III. ASPECTS OF SOCIAL DEVELOPMENT

7
Macroevolution of Technology

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Abstract

What determines the transition of a society from one level of development to another? One of the most fundamental causes is the global technological transformations. Among all major technological breakthroughs in history the most important are the three production revolutions: 1) the Agrarian Revolution; 2) the Industrial Revolution and 3) the Scientific-Information Revolution which will transform into the Cybernetic one.

The article introduces the Theory of Production Revolutions. This is a new explanatory paradigm which is of value when analyzing causes and trends of global shifts in historical process. The article describes the course of technological transformations in history and demonstrates a possible application of the theory to explain the present and forthcoming technological changes. The authors argue that the third production revolution that started in the 1950s and which they call the Cybernetic one, in the coming decades, that is in the 2030s and 2040s, will get a new impetus and enter its final stage – the epoch of (self)controllable systems. There are given certain forecasts concerning the development in such spheres as medicine, biotechnologies and nanotechnologies in the coming decades (the 2010s – 2060s).

Keywords: *production revolution, production principle, historical process, the Agrarian Revolution, the Industrial Revolution, the Cybernetic Revolution, controllable systems, biotechnology, medicine, nanotechnology, technology.*

Among all major technological breakthroughs in history the most important are the three production revolutions: 1) the Agrarian Revolution; 2) the Industrial Revolution and 3) the Scientific-Information Revolution which will transform into the Cybernetic one. From our point of view, each revolution initiates a new phase of development of the world productive forces as well as a transition to a new stage of historical process. In the age of globalization one observes a growing interest in the global technological transformations as well as in other global processes.

The present article introduces a new explanatory paradigm – *the theory of production principles and revolutions* – relevant for the analysis of the causes and trends of major technological breakthroughs as well as of the global shifts in historical process.

1. On Historical Process

One should make a few remarks to clarify our understanding of the 'historical process' notion (for more details see Grinin 2007a, 2012). The first point to note is that this concept is in no way synonymous with 'world history'.[1] Of course, the notion of historical process is based on world history facts. However, firstly, there have been chosen only those facts that are the most important from the point of view of process and changes; secondly, this set of facts has been ordered and interpreted in accordance with the analyzed spatial and temporal scales, trends and logics of historical development of humankind (or at least the World-System) as a whole, as well as the present-day results of this development. In other words, historical process is in no way a mechanical sum of histories of numerous peoples and societies, it is not even just the process resulting from movement and development of these people and societies. The historical process is a growing and even cumulative process of societal integration that has a certain direction and result. The notion of the historical process of *humankind* does not imply that humankind has always been a real system. It implies the following: (a) we select a respective scale for our analysis; (b) we take into account the fact that during all periods of historical process the societies, civilizations and its other actors have been developing unevenly, that is at a different rates of social progress; (c) from the methodological point of view it indicates that for the analysis of historical process the most important is the model of the influence produced by the more developed regions on the less developed ones; (d) the interaction scale expands from one period to another until it reaches the scale of the whole planet (in this situation it becomes equal to the notion of the World-System); (e) thus, the historical process of humankind is, first of all, the process of movement from autonomous and isolated social minisystems towards the formation of the present extremely complex system of actively interacting societies; (f) when (and if) humankind transforms into a subject whose development as a whole is determined (at least partially) by a common and explicitly expressed collective will, the historical process in its current meaning will come to its end, and this will lead to a transition to a new generation of processes.

[1] However, even the very notion of 'world history' and 'universal history', although a number of scholars recognize it as an important concept (*e.g.*, Ghosh 1964; Pomper 1995; Geyer and Bright 1995; Manning 1996), had been considered rather useless for a long time by historians and social scientists. But the most important is that 'while historians increasingly recognize the importance of world history, they remain relatively ignorant about it as a developing field' (Pomper 1995: 1).

Thus, ***historical process*** *is a notion that generalizes an intricate complex of internal transformations and actions of various historical subjects, as a result of which some important societal changes and integration, continuous enlargement of intersocietal systems take place, a transition to new levels of development is going on, and (taking into account the present results and future prospective), the humankind in general transforms from a potential unity into an actual one.*

2. The Production Principles and Production Revolutions

According to the theory that we develop, the historical process can be divided most effectively into four major stages or four formations of historical process. The transition of any of these formations into another is tantamount to the change of all basic characteristics of the respective formation. However, in addition to this principal basis of periodization (that determines the number of distinguished periods and their characteristics), we need an additional basis to work out the chronology in detail.

As such an additional basis we propose the *production principle* (*e.g.,* Grinin 2007a; 2007b; 2012: ch. 1; 2013) that describes major qualitative stages of development of the world productive forces. One may regard three production revolutions (the Agrarian, the Industrial, and the Cybernetic ones) as the borders between production principles.

We single out four **production principles**:

1. Hunter-Gatherer.

2. Craft-Agrarian.

3. Industrial.

4. Scientific-Cybernetic.

Though the qualitative transformations in some spheres of life are closely connected with changes in other ones (and, thus, no factors can be considered as absolutely dominant), some spheres (with respect to their influence) can be considered as more significant; that is, changes within them are more likely to produce changes in other spheres than the other way round.[2] The production principle belongs to such spheres due to the following reasons:

1. Significant changes in the production basis lead to the production of more surpluses and to a rapid population growth. And both these processes lead to changes in all other spheres of life. Still a transition to new social relations, new religious forms, *etc.* is not so directly connected with demographic changes as are the transformations of the production principle.

2. Though a significant surplus can be the result of some other causes (natural abundance, successful trade or war), such exceptional conditions cannot be

[2] Of course, we do not mean continuous and regular influence; we rather mean the moments of qualitative breakthrough. If after a breakthrough within a more fundamental sphere the other spheres do not catch up with it, the development within the former slows down.

borrowed, whereas new productive forces can be borrowed and diffused, and thus, they appear in many societies.

3. Production technologies are applied by all members of a society (and what is especially important, by the lower social strata), whereas culture, politics, law, and even religion are systems developed by their participants (usually the elites).

The change in production principles is connected with production revolutions. The starting point of such revolutions can be regarded as a convenient and natural point from which the chronology of formation change can be established.

The production revolutions are the following: **1) the Agrarian Revolution** (the 'Neolithic Revolution'); **2) the Industrial Revolution; 3) the Cybernetic Revolution**. The production revolutions as technological breakthroughs have been discussed for quite a long time. The Industrial Revolution became an object of extensive research already in the 19th century.[3] The first ideas on the Neolithic (Agrarian) Revolution appeared in Gordon Childe's works in the 1920s and 1930s, and he developed the theory of this revolution in the 1940s and 1950s (Childe 1948, 1949, 1952). In connection with the Cybernetic Revolution (which started in the 1950s as the Information-Scientific one) the interest in the study of production revolutions significantly increased. Much has been written about each of the three production revolutions (see, *e.g.*, Reed 1977; Harris and Hillman 1989; Cohen 1977; Rindos 1984; Smith 1976; Cowan and Watson 1992; Ingold 1980; Cauvin 2000; Knowles 1937; Dietz 1927; Henderson 1961; Phyllys 1965; Cipolla 1976; Stearns 1993, 1998; Lieberman 1972; Mokyr 1985, 1993, 1999; More 2000; Bernal 1965; Philipson 1962; Benson and Lloyd 1983; Sylvester and Klotz 1983); however, there is a surprisingly small number of studies concerning these revolutions as recurrent phenomena, each representing an extremely important landmark in the history of humankind. We have developed a theory of production revolutions (Grinin 2007a, 2007b, 2012) within the framework of general theory of a world historical process.

The production revolution can be defined as a radical turn in the world productive forces connected with the transition to the new principle of management not only in technologies but in the interrelations of society and nature. The difference of a production revolution from various technical overturns is that it touches not only some separate essential branches but the economy on the whole. And finally, the new trends of management become dominant. Such an overturn involves in the economical circulation some fundamentally new renewable or long inexhaustible resources, and these resources must be widespread enough within most territories; it increases labor productivity and/or land carrying capacity (the yield of useful product per unit of area) by orders of magnitude; this is also expressed in the creation of several orders greater volume of production and the demographic revolution (or the change of the demographic reproduction type).

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[3] For example, by Arnold Toynbee (1852–1883). See Toynbee 1927 [1884]; 1956 [1884].

