Demographic Transformations in the Light of Technological Development: Types of Demographic Reproduction in the Past and in the Future

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ABSTRACT

The analysis of the demographic component and demographic dimension of historical process has not been sufficiently studied in the social sciences. The demographic development of humankind is even more rarely studied in its close connection with technological development. However, this is an extremely important aspect that can not only explain essential dimensions of the development, but also provide a basis for explaining current processes and forecasting our futures. Moreover, in many ways, it is an integral aspect of analysis, because it focuses on people, the population, which is the main subject of society and humanity. This work, consisting of two articles, aims at providing a theoretical framework for the correlation between the development of production and technology, on the one hand, and demographic transformations, on the other, during the historical process, and to describe all major demographic transformations during human history. The work describes the historical types of

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population reproduction (TPR) and the reasons for their change. All this makes it possible to make a forecast about the vectors and main features of the coming demographic transformation in the twenty-first century.

In the first article we described theoretical approaches and models of the correlation between production revolutions (Agrarian, Industrial and Cybernetic) and the largest demographic transformations, and also spoke about important factors influencing the population growth and its limitations. We showed that the production revolution and the development of the production principle cycle in general change the type of population reproduction, and together they provide the most powerful impulse for the qualitative reorganization of the entire social structure and social relations and further world-system configurations. Thus, every production revolution is followed by a fundamental change in demography.

In the present (second) article, the relationship between each production revolution and each production principle, on the one hand, and demographic transformations and type of population reproduction, on the other hand, is analyzed not just in a theoretical model, but in connection with the specific course of the historical process and those quantitative data, which science currently has at its disposal. When considering the defined correlation between transformations in production and demography, we give explanation to many important peculiarities.

All these ideas about demographic trends from the Upper Paleolithic to the end of the twenty-first century have also been summarized by us in a convenient tabular form. A particular attention is given to the analysis of the demographic transition in connection with the demographic transformations taking place in the last seven to eight decades; in addition, the connection between the ongoing Cybernetic Revolution and global aging is revealed. Forecasts are made about future demographic transformations associated with the development of the aging process and the formation of a new type of population reproduction. The article was prepared as a part of the research work of the state task of the RANEPA.

Keywords: *demographic revolution, demographic transition, production revolution, largest demographic transformations, type of population reproduction, World System, ecological niche, population growth constraints, production principle, productive forces, global aging, Cybernetic Revolution.*

To begin with, here are the main ideas which we discussed in the previous paper: 1) every production revolution is followed by a fundamental change in demography. And vice versa. The population growth causes such changes in society and intersocietal relations, in communications and diffusion of innovations which greatly accelerate technological development;

2) a production revolution and the progress of the cycle of a production principle in general change the type (or pattern) of demographic reproduction, and together they give a powerful impetus to a qualitative reorganization of the whole social structure and social relations in the World System and in the most countries (societies).

There are four production principles: 1. Hunter-Gatherer; 2. Craft-Agrarian; 3. Trade-Industrial; 4. Scientific-Cybernetic and three production revolutions: 1) the Agrarian Revolution; 2) the Industrial Revolution, and 3) the Cybernetic Revolution (for details see the first article).

In this article, we analyze the relationship between each production revolution and each production principle, on the one hand, and demographic transformations and type of population reproduction, on the other hand, not just in a theoretical model, but in connection with the specific course of the historical process and those quantitative data, which science currently has at its disposal. On this base, we will make our forecasts concerning the demographic transition in connection with the demographic transformations taking place in the last seven to eight decades; in addition, the connection between the ongoing Cybernetic Revolution and global aging is revealed. Forecasts are made about future demographic transformations associated with the development of the societal aging process and the formation of a new type of population reproduction.

1. GENERAL DEMOGRAPHIC CHANGES DURING PRODUCTION REVOLUTIONS AND PRODUCTION PRINCIPLES

1. The Hunter-Gatherer Production Principle corresponds to the type of population reproduction (TPR), which we denote as the *type of simple reproduction* (it can also be called natural [see Table 5]). It is characterized by a lower birth rate than in agrarian societies, since the lifestyles impeded female high fertility and ability to raise many children, and also by a medium-high mortality rate (see about it in the first article). As a result, the population only barely reproduced, and its very slow growth occurred to a high extent due to the settlement of new territories (Siberia, America, territories freed from glaciers in Northern Eurasia, *etc*. [see Grinin, Grinin and Korotayev 2020]).

On the world population in the Upper/Late Paleolithic (40,000–12,000 years ago). The assumptions about the total world population during this period are based on calculations of a possible population density, which was extremely low; although, in turn, it varied greatly depending on local natural environment.[1] The population estimates for the Lower Paleolithic vary greatly from 1 million to 10 million people (Thomlinson 1975; Kapitsa 2009: 38; Livi-Bacci 2017; Korotayev

2020a; for details, see Korotayev, Komarova, Khaltourina 2007: 14–15). But we believe that the real figures were much closer to the larger figure than to the smaller one. Sergey Kapitsa (2006: 19; 2009: 38) estimates the population at about 10–15 million referring to the later date of 9–10 thousand years ago. This was the very beginning of the Agrarian Revolution and it could already be its contribution to the population growth, but only in some and relatively small areas, so it is rather unlikely that the population could grow one and a half to two times within two or three thousand years only due to this phenomenon. Here an important factor was the warming during the Holocene, whereas vast territories cleared from ice and were settled.

About the population growth rate. The world population generally grew so slowly that it could only be distinguished on a secular or even millennial scale. According to some data, the population during the Paleolithic increased only by 3–8 per cent (per millennium!), that is, by 0.003–0.008 per cent per year (Valentei 1974: 236; Vishnevsky 2005: 30; Livi-Bacci 2017: 25, table 1.2). Of course, in some particularly favorable places the population growth could be considerably faster, but on the other hand, many groups often experienced depopulation, and the climate during most of the Upper Paleolithic (40–15 thousand years ago) was quite severe over a large area and demonstrated significant fluctuations (*e.g.*, Bruxelles and Jarry 2011; Clark *et al.* 2019). As for the growth of the world population during the Upper Paleolithic, here the estimates should be considered as hypothetical. However, they can provide some insight. Kapitsa (2009: 37–38), citing Lutz 1994, gives a table that shows that 1.6 million years ago the primordial population was 100 thousand people (*Ibid*.: 38, table 1). However, already at the beginning of the Upper Paleolithic (*i.e*., 40 thousand years ago), the number of people is estimated at 1–5 million (*Ibid*.: 38, Table 1),[2] which is quite consistent with the above estimates. Thus, according to these assumptions, the population growth during the Lower Paleolithic was noticeably lower than that of the Cro-Magnons and amounted to only some tenths of a percent per millennium (compare with 3–8 per cent per millennium during the Lower Paleolithic). As to the scale of population growth in absolute terms, according to Sergey Kapitsa (2006: 19) 'By the onset of the Neolithic 9–10 thousand years ago, the absolute growth rate was already ten thousand times greater than at the beginning of the Stone Age.' In general, such growth is not surprising, since the cultural and material level of the Cro-Magnons, including the ability to speak, was noticeably higher than that of the first sapiens.

2. The Craft-Agrarian Production Principle

The transition from hunting-gathering economy to agriculture, that is, the Agrarian Revolution, eventually increased population by ten times compared to the pre-agrarian period. While before the start of the Agrarian Revolution the world population hardly exceeded 10 million people (12 thousand years ago it was 6 million according to Livi-Bacci 2017: 25, table 1.2), then prior to the Industrial revolution in the fifteenth century, the number was several hundred million people.

The type of population reproduction (TPR) during the craft-agrarian production principle was fundamentally different than in the previous period. There had occurred a transition from medium-high hunter-gatherer fertility to very high fertility. Mortality, however, also increased slightly, but not as much as the birth rate, which ensured a noticeable natural population increase (Cohen 1998, 2009; Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007; Bocquet-Appel 2011; Livi-Bacci 2017). However, the natural increase still remained rather low. But everything is relative. It was significant, that is by more than an order of magnitude higher than in the hunting-gathering society, and still it was extremely low compared to subsequent periods. Thus, according to Urlanis (1941: 91), from 1000 to 1500, the natural increase in Europe was between 0.1–0.2 per cent per year (other researchers define it as less than 0.1 per cent, *e.g.,* 0.07 per cent according to Livi-Bacci 2017: 25, table 1.3). At times, the natural increase was even negative (e.g., during the period of the so-called Black Death or the Mongol conquests). Therefore, we define this TPR as the *type of slow growth* (it can also be called the social-natural type). For its other characteristics, see Table 5.

