The Technological Activity and Competition in the Middle Ages and Modern History: A Quantitative Analysis*

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The paper presents a quantitative analysis of innovative activity and competition in technological sphere in the Middle Ages and Modern Period (till the end of the 20th century). The authors consider the innovative competition in two aspects. The first section of the present paper shows the growth of the number of innovations over half-century intervals in Europe and Asia. As is widely accepted at present, by the early 2nd millennium CE Europe lagged far behind the main eastern countries not only in terms of development of the productive forces but in respect of many relevant parameters. According to some data, Europe failed to outrun China (as regards scientific-technological growth rates) not only in the 12th or 13th, but even in the 14th century. On the other hand, the authors show a rather vigorous acceleration of those rates in Europe since the 12th century with one more such acceleration in the 13th century (when Medieval Europe produced its first paradigm changing inventions – initially, the invention of the spectacles and the mechanical clock). In the 15th century Europe definitely outpaced Asia.

After such historical breakthrough, it is very important to trace how the leadership has changed in this respect within Europe. The second and the following sections of the paper are devoted to this aspect. Here we consider the dynamics of technological inventions in Europe from the 15th to the 19th centuries. Our analysis of the technological innovation dynamics shows that: firstly, the British lead began to show up only in the second half of the 17th century; before Britain had clearly lagged behind Italy and Germany. Thus, during the two initial centuries of the Industrial Revolution Britain absorbed the achievements of European societies, and only then was it succeeded to start its own innovative climb.

Secondly, though we observe the British evident leadership in the technological innovation from the second half of the 17th century to the first half of the 19th century, for a greater part of that period, the overall innovation activity of 'the rest of the West' was higher than that of Britain. The primacy of Britain in the field of technological invention was absolute only during a relatively short period in the second half of the 18th century and the early 19th century, i.e. the period of the final phase of the Industrial Revolution.

Thirdly, by the first half of the 19th century the British endogenous technological growth rate virtually stagnated against the background of a very fast increase

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of those rates in France, Germany and the USA, as a result of which those countries caught up with Britain in a rather significant way.

Fourthly, in the second half of the 19th century Britain finally lost its technological lead, as in the late 19th century the number of major inventions made in the USA, Germany, and France exceeded the number of British inventions.

Keywords: *technology, technological innovations, inventions, Industrial Revolution, Asia, Europe, leadership, quantitative analysis.*

As is known, in regard to the industrial-technological innovation rates, Europe outpaced Asian countries on the eve of the Early Modern Period. However, on the one hand, in some aspects Europe continued to lag behind Asia till the 17th–18th centuries (in more detail see Grinin and Korotayev 2015), and on the other hand, it took more than three centuries for Europe to make a breakthrough in the Early Modern Period. The first section of the present paper shows this technological competition in the aspect of the growth of the number of innovations over half-century intervals in Europe and Asia. The second and the following sections show the increase in the number of innovations in Europe in the period of the Industrial Revolution which began in the 15th century and the change of leaders in the innovation race. It becomes evident that British breakthrough in the 18th century, when the Industrial Revolution occurred first, was based on common European achievements. It also shows that in the second half of the 19th century Britain yielded the leadership to other European countries and the USA.

1. A General Analysis of the Development of Asia and Europe

As is widely accepted at present, by the early 2nd millennium CE Europe lagged far behind the main Eastern countries in terms of development of the productive forces, statehood, urbanization, consumer culture, scientific achievements and other relevant parameters (*e.g.*, Crone 1989; Abu-Lughod 1991; Pomeranz 2000; Maddison 2001, 2010; Christian 2004; Goldstone 2009; Lucas 2005; Saliba 2007; Reinert 2007; Vries 2013; Grinin and Korotayev 2015; Grinin L. and Grinin A. 2016), whereas, according to some estimates, the per capita GDP in the advanced economies of the East was at least twice as high as in Western Europe (*e.g.*, Melyantsev 1996: 74). According to some other estimates, even in the 11th century, Western Europe did not reach the level of production of the 1st century CE Roman Empire (*e.g.*, Cameron 1989; Maddison 2001, 2010). The items that prevailed within the export of European countries to the East were fur, silver, and timber (Abu-Lughod 1991: 47; Postan 1987). Eastern Europe, in addition to valuable furs, also exported honey and wax, as well as skins, and considerable numbers of slaves (Gieysztor 1987; Postan 1987; Ali 1999), whereas the Eastern exports to Europe consisted mostly of finished industrial (handicraft) products and luxury goods (Abu-Lughod 1991: 47; Postan 1987; Ali 1999). In short, in the early 2nd millennium CE Europe looked like a backward periphery of the Asian and North African core.

Consider specially, how Europe, that is Western Europe or the 'West', lagged behind the 'East' as regards such an extremely important indicator as the intensity of innovation in science and technology. In order to insure the compatibility of the analysis results we will use in this paper[1] the database on scientific discoveries and technological inventions

[1] With some exceptions that will be mentioned specially below.

created by Hellemans and Bunch (1988). To start with, consider the levels of innovation activity in the East and the West during the first eleven centuries CE (Fig. 1).

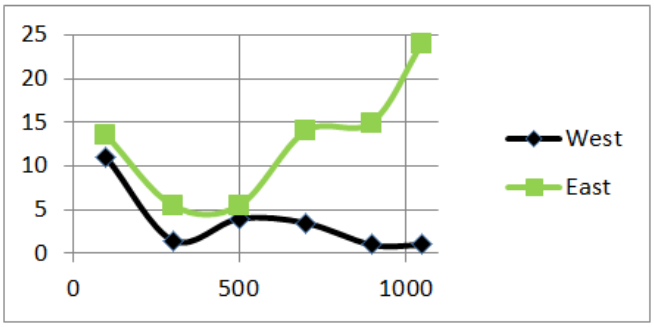

Fig. 1. Inventions and discoveries in the West and the East per century, 1–1100 CE (The Divergence of the 1st millennium CE)

Note: for the period between 1 and 1000 CE the diagram indicates the average number of inventions and discoveries made per century within the respective pair of centuries. For example, the number '11' corresponding to the European datapoint for year 100 indicates that the average number of inventions and discoveries made in the 1st and 2nd centuries CE was 11. Two last datapoints (at 1050 CE) correspond to the number of inventions and discoveries made in Europe and the East in the 11th century.

As we see, in the early 1st millennium CE the levels of innovative activities in the East and the West were rather comparable. Both in the East and the West the World System crisis that started in the second half of the 2nd century CE with the 'Antonin Plague' pandemic (see, *e.g.*, Korotayev 2006) led to a very significant decrease of the rate of innovation within science and technology. However, in the second half of the 1st millennium in the East (but not in the West) one could observe a rather significant increase in the number of serious inventions and discoveries; as a result, the East managed to recover its scientific-technological activity to the pre-crisis level – and to exceed it substantially by the 11th century. As regards this indicator, in the first eleven centuries CE one can observe a rather clear divergence between Europe, on the one hand, and Asia and North Africa, on the other (and not in favor of Europe), which, no doubt, contributed rather strongly to the retardation of the West (in comparison with the East) that became so salient by the 11th century CE.