As a result, the most powerful impetus for qualitative reorganization of the whole social structure is generated. Although the production revolution begins in one or a few places but as it signifies the turn of the *world* productive forces, it represents a long lasting process gradually involving more and more societies and territories. As a result a) the societies where it took place become progressive in the technological, economical, demographical, cultural and often military aspects; b) joining new production system becomes a rule.

Each production revolution has its own cycle. We can speak about three phases, including two innovative phases and between them – a modernization phase of expansion of new production principle, that is a long period of distribution and diffusion of innovations.

Thus, a cycle of each production revolution looks as follows: *the initial innovative phase* (the emergence of a new revolutionizing productive sector) – *the modernization phase* (distribution, synthesis and improvement of new technologies) – *the final innovative phase* (improving the potentials of new technologies up to the mature characteristics). See also Fig. 1.

Each innovative phase of a production revolution represents a major breakthrough in production. During the first innovative phase the new production principle hotbeds are formed; those sectors that concentrate the principally new production elements grow in strength. Then the qualitatively new elements diffuse to more societies and territories during the modernization phase. In those places where the most promising production version has got formed and adequate social conditions have appeared, the transition to the second innovative phase of production revolution occurs, which marks the flourishing of the new production principle. Now the underdeveloped societies catch up with the production revolution and become more actively engaged in it. Thus, we confront a certain rhythm of the interchange of qualitative and quantitative aspects. A general scheme of two innovative phases of production revolution within our theory looks as follows:

Agrarian Revolution: the **initial innovative phase** – transition to primitive hoe agriculture and animal husbandry (12,000–9,000 BP); the **final phase** – transition to intensive agriculture (especially to irrigation [5300–3700 BP] or non-irrigation plough one).

Industrial Revolution: the **initial phase** starts in the 15^{th} and 16^{th} centuries with the vigorous development of seafaring and trade, mechanization on the basis of water engine, the deepening division of labor and other processes. The **final phase** is the industrial breakthrough of the 18^{th} century and the first third of the 19^{th} century which is connected with the introduction of various machines and steam energy.

Cybernetic Revolution: its **initial** phase, which we call the **scientific-information epoch**, dates to the 1950–1990s. Breakthroughs occurred in automation, power engineering, synthetic materials production, space technologies and in particular in the development of electronic means of control, communication and information. The **final** phase will begin in the 2030–2040s and it will last until the 2060–2070s. This forthcoming phase can be called the **epoch of controllable systems** because the main point lies in the ability to create systems that could be self-controlled or indirectly controlled either through other systems or by means of point impact and corrections. As a result there will be much more opportunities to influence without direct human interference upon various natural, social and production processes whose control at present is impossible or quite limited. We suppose the final phase of Cybernetic Revolution will originate in a narrow sphere *at the crossing of medicine and biotechnology,* it may start with a drastic increase of opportunities to influence human biological nature. In the last section of the article we present preliminary ideas and prognoses about the main features and dimensions of the forthcoming phase of Cybernetic Revolution, otherwise called the epoch of controllable systems. There is a number of various suppositions concerning changes of that kind, they are dealt with by intellectuals in different fields starting from philosophers to fantasists (see, *e.g.*, Fukuyama 2002; Sterling 2005). However, our prognoses have an advantage over many of them because we base on the scientific theory.

We believe that the production revolution can be regarded as an integral part (the first 'half') of the production principle, after which the development of mature relations takes place. Such an approach demonstrates in a rather explicit way the main 'intrigue' of the cyclical pattern of historical formations. In their first half we observe mostly the radical production changes, whereas in the second half we deal with especially profound changes of political and social relations, public consciousness and other spheres. Within these periods, on the one hand, political-judicial and sociocultural relations catch up with more developed production forces, and, on the other hand, they create a new level, from which an impulse toward the formation of a new production principle starts.

However, a production principle cycle can be also represented in a classical three-phase fashion: *formation, maturity, and decline*. Yet, in some sense it appears more convenient to represent it in six phases, each pair of which demonstrates an additional rhythm of change of qualitative and quantitative characteristics. Such a cycle looks as follows:

1. The first phase – *the beginning of production revolution and the formation of a new production principle*. The latter emerged in one or a few places, however, in rather undeveloped, incomplete and imperfect forms.

2. The second phase – *the stage of initial modernization*. It is connected with a wider diffusion of new production forms, with reinforcement and vigorous expansion of a new production principle.

3. The third phase – *the final stage of a production revolution.* The production principle obtains mature characteristics.

4. The fourth phase – *the stage of maturity and expansion of production principle*. It is connected with the diffusion of new technologies to most regions and production branches. The production principle acquires its mature forms and that leads to important changes in social-economic sphere.

5. The fifth phase – *the stage of an absolute dominance of a production principle*. It leads to the intensification of production, the realization of its potential almost to the limit.

6. The sixth phase – *the stage of non-system phenomena* or *a preparatory phase* (for a transition to a new production principle). Intensification leads to the appearance of non-system elements (for the given production principle) that prepare the formation of a new production principle (when under favorable conditions these elements can form a system, and in some societies a transition to a new production principle can take place, and a new cycle begins).

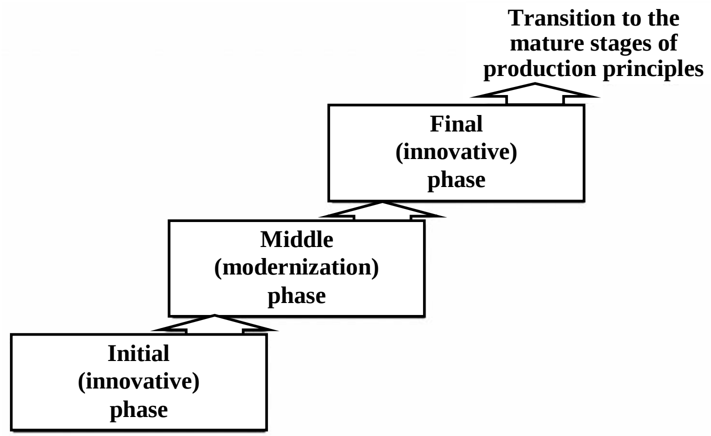

Fig. 1. Structure of Production Revolutions (phases and its types)

3. The Elaboration of the Periodization and Development of Historical Process

3.1. When does historical process start?

Let us consider now our chronology of the production principles, production revolutions, and their phases. We start from the period about 40,000−50,000 years ago (but to facilitate our calculation we take the date of 40,000 years ago), that is, since the appearance of the first indisputable indications of truly human culture and society.[4] To understand the reason for the choice of precisely this

[4] Note that this date is not identical with the modern dating of the emergence of *Homo sapiens sapiens* (100,000–200,000 years ago). Though discoveries of the recent decades have shifted the date of the *Homo sapiens sapiens* formation back in time to 100–200 thousand years ago (see, *e.g.*, Stringer 1990; Bar-Yosef 2002; Bar-Yosef and Vandermeersch 1993; Marks 1993; Pääbo 1995; Gibbons 1997; Holden 1998; Culotta 1999; Kaufman 1999; Lambert 1991; Zhdanko 1999; Klima 2003: 206; White e*t al*. 2003; Shea 2007), the landmark of 40,000–50,000 years ago still retains its major significance. This is that time, since which we can definitely speak about the humans of modern cultural type, in particular, about the presence of developed languages and 'distinctly human'

landmark one should take into consideration that any periodization must have some conceptual and formal unity at its basis. In particular, we believe that it is possible to speak about social evolution in its proper sense only after the social forces became the basic driving forces for the development of human communities. We suppose that the era of anthropogenesis should include not only that long period of time when our apelike ancestors (Ingold 2002: 8) were gradually obtaining an anatomical resemblance to modern human beings (that is approximately till 100–200 thousand years ago), but the subsequent rather long period (that lasted for many thousands of years) when those creatures anatomically similar to us were turning into *Homo sapiens sapiens*, that is becoming people in their intellectual, social, mental and language development. Of course, during this second phase of anthropogenesis the role of social forces in the general balance of driving forces was much larger than it was during the first phase. However, we believe that in general, during the whole process of anthropogenesis the driving forces were primarily biological, and only to a rather small degree were they social. Of course, it was a very long process and one cannot point out a definite moment when a crucial change occurred (as most likely in a literal sense there was not such a radical turn). Nevertheless, we believe that after the above-mentioned landmark of 40,000−50,000 years ago the social component of the evolutionary driving forces became dominant.[5] We also believe that for the same reasons it is impossible to speak about humankind as a set of societies before this time. Thus, the notions serving the basis for our periodization – *formations of historical process* and *production principles* – cannot be applied to the periods prior to 40,000−50,000 years ago. Thus, our periodization starts with the most important production revolution for the humankind; what is more, people themselves are, undoubtedly, part of the productive forces.[6]

culture (Bar-Yosef and Vandermeersch 1993: 94). And though there are suggestions that developed languages appeared well before 40–50 thousand years ago, these suggestions remain rather hypothetical. Most researchers suppose that the dependence on language appeared not earlier than 40,000 years ago (see Holden 1998: 1455), whereas, as Richard Klein maintains, 'everybody would accept that 40,000 years ago language is everywhere' (see Holden 1998: 1455). Klein, a paleoanthropologist at Stanford University, has offered a theory which could explain such a gap between the origin of anatomically modern *Homo sapiens* and much later emergence of language and cultural artifacts: the modern mind is the result of a rapid genetic change. He puts the date of change at around 50,000 years ago, pointing out that the rise of cultural artifacts comes after that date, as does the spread of modern humans from Africa (see Zimmer 2003: 41 ff.). So the period 50,000–40,000 years ago was the time of the beginning of social evolution in the narrow sense (see below).