However, over the centuries, the overall population growth was quite noticeable. Although the mortality rate was high both among hunters and peasants, there were significant differences here as well. In contrast to the TPR of the hunter-gatherer production principle, in some developed agrarian societies the adult mortality was lower (although it increased periodically during epidemics, wars, hardships and famines). The child mortality rate was high in both types of societies, but due to a higher birth rate, the population growth in the craft-agrarian society was noticeably higher than in the hunting-gathering society. Due to high child mortality, the average life expectancy in craft-agrarian societies was not higher than among hunter-gatherers. But as to the adult population, the life expectancy was often higher in developed agrarian societies.[3]

Thus, the TPR changed, in particular, due to the increase in female fertility and in the number of births. What could increase fertili-

ty? Farming made it possible to greatly increase the birth rate due to (a) the transition to sedentism, (b) the use of pack animals (in particular among the nomads); and (c) reduced birth intervals which became possible due to the available domestic animal milk and cooking, and also to the use of various foods (and devices to cut it very small) to feed small children, so a woman could mean a child earlier than in hunter-gatherer societies. In the latter the prolonged breastfeeding was also a form of pregnancy prevention (*e.g.*, Bocquet-Appel 2011; Livi-Bacci 2017). We should also take into account a certain decline in catastrophic mortality.

As a result, already at the initial phases of the Agrarian Revolution, the population growth accelerated sharply, by 5–13 times, reaching 40 per cent per millennium (from 3–8 per cent in the Paleolithic) (Valentei 1974: 236; Vishnevsky 2005: 30–31).

The dynamics of changes of the TPR in relation to the stages of craft-agrarian production principle and the growth of its world-system distribution can be briefly represented in the following way.

The initial and modernization phases of the Agrarian Revolution (*i.e.*, the economy of primitive manual farming) correspond to the first largest demographic transformation (LDT), which we called the 'Neolithic' (see Table 4). That is, these periods already corresponded to the transition to a new TPR with an extremely high birth rate. However, a noticeable sustainable population growth could take place only in some regions with high land capacity, and therefore, with an ecological niche capable of feeding millions and tens of millions of people within the World System.[4]

The final phase of the Agrarian Revolution (when irrigation and plough agriculture had spread) corresponds to the transition to a *much more capacious ecological niche* capable of feeding tens and even hundreds of millions of people within the World System. This was the second LDT, which we call 'civilizational' since its unfolding led to the emergence of states and civilizations (see Table 4).

However, we should remind that the completion of the Agrarian Revolution in different regions proceeded in various ways, and its completion lasted for millennia. It is extremely important that its particular variants strongly depended on the natural environment of societies and regions. As a result, depending on the model of the completion of the Agrarian Revolution (irrigated or non-irrigated plough agriculture), various demographic models developed. The most important among them were the following:

1) irrigation with a very large population number and high population density (Egypt and Mesopotamia are typical examples here);

2) non-irrigated plough agriculture with a lower population density (Europe).

3) mixed models.[5]

The first two models actually formed two cultural and historical developmental paths (eastern, including the Far East) and antique-medieval in Europe, as well as prepared prerequisites for Europe's breakthrough to the Industrial Revolution. Vitaliy Melyantsev (1996: 77) believes that in the Middle Ages the overall land capacity in Europe was five times lower than in the Eastern countries (see also Huang 2002). As a result, it was necessary to cultivate much more land to provide for one person than in the East, which was more difficult with only manual labor.

And this factor, combined with a number of others, made the process of labor saving due to increased mechanization of labor in Europe proceed more intensively than in the East. And this would trigger the Industrial Revolution (for details see Grinin, Korotayev 2015; Grinin 2010; Grinin L., Grinin A. 2015).

After the Agrarian Revolution had completed, the population continued to grow for some time, filling the opened ecological niche and complicating the geography of settlements, the division of labor, trade, *etc*. But after filling the easy-to-settle niches, the population growth became much more difficult and required, as we pointed above, a high organization of society and state, as well as internal peace and order. Such conditions were an exception rather than a rule, but when they did appear (as it happened in China), the population growth gained huge rates. However, sooner or later, such an organized society fell into the Malthusian trap (about it see the first article) and its dynamics acquired a cyclical character, while structural and demographic cycles were from one hundred to three hundred years long (see, *e.g*., Figure 1).

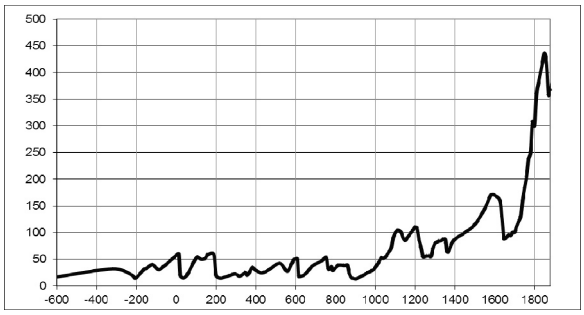

Fig. 1. Demographic dynamics in China (million people) from the 7th century BCE to the mid-19th century CE

Data source: Korotayev, Malkov, Khalturina 2006b.

Table 1

Demographic Changes during the Craft-Agrarian Production Principle

Stage/ phase	dates	Techno-social changes	Demographic changes	Limitations	The world population at the beginning of the period
Initial phase of the Agrarian Revolution	12,000–9,000 years ago	Emergence of agriculture and animal husbandry in some areas of the Middle East. Expansion of the ecological niche	Starting formation of a new type of population reproduction with an increased birth rate	A very narrow territorial base of a new ecological niche	8–10 mln[6]
Modernization phase of the Agrarian Revolution	9,000–5,500 years ago	Development and diffusion of agriculture	Formation of a new type of population reproduction with a high birth rate but within a limited ecological niche	The limited ecological niche and intensifying conflicts due to the complication of societies	13–17 mln[7]
Final phase of the Agrarian Revolution	5,500–3,000 years ago	Transition to large irrigation systems, plough farming and a drastic expansion of the ecological niche; formation of states and civilizations	Development of a new type of population reproduction with a high birth rate already on the basis of a capacious ecological niche; rapid population growth in some places	A narrow territorial base of a new ecological niche in the valleys of large rivers	> 50 mln[7]
Mature stages of the craft-agrarian production principle	3,000 years ago – 1430	Emergence of political conditions for agricultural intensification; rise of urbanization, crafts and trade; expansion of the Afrourasian world-system	A powerful development of a new type of population reproduction with a high birth rate on the basis of a capacious ecological niche with considerably expanded territory. Together with state's impact on the growth of production, internal peace and order, this leads to a relatively rapid population growth	Malthusian trap	about 200–300 mln in the beginning of CE – 400–500 mln in the 15th century[8]

3. The Trade-Industrial Production Principle

General changes. The correlation between industrialization and the largest demographic changes is widely recognized (Armengaud 1976; Minghinton 1976: 85–89; Chesnais 1992; Caldwell *et al.* 2006; Dyson 2010; Livi-Bacci 2017; Mokyr and Foth 2010). Indeed, while by the beginning of the Industrial Revolution in the second third of the fifteenth century the World System may have had 400–450 million inhabitants,[9] then at the turn of the eighteenth and nineteenth centuries the world population had more than doubled and exceeded 1 billion people.[10] The humanity reached 2 billion in about 1927. And in the early 1950s, the world population exceeded 2.5 billion people (Shcherbakova 2011; UN Population Division, 2023).[11] Thus, over the whole period of the Industrial Production Principle (*i.e*., within 525 years), the population increased by 5.5–6 times. This is noticeably less than the relative growth during the Craft-Agrarian Production principle (see above), but significantly more than the number anticipated for the Scientific-Cybernetic one (with maximum fourfold increase; the world population by the end of the present century will be about 10–12 billion people, or less) [UN Population Division, 2023; Vollset *et al*., 2020]).[12]

Thus, in contrast to the technological growth rate, which accelerated in recent time, the demographic growth rate is now slowing down from phase to phase.

The type of population reproduction (TPR), which gradually took shape during the Industrial Production Principle, is characterized by low (compared to the previous type) mortality rate and relatively high, but gradually decreasing, fertility, which leads to high natural increase (first called the demographic revolution, and later – the first phase of demographic transition). The share of young people in the population is increasing and results in the so-called youth bulges (see, *e.g*., Choucri 1974; Goldstone 2016; Urdal 2004; Korotayev, Zinkina *et al*. 2011, Korotayev, Malkov, and Grinin 2014; Korotayev, Sawyer *et al.* 2021; Goldstone, Kaufmann, and Toft 2012; Zinkina and Andreev 2020; Romanov, Meshcherina, Korotayev 2021; Sawyer *et al.* 2022; Khokhlova and Korotayev 2023; Korotayev, Romanov *et al.* 2023). Therefore, we denoted the TPR of industrial production principle as the *type of rapid growth*; it can also be called the *socio-quantitative type* (see Table 5). Never before has the population grown so rapidly! The notion ‘quantitative’ is quite suitable because the notion of ‘social’ means an increase in life expectancy and in its quality due to the improvement of sanitation, medicine and comforts of urban life.

