of new universal regulating mechanisms. It is quite reasonable, taking into account the fact that the forthcoming final phase of the Cybernetic Revolution will be the revolution in the regulation of systems. Thus, the management of the economy should reach a new level. *K-waves appeared at a certain phase of global evolution and they are likely to disappear at its certain phase.*

Change or disappearance of the long-wave cyclicality may also be supported by the intensification of the process of global ageing. By the end of the 21st century, this process will encompass almost all the countries of the world. And thanks to achievements of Cybernetic Revolution the life expectancy is likely to be significantly higher than today even in developed countries. But accordingly one should take into account the point that elderly populations are much more conservative. This conservatism is very likely to be a certain obstacle to the high rate of technological progress.

Thus, ironically, though over the next few decades the population ageing will contribute to technological progress, by the end of the century, it is likely to contribute to the deceleration of scientific and technological development. Thus, it is possible that the population ageing, together with the improvement of planning capabilities, may facilitate the transition of global society to a more calm and slow development (which, incidentally, may be rather close to sustainable development, of which so much is said).

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