[5] Yet in some certain important points the biological adaptation and anthropological transformation lasted for quite a long time even after this threshold. Yet in certain significant respects the biological adaptation and anthropological transformation continued for quite a long time after this threshold (see, *e.g.*, Alexeev 1984: 345–346; 1986: 137–145; Yaryghin *et al.* 1999, vol. 2: 165).

[6] Or using the title of Paul Mellars and Chris Stringer's book such a radical turn can be called 'The Human Revolution' (see Mellars and Stringer 1989).

3.2. The first formation of historical process. The Hunter-Gatherer production principle

Due to the paucity of information on the first formation it appears reasonable to connect the phases of the Hunter-Gatherer production principle with the qualitative landmarks of human adaptation to nature and its acquisition. Indeed, during this period community size, tools, economic forms, lifestyles – that is, virtually everything – depended almost exclusively on the natural environment. If we correlate phases with major changes in environment, it appears possible to connect them with an absolute chronology on the panhuman scale. This appears especially justified, as according to the proposed theory some part of the natural environment (within a theoretical model) should be included in the productive forces, and the more they are included, the weaker is their technological component (see Grinin 2003, 2009).

The **first** phase may be connected with the 'Upper Paleolithic' Revolution (about it see Mellars and Stringer 1989; Marks 1993; Bar-Yosef 2002; Shea 2007) and the formation of social productive forces (however primitive they were at that time). Already for this period more than a hundred types of tools are known (Boriskovskij 1980: 180). The **second** phase (approximately and very conventionally, 30,000–23,000 [20,000] BP) led to the final overcoming of what may be called the residue contradiction of anthropogenesis: between biological and social regulators of human activities. This phase is connected with the wide diffusion of people, the settlement in new places, including peopling of Siberia (Doluhanov 1979: 108) and, possibly, the New World (Zubov 1963: 50; Sergeeva 1983), though the datings here are very scattered (Mochanov 1977: 254; Sergeeva 1983; Berezkin 2007a, 2007b).

The **third** phase lasted till 18,000 – 16,000 BP. This is the period of the maximum spread of glaciers (referred to as the glacial maximum).[7] And though this was not the first glaciation, this time humans had a sufficient level of productive forces and sociality so that some groups managed to survive and even flourish under those severe conditions. Large changes took place with respect to variety and quantity of tools (Chubarov 1991: 94). This is precisely the time when there occurred a fast change of types of stone tools; for example, in France (Grigoriev 1969: 213), in the Levant (18,000 BP) microliths appeared (Doluhanov 1979: 93). During this phase, as well as the subsequent **fourth** phase – *c.* 17,000–14,000 (18,000–15,000) BP – the level of adaptation to the changing natural environment significantly increased. In some places that avoided glaciation, intensive gathering appeared (Hall 1986: 201; Harlan 1986: 200).

The **fifth** phase – 14,000–11,000 (15,000–12,000) BP, that is the end of the Paleolithic and the beginning of the Mesolithic (Fainberg 1986: 130) – may be

[7] During the last glacial epoch, Würm III. The glacial maximum was observed about 20,000–17,000 BP when temperatures dropped by 5 degrees (Velichko 1989: 13–15).

connected with the end of glaciation and climate warming (Yasamanov 1985: 202–204; Koronovskij, Yakushova 1991: 404–406). As a result of this warming and consequent change in the landscape the number of large mammals decreased. That is why the transition to individual hunting was observed (Markov 1979: 51; Childe 1949: 40). Technical means (bows, spear-throwers, traps, nets, harpoons, new types of axes, *etc.*) were developed for the support of autonomous reproduction of smaller groups and even individual families (Markov 1979: 51; Prido 1979: 69; Avdusin 1989: 47). Fishing in rivers and lakes was developed and acquired a major importance (Matjushin 1972). The **sixth** phase (*c.* 12,000–10,000 BP) was also connected with the continuing climatic warming, environmental changes culminating in the transition to the Holocene (see, *e.g.*, Hotinskij 1989: 39, 43; Wymer 1982 [and archaeologically – to the Neolithic in connection with considerable progress in stone industries]). This period evidenced a large number of important innovations that, in general, opened the way to the new, craft-agrarian, production principle (see, *e.g.*, Mellaart 1975). The point of peculiar interest are the harvest-gathering peoples who were a potentially more progressive development of the craft-agrarian branch. Such gathering can be very productive (see, *e.g.*, Antonov 1982: 129; Shnirel'man 1989: 295–296; Lips 1956; Lamberg-Karlovsky and Sabloff 1979).

Forestalling, we would like to say a few words in order to explain the quantitative proportions we have set between the periods of Hunter-Gatherer production principle which are presented below (see Tables 1–4 in Appendix). We have empirically determined certain correlations between the duration of the stages (phases) recurring within each production principle. But to what extent are these proportions relevant to Hunter-Gatherer production principle, if for the identification of the beginning of its periods we involve some exogenous factors of nature and climate changes?

Indeed, since the climate changes could have occurred at some other moment these proportions are random to some extent. However, in general they are not random at all and are endogenously reasonable, because, first, each described successive cyclic change requires more or less definite period of time. This perfectly explains why the durations of the given processes-stages correlate between each other in certain proportions. Second, though in respect of society the climate changes can be considered as external (and therefore random) factors, the diversity of macroevolutional lines significantly neutralizes such randomness. The idea logically following from the Rule of the necessary diversity is that the wider is the diversity, the higher is the probability of required randomness appearance at the right moment and at the right place. The same way a person staking on more than one event at once secures himself from accidents, and so, figuratively speaking, evolution with greater variability can accomplish a breakthrough if not in one place then in another. That is why, although the proportions in the correlation of Hunter-Gatherer production principle stages can slightly shift, nevertheless, they will remain practically the same since the unpreparedness to qualitative changes terminates excessive suitable cases, and in the case of delay of such a shift and the appearance of society's high preparedness ('overmaturity') to the changes necessary for the qualitative breakthrough even less suitable situations can be made use of. In particular, let us repeat that along with periods of maximal cooling in some places (which was on the whole random in respect of social macroevolution at certain time), there were highly specialized gatherers in other places, that was just non-random for social evolution. Consequently, the most important breakthroughs could have followed the same pattern already from 18,000 years ago, what probably would have slightly accelerated the beginning of Agrarian Revolution, but, most likely, would have delayed its transition to the second phase.

3.3. The second formation of the historical process. The Craft-Agrarian production principle

Whatever plants were cultivated, the independent invention of agriculture always took place in special natural environments (see, *e.g.*, [Deopik 1977: 15] with respect to South-East Asia). Correspondingly, the development of cereal production could only take place in certain natural and climate environments (Gulyaev 1972: 50–51; Shnirel'man 1989: 273; Mellaart 1982: 128; Harris and Hillman 1989; Masson 1967: 12; Lamberg-Karlovsky and Sabloff 1979). It is supposed that the cultivation of cereals started somewhere in the Near East: in the hills of Palestine (Mellaart 1975, 1982), in the Upper Euphrates area (Alexeev 1984: 418; Hall 1986: 202), or Egypt (Harlan 1986: 200). The beginning of the Agricultural Revolution is dated within the interval 12,000 to 9,000 BP, though in some cases the traces of the first cultivated plants or domesticated animals' bones are even of a more ancient age of 14–15 thousand years ago. Thus, in a rather conventional way it appears possible to maintain that the **first** phase of the Craft-Agrarian production principle continued approximately within the interval from 10,500 to 7,500 BP (the 9th – 6th millennia BCE [as the reader remembers we regard the first phase of the Craft-Agrarian phase as simultaneously the initial innovative phase of the Agrarian Revolution]). This period ends with the formation of the West Asian agricultural region, and on the whole one may speak about the formation of the World-System during this period, also including its first cities (about cities see Lamberg-Karlovsky and Sabloff 1979; Masson 1989).

