Chapter 2

The Characteristics and the Logic of the Cybernetic Revolution. MANBRIC-Technologies

1. Characteristics of the Cybernetic Revolution

Below we enumerate the most important characteristics and trends of the Cybernetic Revolution and its technologies. Today one can observe them, yet they will be implemented in mature and mass forms only in the future. These features are closely interconnected and corroborate each other.

1.1. The main features of the Cybernetic Revolution

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

1. The increasing amounts of information and complication of information processing (including the capacity of the systems for independent communication and interaction).
2. Sustainably developing system of regulation and self-regulation.
3. Mass use of artificial materials with previously lacking properties.
4. Qualitatively growing controllability a) of systems and processes of various nature (including living material); and b) of new levels of organization of matter (up to sub-atomic level and usage of tiny particles as building blocks).
5. Miniaturization and microtization[1] as a trend of a constantly decreasing size of particles, mechanisms, electronic devices, implants, *etc.*
6. Resource and energy saving in every sphere.
7. Individualization/personalization as one of the most important technological trends.
8. Implementation of smart technologies and the humanization of their functions (use of common language, voice, *etc.*).
9. Control over human behaviour and activity to eliminate the negative influence of the so-called human factor.[2]

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

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

The characteristics of technologies of the Cybernetic Revolution:

1. The transformation and analysis of information as an essential part of technologies.
2. The increasing connection between technological systems and environment.
3. A trend towards autonomation and automation of control along with an increasing controllability and self-regulation of systems.
4. The capabilities of materials and technologies to adjust to different objectives and tasks (smart materials and technologies) as well as ability to *choose optimal regimes for certain goals and tasks*.
5. A large-scale synthesis of materials and characteristics of the systems of different nature (*e.g.*, of animate and inanimate nature).
6. The integration of machinery, equipment and hardware with technology (know-how and knowledge of the process) into a unified technical and technological system.[3]
7. The self-regulating systems (see below) will become the major part of technological process. That is the reason why the final (forthcoming) phase of the Cybernetic Revolution can be called *the epoch of self-regulating systems* (see below).

Various directions of development should generate a systemic cluster of innovations.[4]

1.2. Why do we denote the latest production revolution as 'Cybernetic'?

The theory of production revolutions proceeds from the assumption that the essence of these revolutions can be most clearly observed only during the final phase. One can retrospectively outline the future features in initial and intermediate phases which do not form a clear system yet. Thus, the designation given to the third production revolution is based

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

[4] 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).

on our forecasts concerning its final phase. We suppose that *the most important thing about this phase will be a wide implementation of* ***the principle of self-regulation and self-controlling in different technological systems*** *which as a result will transform into self-regulating systems. At the same time the new-type systems will combine the characteristics of living matter with technological principles.* We denote this revolution as 'Cybernetic' since it will lead to a wide spread of self-regulating systems. We base our analysis of such systems on the ideas from cybernetics which is a theory of control over different complex regulated systems based on communication (*i.e.* of receiving, transformation and transfer of information) (see, *e.g.*, Wiener 1948; Ashby 1956; Beer 1959, 1994; Foerster and Zopf 1962; Umpleby and Dent 1999; Tesler 2004).

Cybernetics can also be defined as a study of general laws of receiving, storage, and transfer of information in complex controllable systems. Its main principles are quite suitable for the description of self-regulating and self-controlling systems.[5] In any case the notions of regulation and information are considered as the most important ones for cybernetics, as it is impossible to control anything without transforming information. Within the Cybernetic Revolution, the technologies connected with information processing and more complex systems of control become of utmost importance. That is the reason why it makes sense to consider changing information technologies as the initial phase of the Cybernetic Revolution since information technologies underlie the transition to regulating technologies. Regulation and self-regulation (as the highest form of regulation) within systems are also the most important categories in cybernetics.

1.3. What are self-regulating systems?

Thus, *the main characteristic of the Cybernetic Revolution is the emergence and wide spread of systems of peculiar type: of controllable systems (in some respect they can be denoted as self-contained systems, i.e. systems which are able to operate independently), and the systems of higher level – self-regulating ones*.

[5] In the present work by self-controlling systems we mean not only self-controlling machines and self-controlling processes but a wider range of systems with high level of self-regulation as well as technologies of biological, techno-biological and other nature which are and will be implemented in medicine, genetic engineering, robotics and other branches and spheres. Different self-regulating systems will be also used for regulation of human behavior in different situations.