However, one should distinguish three stages in the historical dynamics of this TPR. During the first stage (that lasted since the fifteenth to the early nineteenth century), the mortality rate decreased (mainly due to smoothing out of the catastrophic mortality [*e.g.*, Urlanis 1941; Russel 1975; Armengaud 1976; Vishnevsky 2005]) considerably but still not enough; the second stage – from the nineteenth to early twentieth century – a sharp decrease in mortality rate along with maintaining a high birth rate, the period of the actual demographic revolution in Europe; and the third stage, 1920–1940, when the birth rate in the West gradually decreased and reduced natural growth rate there (*e.g.*, Landry 1934; Urlanis 1941; Chesnais 1992). But in general, until almost the very end of the Industrial Production Principle, the birth rate in Europe considerably surpassed the replacement level.

The development in the sixteenth–eighteenth centuries. Although the initial stages of the Industrial Revolution took place between the fifteenth and eighteenth centuries (see Grinin, Grinin 2015; Grinin, Grinin and Korotayev 2020; Grinin, Korotayev 2015), the decline in mortality rate could hardly be caused by technological advances in manufacturing. It became evident far from immediately, since for a long time there were no scientific and technological prerequisites for this (poor medicine, low level and quality of urbanization and life-saving technologies). Nevertheless, thanks to the growing production, literacy, culture and science, as well as to the spread of the media and freedom of occupation in a number of countries, primarily in the north-west of Europe, in the sixteenth–eighteenth centuries, one may trace rather considerable changes that led to the expansion of the ecological niche and a noticeable population growth in a number of countries. Particularly, in Britain in the seventeenth and eighteenth centuries, thanks to innovation and productivity growth, the agricultural output began to overtake the rather considerable population growth.

So, over a century and a half (from the sixteenth to the first half of the seventeenth centuries), the population of Britain increased from 2.8–3 million to 5–5.5 million people, that is, the growth was by 66–100 per cent. And the population growth rate reached 1 per cent per year. During the second half of the seventeenth and in the first decades of the eighteenth centuries, the population in Britain hardly grew.[13] However, agriculture (along with industry) continued to develop actively, so that the country managed to export large amount of grain to Europe.[14] Within a century (1700–1800) the English agriculture doubled its output (Reisner 1986: 233). But the population growth in the second half of the eighteenth century was impressive, all the more since a decrease in excess mortality in lean years was already

noticeable. '... Within a century (1700–1800) the English agriculture doubled its output with the growth of the country's population from 5.5 million to 9 million,' that is, with a hundred-percent increase in food production, the population grew by 64 per cent (Reisner 1986: 233; see also Mantoux 1937: 127; Trevelyan 1959: 358; Bairoch 1971: 47). In the previous periods, a two-thirds population increase would most likely have caused a socio-demographic catastrophe (see, *e.g*., Korotayev, Malkov and Khaltourina 2006b).

Let us note that in the sixteenth – early seventeenth centuries, the population of other European countries, in particular, France and Germany, considerably grew, but in the latter the Thirty Years' war led to its depopulation (*e.g*., Turchin and Nefedov 2009; Parker 2013).

Since the sixteenth century, one may speak about the beginning of the escape from the limitations of the Malthusian trap (Grinin, Korotayev, and Malkov 2008a, 2008b; Grinin *et al*. 2009; Grinin, Korotayev 2012b; Korotayev, Zinkina *et al*. 2011, Korotayev, Malkov, and Grinin 2014). No wonder some growth theorists call the period before 1750 the Malthusian era (Clark 2007; Mokyr, Foth 2010). But this escape was a long and difficult process, ending only in the late nineteenth century (see above about this in the first article).

We should note that *in the sixteenth–eighteenth centuries two demographic models competed within the World System: the European (technological) and the Chinese-Far Eastern (preserving the former Malthusian pattern [and in addition having closed the countries from Europe]*). The latter model is clearly ahead of the former in absolute terms (above we spoke about more than threefold demographic growth in China in the seventeenth–nineteenth centuries). But such rivalry remained relevant only until the end of the Industrial Revolution in Britain.

The formation of a new TPR in the eighteenth–nineteenth century. The decreasing mortality was perceived from the end of the eighteenth century and it was associated with the development of science, medicine, education, the quick spread of knowledge and changes in the sanitary and medical policy of states (*e.g*., Chesnais 1992; Livi-Bacci 2017; see also Dean 1965: 259–261).[15] Along with other factors, this contributed to a rather significant acceleration of demographic growth in many European countries in the late eighteenth century, although the discrepancies were significant (Mokyr, Foth 2010).[16]

But all these changes do not conform yet to the new largest demographic transformation related to the level of the Industrial Revolution because the required level in medicine and social relations is not achieved. The largest demographic transformation seems to lag be-

hind, as we pointed out above. It is only as a result of the completed Industrial Revolution and the mature phases of the Industrial Production Principle that the largest demographic transformation (LDT) takes place. In Table 4, it is designated as *anti-Malthusian, or urban*, since without urbanization it could hardly have ever taken place. And as a result, the TPR of the industrialism period is formed: the reduced mortality with preserved or slowly reducing birth rate. And this model unfolded already during the mature phases of industrial production principle. As a result, the population in Europe rapidly, almost hyperexponentially, grew. The spread of medicine supported the population growth even in not completely industrialized countries, like Russia – this is a harbinger of the future population explosion in the Third World. As a result, in the second half of the nineteenth century, the escape from the Malthusian trap became evident due to the development of transport, global trade, specialization of countries in certain agricultural crops and involvement of huge agricultural lands into circulation.

The reduction of mortality rate was observed among various groups of population in particular due to the elimination of such problems as deadly epidemics and famine. We should particularly note the reduction in infant and female (especially maternal) mortality, and these phenomena intensified compared to the Middle Ages due to the growth in the population of cities where the necessary sanitary requirements for women in labor were not observed for a long time (Waller 2003: ch. 2; Chesnais 1992). This process of spreading necessary sanitation became noticeable from the late seventeenth century, but especially in the eighteenth and nineteenth centuries.

Life expectancy also grew in the period from 1800 to 1900, that is, over a century. However, in this respect, Europe and North America were very different from the rest of the world. While in the world-system core countries (Western Europe and the USA) the life expectancy increased from 35 to 47 years, then in the world in general this increase was rather insignificant – from 31 to 33 years (Urnov 2022: 95). We can add that the spatial distribution of population dramatically changed due to a rapidly growing urbanization (see Davies 2002; Zinkina *et al*. 2019).

The transformation of the type of high population growth. As for the third period, which started with the First World War, it involved mostly only Western Europe and should rather be associated with the subsequent type of population reproduction which was characteristic for the start of the Cybernetic Revolution. Although in the 1920s–30s the birth rate (together with natural increase) markedly dropped in a number of Western European countries, these were al-

ready the characteristic features of the scientific-cybernetic production principle, since at the end of the industrial production principle the family planning practices started to be introduced through the primary development of contraception and the mass distribution of medically safe abortion (see Urlanis 1941: 368; Landry 1934; Coale 1983, 2013; Livi-Bacci, 2017).[17] About this period, see more below in a special paragraph.

Table 2

Demographic Changes during the Industrial Production Principle

Stage/ phase	dates	Techno-social changes	Demo-graphic changes	Limitations	World populati-on at the beginning of the period
Initial phase of the Indus-trial Revo-lution	1430s – 1600s	The develop-ment of global trade and colonial economy, development of the first ma-chines and man-ufactories, the growth of agri-cultural produc-tivity in Europe	Some acceler-ation of popu-lation growth, urbanization and the start-ing escape from the Mal-thusian trap	Weak devel-opment of science, medi-cine, and sani-tation	400–450 mln[18]
Moderni-zation phase of the Indus-trial Revo-lution	1600s–1760s	Active growth of primary industry and agriculture in Europe, especial-ly in Britain; development of state policy, education, and science. Spread of new types of food in the world (corn, potatoes, sweet potatoes, *etc*.)	The beginning of a noticeable reduction in mortality rate in Europe, the acceleration of population growth; dra-matic popula-tion growth in China which followed the old develop-ment trajecto-ry	Insufficient conditions for the growth of education and population mobility with-in the estate states	About 500–600 mln[19]

Table 2 (continued)