The **second** phase can be conventionally dated to 8000–5000 BP (the 6th – mid-late 4th millennia BCE), that is up to the formation of a unified state in Egypt and the development of a sophisticated irrigation economy in this country. It includes the formation of new agricultural centers, diffusion of domesticated animals from West Asia to other regions. The husbandry of sheep, goats and the first draught animals is developed. The active interchange of achievements (domesticates and their varieties, technologies, *etc.*) is observed. During this period (starting from the 5th millennium BCE) the first copper artifacts and tools appeared in Egypt and Mesopotamia (and a bit later in Syria) (Tylecote 1976: 9). According to Childe the so-called urban revolution took place at that time (Childe 1952: ch. 7; see also Lamberg-Karlovsky and Sabloff 1979; Masson 1989; Oppenheim 1968; see also Adams 1981; Pollock 2001: 45; Bernbeck and Pollock 2005: 17).

During the **third** phase, 5000–3500 (5300–3700) BP, that is 3000–1500 BCE the agriculture emerges; animal husbandry, crafts and trade are differentiated into separate branches of economy (as reader remembers the third phase of Craft-Agrarian phase we regard simultaneously as the final innovative phase of the Agrarian Revolution). Though, according to our theory, crafts did not determine the development of agricultural revolution, it appears necessary to note that, according to Chubarov's data at the end of the second phase and the beginning of the third a very wide diffusion of major innovations (wheel, plough, pottery wheel, harness [yoke], bronze metallurgy, *etc.*) is observed (Chubarov 1991; see also about plough McNeill 1963: 24–25; Kramer 1965; on bronze metallurgy Tylecote 1976: 9). This was the period when the first states, and later empires, appeared in the Near East. Urbanization also went on reaching new regions. This period ends with a major economic, agrotechnical, and craft upsurge in Egypt at the beginning of the New Kingdom (Vinogradov 2000).

The **fourth** phase (3500–2200 [3700–2500] BP, or 1500–200 BCE) is the period when systems of intensive (including non-irrigation plough) agricultures formed in many parts of the world. We observe an unprecedented flourishing of crafts, cities, trade, formation of new civilizations and other processes that indicate that the new production principle began to approach its maturity. This phase lasts till the formation of new gigantic world states from Rome in the West to China in the East, which later led to major changes in productive forces and other social spheres.

The **fifth** phase (the late 3rd century BCE – early 9th century CE) is the period of the most complete development of the productive forces of the craft-agrarian economy, the period of flourishing and disintegration of the ancient civilizations and formation of civilizations of a new type (Arab, European, *etc*.).

The **sixth** phase (from the 9th century till the first third of the 15th century). At its beginning one can observe important changes in the production and other spheres in the Arab-Islamic world and China; in particular, in the second half of the 1st century BC the wide international trade network from the East African Coast to South-East Asia and China developed in the Indian Ocean basin (Bentley 1996). Then we observe the beginning of urban and economic growth in Europe, which finally creates first centers of industry and preconditions for the Industrial Revolution (see also Grinin and Korotayev 'Globalization and the World System Evolution' in the present volume).

3.4. The third formation of the historical process. The Industrial production principle

The first phase of the Industrial production principle (as the reader remembers it means respectively the beginning of the initial phase of the Industrial Revolution) may be dated to the period lasting from the second third of the 15th century to the late 16th century.[8] This phase includes those types of activities that were both more open to innovation and capable of accumulating more surplus (trade [Mantu 1937: 61–62; Bernal 1965] and colonial activities [Baks 1986], which had become more and more interwoven since the 16th century) came to the forefront. Besides, at that time, primitive industries (but still industries) developed in certain fields. It is during that period when according to Wallerstein (1974, 1987) the capitalist world-economy was formed.

From the late 16th century to the first third of the 18th century there lasted the **second** phase of the new production principle, a period of growth and development of new sectors that had become dominant in some countries (the Netherlands and England).

The **third** phase of the Industrial production principle began in the second third of the 18th century in England. As the reader remembers it meant the beginning of the final phase of the Industrial Revolution that led to the development of the machine-based industries and the transition to steam energy. Supplanting handwork with machines took place in cotton textile production that developed in England (Mantu 1937; Berlanstein 1992; Mokyr 1993, 1999; Griffin 2010). Watt's steam engine started to be used in the 1760s and 1770s. A new powerful industry – machine production – had developed. The industrial breakthrough was more or less finalized in England in the 1830s. The successes of industrialization were evident in a number of countries by that time and it was also accompanied by significant demographic transformations (Armengaud 1976; Minghinton 1976: 85–89).

The **fourth** phase (from the 1830s to the late 19th century) is the period of the victory of machine production and its powerful diffusion. The **fifth** phase took place in the late 19th century − the early 20th century up to the world economic crisis of the late 1920s–1930s. During that period there occurred huge changes. The chemical industries experienced vigorous development, a breakthrough was observed in steel production, the extensive use of electricity

[8] The point of view that, besides the 18th century industrial revolution, there was also an earlier industrial revolution (or even industrial revolutions) is widely accepted in Western science (Bernal 1965; Braudel 1973, 1982, 1985; Hill 1947; Johnson 1955, *etc.*), but until now within Russian academic community it has quite a few advocates. Still it appears that in the last two decades the idea of marking out Early Modern Period (the end of the 15th – 18th centuries) has attracted a number of supporters. However, these scholars do not associate Early Modern Period with earlier industrial revolution.

(together with oil) gradually began to replace coal. Electrical engines changed both the factories and everyday life. Development of the internal combustion engines led to the wide diffusion of automobiles. The **sixth** phase continued till the mid-20th century. A vigorous intensification of production and the introduction of scientific methods of its organization took place during this period. There was an unprecedented development of standardization and the enlargement of production units. Signs of the forthcoming Information-scientific Revolution became more and more evident.

3.5. The fourth formation of the historical process. The Scientific-Cybernetic production principle and Cybernetic Revolution

The Scientific-Cybernetic production principle is only at its beginning (see Fig. 2.); only its first phase has been finished and the second phase has just started. Hence, all the calculations of the forthcoming phases' lengths are highly hypothetical. These calculations are presented in Tables 1 and 2 (see Appendix).

The **first** phase of the Scientific-Cybernetic production principle took place between the 1950s and mid-1990s, when a vigorous development of information technologies and the start of real economic globalization were observed. As the reader should remember, the first phase of production principle corresponds to the initial phase of production revolution. **The production revolution** that began in the 1950s and continues up to the present is sometimes called the 'scientific-technical' revolution (*e.g.*, Benson and Lloyd 1983). However, in any case it would be more appropriate to call it the 'information-scientific' revolution, as it is connected with the transition to scientific methods of production and circulation management. Especially important changes took place in information technologies. In addition, this production revolution had a few other directions: in energy technologies, in synthetic materials production, automation, space exploration, and agriculture. However, its main results are still forthcoming. And as we will show below this revolution can be called the Cybernetic one because the main changes will involve a rapid increase in opportunities to control various processes by means of creating self-regulated autonomous systems or through the impact on the key parameters and elements that are able to launch a necessary process, *etc.* Cybernetics is commonly known as a transdisciplinary approach to the study of regulatory systems.

The **second** phase of the Scientific-Cybernetic production principle (= the middle phase of the Cybernetic Revolution, see Fig. 2) began in the mid-1990s due to the development and wide diffusion of user-friendly computers, communication technologies, cell phones and so on. It has been going on up to the present.