Let us explain. *Controllable (self-contained) systems are based on* ***the principle of controllability****, this means a higher level of control which is not a direct human control but a control via some inanimate system or subsystem of control (technical or of some other kind). In fact such kind of regulated systems should have a greater autonomy.* Just as even a primitive machine differs from a mechanical appliance, so the control by the autonomous systems differs from human control or control by means of primitive appliances. The highest level of controllability will be denoted as *self-regulation.*

Self-regulation and self-regulating systems. Self-regulating systems are systems that by means of the embedded programs and smart (and other) components can regulate themselves, responding in a pre-programmed and intelligent way to the feedback from the environment[6] as well as operate independently (or suggest alternatives) in a wide range of variations, having opportunities for *choosing optimum regimes in the context of certain goals and tasks*. These are systems that operate with minimal to zero human intervention.

On the whole, this refers to the type of regulation via technologies allowing the systems: a) to work most of the time without human controlling interference; b) to have more opportunities to independently respond to changes and to make operative decisions (and in future responsible decisions as well); c) to self-regulate and to self-adjust. In other words, these specific technologies allow the required processes to proceed autonomously, intervening only in the case of unexpected deviations from the predetermined parameters or in the case of some important reset of the parameters (of course, it is necessary to provide the signal about changing parameters and a message inquiring the permission for some changes, or a number of possible options will be provided). Let us emphasize that this refers not only to technical but also to biological, compound or some other types of systems.

Today there are many self-regulating systems around us, for example, the artificial Earth satellites, pilotless planes, navigators laying the route for a driver. Moreover, there emerge self-driving electric vehicles (for more details see Chapter 6). Another good example is life-supporting systems (such as medical ventilation apparatus or artificial heart). They can regulate a number of parameters, choose the most suit-

[6] The connection with the environment and the 'selection' of this or that 'decision' by the system on the basis of environment changes are also the most important ideas in cybernetics.

able mode and detect critical situations. There are also special programs that determine the value of stocks and other securities, react to the change of their prices, buy and sell them, carry out thousands of operations in a day and fix a profit. A great number of self-regulating systems have been created. But they are mostly technical and informational systems (like robots or computer programs). During the final phase of the Cybernetic Revolution there will emerge a lot of self-regulating systems connected with biology and bionics, physiology and medicine, agriculture and environment. The number of such systems as well as their complexity and autonomous character will dramatically increase. Besides, they will essentially reduce energy and resources consumption. Human life will become organized to a greater extent by such self-regulating systems (*e.g.*, via health monitoring, regulation or recommendations concerning physical exertion, diet, and other controls over the patients' condition and behaviors; prevention of illegal actions, *etc.*). As a result, the opportunity to control various natural, social, and industrial production processes without direct human intervention (which is impossible or extremely limited at present) will increase.

Nowadays, there are a number of so-called ‘smart’ technologies and things which in a proper and rather flexible way respond to external impacts. The simple but very illustrative example here can be mattress or pillows which take (or remember) the form of body (head) of a user; another example is chameleon sunglasses which change the intensity of sun protection depending on the brightness of the sunlight. However, these technologies as well as some automatic systems like auto-open doors, auto-switch light, *etc.* apply only some elements of self-regulation. Within self-regulating systems, the processes of identification, memorizing and selection of regime should operate on a much larger scale; it will often be the choice within the framework of uncertain opportunities. One can say that ‘smart’ technologies with elements of self-regulation have the reaction amplitude within the predetermined range. For example, a temperature regulator (connected through WiFi to Internet) which memorizes the climatic habits of an individual in a given period of time, has a rather small amplitude of preferences. Whereas for self-regulating systems, the amount of variations is largely unlimited, such a system is capable of choosing a proper action model in any combination within the framework of its opportunities.

Let us consider the navigator. There are usually several ways to reach destination, but since navigators can get direction from every point a navigator is supposed to lead the driver to the destination from any place. The number of routes to reach the destination is not limited (since even when there are several possible routes, the number of variations grows). Here the degree of self-regulation can be considered high, though the device itself is not too complicated.

1.4. The main directions of the Cybernetic Revolution

We suppose that during the final phase of the Cybernetic Revolution different *developmental trends will produce a system cluster of innovations as is often the case with the innovative phases of production revolutions*. Thus, as for the forecasts for the final phase of the Cybernetic Revolution in our opinion *the general drivers of the final phase of the Cybernetic Revolution will be medicine,* additive (3D printers), *nano- and bio technologies, robotics, IT, cognitive sciences,* which together will form *a sophisticated system of self-regulating production.* We denote this complex as **MANBRIC-technologies** (about the order of the letters in the acronym see also Note 2 in the previous chapter).