However, while Europe lagged far behind Asia, by the 11th century it had some potential advantages – first of all, it had more stimuli to invest in labor-saving techno-logies, and it was better provided with sources of energy (*e.g.*, Chaunu 1979; Wigelsworth 2006). Of course, those potential benefits could be realized only under certain conditions. Such conditions began to take shape in Europe in the centuries that followed; an important role was played by the readiness of some Western European societies to borrow technologies from the East and to improve them. At the same time in the East in the Early Modern Period, even long-known methods of mechanization could not be applied widely, and their application even sometimes declined (see, *e.g.*, Vanina 1991: 96–98 with respect to India; Landes 2006 about China, and Allen 2011 as regards Japan).

Technical and scientific upswing of the late medieval period in Europe and the issue of the 'Early Industrial Revolution'

In the period between 1100 and 1400, but especially in the 15th and 16th centuries, the European labor-saving tendencies became implemented to a sufficiently large degree (about the 16th and the next centuries see Huang 2002), which resulted in a fairly rapid development of technologies and a number of key inventions (more about them see below and also in Fig. 2) and the development of the process of division of labor. This technological upswing that took place in Europe between 1100 and 1600 was noticed long ago – back in the 1930s – starting with the work of Lewis Mumford (1934), Marc Bloch (1935), Eleanora Carus-Wilson (1941) and was actively studied by economic historians in around 1950–1980 (Lilley 1976; Forbes 1956; Armytage 1961; Gille 1969; White 1978; Gimpel 1992; see also Hill 1955; Johnson 1955; Bernal 1965; Braudel 1973; for more details see Lucas 2005). This period also quite rightly considered as the time of scientific breakthrough, or rather a number of revolutionary breakthroughs in such areas as mathematics, astronomy, geography, cartography, *etc.* (see, *e.g.*, Singer 1941).

The analysis of the Hellemans–Bunch database may suggest that with respect to scientific-technological growth rates the West caught up with the East as early as in the 12th century, whereas in the second half of the 13th century the West might have already somehow outrun the East (see Fig. 2).

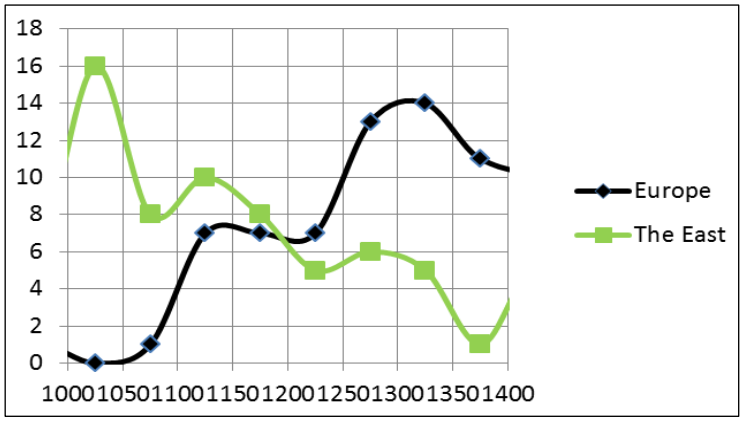

Fig. 2. Inventions and discoveries in Europe and the East per half a century, 1000–1400 CE

Note: each datapoint indicates the number of inventions and discoveries made in a respective half of a century. For example, the number '14' corresponding to the European datapoint for the year 1325 indicates that the number of inventions and discoveries made between 1300 and 1350 in Europe was 14.

Source: Hellemans and Bunch 1988.

However, one should take into account the following consideration. The point is that, starting from the 12th century, Hellemans and Bunch appear to have become obsessed with the registration of the explosively growing stream of the European inventions, and that is why they start to pay much less attention to the registration of the Eastern scientific-technological innovations. That is why there is good cause to suppose that the decline of the scientific-technological activity rates suggested by Fig. 2 may actually be an artefact of such an underregistration. In this respect, it has turned out to be necessary to use a data survey

on the dynamics of the number of innovations in science and technology in China in the period between the 10th and 19th centuries (Goldstone 2009: 122).[2] Its application produces the following result (see Fig. 3) that appears more reliable than the one presented above in Fig. 2.

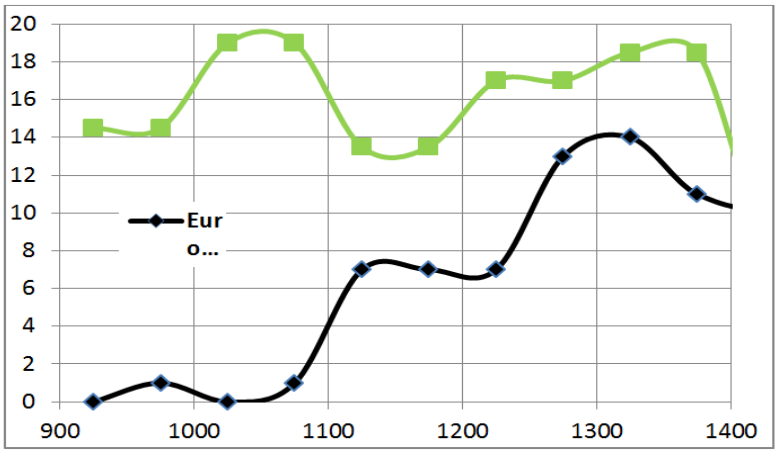

Fig. 3. Number of innovations in science and technology in Europe and China per half a century, 900–1400 CE

Source: Hellemans and Bunch 1988; Goldstone 2009: 122.

According to these data, Europe failed to outrun China (as regards scientific-technological growth rates) not only in the 12th or 13th, but even in the 14th century. On the other hand, the figures above suggest a rather vigorous acceleration of those rates in Europe in the 12th century with one more such acceleration in the 13th century (when Medieval Europe produced its first paradigm changing inventions – initially, the invention of the spectacles and the mechanical clock).

In the 15th century Europe definitely outpaced Asia. Thus, from the 12th to the 15th centuries, the overall trend appeared as follows: the most developed European countries were constantly catching up with the most developed countries of the East, and in certain respects they even left them behind. And in those respects (which included science, military/navy technologies, and some fields of engineering) the gap between the West and the East was constantly increasing in the Early Modern Period. However, up to a point, this superiority had not yet materialized in the West's overwhelming dominance.