Stage/ phase	dates	Techno-social changes	Demo-graphic changes	Limitations	World populati-on at the beginning of the period
Final phase of the Indus-trial Revolu-tion	1760–1830s	Creation of the primary ma-chine industry in Britain, the USA and devel-opment of new types of trans-port (railway and steamboats), expanding glob-al trade	Reducing mortality rate in the world-system core, accelerating population growth, in-creasing ur-banization; the beginning of the for-mation of thee TPR of rapid growth	Insufficient development of industry and medicine in many Eu-ropean coun-tries and very weak devel-opment in the world	About 800 mln[20]
Mature stages of the Indus-trial Pro-duction Principle	1830s–1940s	Industrial Rev-olution, devel-opment of ur-banization, education, cul-ture and gov-ernance spreads across the World System	Continued reduction in mortality rate, the develop-ment of TPR of rapid growth, which prepares a future popula-tion explosion in many colo-nies and semi-colonies; start-ing reduction of fertility and slowing down population increase in a number of Western coun-tries in the first half of the 20th century	Still weak expansion of modernization in most coun-tries of the World System; global and social cata-clysms of the first half of the 20th century	About 1.2–1.3 bln[21]

Table 2 (continued)

Stage/ phase	dates	Techno-social changes	Demo-graphic changes	Limitations	World populati-on at the beginning of the period
Turn of the Industrial and Cyber-netic Pro-duction Principles. An event chronologi-cally refers to the be-ginning of the Cyber-netic Pro-duction Principle, but its type of popula-tion repro-duction refers to the Industrial one[22]	1940s–1970s	The end of the war, emergence of the new world order, liberation of colonies against the background of a powerful sci-entific and tech-nological rise and develop-ment of medi-cine	Unprecedent-ed population growth in developing countries (de-mographic explosion) due to the penetra-tion of the latest medical technologies. Formation of the TPR of rapid growth throughout the World System	Poor devel-opment of agriculture not conforming the demo-graphic rise; poor devel-opment of education, culture and urbanization in large parts of the World System	2.3–2.5 bln[23]

4. The Scientific-Cybernetic Production Principle

We denote the type of population reproduction associated with the Cybernetic Revolution as the type of qualitative changes, or it may be also called a social-qualitative type. And although over its seventy years' operation, the world population has considerably grown from 2.5 billion people in 1950 to 8 billion in 2022 (UN Population Division 2023), that is, more than a threefold increase, the quantitative growth, in our opinion, will not be the main hallmark of this TPR. And the main characteristics of the new TPR will be associated with the completion of the so-called demographic transition, that is, the low mortality and low birth rates and near-zero or negative natural increase, high life expectancy and a high proportion of the elderly and old population in its general structure.

What does a qualitative growth mean? This is, firstly, a noticeable increase in life expectancy, and secondly, ensuring the movement towards the so-called healthy aging, to a fairly secure, active and full-fledged lifestyle in declining years with the help of medicine, technologies and social programs; thirdly, ensuring adequate care for the elderly and the disabled; fourthly, the increasing adaptation of people with disabilities to an active lifestyle with the help of medicine, technologies and social programs. *Thus, aging and an increase, probably, even a dramatic increase in life expectancy, and an ever more profound and more diverse adaptation to the aging of society and an individual* – these are the main trends of demographic changes within the Cybernetic Production Principle.

General changes. The increase in the life expectancy over the past 120 years is impressive. In the first half of the twentieth century, that is, at the end of the final phase of the industrial production principle, the life expectancy grew considerably both in the world – from 33 years in 1905 to 50 years in 1955, – and in the core countries, respectively, from 47 years to 67 years (Urnov 2022: 95; UN Population Division, 2023). In the first decades of the Cybernetic Revolution, that is, in the second half of the twentieth century, life expectancy also grew considerably, but relatively less: from 47 years to 67 in the world, and from 64 to 75 years in the core countries. It continued to grow in the first two decades of the twenty-first century, but at a somewhat slower pace (which is quite natural, since now every extra year of life expectancy is a big victory). But it is important that during this period, the general life expectancy in the world grew faster (due to developing countries catching up with developed ones) from 66.5 years in 2000 to 72.8 in 2019. Respectively, in developed countries it grew from 75.3 years to 79.8 years. However, in 2020–2021 there was observed an obvious decline due to the COVID-19 pandemic (about excessive mortality caused by the pandemic see, *e.g.*, Zhigalkin 2021; Efremov 2023) (see Fig. 2).

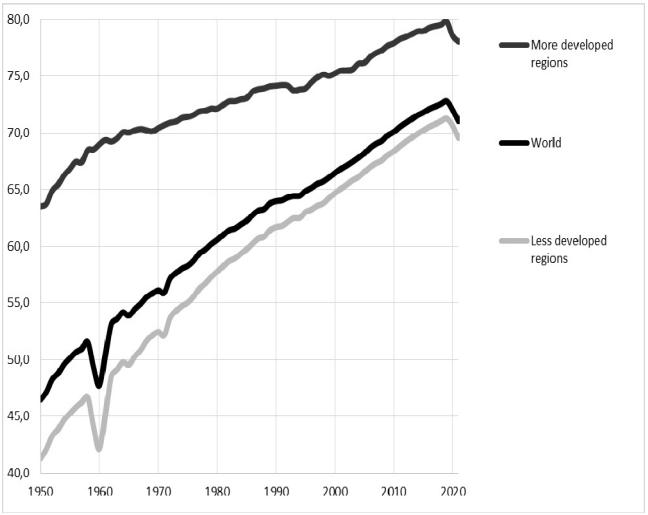

Fig. 2. Life expectancy dynamics in the world, more and less developed regions, years, 1950–2021

Data source: UN Population Division, 2023.

On the demographic transition. Most, if not all, demographers consider the so-called demographic transition as a continuous (or almost continuous) process that in individual countries usually takes for over a hundred to a hundred and fifty years.

The demographic transition consists of the following phases: 1) a reduction in mortality rate with preserved (or even increased) high birth rate, which leads to high natural increase rate and rapid population growth; and 2) continued reduction in mortality rate, but at an increasingly slowing pace and a rapid reduction in the birth rate, as a result of which the natural increase rate becomes slower, then close to zero or even negative; the population number grows, becomes stable or even starts to decline. At the same time, at the first phase, the share of children and young people in the demographic structure grows and the so-called youth bulges emerge. Meanwhile, the increase in the share of young people, especially in the context of modernization, increases the risks of social upheavals (see, *e.g.*, Moller 1968; Choucri 1974; Goldstone 2001, 2002, 2016; Urdal 2004, 2006; Korotayev *et al.* 2011, Korotayev, Malkov, and Grinin 2014, Korotayev *et al*. 2021; Goldstone, Kaufmann, and Toft 2012; Weber 2019; Romanov, Meshcherina, Korotayev 2021; Korotayev, Romanov *et al*. 2023; Sawyer *et al.* 2022). During the second phase, the share of the working age population first increases (due to the decreasing number of

children), and this brings the so-called demographic dividend that provides society with significant benefits in economy and standard of living (Bloom and Williamson 1998; Bloom and Canning 2008; Bloom *et al.* 2007; Hawksworth and Cookson 2008: 7–10; Lee and Mason 2006, 2011; Barsukov 2019; Groth *et al.* 2019; Kotschy *et al.* 2020; Korotayev *et al.* 2022). It was especially evident in Europe in the 1960s–1980s; and in China – in the 1990s–2000s, but now the demographic dividend has been largely 'eaten up' there. Almost at the same time, yet with a lag of a couple of decades, the process of population aging gains momentum, which will take much more time than the process of the demographic dividend exhausting. At the moment, the process of global aging is gaining momentum.

If one considers the demographic transition in the world-system context then it has been going on for more than two hundred years by now and will continue for several more decades. Having started in Europe in the nineteenth century (or even in the eighteenth, if we take France, England and some other countries), it ended in the countries of the First World by the end of the twentieth century. Its development involved the rest of the World System countries from the late nineteenth century and especially from the mid-twentieth century, but for Tropical Africa and some other countries this process has not entered its final phase yet.

The demographic transition and the Cybernetic Revolution. All the above described is generally known, and we have outlined these changes in order to make it easier to explain the important ideas of our theory. Indeed, due to the acceleration of technological progress in the twentieth century, the demographic transition actually took place almost continuously. And, from the point of view of demographic science, it is absolutely correct to consider it as a single and continuous process.

However, within the theory of production revolutions and production principles in their relationship with demographic transformations and TPR, it is particularly important to keep in mind that the *first and second phases of the demographic transition must be attributed to different production principles*. Our approach can be formulated in the following statements:

1. The demographic transition could not end during the industrial production principle. There were neither technological nor, respectively, scientific and medical prerequisites for this. Industrial capitalism could not sustain economically the increasing number of elderly and unemployable people, and hence, the growth of life expectancy would begin to decline.

2. Although the beginning of demographic transition in European countries corresponds to the last phases of Industrial Production Principle, the social-qualitative type of population reproduction is not typical for Industrial Production Principle due to a relatively modest standard of living, extremely weak social policy and huge property stratification.

3. The demographic transition in its proper sense (*i.e.*, its second phase) is a phenomenon generally characteristic of the initial phases of the Cybernetic Production Principle.