Another point is in what sphere will the final phase of the Cybernetic Revolution start? Which one will be the first? First of all, one should remember that the 'breaking through' sphere will be narrow as it happened during the Industrial Revolution (when the breakthrough occurred in a narrow field – cotton industry). 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 the future breakthrough area should be highly attractive in commercial terms and have a large market, we anticipate that the final phase (the one of self-regulating systems) of this revolution will begin in one of the new branches of medicine or its associated field. However, the development will follow the path of spreading the self-regulating systems into different new fields, their integration and development of the complex of MANBRIC-technologies.

Our assumption that the first field will be a new branch in medicine is based: a) on the analysis of the latest achievements in technologies; b) on a number of observed demographic and economic trends favorable for the rise of medicine (see in Ch. 3); c) on the regularities discovered within the theory of production revolutions which we analyze in the following section.

2. The Logic of the Production Revolution: The Analysis of Utility and Correlations between the Phases

The significance of the theory of production principles and production revolutions consists in the fact that they allow a more detailed and fruitful description of the evolution of production and technological development as well as provide the means to forecast the unfolding of the Cybernetic Revolution and of the scientific-cybernetic production principle. These instruments prove the scientific nature of this theory. Our forecast is based on the identified regularities in the phases of production revolutions. This section will define these regularities and the way they can be employed in forecasting.

Let us remind that the fundamental idea of the proposed conception of production revolutions is that *within every production revolution each of its three phases plays functionally the same role while the ratio between the duration of phases within the framework of each cycle remains approximately the same* (see Appendix 2 for more details). Thus, on the basis of the regularities identified within the Agrarian and Industrial Revolutions, one can make assumptions about the following points:

– *First*, about the duration of the intermediate (modernization) phase of the Cybernetic Revolution;

– *Second*, about the beginning and approximate duration of the final phase of the revolution;

– *Third*, about the sectors and directions that will be affected by the new technological breakthrough.

Therefore, the theory of production revolutions provides a methodological approach to ground our forecasts about the future technological shifts within the Cybernetic Revolution. Let us remind the reader that the initial phase of the Cybernetic Revolution has already completed (it lasted from 1950 to the early 1990s) and the modernization one is approximately half way through its development (it started in the 1990s and presumably will last till the end of the 2020–2030s). So we can compare the forecasts of the theory concerning each phase of production revolution with the present-day reality, and we can also infer the role that technologies will play in the final phase of the Cybernetic Revolution.

To give a better explanation to such a methodology, we formulate a number of functional and processual relations between the initial and final phases of a production revolution, between the initial and intermediate phases, and between the intermediate and final phases of the production revolutions. Knowing the algorithm of how the processes manifested in the initial phase of the production revolution can be transformed at the intermediate and final phases, we provide forecasts of the Cybernetic Revolution development for the upcoming decades proceeding from the study of its initial and uncompleted middle phase.

2.1. The peculiarities of the initial phase: Amalgamation of non-system tendencies into a system and the development of new ones

The *initial phase* of the production revolution is marked by the following peculiarities:

1. *A number of trends and innovations that used to be non-systemic within the previous production principle get a systemic character.* The non-systemic character means that within the previous production principle these phenomena did not play a crucial role and did not result from its main characteristics, whereas within a new production principle the role of these characteristics significantly increases. This can be exemplified by automatization which was developed to a certain extent within industrial production long before the Cybernetic Revolution. One of the main characteristics of the industrial production principle is that production is carried out by machines operated by humans who use their sense organs, power, and qualification. At the same time, some operations were performed without human intervention, in other words automatically. But the automatization of processes was not essential and it was not a necessary characteristic of the industrial production principle but its extra bonus. In the early twentieth century, automatization started to vigorously develop (*e.g.*, in electrical engineering for the prevention of accidents, in engines for convenient control, *etc.*). But still it had no decisive importance as it was not generally used for the automatization of technological processes.