Thus, the Early Modern Period is characterized by a dual process. On the one hand, we observe a process of convergence, but we also observe a partial advance of the West in comparison with the most developed Eastern countries in many ways. This duality (on the one hand, a higher level of overall development in the East, on the other – the growth of partial advantages of the West) has led to numerous disputes in which each party is in its own right. That is why we prefer to denote the Early Modern Period as the period of 'catching up divergence'. Indeed, during this period, on the one hand, Europe was still

[2] Note that in his turn Goldstone based himself on the survey produced by Li Chen and Ugurlu Soylu (2004).

lagging behind the East, it was catching up with it in many points. Thus, this was a convergence in a number of respects (such as literacy, urbanization, statehood, national culture, productivity, industrial production volumes), and a divergence with respect to some military-technical and scientific aspects, the dissemination of knowledge, and so on. It is very important to take into account the point that in the Early Modern Period the convergence could not be achieved by the West by rapid population growth (on the contrary, until the mid-19th century, the gap in population between China and Western Europe only increased, see Fig. 4).

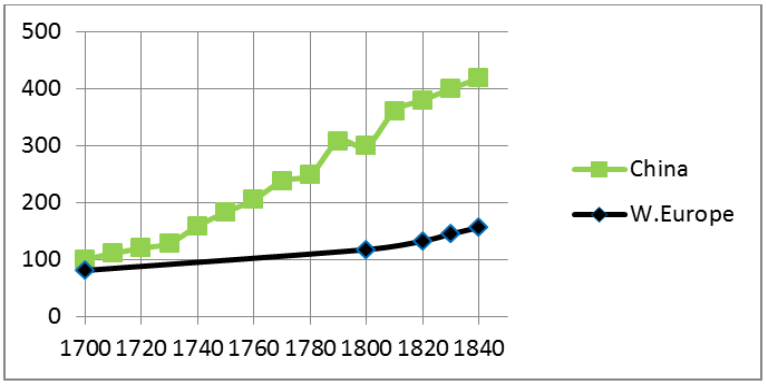

Fig. 4. Population dynamics in China and Western Europe, 1700–1840, millions

Sources: Durand 1960; Zhao and Xie 1988; Korotayev, Malkov, and Khaltourina 2006; Cipolla 1981: 4; Clark 1968: 64; Cipolla 1972: 36; Maddison 1991: 226–227; McEvedy and Jones 1978: 49, 51, 107; Maddison 2001, 2010.

Thus, the overwhelming dominance Europe could be traced only since the 18th century and it became ultimate in the next century.

2. The Industrial Revolution as a Pan-European Achievement

Now, it is very important to trace how the leadership has changed in this respect within Europe and how the technological leaders changed among European countries.

It is important to point out that the theory of early industrial revolutions that preceded the Industrial Revolution of the 18th century has rather solid foundations (Lilley 1976; Forbes 1956; Armytage 1961; Gille 1969; White 1978; Gimpel 1992; Lucas 2005; see also Hill 1955; Johnson 1955; Bernal 1965; Braudel 1973]). However, later this theory was (without any reasonable grounds) relegated to the periphery of the historical mainstream (*e.g.*, researchers belonging to the California School hardly mention the early European Industrial Revolution). However, ignoring the early European Industrial revolution, we believe, appears to be counterproductive in solving many important problems, including the search for reasons why the Industrial Revolution occurred in Britain (Grinin and Korotayev 2015; for more details see also Grinin 2007, 2012, 2006; Grinin L. and Grinin A. 2015). In addition, this question is somewhat artificially separated from the more general question about the causes of the technological breakthrough in the West in the Early Modern Period. Our view is that the idea of the early industrial revolution in explanatory terms

is very useful, but it requires its own conceptual development from a perspective that allows treating this early revolution not so much as a separate isolated phenomenon, but as the initial phase of the Industrial Revolution. Then in fact the industrial breakthrough of the 18th century should be regarded as the final phase of the Industrial Revolution. We would say that the Industrial Revolution continued for at least three centuries (*Ibid.*); and against the background of many millennia that preceded those three centuries – this was a rather short, quite revolutionary period.

Very schematically, this approach may be outlined as follows. The period between 1100 and 1450 may be regarded as a preparatory period of the Industrial Revolution with quite a vivid manifestation of early capitalist relations and forms of production in some regions of Europe (Northern Italy, Southern Germany, the Netherlands, Southern France [see, *e.g.*, Pirenne 1920–1932; Wallerstein 1974; Postan 1987; Milskaya and Rutenburg 1991; Lucas 2005]).

The period from the late 15th century till the early 17th century (often denoted as 'the long 16th century') is the initial phase of the Industrial Revolution, associated with the development of navigation, engineering and mechanization on the watermill basis, the diffusion and improvement of different machines, and the development of division of labor. At this time, in different parts of Europe, there were significant breakthroughs in a variety of directions, which by the end of the period are synthesized into the general Western European system (Johnson 1955; Braudel 1973; Wallerstein 1974; Barg 1993; Yastrebitskaya 1993; Davies 1996). Changes in one country tended to produce substantial impact on the economy and the lives in other countries – through the spread of innovations, through the publication of special technical books, through the movement of technical experts to different countries, through the introduction of various advances and innovations by kings and emperors to their realms, *etc.* Thus, we find impressive achievements in the field of mechanization in mining operations in Southern Germany and Bohemia; major contributions to the development of navigation, geographical discoveries and world trade accomplished by the Spanish and Portuguese, but also by the British; significant developments of technologies of manufacturing in Italian and Flemish cities; significant shifts in agriculture in Northern France and the Netherlands; important scientific and mathematical discoveries made by scientists in Italy, France, Poland, England; and finally, new financial technologies developed in Italy (Hale 1993; Davies 1996, 2001; Collins and Taylor 2006; Goldstone 2009, 2012; Ferguson 2011; Porter 2012). But all of this, anyway, quickly became the common heritage of Europe.

The period from the early 17th century to the second third of the 18th century is the middle phase, when one could observe the formation of a complex industrial sector and the capitalist economy with increased mechanization and the deepening division of labor. This is the age of trade leadership by the Dutch, the successor to the hegemony of Spain and Portugal. The Netherlands created an unprecedented industry of shipbuilding, mechanized port facilities and fishing (Boxer 1965; Jones 1996; de Vries and van der Woude 1997; Rietbergen 2002; Israel 1995; Allen 2009). But the 17th century was a century of very large changes in military technology, science, and engineering; whereas as a result of wars and other processes the Netherlands lost its leadership, which was gradually moving to Britain (Rayner 1964; Boxer 1965; Snooks 1997; Jones 1996; de Vries and van der Woude 1997; Rietbergen 2002).