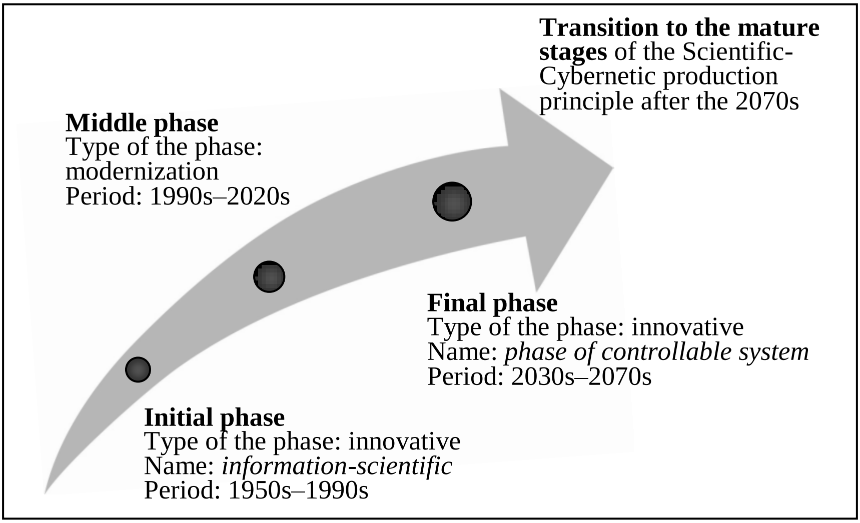

Fig. 2. Phases of the Cybernetic Revolution

The **third** phase may begin approximately in the 2030s–2040s. It will mean the beginning of the final phase of the Cybernetic Revolution that in our view may become the epoch of **'controllable system'**, that is, the vast expansion of opportunities to purposefully influence and direct various natural and production processes (see Grinin 2007a, 2012).

For the expected lengths of the **fourth, fifth,** and **sixth** phases of the Scientific-Cybernetic production principle see Table 1 in Appendix. In general, it may end by the end of this century, or by the beginning of the next one.

Instead of a Conclusion. Some Ideas about the Cybernetic Revolution

Now let us make a predictive analysis of major changes that the Cybernetic Revolution has already yielded and will bring about. Our forecast is based on the revealed developmental patterns at the final and initial stages of the previous production revolutions and already visible trends of the Cybernetic Revolution.

We suppose that the leading trends of the epoch of controllable systems will be: biotechnologies, human medicine and to a lesser extent nanotechnologies.

The most important characteristics of the Cybernetic Revolution are the following:

1. A qualitative growth of control over systems and processes of various kinds, scales, complexity, and levels. It means an ability to create sustained

systems, which can self-regulate without human interference; as well as such systems' capacity to autonomous functioning and adaptation to changes.

Within this leading trend there exist and will appear numerous variants of providing such control and self-regulation, including the influence on the key elements of systems and process steps; a controllable maintenance of the weakest elements of the system by means of resources of the system itself or with minimal interference; a prognosis and prevention of possible failures, probable regeneration of particular, most vulnerable elements, *etc*.

2. The determination of optimal operations within particular objectives and tasks (as a logic consequence of the first characteristics).

3. The creation of complex synthesized systems (which can be termed the *transcybernetic* ones) resulting from the development of self-regulation. One can speak about a large diversity of synthesis of principles and materials of different levels, as well as of an active development of systems comprising principles and materials of different levels of systems: inanimate, animate and technical, *etc*.

In particular, there will start a process of creation of biotic (biotechnical) systems (including human organism) which will involve to a different degree principles and materials of animate and inanimate nature functioning on the basis of both biological and technological principles, as well as on the more complex biosocial and technological ones.

The group of attributes of task-aware adaptation of materials and system:

4. Individualization as a guideline in the development of technologies and business strategies. Individualization manifests in the development of technologies of mass short-run or individually-tailored production with account of a consumer's particular demands as well as in the creation of goods that adapt to the consumer's desire (given him or her an opportunity to adjust them rather significantly to one's own demands). In the future, the opportunities will grow to choose an individual strategy as the most optimal (here one can also trace the connection with Item 2), in particular to solve certain tasks, to meet the individual's goals, for particular farming lands, *etc*. With development of medicine, the orientation to individual peculiarities of human organisms and people's desires will become much more important than in modern economy.

Miniaturization trend; that is a constant decreasing of the size of particles, mechanisms, electronic devices, *etc*.

6. The resource and energy saving in any sphere of activity also through the miniaturization of systems, localization of domain of impact, *etc*. (here the nanotechnologies come to the fore).

7. The development of the predetermined but previously non-existent properties in chemical, biological and bionic (techno-biological) systems.

We will shortly discuss some of these criteria.

We suppose that all trends of the Cybernetic Revolution will be tightly interconnected and support each other.

Biotechnology

Biotechnology is one of the most rapidly developing branches of industry. By the 2020s, the global market of biotechnological industries is expected to reach 700 billion dollars. Biotechnology is tightly connected with food, pharmaceutical[9] and biochemical industries.

In biotechnology production we can see the trends that lead to the formation of self-regulatory systems. This will affect the production processes, which will become more efficient and cost effective. Nowadays, the self-regulation is well traced at the genome level. In gene construction the scientists insert, alongside with a useful gene, special controlling genes-promoters that launch a necessary gene only under certain conditions. In future this technology will develop. A number of gene constructions will be inserted in an organism at once. This will provide flexible response to different changing factors, such as weeds, vermin, drought and others. The genetic engineering allows manipulating genes and expanding an organism's biological properties for specified purposes. Due to huge internet databases and automatization of manipulations with DNA, even today one can select a necessary gene for a plant or an animal and insert it in the organism. Genetic modification can already change a whole population, for example, the mosquitoes carrying the gene of infertility are being introduced into the wild population, spreading the gene, when crossed, and thus reducing the number of insects (Tkachuk *et al.* 2011).

The number of genetically modified organisms grows every year. As a result of completed cybernetic revolution the genetic engineering will be individualized for the sake of the slightest peculiarities. In other words, producers will be able to create a plant or a domestic animal variety in small home laboratories according to their requirements for particular climate and regions. Cloning is an important part of individualization. Nowadays it is well worked-out and employed for plants. With respect to the animal organisms cloning is not that efficient. It is highly improbable that human cloning will develop. One can find much more opportunities for therapeutic cloning when an organism's development is stopped in order to get the stem cells and use them for growing the necessary organs and tissues. In the future this can become an important source of tissues and organs in human medicine.

The biotechnological industry provides a *significant production cost saving.*

Very promising are biofuels, which today accounts for 10 % of the total energy output. Its use may increase by more than 10 times by 2035 (Kopetz

[9] For example, the biotechnological way of medicine production gives a huge number of innovate drugs every year (Woollett 2012).

2013). Biotechnology allows producing new eco-friendly materials (*e.g.*, bioplastic). The range of products made from bioplastics is already very wide. In the period from 2000 to 2008, global consumption of biodegradable plastics based on starch, sugar and cellulose increased by 600 % (Ceresana Research 2011).

We will see a very broad invasion of biotechnology in our lives: a power supply system, a variety of materials, medicine, *etc*. We think that in the future it is the biotechnologies that can help developing countries to make a qualitative breakthrough, get cheaper energy, establish low-cost production of pharmaceuticals and nutritional supplements, develop agriculture and increase the standard of life.

Medicine

In the second half of the 20^{th} century, the significance of health care as an economic sector has sharply increased. We suppose that during the Cybernetic Revolution its role will radically grow. The most actively developing branches of medicine are: pharmaceuticals; aesthetic medicine; fight against cureless diseases; implantation; reproductive medicine and gene therapy.

Medicine becomes more and more *individualized*. This is especially obvious in the selection of an individual treatment program for every person by computers and in the field of aesthetic medicine. The wealthier is a society, the larger part of the income people spend on health and beauty. In the nearest decades one can suppose an explosive growth of all types of aesthetic medicine. Individualization will also manifest at the level of gene therapy by means of which some serious genetic diseases are already treated. In the future every patient will be treated according to his genetic record and the defected genes will be repaired. Bionics will allow expanding human individual properties. The equipment has already been worked out that helps paralyzed people speak, write and even work with computers. One of the criteria for assessing the development of medicine is the production of medicines, their number is steadily increasing. The developed countries invest heavily in the development of drugs (Baker 2013). Pharmaceuticals will become more individualized. Drug production has been steadily increasing. In the future, patients will be prescribed drugs according to the individual characteristics of their organism and transportation of drugs in the body will become so accurate that will require miniscule doses. An important direction of the individual treatment is creation of the artificial immune system (Woollett 2012; Dickert, Hayden, and Halikias 2001). One of the promising trends in medicine is the slowing aging at the molecular level (Slagboom, Droog, and Boomsma 1994). Medicine has a direct impact on life expectancy, which in the future may achieve 90–100 years.