4. The reduction in the birth rate to the levels of population replacement in Europe could take place only as a temporary and rather unsustainable phenomenon due to the fact that the first half of the twentieth century appeared an unfavorable period (wars, social catastrophes, crises, and especially the Great Depression). And this obviously affected the desire to have children. Not without reason, after the situation improved in the late 1940s, a baby boom started along with an increase in the birth rate (see below).

5. In our theory we point out that at the last stages of any production principle, there appear non-typical for it and non-systemic phenomena (Grinin 2006; Grinin L., Grinin A. 2015). A dramatic decline in the birth rate in Europe in the 1930s (noted by Landry 1934, Urlanis 1941 and other demographers) was just that non-systemic phenomenon (however, the decline in the birth rate during economically and socially hard periods is a phenomenon characteristic of the whole human history).

6. The population explosion in developing countries which became explicit since the 1950s, in its essence refers to the Industrial Production Principle (when modernization was expanded to the periphery), but it also started in the last phases of Industrial Production Principle. And in this sense, it also refers to non-systemic manifestations of the latter.

Thus, within our theory *the first phase of a single in its logic process – i.e., of the demographic transition, – should be attributed to the Industrial Production Principle; while its second phase should be attributed to the initial stages of the Cybernetic Production Principle.*[24] However, a new considerable demographic transformation awaits us at the mature stages of the Cybernetic Production Principle (see below).

The demographic changes at the initial and modernization phases of the Cybernetic Revolution (in the 1950s–1990s). Since the late 1950s, that is, already at the very beginning of the Cybernetic Revolution, one can quite clearly see the acceleration of the transition to a new TPR (with low mortality and high birth rate) in developing

countries, in fact, in the main part of the World System. This transformation gained momentum in the 1950s and 1960s, then slowed down a little, but still remained very noticeable in the 1970s and 1980s. As a result, as mentioned in the first article, they started to speak about demographic explosion or demographic revolution in the World System. But one should note that the acceleration of population growth and the decline in mortality rate in many colonies and semi-colonies actually began already in the late nineteenth – early twentieth centuries due to the reduction of the catastrophic mortality and the start of introduction of advanced medicine in some places. As a result, the population more than doubled in Africa over the 60-years' period from 1890 to 1950, growing from 93 million to 225 million (McEvedy and Jones 1978: 206; UN Population Division 2022); while before this period the population had doubled only over the period of several centuries, from 1500 to 1890 when it grew from 46 to 93 million people (McEvedy and Jones 1978: 206). The beginning of the Cybernetic Revolution, the liberation of colonies and a powerful introduction of advanced medical and sanitation technologies ensured an impressive rise in the World System population, which continued during the modernization phase and will continue driven by Africa. In fact, this was the largest demographic transition of the Industrial Production Principle, but it was shifted in time, chronologically coinciding with the beginning of the Cybernetic Production Principle. In Table 5, we denote it as the 'Third World' LDT.

However, the start of the Cybernetic Revolution triggered not only the population explosion in the Third World, but also to a rather noticeable rise in the birth rate in the First World, where the pre-war trends of declining birth rates were replaced by a baby boom.[25] Thus, the emerging trend towards decreasing birth rate in developed countries was interrupted for two decades. Probably, if one imagines that the situation in Europe in the first half of the twentieth century would have been peaceful, calm and fairly well-off, then the deceleration of the birth rate in the 1920s–1940s would have been slower, and there would have been no baby boom in the 1950s–1960s. The end of the baby boom, although it was quite logical, was clearly accelerated by the massive supply of contraception in the 1960s, along with the accompanying ideological justification. There occurred revolutionary changes in the ability to control conception and to plan a family. As a result, the process of a drastic reduction in the birth rate began in developed countries. So there started the second phase of the demographic transition: low birth rate, low mortality rate and low or even negative natural increase; and the modern demographic structure of the population gradually emerges with a trend towards societal aging.

A different model was formed in the Third World in the first decades. In fact, this was a model of the Industrial Production Principle, but (a) it developed in countries with a lower level of development than the one observed in the European countries in the nineteenth and early twentieth centuries, since the role of agriculture was more considerable in developing countries than in Europe, and respectively, children were more valued as workers than they were among the city dwellers; (b) it employed the achievements of the initial phase of the Cybernetic Revolution in medicine; and (c) in societies with traditional ideologies encouraging large families the fertility is higher. But then, in a number of developing countries (however, hardly in all of them), the turn to the second phase of the demographic transition began, that is, to a strong decline in the birth rate.

In general, the initial phase of the Cybernetic Revolution coincided with the end of the population explosion in developing countries (even in Africa the birth rate began to decline for some time at a rather rapid pace, yet, later this decline would considerably slow down [*e.g.*, Zinkina and Korotayev 2014]) and the approach to completion of the demographic transition in the first world and the beginning of marked global aging. There was observed a dramatic reduction in mortality rate in all categories of population and an increase in life expectancy all over the world.

The modernization phase of the Cybernetic Revolution and the results of its first two phases (the 1950–2020s). The transformation that emerged during the initial phase of the Cybernetic Revolution, associated with the new TPR (with very low mortality, very low birth rate, low growth and high life expectancy, that is, population aging) intensified during the modernization phase. The demographic dividend in the first-world countries, as well as in less developed countries, including China, is now practically exhausted; the share of young people has decreased while the shares of elderly groups have increased. The birth rate has fallen far below even the replacement level, so in some countries, like Japan and Germany, depopulation has already started (in the latter, only migration mitigates it). But depopulation or stabilization of population is traced not only in the first world but in less developed countries as well (in the former second world: Russia, Ukraine, Bulgaria, *etc*.), and even in some developing countries. According to the UN Population Division estimates, depopulation has already begun in the PRC, yet here it proceeds at a very slow pace (UN Population Division 2023). In this regard, Landry (2014 [1934]) exclaimed that the humanity no longer reproduces itself. Many countries, including India, are actively moving along this path.

However, in most African countries, the type of the previous phase is still preserved which results in a fast population growth in sub-Saharan Africa.

So, we can *summarize the results of the first two phases of the Cybernetic Revolution*. This is important, since we already observe some important ongoing processes while others are predictive:

1) the emergence (for the first time in history) of technologies that can effectively control the birth rate;

2) the active movement of more and more countries to the second phase of the demographic transition;

3) the emergence of the type of reproduction with low birth rate and low mortality rate (TPR qualitative changes or socio-qualitative, see Table 5);

4) the emergence of an aging society (for the first time in history);

5) increasing attention is paid to the elderly and disabled, the society is increasingly turning to them, and many technologies have already created and are designed to improve the quality of their biological life. However, there are a lot of problems and issues that will exacerbate;

6) trends have clearly emerged that will determine not only demography, but the whole way of life, as well as the development of technologies in the twenty-first century, the final phase of the Cybernetic Revolution and after it. These are a) global population aging and a dramatic change in the demographic structure of population, when the share of old people is growing, while the share of children and youth is reducing; b) the started depopulation in a number of countries, and not only in very developed ones; c) division of the countries of the world into young and old; and d) an increasing need for migration (Aleshkovski *et al*. 2023).

We assume that *the final phase of the Cybernetic Revolution* will start in the 2030s and last until the 2070s or even later. And one of the most important intrigues of the final phase of the Cybernetic Revolution is how quickly African countries will switch to a low birth rate pattern? This will define a) the total population of the planet; and b) Africa's role in planetary affairs and possibly a planetary crisis if the population growth continues (Shulgin *et al*. 2023).

However, the most important problem of this period will be population aging, the difficulties associated with it, and the search for the ways to adapt to societal aging. At the same time, many countries face severe problems associated with societal aging: labor shortages, pension crisis, and conflicts over the inevitable increase in the working age limit, various forms of ageism, problems associated with the

growth of layers / communities of migrants, as well as geopolitical problems caused by demographic changes. We can only add that the scarcity of working-age population will be actively compensated by attracting workers in young countries through remote work.

One way or another, population aging and the fight against aging-associated disease (oncology, dementia, *etc*.), an increase, probably even a dramatic increase in life expectancy, and an ever more profound and more diverse adaptation to the aging of society and an individual (including, of course, growing attention to the adaptation of disabled people) – *these are the main trends in the development of demographic processes in the next seven–eight decades, the main demographic transformations of the final phase of the Cybernetic Revolution*. Thus, in its final phase, in contrast to previous production revolutions, the population growth gradually becomes less and less important (the growth of the world population will tend to stabilize, or even decline to negative values), while *improving the quality of life* (duration, biological activity, satisfaction with life, the level of relief of diseases and disability, *etc*.) comes to the fore.