Finally, the period between 1760 and 1830 may be identified as the final phase of the Industrial Revolution, which was also accompanied by the creation of the sectors of the machine cycle of production and the use of steam power. Although Britain was here clearly the leader, we also observe in this period a number of important processes that can be identified as pan-European (including the development of military technology, trade, science, pan-European commercial and industrial crisis of the second half of the 18th century, the beginning of the demographic transition). In this concept, we clearly see in the Industrial Revolution the result of the collective achievements of different societies of Europe, a sort of relay-race of achievements (see below).

3. Technological Innovation Activities in Britain and other Western Countries (1400–1900)

As has been shown above, as regards the scientific-technological innovation rates, Europe outpaced China (and the East in general) in the 15th century (see Fig. 5. which supports our idea that the Industrial Revolution started in Europe in the 15th century). It started in the belt that included the Netherlands, Southern Germany, Northern Italy, as well as some parts of France, Spain and Portugal. We suggest identifying the last third of the 15th century and the 16th century as the initial phase of the Industrial Revolution. During the 16th and the first half of the 17th century, the achievements of different European countries were consolidating and diffusing, thus creating a new foundation for growth. This phase of modernization (in terms of inventions) can be subdivided into two subphases: the first was characterized by comparable levels of technological innovation activities in a number of European countries; at the second phase an undeniable lead belonged to Britain.

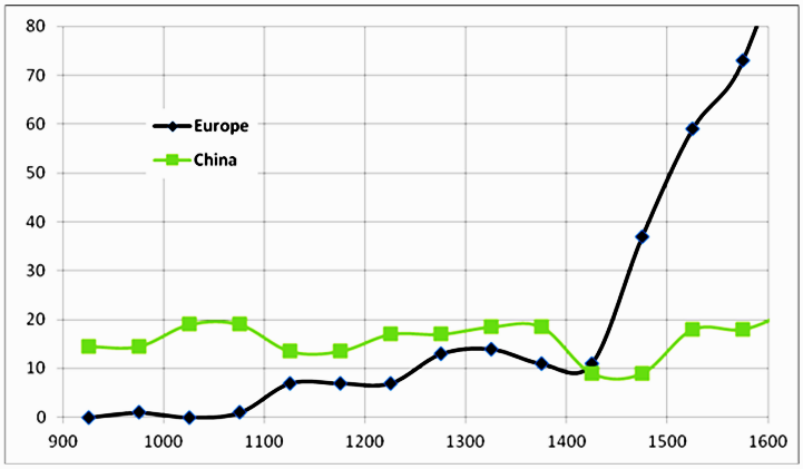

Fig. 5. Number of innovations in science and technology in Europe and China per half a century, 900–1600 CE

Source: Hellemans and Bunch 1988; Goldstone 2009: 122.

As regards technological innovation, a comparison of Britain with its European neighbors very clearly shows that the British lead began to appear only in the second half of the 17th century (see Figs 6–11; in Figs 9–10 this can be seen particularly well). Before that, Britain clearly lagged behind Italy, Germany, and (for some period) the Netherlands. Thus,

it is clear that during the two initial centuries of the Industrial Revolution Britain absorbed the achievements of European societies, and only then it was able to start its own innovative climbing. This British lead gradually grew until it reached its peak in the second half of the 18th century. But this superiority could not continue too long. Already in the first decades of the 19th century it became visible that some other European countries and the USA were trying quite successfully to catch up with Britain (Figs 11–12), and in the second half of the 19th century (from the 1860s) Britain ceased to be a technological leader, and its role in the global technological invention process decreased from decade to decade. The technological leader role started to be performed by the USA (see Figs 12–13).

We emphasize again that, on the one hand, one can see an evident technological innovation leadership of Britain for two centuries (from the second half of the 17th century to the first half of the 19th century); but, on the other hand, for a greater part of this period, the overall innovation activity of 'the rest of the West' was higher than the one of Britain (Figs 14–15). Thus, the primacy of Britain in the technological invention field was relative, except for only one relatively brief period of the second half of the 18th century and the early 19th century, *i.e.*, the period of the final phase of the Industrial Revolution, when the leadership of Britain was absolute (Figs 14–15).

METHODOLOGY. The main database used for calculations below in this paper is Hellemans and Bunch 1988, which was augmented with data from Kondratieff 1926, 1935, 1984; Usher 1954; Haustein and Neuwirth 1982; van Duijn 1983; Ryzhov 1999; Silverberg and Verspagen 2003; Ballhausen and Kleinelümern 2008; Challoner 2009). For Figs 6–15 we have only taken into account technological inventions, excluding purely scientific discoveries (note that in Figs 1–3 and 5 we have tried to quantify the innovation dynamics in science and technology – hence, there we take into account both technological inventions and scientific discoveries). In addition, we take into account only those inventions that were actually implemented within a century (thus, we do not take into account those sketches of Leonardo da Vinci that remained on paper only). With regard to scientific discoveries, the only exception was made to those of them with a direct technological significance.

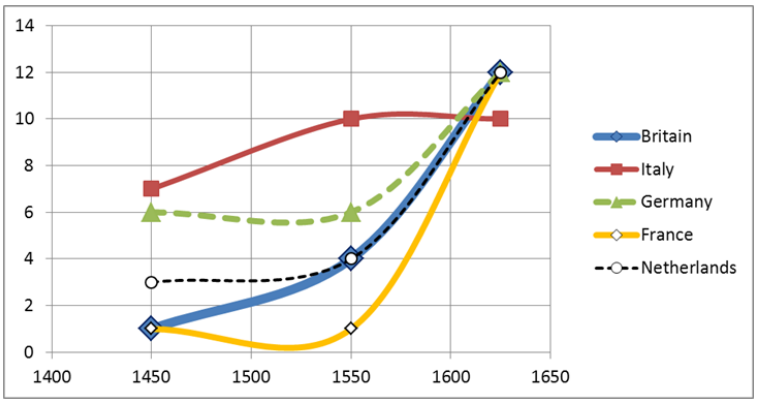

Fig. 6. Dynamics of technological inventions (= endogenous techno-logical growth rate) in five leading countries of Early Modern Europe, 1400–1650

Note: Datapoints for 1450 refer to the 15th century, datapoints for 1550 – to the 16th cen-tury, datapoints for 1625 – to the first half of the 17th century. The diagram indicates the number of important

technological innovations (listed in our database) made in respective countries per century. If a database refers to half a century, we provide the endogenous technological growth rate as inventions per century (to make all the datapoints comparable). Hence, for the Netherlands, the datapoint for 1450 indicating '3' means that for the 15th century our database lists three inventions (which yields a '3 inventions per century' growth rate), for the 16th century it increases to '4 per century'; for the first half of the 17th century our database records 6 inventions in the Netherlands, which yields for the Netherlands for 1600–1650 the endogenous technological growth rate of '12 inventions per century'.