Self-regulation in medicine is expressed at different levels. For example, many processes of self-regulation are provided by special biochips implanted in the organs which make it possible to control vital processes. Thus, the treatment can proceed even without human interference. In 2011, the first pancreas transplantation was fully performed by the surgical robot Da Vinci. The surgery required only a seven centimeter incision and three small holes in the abdominal wall. In future such surgeries will become common. Thus, the job of a doctor in its present sense can disappear at all.

The struggle with incurable diseases is the most important branch of medicine. According to the World Health Organization in the developed countries the most frequent diseases that lead to death are heart diseases (12.8 % mortality), strokes, and other cerebrovascular diseases (10.8 %), AIDS (3.1 %), cancer (2.4 %), diabetes (2.2 %) and others (WHO 2011). In the future many incurable diseases will respond to treatment. Cancer control progress is associated with early diagnosis and increasing recovery rates. There appear some ideas how to outwit cancer (Marx 2013). However, it is very likely that by the 2030s cancer still will not be defeated. Surely this victory itself can be a powerful impetus for a general breakthrough in medicine.

Energy and resource saving. The most precise diagnostic methods will give an opportunity to define the required concentrations and forms of medicines, thus reducing the patient's expenses and cheapening the treatment. And nanotechnologies will allow transporting the necessary active substances to the sick cells thus minimizing side effects.

Nanotechnology

Nanotechnology is the manipulation with matter on an atomic and molecular scale. Nanotechnology works with materials, devices, and other structures with at least one dimension sized from 1 to 100 nanometres.

Since ancient times the humankind has used nanomaterials, for example, to produce paints, iron and steel.

Nanotechnologies are among the most actively developing economic sectors. Today nanotechnology is a multi-million dollar industry. The sales achieve nearly 20 billion dollars and by 2017 they will probably grow to 49 billion (BCC Research 2012). Current nanotechnologies are used practically everywhere: in medicine, heavy industry, electronics, and chemical industry, *etc*. The fastest economically developing sectors are biomedical, optoelelectronics and alternative energy. Despite the substantial progress of nanotechnology in electronics and other industries, a real breakthrough of nanotechnology is likely to happen first in medicine, which will give impetus to the development in other areas. One lays great hopes on nanotechnologies in the sphere of defeating cancer.

Self-regulation in nanotechnologies. A close connection between nanotechnologies and increasing self-regulation of systems is due to the fact that nanotechnology itself is based on the aspiration to make molecules and atoms become ordered in a certain spatial and structural pattern, that is the idea to harness the self-regulatory processes of matter. Many nanotechnological systems are capable *to autonomous control.* One can mention as an example the self-cleaning mechanism of the car glass treated with special polish. The self-cleaning mechanism is based on the so-called lotus effect. The surface is modified in such a way that a water drop slips down taking dirt with itself. So for this car glass even some rain water is enough to make it clean.

Individualization in nanotechnologies can be traced in the connection with medicine at the level of biochips created on the biotechnological basis. For example, biosensors will be able to monitor the spread of a virus in blood in an online mode (Cavalcanti *et al.* 2008). It is supposed that nanotechnologies can help to change the tilling land technique by means of nanosensors, nanopesticides and a system of centralized water purification. Individualization will be connected with technical devices. Future models of mobile phones can be able to change the form, size or color according to the individual preferences.

The resource and energy saving. Many nanotechnologies aim at reducing energy consumption as well as at creating alternative energy sources. For example, 'clever glass' for buildings that can react to the changing temperature and light with the respective change in transparency and thermal conductance. This is tightly connected with self-regulation in nanotechnologies. A wide usage of electronic paper can save forests on the Earth.

* * *

Finally, one should note that the forthcoming changes may bring about serious ethic issues. The radical changes in human organism may seriously damage such vital aspects as family, gender, and outlook on life. That is why the forecasts of the development of the Cybernetic Revolution are important. They can help to create beforehand some optimal social, legal and other means so that those changes will not surprise and their negative consequences could be minimized. On the whole, the revolution of controllable systems will also involve social systems, so we should work out certain mechanisms of social forecasts and prevention, which will be introduced at least before the mass diffusion of dangerous innovations or forestall their influence.

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APPENDIX: Mathematical Interpretation of Historical Process

With regard to social disciplines, a question continually arises: are mathematical methods suitable for analyzing historical and social processes? Obviously, we should not absolutize the differences between fields of knowledge, but the division of sciences into two opposite types, made by W. Windelband and H. Rickert, is still valid. As is known, they singled out sciences involving *nomothetic methods,* that is, looking for general laws and generalizing phenomena, and those applying *idiographic methods*, that is, describing individual and unique events and objects. Rickert attributed history to the second type. In his opinion, history always aims at picturing an isolated and more or less wide course of development in all its uniqueness and individuality (Rickert 1911: 219).

However, since the number of objects and problems investigated and solved by precise methods is growing rapidly, we may assume that, with time, historical knowledge will also be analyzed by some branches of mathematics.

Thus, the problem remains debatable. Nevertheless, rational attempts to use mathematical methods in theoretical or applied trends of the humanities are on the whole positive. Yet, they 'dry up' the soul of history to some extent, but at the same time, they promote self-discipline and self-testing of thoughts, ideas, and concepts of many specialists in the humanities, who, unfortunately, often do not bother to find any methods of testing their conclusions. In addition, this could somewhat reduce the polysemy of the scientific language of the humanities. R. Carnap in his *Philosophical Foundations of Physics* (Carnap 1966) wrote that, even in physics, the use of terms from ordinary language (as the notion of *law)* for an accurate and unambiguous expression of ideas complicates proper understanding. However, physicists, as well as other representatives of natural sciences, long ago agreed on fundamentals (such as units of measurement and symbols). As for the humanities, which analyze social phenomena, the same objects sometimes have up to ten meanings and hundreds of definitions. Perhaps, the very necessity to formalize the humanities will lead at last to certain conventions and the ordering of terminology. Nevertheless, even today the use of mathematics may help in searching for a common field of research.

Can we after all construct any mathematical models for such a complex subject of inquiry as the historical process? The answer to this question is obvious: yes, it is quite possible when examining countable objects.

However, when we speak about some global general theories, like macroperiodization of the world historical process, any figures, cycles, diagrams and coefficients, of course, cannot prove too much by themselves. Especially, if the respective analysis includes ancient periods for which all the figures are likely to be too much approximate and unreliable. Thus, for general theories covering immense time spans and space, the main proves are a good empirical basis, logics, internal consistency and productivity of theoretical constructions; that is, a theory's ability to explain the facts better than other theories do. On the other hand, any theory is better when it is supported by more arguments. Mathematical proofs can be rather convincing (when they are relevant, of course). This is especially relevant with respect to those aspects that are more liable to mathematical analysis, for example, those connected with demography.

In this paper we have chosen such an aspect that is liable to mathematical analysis and quite suitable for it. This is the *temporal* aspect of history. Its suitability for mathematical analysis is connected with the following: though it is quite possible to speak about the tendency of historical time toward acceleration, the astronomic time remains the same. Thus, within this study we have a sort of common denominator that helps to understand how the 'numerator' changes. Hence, we believe that for the analysis of periodization of history the application of mathematical methods is not only possible, but it is also rather productive.

Now we can start our mathematical analysis of the proposed periodization. Mathematical methods are quite widely used in historical research, but, unfortunately, mathematical studies of historical periodization are very few indeed.[10] However, it is worth mentioning that there have been published several issues of the almanac with a telling title – *History and Mathematics* (Grinin, de Munck, and Korotayev 2006; Turchin *et al.* 2006; Grinin, Herrmann, Korotayev, and Tausch 2010). In the meantime the discovery of mathematical regularities within an existing periodization may serve as a confirmation of its productivity and as a basis for tentative forecasts. *Time* as a parameter of historical development is quite suitable for mathematical analysis, for example, economic and demographic historians study actively temporal cycles of various lengths (about Juglar and Kondratieff cycles see Korotayev and Grinin 2012; Grinin, Korotayev, and Malkov 2010). Cycles used as a basis for this periodization are not different in any principal way from the other temporal cycles with regard to the possibility of being subject to mathematical analysis.

Table 1 ('Chronology of Production Principle Phases') presents dates for all the phases of all the production principles. However, it should be taken into account that in order to make chronology tractable all the dates are approximated even more than the ones used in the text above. Table 2 ('Production Principles and Their Phase Lengths') presents the absolute lengths of the phases in thousands of years.