The mature stages of the Cybernetic Production Principle. As we pointed in the first article, the above discussed *will lead to merging of the everyday biological life with a total technological environment and will require the creation of special public institutions and an increase in their role in adapting to aging* (see Grinin, Grinin, Korotayev 2023a, 2023b).[26] However, as society adapts with the help of future technologies of the Cybernetic Revolution and new social institutions, gradually solving and experiencing complex internal and international problems and tensions, the features of a new LDT (LDT-6, 'techno-biomedical', see Table 4) will become evident. The trend towards increasing life expectancy, yet, with dramatic rollbacks (their harbingers we observed during the COVID-19 pandemic) will remain after the completion of the Cybernetic Revolution. However, in order to achieve a radical life extension, it is necessary to considerably increase the technological component of assistance to the elderly, the disabled, the infirm and other categories needing care and supervision. This is not just about more technologically advanced medicine, where many self-regulating systems will be involved, but about the situation when the *biotechnological environment will become permanent so that life may become impossible without it* (as today we feel uneasy without the Internet and gadgets). And this, of course, together with increasing duration and comfort of biological life, will also create many insecurities and problems. *Against the background of the in-*

creasing conservatism of an aging society the necessity of crucial changes will become a new page in history.

Thus, after the completion of the Cybernetic Revolution at the mature stages of the Cybernetic Production Principle, we will witness the beginning of the new largest demographic transformation (LDT), associated with the starting accelerated creation of a sustained biotechnological environment and cyborgization, which we discussed in the introduction and will consider more (for details see Grinin A., Grinin L. 2021).

One should note that as society ages and adapts to the aging, different scenarios may become possible in the future: from minor and controlled growth and complete stabilization of the population number, to a more or less slow but stable depopulation. It is also possible to move towards technologies of (semi)artificial reproduction, at least one can expect a very wide distribution of improved IVF technologies (already during the final phase of the Cybernetic Revolution).

Table 3

Demographic changes during the Scientific-Cybernetic Production Principle

Phase	Dates	Techno-social changes	Demographic changes	Limitations	Population at the start of the phase
Initial phase of the Cybernetic Revolution	1950s–1990s	Powerful growth of science, technology and medicine. Major political and social changes in the World System; liberation of colonies; the rise of social policies	In developing countries, due to the reduction in mortality, a very rapid population growth began; in developed countries, after a period of rising birth rates, there was a transition to a decrease in the birth rate to the replacement level	Huge gap in the level of development between the core and periphery of the World System; advances in medicine, the rise of female education and rights, and economic policy led to declining birth rates in the developed world[27]	2.5 billion

Table 3 (continued)

Phase	Dates	Techno-social changes	Demographic changes	Limitations	Population at the start of the phase
Modernization phase of the Cybernetic Revolution	1990s–2030s	Mass diffusion of ICT and AI, growth of education in the developing countries	Transition to TPR of high life expectancy and population aging in most parts of the World System	In terms of reducing the birth rate, traditional and religious ideologies and practices are limitations	5.27 billion[28]
Final phase of the Cybernetic Revolution	2030s–2070s	Emergence of major breakthroughs in medicine; the impact of aging on society; struggle for a new world order	Global aging and adaptation to it; possible completion of the demographic transition in Africa	Traditional and religious ideologies in Africa and parts of Islamic countries	8.37–8.65 billion (forecast)[29]
Mature phases of the Scientific-Cybernetic Production Principle	2070s–2120s	Growth of conservatism, the final formation of new social institutions associated with aging	Noticeable increase in life expectancy; growth of adaptability to aging and disability due to the mass distribution of techno-biological technologies among the population[30]	Conservatism of the aging society; dangers of excessive techno-medical power; unpredictable dangers	10–12 billion (according to different forecasts; see Endnote 30)

CONCLUSION. MAJOR DEMOGRAPHIC TRANSFORMATIONS AND TYPES OF POPULATION REPRODUCTION IN THE HISTORICAL PROCESS

Thus, within the historical process we identify six largest world-system demographic transformations (LDT) and four types of population reproduction (TPR). It is worth making clarifications about the correlation between LDT and TPR and explaining the difference in their numbers. Each production principle corresponds to its own type of population reproduction (see Table 4 below). The type is

not formed immediately but in two stages since the technological development within the production principle is not linear either, but has a staged development with large leaps from one level to another. Therefore, *for each type of population reproduction (TPR), we identify two major demographic transformations* (see Column 4 in Table 4). However, the first, that is the Hunting-Gathering, Production Principle is not associated with any world-system demographic transformation (LDT), with a possible exception for the Upper Paleolithic or Human Revolution of about 45,000 ybp. Accordingly, the TPR of the Hunting-Gathering Production Principle is not associated with LDT, except for the origin of Homo sapiens sapiens culture around 45–40 thousand years ago (a period called the Upper Paleolithic or Human Revolution). Therefore, the remaining three TPRs (corresponding to Craft-Agrarian, Trade-Industrial and Scientific-Cybernetic production principles) quite logically correspond to the six largest demographic transformations. Their characteristics are systematized in Table 4 ('The largest world-systemic demographic transformations'). Let us recall that the fifth LDT ('adaptation to aging') is still emerging, while the sixth is very likely but still hypothetical. Also, the fourth TPR is still evolving, although many of its features have already manifested themselves.

The first two *world-system demographic transformations* **(**LDT) relate to the Craft-Agrarian Production principle (one took place during first two phases of the Agrarian Revolution, the second began in the final phase of the Agrarian Revolution and ended already at the mature stages of the Craft-Agrarian Production Principle). The third LDT occurred during the Trade-Industrial Production Principle; and the fourth demographic transformation took place at the end of the Industrial Production Principle and the start of the Cybernetic Revolution (it involved the developing countries, as we have already pointed above).

Finally, during the first two phases of the Cybernetic Revolution (the 1950s – 2020s), the fifth LDT has been actively going on and the features of a new type of population reproduction (TPR) are being formed. By the way, we may note here that some signs of the next LDT can be retrospectively guessed already at the last stages of the previous production principle. For example, in the first half of the twentieth century it is evident in a number of European countries, where the birth rate approached the replacement level. And this is already typical for the Cybernetic Production Principle. Today, the signs of the coming demographic transformation can also be traced.

And at the final phase of the Cybernetic Revolution, we assume the beginning of the transition to a new LDT (LDT-6), which will take place already at the mature phases of the Scientific-Cybernetic Production Principle. So, *for the formation of the future cybernetic society we expect a new (future) world-system demographic transformation, which we denote as* 'techno-bio-medical' (see line 6 in Table 4). *Also, the fourth type of population reproduction (TPR) is developing* (see line 4 in Table 3) although many of its features can be already identified.

Table 4

The Largest World-System Demographic Transformations (LDTs)

N	Name	Description	Type of population reproduction	Correspondence to the stages of the production principle	Dates	Part of the World-System
1	Neolithic	Transition from medium-high fertility among hunter-gatherers to a model of high fertility among primitive farmers with transition from medium-high to high mortality;[31] although generally small, but more or less constant natural increase appeared.[32] Yet this is a model of high fertility with a limited ecological niche	Slow growth	Initial and modernization phases of the Agrarian Revolution	10,000–5,000 years ago	Different regions of Eurasia and North Africa[33]
2	Civilizational	Development of the established model with a high birth rate and the achievement[34] of a somewhat lower mortality for a significant part of population on the basis of a capacious ecological niche, which made it possible to increase natural growth and consequently the population growth; as well as improve the quality of life	Slow growth	Final phase of the Agrarian Revolution and mature stages of the craft-agrarian production principle	5,000–500 years ago	In the most part of the Afrasian world-system and partly in American world-systems
3	Anti-Malthusian	Transition to a model of reduced mortality while maintaining a relatively high birth rate; this resulted a high natural growth rate	Fast growth	Final phase of the Industrial Revolution and mature stages of Industrial Production Principle	1700s–1930s	In Europe, North-America and several other places

Table 4 (continued)

4	Third World	Transition to a model of considerably reduced mortality while maintaining a high birth rate; all this gave rise to an explosive global population growth	Fast growth	Last stage of the Industria Production Principle and initial phase of the Cybernetic Revolution	1890–1980	In the developing countries
5	Adaptation to Aging	Transition to a model of an elderly society with relatively low mortality and very low birth rates, minimal growth and an increase in the share of the elderly and old population	Qualitative changes	Initial, modernization and final phase of the Cybernetic Revolution	1960–2050	In the majority of the World System countries
6	Techno-bio-medical	Transition to the model of total technological support for health and quality of biological life with the stabilization (or reduction) of the population, with a very large proportion of the elderly population	Qualitative changes	Final phase of the Cybernetic Revolution, mature stages of the Cybernetic Production principle, and probably beyond it	2060s – 2220s	within the World System

The main characteristics of all four types of population reproduction (TPRs) are described in Table 5 ('Production principle and type of population reproduction'). The formation of TPR took place during the whole production principle and could even partially involve the subsequent production principle (as we can see by the example of the Trade-Industrial and Scientific-Cybernetic Production Principles). *It is very important that the type of population reproduction associated with the Cybernetic Production Principle changes and will change dramatically the previous trajectory of the development of demographic trends*, replacing quantitative growth with qualitative changes in the life of the whole population and every individual. Therefore, an important conclusion can be repeated: in contrast to the rate of technological growth, which accelerates over time from phase to phase (see Grinin, Grinin & Korotayev, 2020), the rate of demographic growth from phase to phase begins to slow down starting from the 1970s.