For the initial phase of the Industrial Revolution and the first half of its intermediate phase (the 15th, 16th, and 17th centuries), we have identified five major players in the technolo-gical innovation sector: Italy, Germany, France, the Netherlands, and Britain (Figs 6–9). Of course, some important techno-logical inventions were made in some other European countries (see Figs 11–13), and their total number exceeded in the 15th and 16th centuries the one recorded for France. But in general, they did not play any significant role until the early 18th century. Their role began to grow afterwards, which confirms our idea of a common European space for open innovation during the Industrial Revolution. Figs 11, 12 and 13 clearly demonstrate that in the 18th century the total number of major inventions made in the rest of Europe (including Russia) exceeded the number of innovations in such a former leader as Germany, in which the innovative activity in the technological area during this time slowed down.

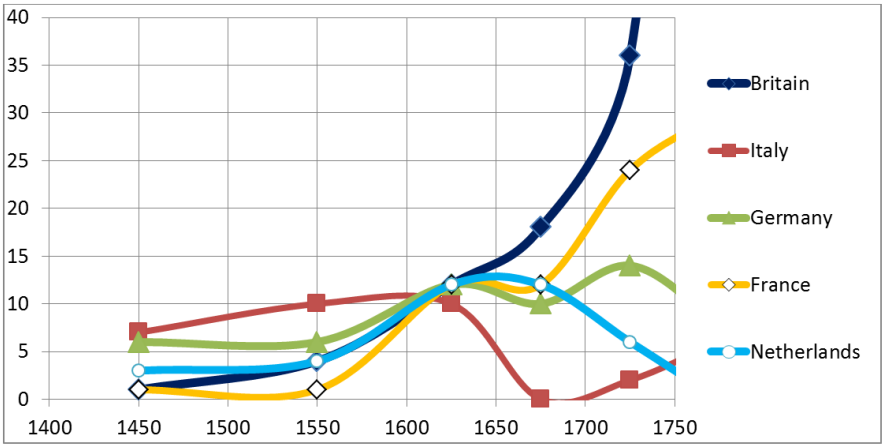

Fig. 7. Dynamics of technological inventions (= endogenous techno-logical growth rate) in five leading countries of Early Modern Europe, 1400–1700

Note: datapoints for 1625 and 1675 refer to the first and the second half of the 17th century respectively. Recall that in such cases we still measure the endogenous technological growth rate as inventions per century (to make all the datapoints comparable). Hence, for example, for the first half of the 17th century our database records 6 inventions for Germany, which yields for Germany for 1600–1650 the endogenous technological growth rate of '12 inventions per century'. For the second half of the 17th century 5 major inventions are recorded in Germany, which yields for Germany for 1650–1700 the endogenous technological growth rate of '10 inventions per century', *etc.*

For over a century and a half (until the early 17th century) Italy remained the technological innovation leader. It also fully corresponds to an important fact – it is in Italy (especially in Venice) where in the 15th and 16th centuries one could observe the most advanced legislation and practice for registering inventions. However, the growth of its activity stopped in the middle of the 16th century, while other countries were catching up with

Italy. The stagnation of the innovation activity in Italy correlated quite well with the start of economic and political crisis, associated with changes of world trade routes, its inability to change the political model of development and foreign policy challenges. At the same time, we note that future long-term leaders in innovation, Britain and France at the start of the Early Modern Period were lagging far behind Italy and Germany (Figs 6–9).

Figs 6–10 indicate a rather interesting point, as in the early 17th century four European powers converge as regards the number of important innovations per country, which supports the idea that for the 17th century it is quite possible to speak about a general Western European level of technological innovation activity. Although the further development of innovative activity in different countries was rather different, it is evident that a certain base was established at a fairly high level, which was necessary to begin a new breakthrough, a new phase of the Industrial Revolution. Also Figs 8 and 9 show quite clearly the stagnation of Italy, where in the 17th century the technological innovaton activity rates fell almost to zero, which correlated quite well with the political and social decline of Italy. Innovative activity from the south of Europe moved to the North-West (including France) (see Fig. 7).

In the first half of the 18th century a certain divergence was observed in the European North-West itself. The endogenous technological innovation rates grew very substantially in France, but especially in Britain (see Fig. 8).

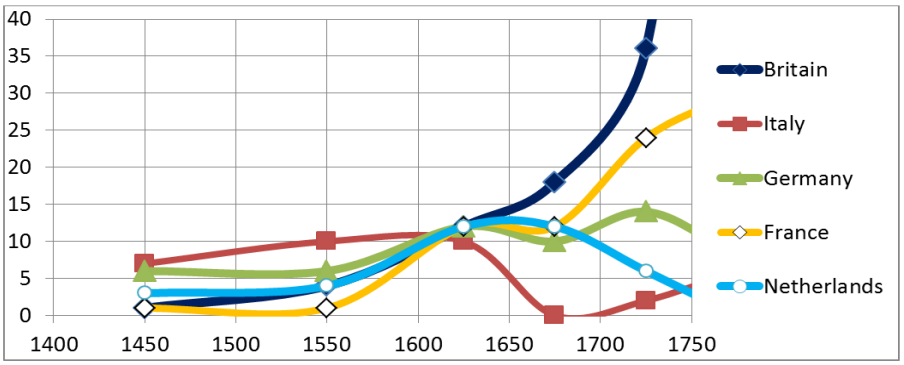

Fig. 8. Dynamics of technological inventions (= endogenous techno-logical growth rate) in five leading countries of Early Modern Europe, 1400–1750. Change of the leaders

Thus, already in the first half of the 18th century the British technological lead became quite visible. But it only became really absolute in the second half of the 18th century (see Fig. 9).

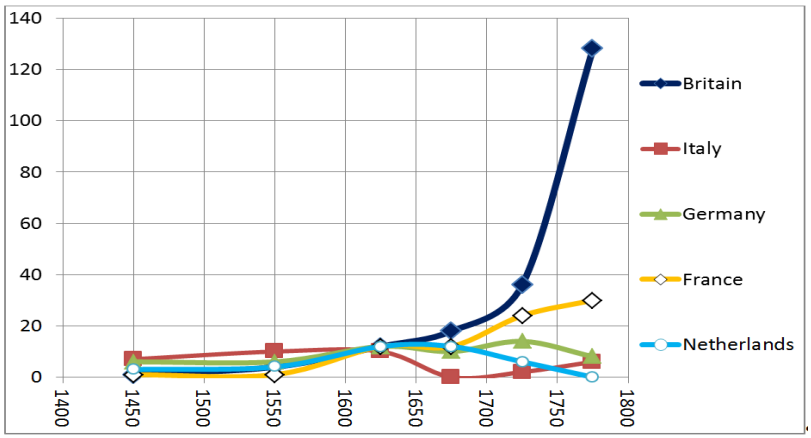

Fig. 9. Dynamics of technological inventions (= endogenous techno-logical growth rate) in five leading countries of Early Modern Europe, 1400–1800. The absolute technological lead of the British in the late 18th century

As we see, in the second half of the 18th century in Britain the endogenous technological growth rate increased by more than 250 %. This happened against a rather slow growth of this indicator in France, a weak recovery in Italy and clear decline in Germany and especially the Netherlands. As a result, the technological lead of Britain became almost absolute – in the second half of the 18th century the overwhelming majority of all the important technological inventions were made in Britain (see Fig. 14). The enormous lead of Britain with respect to the technological leaders of the start of the Early Modern Period becomes especially visible if we delete the French curve from our graph (see Fig. 10).