Therefore, in that period automatization can be regarded as a hyper-development of such essential phenomenon as mechanization. Besides, in the first half of the twentieth century, automatization was not the leading trend of the industrial production principle. On the contrary, the leadership belonged to the processes of the latest division of labor including the wide distribution of assembly-flow production (a constant intensifying division of labor is an essential and transparent characteristic of the industrial production principle, strikingly manifested already in manufactures). The development of automatization in the second half of the twentieth century is quite a different matter. It became the most important characteristic of the scientific-cybernetic production principle (at its initial stages), finding new forms of application and implementation in releasing human costs in controlling over process (especially in Information and Communications Technologies [ICT]).

Thus, *the initial phase of production revolution develops to the highest degree the non-system elements of the previous period.* In this respect, automatization succeeded mechanization (see, *e.g.*, Lilley 1966; Philipson 1962; Bernal 1965); similar as the chemistry of synthetic materials was sequential to organic chemistry (Zvorykin *et al.* 1962); and as the Green Revolution in agriculture was sequent to agronomy (Thirtle *et al*. 2003). The development of radio and television technologies continued the trend of new means of information transfer which had emerged earlier. Such continuity can conceal the intensity of the transition from one epoch to another. So it is not surprising that in the 1950s and 1970s the scientific and technological development was considered as the continuation of the Industrial Revolution, and at best it was defined as a new industrial revolution (scientific and technological revolution [Bernal 1965]). However, this super-development possessed some qualitative characteristics which we will describe below.

2. *The former non-system characteristics together with newly emerging ones now merge into a unified system manifesting a new production principle.* Automatization, chemical synthesis of materials, a powerful development of non-computer electronics and means of communication, the emergence of various engines, a general transition to a new type of energy and fuel, the breakthrough in selection and plant protection, the discharge of a million workers previously employed in agriculture and industry and their transition to the service sector; together with a number of new directions in technology, informatics and science – all this creates a principally new situation in economy and also evidences the start of a new production revolution, namely, of the Cybernetic one.

3. *An important factor with a powerful synergistic effect is a temporal density (a cluster pattern) of formation and development of a number of directions which, to a greater or lesser extent, is typical of a new produc-*

tion principle. Such directions in the 1950s and 1960s were the nuclear power industry, space exploration and usage of space frequencies for communication and other purposes, deep-sea exploration, information and computer technologies, multiplying equipment, laser technologies, and other areas (*e.g.*, genetics, medicine and biotechnology).

4. *However, these innovative spheres can have different destinies*: some of them get peculiar and important development in the second half of the initial phase and at the intermediate phase; while other trends will develop less intensively. Some can turn (at least, temporally) into dead-ends. Thus, at present the atomic energy industry faces severe constraints due to environmental problems, the hopes to master thermonuclear energy fell short of expectations while deep-sea exploration (except for shelf sea) still remains exotic. At the same time, the development of ICT has become the leading trend.

5. *The change of the leading sector in the course of production revolution.* The leading role of some peculiar characteristics and sectors of a new production principle becomes especially obvious by the end of its initial phase or during the modernization phase (as in the case with ICT). These sectors need some time to reach maturity and acquire a systemic character. *Thus, during these two first phases of production revolution there is a constant alteration of leading branches and sectors as well as the formation of new sectors.* One of the branches of a new production principle starts to dominate over the others for quite a long period of time (from the end of the initial phase till the intermediate phase). This branch becomes the key phenomenon of the production revolution and its driving force. *But later its role as a driving force decreases.* For example, the wool industry (the most important branch of the initial phase of the Industrial Revolution) appeared to be unimportant in the final phase when it was replaced by the cotton industry.[7] So one can make an assumption that at the final phase of the Cybernetic Revolution the ICTs will hardly remain the most important sphere. They can make (and most likely will do) a breakthrough triggered by new advanced technologies but this will happen after the start of the final phase of this revolution. Later, in the course of the final phase of the Cybernetic Revolution (approximately in the 2040–2050s) one can expect a new qualitative breakthrough in ICTs. For example, one can assume that sooner

[7] Animal husbandry which developed at the modernization phase of the Agrarian Revolution did not become the leading direction of the final phase of this revolution.

or later serious changes will inevitably occur in programming. At present this process is labor-intensive and slow. It will most likely develop in the direction of simplification and robotization of some elements of programming and especially in implementation of programs. In other words, machine programming will largely substitute human programmers and 'the self-programming' trend will advance.

6. *Already at the initial phase there emerge prototype sectors which will become the leading ones at the final phase. But at the initial phase they do not play the leading role* (see more details about future leading sector below).