Table 1. Chronology of production principle phases (figures before brackets correspond to absolute datings (BP); figures in brackets correspond to years BCE. Bold figures indicate phase lengths (in thousands of years)

Production principle	*1st phase*	*2nd phase*	*3rd phase*	*4th phase*	*5th phase*	*6th phase*	*Overall for production principle*
1	2	3	4	5	6	7	8

[10] It appears reasonable to mention here the works by Chuchin-Rusov (2002) and Kapitza (2004, 2006). Some ideas about the detection of mathematical regularities were expressed by Igor Dyakonov. In particular, he wrote the following: 'There is no doubt that the historical process shows symptoms of exponential acceleration. From the emergence of *Homo Sapiens* to the end of Phase I, no less than 30,000 years passed; Phase II lasted about 7,000 years; Phase III – about 2,000, Phase IV – 1,500, Phase V– about 1,000, Phase VI – about 300 years, Phase VII – just over 100 years; the duration of Phase VIII cannot yet be ascertained. If we draw up a graph, these Phases show a curve of negative exponential development' (Dyakonov 1999: 348). However, Dyakonov did not publish the graph itself. Snooks suggests a diagram called 'The Great Steps of Human Progress' (Snooks 1996: 403; 1998: 208; 2002: 53), which in some sense can be considered as a sort of historical periodization, but this is rather an illustrative scheme for teaching purposes without any explicit mathematical apparatus behind it.

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**

Table 1 (continued)

1	2	3	4	5	6	7	8
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**	35000–2200 (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. 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	1955–2000 (1955–1995)* **0.04–0.045**	2000–2040 (1995–2030) **0.035–0.04**	2040–2070 (2030–2055) **0.025–0.03**	2070–2090 (2055–2070) **0.015–0.02**	2090–2105 (2070–2080) **0.01–0.015**	2105–2115 (2080–2090) **0.01**	1955–2115 (2090) [forecast] **0.135–0.160**

Note: In this line figures in brackets indicate the shorter estimates of phases of the Scientific-Cybernetic production principle (the fourth formation). Starting from the second column of this row we give our estimates of the expected lengths of the Information-Scientific production principle phases.

Table 2. Production principles and their phase lengths (in thousands of years)

Production principle	*1st phase*	*2nd phase*	*3rd phase*	*4th phase*	*5th phase*	*6th phase*	*Overall for production principle*
1. Hunter-Gatherer	10	8	5	3	2.5	1.5	30
2. Craft-Agrarian	2.7	2.3	1.5	1.3	1.0	0.6	9.4

3. Industrial	0.17	0.13	0.1	0.06	0.04	0.025	0.525
4. Scientific-Cybernetic	0.04–0.045	0.035–0.04*	0.025–0.03	0.015–0.02	0.01–0.015	0.01	0.135–0.160

Note: * This line indicates our estimates of the expected lengths of the Scientific-Cybernetic production principle phases.

Table 3 ('Ratio of Each Phase [and Phase Combination] Length to the Total Length of Respective Production Principle [%%]') presents results of our calculations of the ratio of each phase's length to the length of the respective production principle using a rather simple methodology.[11] Table 4 ('Comparison of Phase Length Ratios for Each Production Principle [%%]') employs an analogous methodology to compare lengths of phases (and combinations of phases) within one production principle. For example, for the Hunter-Gatherer production principle the ratio of the first phase length (10,000 years) to the second (8,000 years) equals 125 %; whereas the ratio of the second phase to the third (5,000 years) is 160 %. In the meantime the ratio of the sum of the first and the second phases' lengths to the sum of the third and the fourth (3,000 years) phases equals 225 %. Tables 3 and 4 also present the average rates for all the production principles.

Table 3. Ratio of each phase (and phase combination) length to the total length of respective production principle (%%)

Production principle	*1*	*2*	*3*	*4*	*5*	*6*	*1–2*	*3–4*	*5–6*	*1–3*	*4–6*
1. Hunter-Gatherer	33.3	26.7	16.7	10	8.3	5	60	26.7	13.3	76.7	23.3
2. Craft-Agrarian	28.7	24.5	16.0	13.8	10.6	6.4	53.2	29.8	17	69.1	30.9
3. Industrial	32.4	24.8	19	11.4	7.6	4.8	57.1	30.5	12.4	76.2	23.8
4. Scientific-	28.1 (29.6)*	25 (25.9)	18.8 (18.5)	12.5 (11.1)	9.4 (7.4)	6.3 (7.4)	53.1 (55.6)	31.3 (29.6)	15.6 (14.8)	71.9 (74.1)	28.1 (25.9)

[11] The absolute length of a phase (or a sum of the lengths of two or three phases) is divided by the full length of the respective production principle. For example, if the length of the hunter-gatherer production principle is 30,000 years, the length of its first phase is 10,000, the one of the second is 8,000, the duration of the third is 5,000, then the ratio of the first phase length to the total production principle length will be 33,3 %; the ratio of the sum of the first and the second phases' lengths to the total production principle length will be 60 %; and the ratio of the sum of the first, the second, and the third phases' lengths to the total production principle length will be 76,7 %.

Cybernetic											
Mean	30.6**	25.3	17.6	11.9	9	5.6	55.9	29.6	14.6	73.5	26.5

Note: * In this line figures in brackets indicate the shorter estimates of phases of the Scientific-Cybernetic production principle (the fourth formation).

** The calculation of mean took into account only one version of the Information-Scientific production principle evolution (that is figures before brackets).

Table 4. Comparison of phase length ratios for each production principle (%%)

Production principle	*1:2*	*2:3*	*3:4*	*4:5*	*5:6*	*(1+2): (3+4)*	*(3+4): (5+6)*	*(1+2+3): (4+5+6)*
1. Hunter-Gatherer	125	160	166.7	120	166.7	225	200	328.6
2. Craft-Agrarian	117.4	153.3	115.4	130	166.7	178.6	175	224.1
3. Industrial	130.8	130	166.7	150	160	187.5	246.2	320
4. Scientific-Cybernetic	112.5 (114.3)	133.3 (140)	150 (166.7)	133.3 (150)	150 (100)	170 (187.5	200 (200)	255.5 (285.7)
Mean*	121.4	144.2	149.7	133.3	160.9	190.3	205.3	282.1

Note: * The calculation of mean took into account only one version of the Scientific-Cybernetic production principle evolution (that is figures before brackets).

Thus, the proposed periodization is based on the idea of recurrent developmental cycles (each of them includes six phases); however, each subsequent cycle is shorter than the previous one due to the acceleration of historical development. No doubt that these are recurrent cycles, because within each cycle in some respect development follows the same pattern: every phase within every cycle plays a functionally similar role; what is more, the proportions of the lengths of the phases and their combinations remain approximately the same (see Tables 3 and 4). All this is convincingly supported by the above mentioned calculations, according to which with the change of production principles stable proportions of the lengths of phases and their combinations remain intact.

In general, our mathematical analysis represented in diagrams and tables indicates the following points: a) evolution of each production principle in time has recurrent features, as is seen in Diagrams 1–4; b) there are stable mathematical proportions between lengths of phases and phase combinations within each production principle (Tables 3 and 4); c) the cycle analysis clearly indicates that the development speed increases sharply just as a result of production revolutions (see Diagram 5); d) if we calibrate the Y-axis of the diagram,[12] the curve of historical process acquires a hyperbolic (Diagram 6) rather than exponential shape

[12] Within the calibrated scale the changes from one principle of production to another are considered as changes by an order of magnitude, whereas changes within a principle of production are regarded as changes by units within the respective order of magnitude. Such a calibration appears highly justified, as it does not appear reasonable to lay off the same value at the same scale both for the transition from one principle of production to another (*e.g.*, for the Agrarian Revolution), and for a change within one principle of production (*e.g.*, for the development of specialized intensive gathering). Indeed, for example, the former shift increased the carrying capacity of the Earth by one-two orders of magnitude, whereas the letter led to the increase of carrying capacity by two-three times at best.

(as in Diagrams 1–4), which indicates that we are dealing here with a blow-up regime (Kapitza *et al.* 1997).