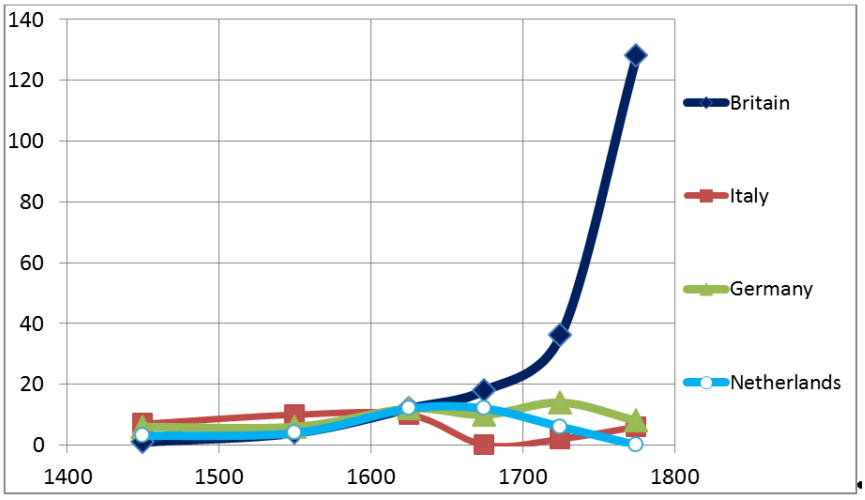

Fig. 10. Dynamics of technological inventions (= endogenous techno-logical growth rate) in four leading countries of Early Modern Europe, 1400–1800. With France excluded the absolute technological lead of the British with respect to Germany, the Netherlands and Italy in the late 18th century looks even more salient

However, this British absolute tecnnological prevalence continued just for half a century. Already in the first half of the 19th century the British endogenous technological growth rate virtually stagnated against the background of a very fast increase in those rates in France, Germany and the USA, as a result of which those countries caught up with Britain in a rather significant way (see Fig. 11), whereas the number of major inventions made outside Britain exceeded substantially the number of British inventions (see Fig. 15).

In the first half of the 19th century the Industrial Revolution was completed. Figs 6–11, as well as Figs 14–15 in different projections well confirm our idea that the Industrial Revolution from the 15th to the 19th century passed through three phases: initial, intermediate, and final.

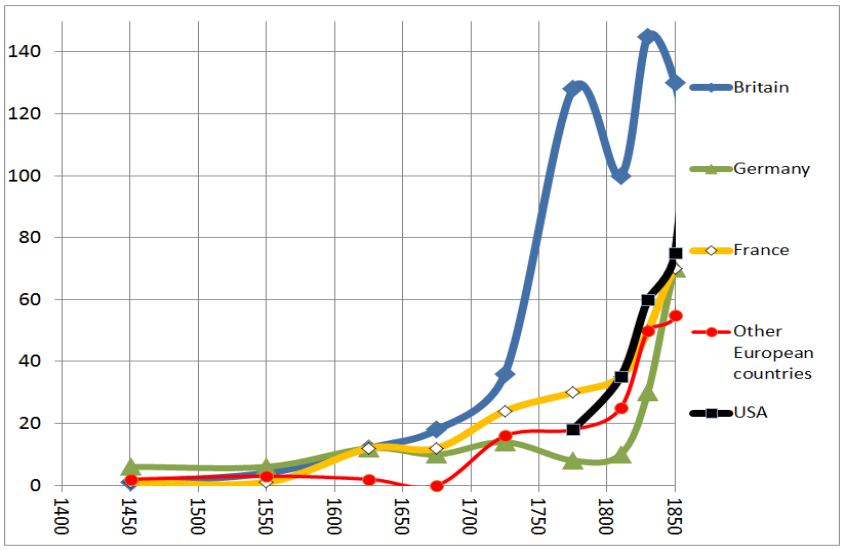

Fig. 11. Dynamics of technological inventions (= endogenous techno-logical growth rate) in Europe and the USA, 1400–1850. A few Western countries are catching up with Britain in the first half of the 19th century

In the second half of the 19th century Britain finally lost its technological lead, as in the late 19th century the number of major inventions made in each of the USA, Germany, and France exceeded the number of British inventions (see Fig. 12), whereas in 1880–1900 the number of major inventions made in Britain constituted just about 10 % of all the major inventions made in the West (see Fig. 15). The technological lead by the end of the 19th century was clearly taken by the USA (see Fig. 12).

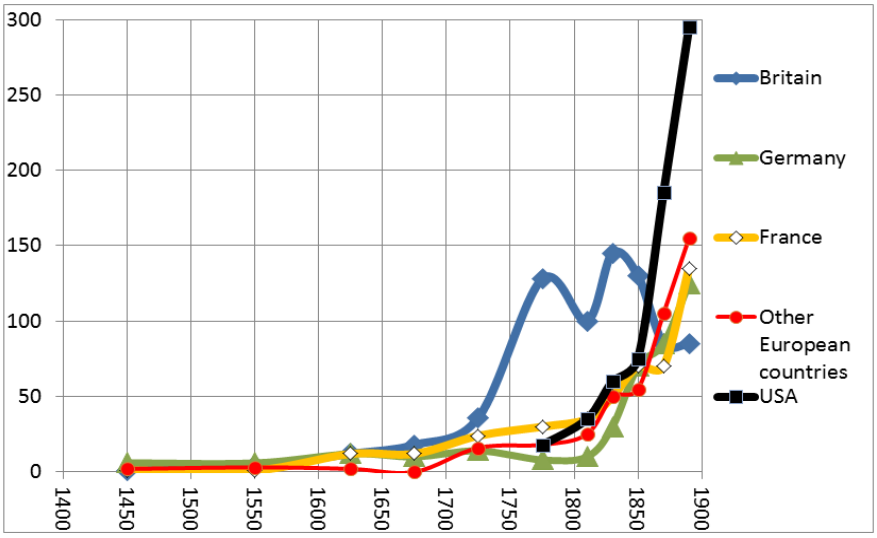

Fig. 12. Dynamics of technological inventions (= endogenous techno-logical growth rate) in Europe and the USA, 1400–1900. Convergence among the leading European countries and the USA lead in the second half of the 19th century