2.2. The characteristics of the intermediate (modernization) phase: accumulation of innovations and search for a breakthrough point

1. *The large scale of already existing tendencies and formation of new ones.* On the one hand, at this phase many processes develop (to a varying degree) that have been formed at the initial phase of production revolution. On the other hand, at the modernization phase we can trace the roots of those forms which will turn leading at the final phase of production revolution. Therefore, it is important to distinguish between the trends which have already turned mature and the tendencies which are only being formed, as well as to understand which of them will increase and which of them will be of less importance, become stable or later will decrease.

2. *The expanded development. The necessity of profound social and political changes.* The expansion of new technologies is especially noticeable in the first half of the modernization phase. In its second half this expansion undergoes certain saturation and slows down and thus, increases innovation activities. There appears an anticipation of something important. But the decisive component for the formation of a new system is still lacking. Besides, this gap can be manifested in the absence not only of basic technological innovations but also of the social conditions for its implementation. One of the most important characteristics of the modernization phase is that *during this period some profound changes or even breakthroughs in social and political relations should occur*. With respect to the Industrial Revolution, the period between the seventeenth and eighteenth centuries was the time of social revolutions in Great Britain, the Netherlands, the USA, and France which

had changed the world. It was also the time of changes in the world policy: The Thirty Years' War (1618–1648) and the subsequent Piece of Westphalia laid the foundations for international relations for a long time. Globalization and the period which we denoted as the epoch of new coalitions (Grinin 2009a, 2012b; Grinin and Korotayev 2010b, 2015) will significantly change the world and this process is already underway.

3. *The idea of a decisive component*. During the modernization phase opportunities and improvements accumulate which will contribute to the start of the final phase of the revolution. All components should be ready for this start. However, we emphasize that innovations can form a new system only after the key component emerges. At the same time the reconstruction of the relationships within the production system in general will be considerable.

4. *The emergence of a decisive innovation in the new field.* Basing on our analysis of production revolutions we can deduce that the decisive innovation will hardly appear within the most important economic sector. (Just as irrigated agriculture failed to become the most important sector of agriculture in pre-state barbarian societies while the cotton industry was not the most important industrial sector in the first half of the eighteenth century.) Moreover, within this field there should appear certain conditions including high commercial profitability and attraction which will provide a steady demand for a long period of time. Nevertheless, the emergence of the decisive innovation can remain underestimated for some time.

The decisive innovation for the final phase of the Cybernetic Revolution to start can emerge in some fields of bio- or nanomedicine (or another new branch of medicine). This can be a series of innovations which will make the growing number of innovations into a qualitatively new system. It is quite possible that such a breakthrough will associate with the invention of successful methods to fight cancer since this disease differs significantly from other diseases and requires solutions at the genetic level as well as an application of fundamentally new technologies.

2.3. The peculiarities of the final phase

1. *The main characteristics of the production revolution reach maturity.* One can find all the basic characteristics of the final phase of the revolution already at its initial phase though in undifferentiated, incomplete or

undeveloped state. These characteristics of the future system show up at the intermediate phase when the production principle takes a relatively complete although undeveloped form.

Thus, one may infer about the main characteristics of the Cybernetic Revolution basing on the analysis of the initial and intermediate phases, through a focus on their features and developmental dynamics. This analysis allows singling out the most important characteristics of the Cybernetic Revolution including resource saving, miniaturization, individualization, a wider implementation of artificial and smart materials, *etc.* These characteristics already show up in our epoch but they will absolutely dominate in the next epoch.

2. S*ome of the numerous directions which developed during the initial phase will inevitably become the leading directions at the final phase.* At the same time at the initial phase they play a less significant role. Thus, while at the final phase of the Industrial Revolution the main focus was on mechanisms, machines, and replacement of manual labor by machinery, at its initial phase machinery was only a part of this new direction. In the beginning of the Industrial Revolution, the technical innovations (replacement of manual labor by machines) were of less importance and the main factor was the intensifying labor division. If one considers the Agrarian Revolution, the leading direction of manual (hoe) agriculture was the use of fertile areas with the help of manual labor (*e.g.*, with the help of a sharp stick or stone hoe). The soil fertility was natural or was achieved by burning plants. As to irrigation technologies, at the initial phase of the Agrarian Revolution they were not so widespread and were determined by the local environment. But at the final phase they came to the fore and remained leading ones during the whole period when the craft-agrarian principle dominated in production.

Therefore, the leading sector of the final phase of the Cybernetic Revolution has already formed, but it is one of those sectors which do not, as yet, play a decisive role in economy. In our opinion, medicine (or one of its new branches) will play the leading role in the unfolding final phase of the Cybernetic Revolution.