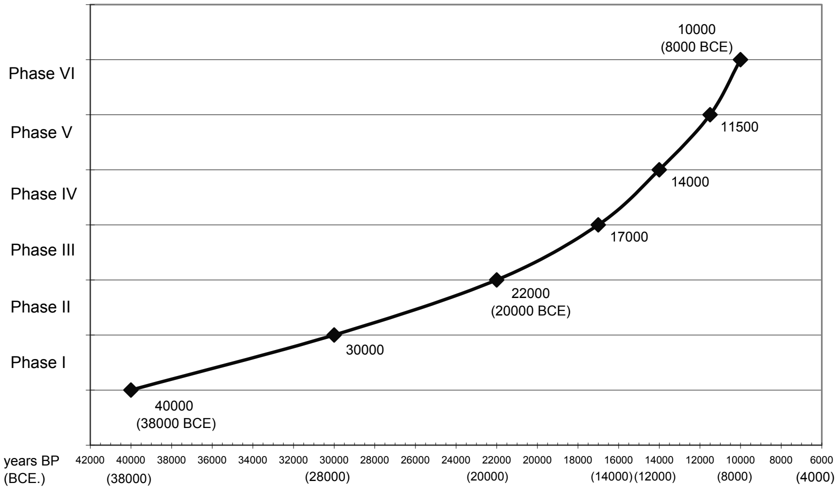

Diagram 1. Hunter-Gatherer production principle

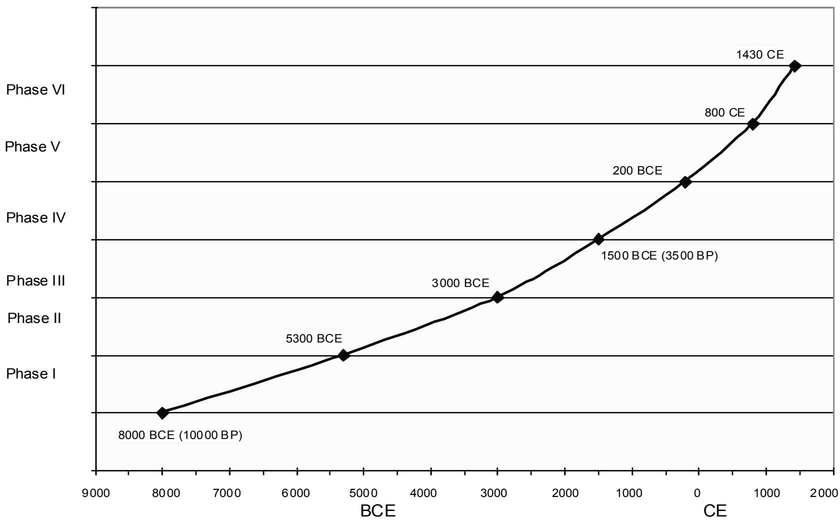

Diagram 2. Craft-Agrarian production principle

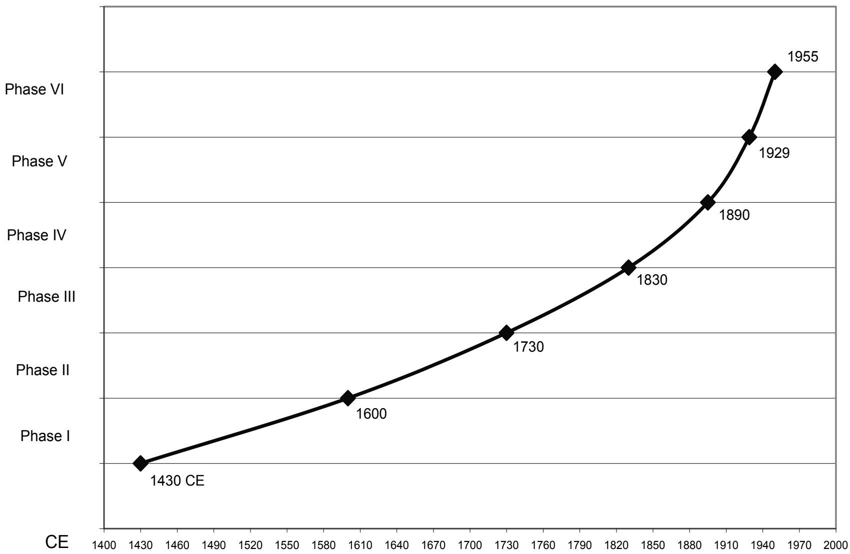

Diagram 3. Industrial production principle

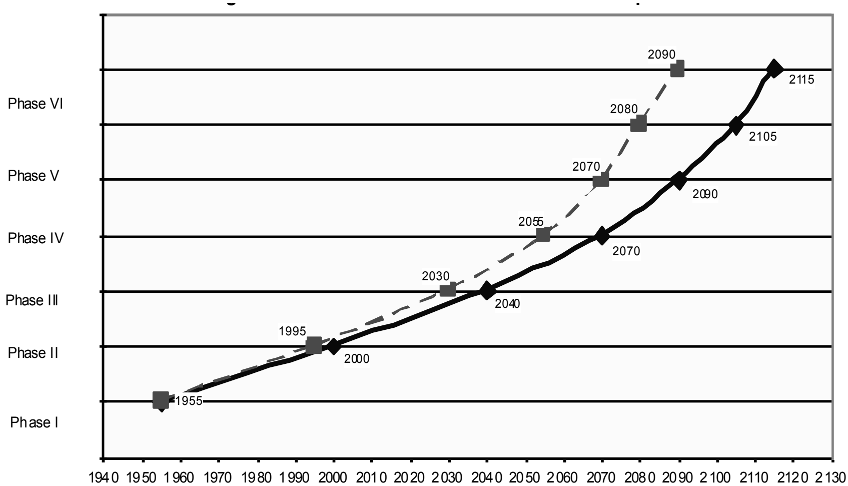

Diagram 4. Scientific-Cybernetic production principle (Note: the broken line indicates the forecast version for the expected development of the Information-Scientific production

principle corresponding to dates in brackets in the line of Scientific-Cybernetic Production Principle in Table 1)

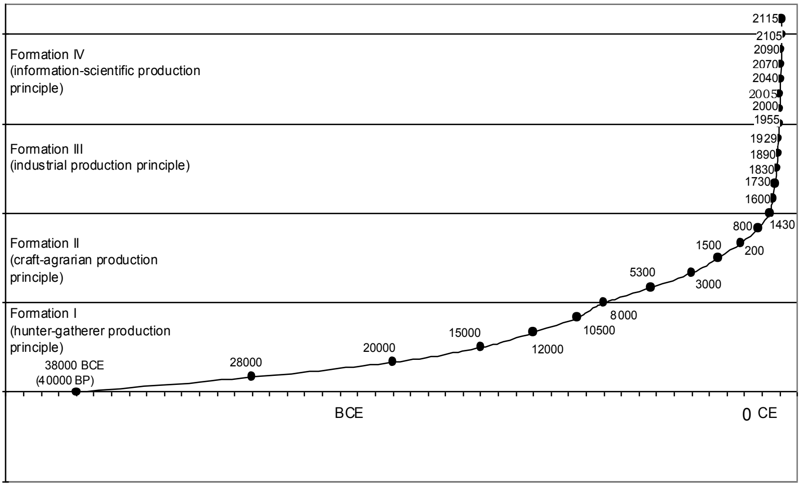

Diagram 5. Evolution of historical process in time

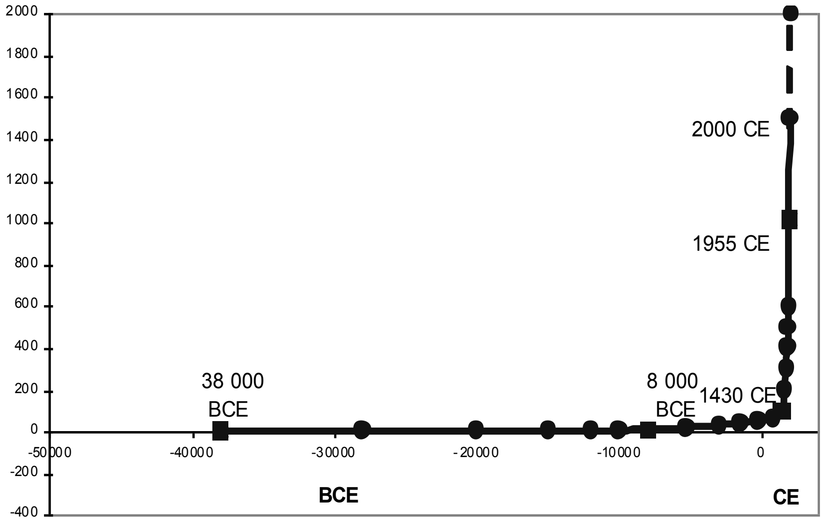

Diagram 6. Hyperbolic model of historical process dynamics

The analysis of stable proportions of production principle cycles makes it possible to propose some tentative forecasts (as mentioned above, we base on such forecasts to estimate the lengths of the remaining phases of the Scientific-Cybernetic production principle).