We continue to talk about the three phases of the Industrial Revolution as an inter-connected process, during which, however, technological leaders were changing, which is quite clearly reflected in Figs 12 and 13. At the initial phase (1450–1600), we already see a fairly high rate of technological innovation activity (especially in comparison with earlier periods that preceded the onset of the Industrial Revolution), which further increased during the second half of the 16th century. This indicates a transition to the intermediate phase when the base of the Industrial revolution greatly increased. As we remember (see Figs 6–9), at this phase technological leaders were Italy and Germany, but one could also observe a gradual growth of the role of some other European countries: England, France and the Netherlands. However, in the late 16th century it was not clear yet which country would be the future leader. The intermediate phase was characterized by the emergence of new centers of technological innovation, as well as by the dissemination and improvement of previous innovations. Important improving inventions were made, which were extremely important for the future of the Industrial Revolution. The dynamics of the process was not linear, as the further development of the technology base required a serious political change. This is quite visible in the diagrams (*e.g.*, Figs 8 and 14). First, we see a general continuation of the innovation activity growth in the first half of the 17th century (except Italy, which in terms of invention rates stagnated – though still at a rather high level) and the convergence of the endogenous technological growth rates on all the main countries of Western Europe. In the second half of the 17th century in all the main Western European countries (except Britain) the technological invention activity stagnated or even decreased, yet it generally remained higher than at the previous (initial) phase of the Industrial Revolution. In Germany, after a certain decline in 1650–1700, it somehow increased in the first half of the 18th century, but Germany was no longer one of technological leaders of Europe. Real technological innovation rise started there only in the first half of the 19th century. However, during this period (the 17th century and the first half

of the 18th century) a number of important innovations in military tactics and strategy as well as in international relations were made, which, however, by definition, we could not reflect in our calculations. In any case, in the 17th century in Britain (notwithstanding the political revolution and civil war) the technological invention activity did not stagnate or decrease at all; what is more, it increased very significantly, indicating the preparation of the technological breakthrough in Britain (to some extent this was also a reflection of legislation on patents and monopolies that was enacted in the early 17th century). Nevertheless, it is clear (see Figs 14 and 15) that in the 17th century and even in the first half of the 18th century, the total invention activity of Continental Europe was substantially greater than the invention activity of Britain alone. In addition, two other new technological innovation leaders emerged in the 17th century – the Netherlands and France, which reflected the well-known World System hegemony of the Netherlands in this century (see, *e.g.*, Braudel 1981–1984; Arrighi 1994; Modelski 1987, 2006; Modelski and Thompson 1996) as well as military-political growth of France (this, in its turn, reflected the growing might of France as the leading continental power, which was the first in Europe to create a new type of state – a mature state [see Grinin 2011, 2012; Grinin and Korotayev 2006]).

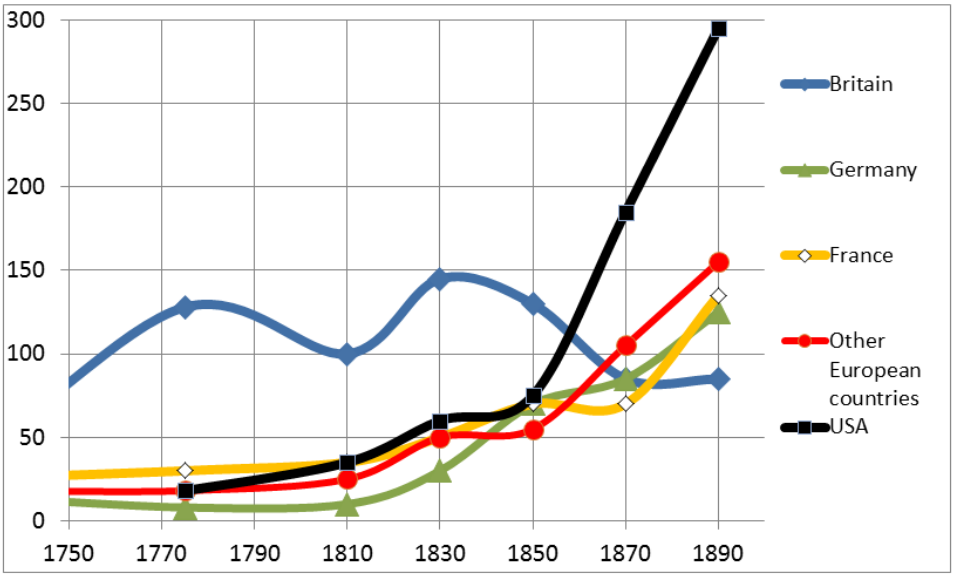

Fig. 13. Dynamics of technological inventions (= endogenous techno-logical growth rate) in Europe and the USA, 1750–1900

Return now to the idea of comparing Britain with the rest of the West (Figs 14 and 15). As one can see, before 1650 the number of major inventions made in Britain was a few times less than in the rest of Europe; in 1650–1750 this gap decreased very significantly, but still the number of major inventions made in the Continent substantially exceeded the number of such inventions made in the British Isles. We draw attention once again to the point that the overall growth of innovation in Continental Europe slowed down very substantially in the period after the Thirty Years War (and in Britain despite its revolution the tech-nological innovation continued to accelerate). A new wave of invention activity growth started in the European Continent in the first half of the 18th century (see Fig. 14).

However, in the second half of the 18th century one could hardly observe in Continental Europe anything comparable with the explosive growth of major technological inventions that was observed in Britain during this period of time (corresponding to the industrial breakthrough). In the second half of the 18th century Britain became an absolute global technological leader, the main engine of world technological progress. But if we look at Fig. 15, we can clearly see that in the overall picture of the Industrial Revolution this is a relatively short period when Britain had an almost total global superiority in the field of technological innovation, when more technological inventions were made in Britain than in the rest of the world. Already in the first half of the 19th century, a few Western countries managed to catch up with Britain in a very significant way, and by the end of the 19th century the USA, Germany, and France were outperforming Britain. Just because many countries of Continental Europe (as well as the USA) were ready to use those possibilities that were opened by the Industrial Revolution, this revolution was able to produce a world historical effect.