3. *The mutual integration of innovative sectors starts after the formation of the decisive innovations or their group.* This process especially intensifies at the final phase of production revolution. Innovations are mutually integrated and form a fundamentally new system. That was the case with the invention of the power spinning loom in the 1760s (which

was then constantly being improved). Before that, for two decades separate important directions (steam engines, steam energy, new types of machines, principles of management at large enterprises, establishing the institution of inventions and different technological innovations) allowed the formation of the fundamentally new sector of cotton mills. This caused a cumulative effect of rapid development of lacking innovations in the field of cotton carding (*i.e.*, the separation of cotton fibers), painting, printing, *etc.*

Thus, the breakthroughs in medicine and allied technologies will cause the 'catching up' and amalgamation of different innovations into a system which might bring about the completion of the Cybernetic Revolution.

4. One should *distinguish between the field of breakthrough and the essence of a new production system.* The field of breakthrough just initiates profound transformations. The production revolution will fully gain its logic and 'sense' or 'essence' only later when the transformations become profound and expanded. However, one can try to guess this 'meaning', 'sense' and 'essence' on the basis of the processes occurring during the initial and intermediate phases of production revolution.

Thus, the general idea of the Cybernetic Revolution can be connected with a constant and comprehensive energy, resources and materials saving which will start due to mass development of self-regulating systems at a fundamentally new level. In fact, without the breakthrough in saving there will be no growth of living standards of the world population whose number will grow at least until the 2070s (according to most forecasts, see, *e.g.*, UN Population Division 2012).

3. The Determination of the Future Sector of the Breakthrough. Why Medicine?

3.1. Characteristics of the future sector of a breakthrough area

As we have shown above one of the number of directions defined in the initial and middle phases of any production revolution becomes a breakthrough area by the beginning of its final phase. But this factor does not play a leading role in the economy until the beginning of the breakthrough.

The analysis of the actual development of production revolutions also suggests the following characteristics of the future sector:

- the commodity produced in this sector should be of prime necessity. Thus, cereal in the period of the Agrarian Revolution and cotton in the period of the Industrial Revolution were basic necessities;
- the direction of development of the sector should conform to the leading tendencies and problems in the society (irrigation agriculture could support and increase the sudden exponential population growth; the cotton industry met the needs of increasing urbanization and made use of the surplus labor force which had emerged in the agrarian sector);
- the sector can influence a significant number of spheres and integrate them (*e.g.*, in the period of the Agrarian Revolution the irrigation facilities required joint actions in society; and in the period of the Industrial Revolution the transition to machines and steam-engine in the cotton industry caused a rapid growth of economy, the reconstruction of transportation routes and trade);
- technological conservatism in this sector is relatively weak;
- the breakthrough sector should provide high profits and rely on steady demand, otherwise it will fail to attract major investments. Besides, borrowing from this sector new technologies which arose in the advanced society will face no obstacles (*e.g.*, government's ban, *etc.*) in other societies;
- the sector must have a great potential for the growth of its productivity and the need for the growth of productivity must remain high for a long time to stimulate the innovations and investments.

Let us consider these conclusions in the context of the Cybernetic Revolution. It is evident that the future breakthrough sector of the final phase of this revolution should have already developed. But which of the existing ones meets the mentioned characteristics? We argue that there will be no breakthrough, for example, in the field of green (low-carbon) energy sector (despite the fact that at present wind and solar power demonstrate high growth rates) because green power will be unable to completely replace traditional energy resources but it will coexist with it similar to hydro- and nuclear power coexist with carbon energy. We think that robotics could become the breakthrough direction if there were created robots that could perform different functions in the service sector. Not without reason the future scientific and technological progress was thought to be connected with achievements in the sphere of robotics. At present robotics finds wide application and is rapidly developing (see, *e.g.*, Makarov and Topcheev 2003; Gates 2007). But still one can hardly say that robotics will become the breakthrough direction judging by the current volume of investments in this sphere which grows slowly, and much smaller capital is invested in the biotechnology field. However, it will play a very important part in the final phase of the Cybernetic Revolution and should achieve outstanding results though somewhat later, perhaps in the middle of the final phase of the Cybernetic Revolution (for more details see Chapter 6). We consider the development of self-driving cars as a vivid sign that the future technological breakthrough will be associated with self-regulating systems. Yet, there are many legal and social obstacles hampering a wide introduction of self-driving vehicles. Thus, we consider the development of robotic vehicles as the precursor of the coming final phase of the Cybernetic Revolution but not of its beginning.