Table 5

Production Principles and Types of Population Reproduction

N	Production Principle	Type of Population Reproduction (TPR)	Birth rate	Death Rate	Natural increase	Life expectancy	Settlement type	Quality of biological life[35]
1	Hunter-Gatherer	Simple reproduction (natural)	Medium-high[36]	Medium-high for all population groups[37]	Very low	Medium low	No permanent settlements	Low
2	Craft-Agrarian	Slow growth (socio-natural)	Very high[38]	High (especially for children)[39]	Low with a tendency to slow acceleration	Average low; but higher for adults	Rural settlements; but the number of dwellers is gradually growing	Low (while improving in some aspects)
3	Trade-Industrial	Fast growth (socio-quantitative)	High	Medium-low	High	Medium-high	Cities	Medium
4	Scientific-Cybernetic	Qualitative changes (socio-qualitative)	Low	Low	Low	High and very high	De-urbanization	High

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NOTES

[1] According to some data, the average population density in the pre-agrarian era was 0.1 people per 1 sq. km. of land (see, *e.g.*, Childe 2012 [1942]: ch. 2; Andrianov 1978: 21). At the same time, this density fluctuated significantly. In the most favorable areas, it reached 0.66 people per 1 sq. km (Childe 2012 [1942]: Ch. 2). In less favorable areas, the density was one person per hundreds of kilometres. Thus, according to Boris Dolgikh, in the seventeenth century among the Yukaghirs, one person was found per 200–300 sq. km (Andrianov 1978: 22). A similar situation was observed among the Tungus hunters (see Dolgikh 1960: 15). And according to David Christian's calculations (Christian 2004: 198), the average population density in the period around 10 thousand years BC was one person per 25 sq. km (that is, even less than according to Andrianov's estimates of one person per 10 sq. km).

[2] But here one should keep in mind that 1.6 million years ago *Homo habilis* lived in East Africa, and it was not a direct ancestor of *Homo sapiens*, whose

number at the very beginning was less than 100 thousand (perhaps even around 30 thousand). Therefore, it would be more correct to start calculating the growth of the human population from the first *Homo sapiens*, who lived in Africa (and not only in East) 200–300 thousand years ago.

[3] On demographic changes during the period of the Agrarian Revolution see Kozintsev 1980; Korotayev, Malkov, and Khaltourina 2007: 173–175; Grinin 2011; Bocquet-Appel, 2011; Livi-Bacci, 2017; see also Claessen and van de Velde 1985; Claessen 2002, 2010, 2016.

[4] There was also a marginal TPR among the nomads, with lower birth rates than among farmers but higher than among hunter-gatherers and apparently lower regular mortality.

[5] Here we can mention the two following types: 3) fertile lands with partial irrigation, but mostly not irrigated. This is, in particular the Near East, where a model has developed with a higher than in Europe but lower than in China population density due to more fertile soils; 4) an arid model, with infertile lands and sparse population, where nomadic animal husbandry was developed. Both models played important roles in history; the nomads were an element that united the World System and was a kind of barbarian periphery (Grinin, Korotayev 2012a, 2018; Korotayev, Grinin, Grinin 2021, 2022). In addition, we may also speak about the African model, where farming was mainly non-irrigated and manual (Grinin 2011; Korotayev and Khaltourina, 2006; Korotayev *et al*. 2016). But this model played a minor role in the historical process. We can also mention models with a sparse population and difficult conditions for agriculture, where economic types of a non-agricultural type (fishermen, sailors, warriors, *etc*.) were formed. The examples here are some Scandinavian communities.

[6] 10–15 million in the period of 9–10 thousand years ago (Kapitsa 2006: 19; 2009: 38).

[7] Valentei 1974: 236; Vishnevsky 2005: 31.

[8] The estimates referring to the beginning of our era range from 170 mln (McEvedy and Jones 1978) to 250/252 (Arab-Ogly 1978: 88; Livi-Bacci 2017: 25, table 1.3; Korotayev, 2020a: 590) and 300–330 million people (Durand 1977; Scherbakova 2011; Akimov 1999), and sometimes even 400 mln (see Korotayev, Komarova, and Khaltourina 2007: 114; Korotayev, Malkov, Khalltourina, 2006b).

[9] The variability is from 350 million to 390 million referring to the earlier period of 1400 and from 425 to 540 million estimated for a later period of 1500 (Durand 1974; Clark, 1967; Biraben, 1980; Maddison, 2003; McEvedy and Jones, 1978; Tanton, 1994; Livi-Bacci 2017: 25, table 1.3; Korotayev, 2020a: 590; see also Arab-Ogly 1978: 88; Chesnais 1992; Kapitsa 2009: 38, table 1; see also Kapitsa, Kourdyumov, and Malinetsky. 2003: 218 (with reference to Chesnais 1992).

[10] This threshold is dated to 1804, but its estimates vary greatly: from 629 to 961 million people in 1750, and from 813 to 1125 million people in 1800 (see Scherbakova 2011; *e.g*., respectively 771 and 954 mln according to Livi-Bacci [2017: 25, table 1.3]); see also Korotayev, 2020a: 590.

[11] The estimates of the world population in the mid-twentieth century range from 2,400 to 2,557 million people (Scherbakova 2011; UN Population Division, 2023).

[12] The most recent studies [UN Population Division 2023] have increased the population forecast, previously it was around 9–10 billion with a maximum of

11 billion people. However, the forecast of 10–12 billion people can change either downwards or upwards, and will change periodically since the population dynamics depend on many factors.

[13] Among the effecting factors were the Civil War (Goldstone 2016), emigration to America, plague epidemics, adverse natural and climatic changes (Parker 2013), very high mortality rate from excessive alcohol consumption (and falling birth rates for the same reason), in particular, the consumption of cheap gin grew very rapidly in the first half of the eighteenth century; there were also some other, not entirely clear reasons.

[14] By 1750, the country's grain exports had reached 200 thousand tons, or 13–15 per cent of its domestic consumption. Thus, in the eighteenth century, England was called the breadbasket of Europe (Galich 1986: 191 with reference to Bairoch 1971: 30). Europe and the whole world experienced breakthroughs in the organization of international trade, since almost for the first time they began to actively trade in bulk commodities (timber, wheat, *etc.*). According to some reports, large consignments of rye and wheat were exported from Poland to European countries in the sixteenth century. In particular, some historians cite data that up to 220 thousand tons of rye were exported annually from Gdansk (see Yakubsky 1975: 34), which, according to our calculations, could feed up to 1 million people, that is, one third of the population of Holland or 20 per cent of the population of England at that time. In Holland, bread imports in the seventeenth century actually covered up to a quarter of the country's needs (Cameron 2001: 143).

[15] During this period, one may trace the origins of the current decline in the birth rate because of development of medicine (condoms, other types of contraception and medical recommendations) and the reluctance of women to have children. Thus, according to the French researcher Moheau, the eighteenth-century French aristocrats considered the birth of children ‘the stupidity of all times’ (cited in Urlanis 1941: 226).

[16] Instead of 0.2 per cent annual growth in the sixteenth and seventeenth centuries (which was higher on average than in the previous five centuries, see above), in the eighteenth century this number tripled and the annual growth rate reached 0.6 per cent (Urlanis 1941: 220). This is an unprecedented result so far. At the same time, throughout the century, the annual natural growth increased from 0.19 per cent in the first quarter to 0.71 per cent in the last (*Ibid*.: 222). The growth was supported by decreasing mortality (*Ibid*.: 222–227) and to some extent by the increasing birth rate, yet not in all countries, but only in some (Britain, Germany) (*Ibid*.: 227).

[17] Abortion services were advertised in the newspapers, although in many countries they were banned along with some contraceptives, yet, at the same time they were widely sold in stores (Sakevich 2003).

[18] See Note 9.

[19] According to Akimov (1999) in 1650 there lived 500 mln, and in 1750 – 795 mln.[20] The estimates vary greatly, see Note 9.

[21]In 1850, there lived 1,265 mln people according to Akimov (1999) and 1,241 mln according to Livi-Bacci 2017: 25, table 1.3.

[22] However, one should keep in mind that for many developing countries, including African ones, the initial demographic changes (less evident to the Europe-

ans, but very impressive for that time) must be dated to the early twentieth century, and in some regions to the late nineteenth century. See more about it below.

[23] World population estimates for the mid-twentieth century range from 2,400 to 2,557 million people (Scherbakova 2011; UN Population Division, 2022).