3.2. Why is medicine to become the breakthrough sphere?

On the basis of the analysis of the current situation one can conclude that the only field which meets all the requirements is medicine. That is why medicine will be the first sphere to start the final phase of the Cybernetic Revolution, but, later on, the development of self-regulating systems will cover the most diverse areas of production, services and life.

We treat medicine in a broad sense, because for its purposes it will involve (and already actively involves) a great number of other scientific-technological branches. These are the use of robots in surgery and taking care of patients, information technologies in remote medicine, neural interfaces for treatment of mental illness and brain research; gene therapy and engineering, nanotechnologies for creation of artificial immunity and biochips which monitor an organism; new materials for growing artificial organs and many other things to become a powerful sector of economy.

Let us consider in detail why medicine is to become the breakthrough sphere.

a) Medicine is unique because it inspires constant activity in the field of new high technologies.

b) 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 (we define this complex as MANBRIC-technologies).

c) There are far fewer social, cultural, or structural obstacles to the implementation of these technologies in medicine than in other fields (the same situation with respect to the obstacles to adoption of innovations is observed in country of invention as well as in many other countries).

d) The commercial prospects and profits of new technologies in this sphere are huge since people are always ready to pay for them.

e) Some important demographic and global trends with growing urgency. Let us examine them.

First. A rapid growth of the world middle class and of the population education level, especially in the developing countries (NIC 2012) is anticipated by the 2030s. Besides, poverty and illiteracy will be reduced in the peripheral countries. As a result, the focus will shift from elimination of the most unbearable conditions to the problems of raising the standards of living, healthcare, *etc*. Thus, there is a huge potential for the development of medicine.

Second and the most important. In the nearest decades not only the developed but also many developing countries will face population ageing (see Figs 5, 6), shortage of labor resources and the necessity to support a growing number of elderly people. Moreover, in the remaining period of the modernization phase of the Cybernetic Revolution (until the 2030s) the increasing life expectancy will be the largest in developing and medium-developed countries where life expectancy is significantly lower than in developed countries.[8] By 2030, the number of people aged 65 and over in the world will amount a billion (see Fig. 5).

[8] Simultaneously by that time, the birth rates in many developing countries will significantly decrease. Therefore, the governments in these countries will start to be concerned about the health of the national population and not with limiting population growth.

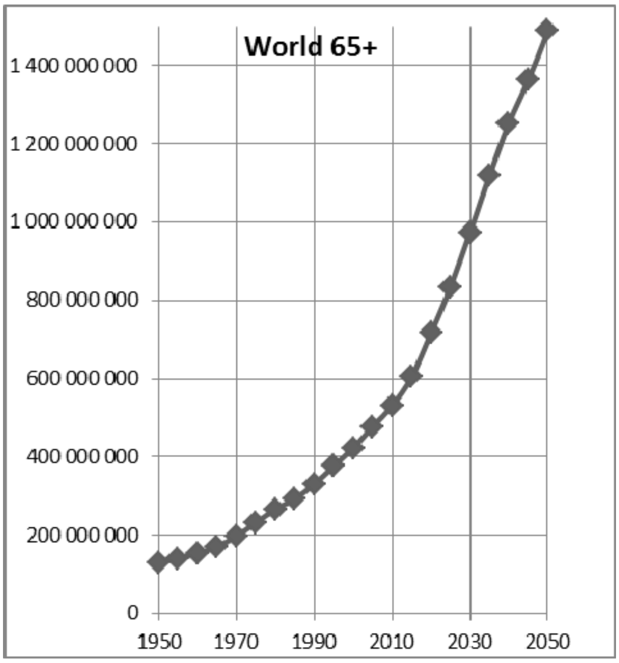

Fig. 5. Predictable increase in the number of people aged 65+, estimated for 1950–2015 and projected to 2050

Source: UN Population Division 2015; see also Grinin and Korotayev 2015b.

At present we observe the dynamics of increasing life expectancy, when the average life expectancy in some countries is more than 80 years. Fig. 6 shows the dynamics of growth rate of persons aged 80 years. By 2030s the number of people aged 80+ will be 200 million. Their growth during the final phase of the Cybernetic Revolution will generate new and new invention in medicine. Even in the case of inertial prognosis the number of persons 80+ will reach seven hundreds of millions. But in fact in the end of the final phase of the Cybernetic Revolution the number of people 80+ can increase much more.

In result of progress of ageing pension issues will become more acute (as the number of retirees per worker will increase) and at the same time a shortage of qualified labor force will increase (which is very critical in a number of countries). *Thus, we will have to solve the problem of labor force shortages and pension contributions by increasing the retirement age by 10–15 or more years.* It also refers to the adaptation of people with disabilities for their full involvement in the working process due to new technologies and achievements of medicine.

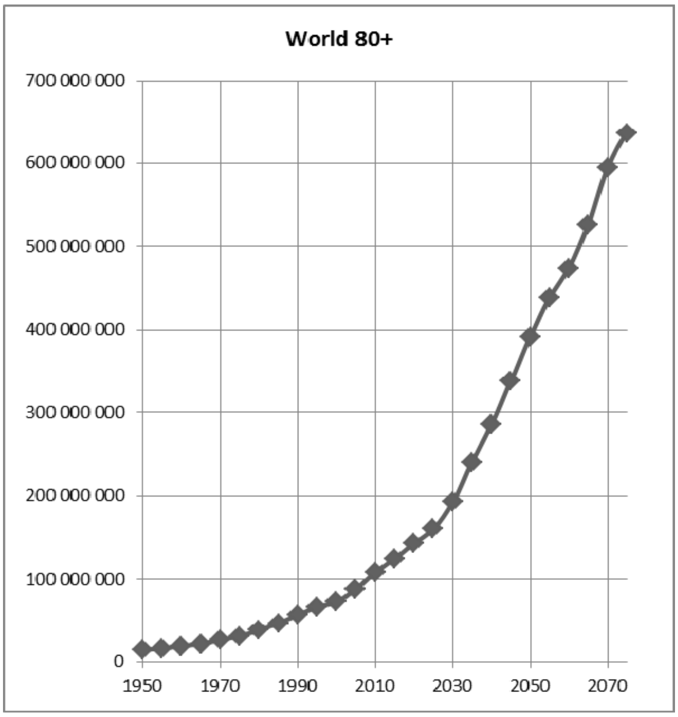

Fig. 6. Predictable increase in the number of people aged 80+, estimated for 1950–2015 and projected to 2075

Source: UN Population Division 2015; see also Grinin and Korotayev 2015b.

3.3. Medicine as a sphere of the initial technological breakthrough; the development of MANBRIC-technology complex

It is worth again 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 for ways to mechanize spinning. However, the solutions for these narrow tasks caused an explosion of innovations mediated by many of the major elements of machine production (including abundant mechanisms, primitive steam-engines, the 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, namely medicine.[9] By the 2030s there can appear unique opportunities for a breakthrough in medicine. However, when speaking about medicine, one should keep in mind that with respect to potential revolutionary transformations medicine is a very heterogeneous sphere. That is why the breakthrough will not occur in all spheres of medicine but in its one or two innovative fields. Perhaps, it has already formed (as biomedicine or nanomedicine) or it can form as a result of involving other innovative technologies into medicine. As for other branches of medicine, 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.

In general, the breakthrough vector in medicine and associated branches can be defined as a rapid growth of *opportunities for correction or even modification of our biological nature*. In other words, it will be possible to extend opportunities to alter a human body, perhaps, to some extent, its genome; to widen sharply opportunities for minimally invasive operations instead of the modern surgical ones; to use extensively cultivated biological materials, bodies or their parts and elements for regeneration and rehabilitation of an organism, and also to make and use artificial analogues of this biological material (organs, tissues, bodies, receptors), *etc.* This will make it possible to *radically expand the opportunities to dramatically increase life expectancy and improve physiological abilities of people as well as health-related quality of life (HRQoL).* Of course, it will take a rather long period (about several decades) from the first steps in that direction (in the 2030–2040s) to their common use.

On the whole, *the drivers of the final phase of the Cybernetic Revolution will be* complex ***MANBRIC-technologies****,* namely, *medicine, additive* (3D printers), *nano- and biotechnologies, robotics, ICT, cognitive sciences.*

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[9] It should be noted that Leo Nefiodow has been writing about medicine as the leading technology of the Sixth Kondratieff Wave (Nefiodow 1996; Nefiodow and Nefiodow 2014a, 2014b). We generally support his ideas about the role of medicine (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 consist, first of all, in their ability to solve the major medical problems. That is why, it makes sense to speak about medicine as the core of new technological paradigm.