[24] Such uniting processes can be observed at the junctions of different production principles. For example, the development of kin systems was characteristic already at the latest stages of the hunter-gathers production principle, but they manifested especially evidently at the first stages of the craft-agrarian production principle. Monarchical power actively developed within the framework of the craft-agrarian production principle, but it arose in the form of an absolute monarchy already at the first phases of the Industrial Revolution.

[25] Thus, between 1925 and 1940, the total fertility rate in the United States fell from 3.13 to 2.06 children per woman. And between 1940 and 1960, it rose from 2.06 to 3.58 children per woman (Chesnais 1998; UN Population Division, 2023). This boom interrupted for a while the trend towards the formation of the TPR with a small increase. The obvious reasons were the new psychology of people who survived the war and strove to maintain the optimism of life and this was accompanied with very high growth rates of the GDP and living standards, which was directly opposite to the pre-war situation.

[26] In these works see also about the major social problems associated with these changes, abuses, the danger of the growth of techno-medical power and social tension. All this can cause both great socio-political difficulties and intensification of internal social conflict due to the growing ageism.

[27] During this period, the danger of resource depletion on a planetary scale was also actively discussed, which has not yet been confirmed (Meadows *et al.* 1972).

[28] Akimov 1999; Shcherbakova 2011.

[29] UN Population Division 2023.

[30] Among all population groups, but especially among the elderly, disabled and incapacitated (requiring constant care).

[31] At the same time, the birth rate increased significantly more than the death rate.

[32] A higher birth rate also determined a higher mortality rate, primarily child mortality, but it is important that the number of surviving children (per 100 people of the population) among agriculturalists was noticeably higher than among hunters. Due to this, natural growth accelerated.

[33] = Afroeurasian World System.

[34] In a number of cases.

[35] Includes a certain comfort level, the development of medicine and care services, including ones for the elderly and the disabled.

[36] Twenty-five–thirty life births per thousand per year.

[37] Twenty-five–thirty deaths per thousand per year.

[38] More than 45 live births per thousand per year.

[39] More than 40 deaths per thousand per year.

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Appendix

Table 6

Dynamics of the global population growth

Date	World population	Time to grow by 1 billion
1801	1 billion	> 200,000 years
1925	2 billion	124 years
1960	3 billion	35 years
1974	4 billion	14 years
1987	5 billion	13 years
1998	6 billion	11 years
2010	7 billion	12 years
2022	8 billion	12 years
2037	9 billion	15 years
2058	10 billion	21 years
?	11 billion	?

Data sources: Akimov 1999 (till 1950); UN Population Division, 2023 (empirical estimates for 1950–2021; medium projection for 2022–2100).

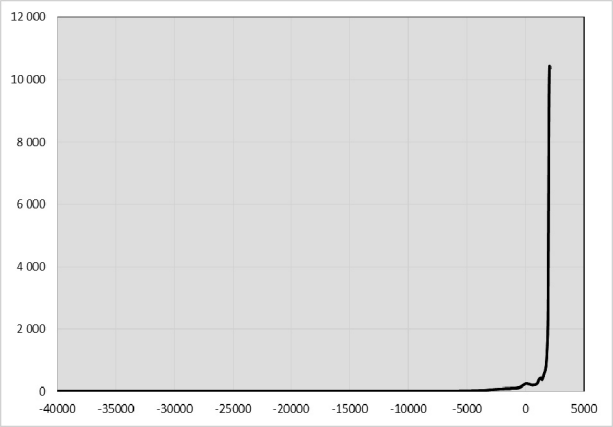

Fig. 3. World population dynamics, millions, 40,000 BCE – 2021 CE, with the UNPD medium projection till 2100

Data sources: Kremer, 1993; Livi-Bacci, 2017; Korotayev, 2020a; UN Population Division, 2023.

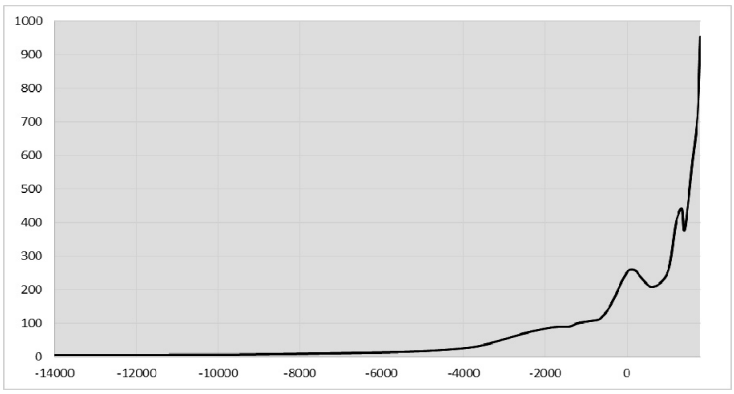

Fig. 4. World population dynamics, millions, 14,000 BCE – 1800 CE, natural scale

Data sources: Livi-Bacci, 2017; Korotayev, 2020a.

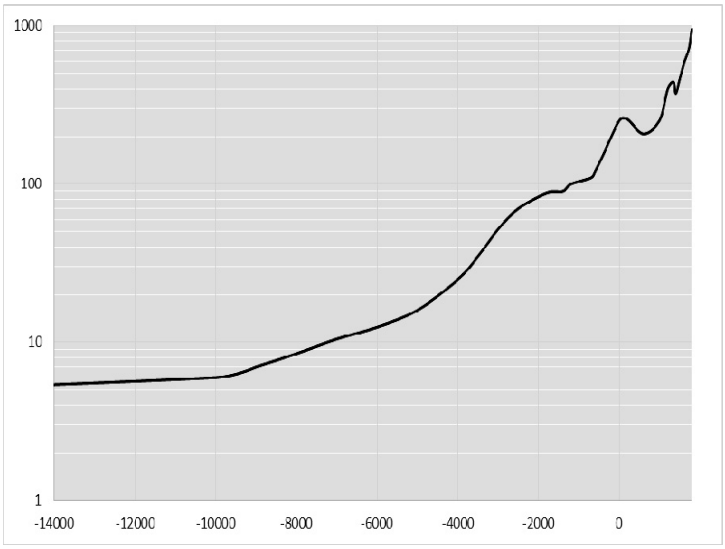

Fig. 5. World population dynamics, millions, 14,000 BCE – 1800 CE, logarithmic scale

Data sources: Kremer, 1993; Livi-Bacci, 2017; Korotayev, 2020a.

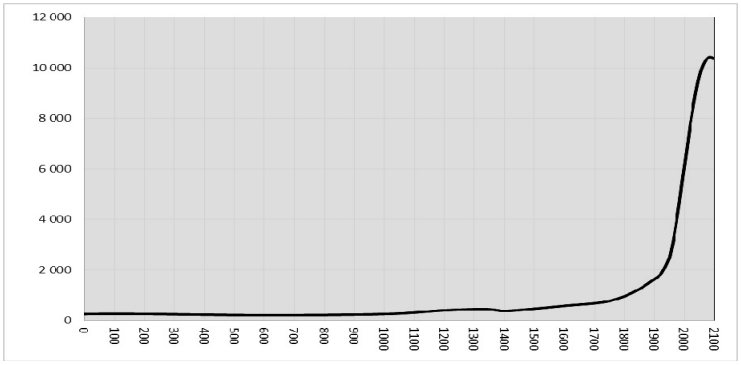

Fig. 6. World population dynamics, millions, 1 – 2021 CE, with the UNPD medium projection till 2100

Data sources: Kremer 1993; Livi-Bacci 2017; Korotayev 2020a; UN Population Division, 2023.

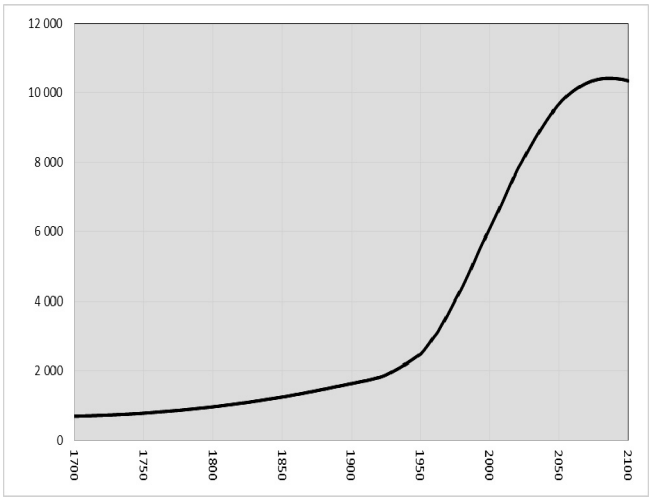

Fig. 7. World population dynamics, millions, 1700 – 2021 CE, with the UNPD medium projection till 2100

Data sources: Kremer, 1993; Livi-Bacci 2017; Korotayev, 2020a; UN Population Division, 2023.