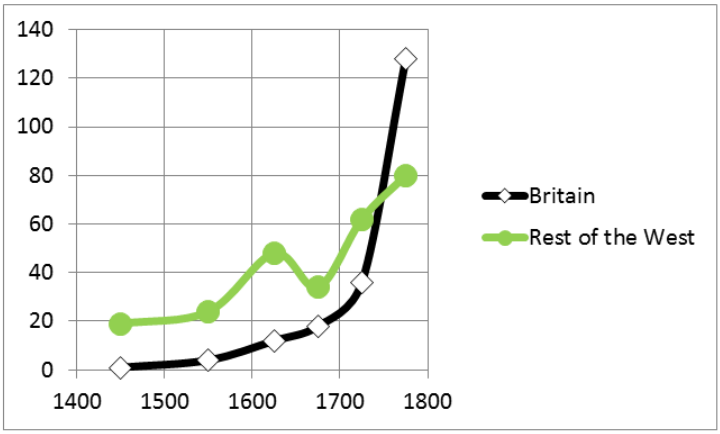

Fig. 14. Comparison of technological innovation rates in Britain and the rest of the West, 1400–1800

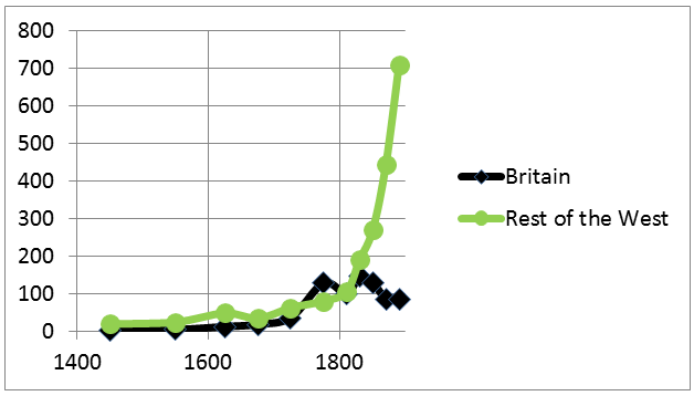

Fig. 15. Comparison of technological innovation rates in Britain and the rest of the West in 1400–1900

So, in conclusion, one can note that the US coming to the first place with respect to technological innovation rates (Fig. 13) meant not only the loss of leadership by Britain, but the fact of the formation of the West in the full modern sense of the word, of the West, which is not isolated only within Western Europe but includes North America, and Central Europe. And it meant the formation of the really well integrated World System.

References

Abu-Lughod J. 1991. *Before European Hegemony*. Oxford, UK: Oxford University Press.

Ali W. 1999. *The Arab Contribution to Islamic Art from the Seventh to the Fifteenth Centuries*. Cairo: The American University of Cairo Press.

Allen R. C. 2009. *The British Industrial Revolution in Global Perspective.* Cambridge: Cambridge University Press.

Allen R. C. 2011. *Global Economic History: A Very Short Introduction*. Oxford: Oxford University Press.

Armytage W. H. G. 1961. *A Social History of Engineering*. London: Faber and Faber.

Arrighi G. 1994. *The Long Twentieth Century. Money, Power and the Origins of Our Times.* London: Verso.

Ballhausen H., and Kleinelümern U. 2008. *Chronik griffbereit: Die wichtigsten Erfindungen der Menschheit: Geniale Ideen, die die Welt veränderten*. Munchen: Wissen Media Verlag GmbH.

Barg M. A. 1993. Introduction. *History of Europe*. In 8 vols. Vol. 3. *From the Middle Ages to the New Age (the End of the 15th – the First Half of the 17th Century*) / Ed. by L. T. Milskaya, and V. I. Rutenburg, pp. 11–15. Moscow: Science. *In Russian* (Барг М. А. Введение. *История Европы:* в 8 т. Т. 3. *От средневековья к новому времени (конец XV – первая половина XVII в.*) / Ред. Л. Т. Мильская, В. И. Рутенбург, с. 11–15. М.: Наука).

Bernal J. D. 1965. *Science in History*. 3rd ed. New York: Hawthorn Books.

Bloch M. 1935. Avènement et conquêtes du moulin à eau. *Annales d'histoire économique et sociale* 7*:* 538–563.

Boxer Ch. R. 1965. *The Dutch Seaborne Empire 1600–1800.* New York, NY: Alfred A. Knopf.

Braudel F. 1973. *Capitalism and Material Life, 1400–1800.* New York, NY: Harper and Row.

Braudel F. 1981–1984. *Civilization and Capitalism, 15th – 18th Century.* 3 vols. New York, NY: Harper and Raw.

Cameron R. 1989. *A Concise Economic History of the World: From Paleolithic Times to the Present*. New York: Oxford University Press.

Carus-Wilson E. 1941. An Industrial Revolution of the Thirteenth Century. *Economic History Review* 11: 39–60.

Challoner J. 2009. *1001 Inventions that Changed the World*. Hauppauge, NY: Barron's.

Chaunu P. 1979. *European Expansion in the Later Middle Ages.* Amsterdam: North Holland Pub. Co.

Christian D. 2004. *Maps of Time: An Introduction to Big History*. Berkeley, CA: University of California Press.

Cipolla C. M. (Ed.) 1972. *The Fontana Economic History of Europe.* Vol. 1. *The Middle Ages.* London: Collins/Fontana.

Cipolla C. M. 1981. *Before the Industrial Revolution. European Society and Economy. 1000–1700.* London.

Clark C. 1968. *Population Growth and Land Use.* New York, NY.

Collins J. B., and Taylor K. L. (Eds.) 2006. *Early Modern Europe. Issues and Interpretations.* Malden, MA: Blackwell.

Crone P. 1989. *Pre-Industrial Societies.* Oxford: Blackwell.

Davies I. N. R. 1996. *Europe: A History*. Oxford: Oxford University Press.

Davies I. N. R. 2001. *Heart of Europe: The Past in Poland's Present.* Oxford: Oxford University Press.

Duijn J. J. van. 1983. *The Long Wave in Economic Life.* Boston, MA: Allen and Unwin.

Durand, J. D. 1960. The Population Statistics of China, A.D. 2–1953. *Population Studies* 13: 209–256.

Ferguson N. 2011. *Civilization: The West and the Rest.* New York: The Penguin Press.

Forbes R. J. 1956. Power. *A History of Technology. The Mediterranean Civilizations and the Middle Ages, c. 700 B.C. to c. A.D. 1500.* Vol. 2 / Ed. by Ch. Singer *et al.*, pp. 601–606. London: Oxford University Press.

Gieysztor A. 1987. Trade and Industry in Eastern Europe before 1200. *The Cambridge Economic History of Europe.* Vol. 2. *Trade and Industry in the Middle Ages* / Ed. by M. M. Postan, and E. Miller, pp. 474–524. Cambridge, MA: Cambridge University Press.

Gille B. 1969. *The Problems of Power and Mechanization. A History of Technology and Invention: Progress through the Ages*. Vol. 1. *The Origins of Technological Civilization* / Ed. by M. Daumas; transl. by E. B. Hennessy. New York, NY: Crown Publishers.

Gimpel J. 1992. *The Medieval Machine: The Industrial Revolution of the Middle Ages.* 2nd ed. London: Pimlico.

Goldstone J. A. 2009. *Why Europe? The Rise of the West in World History. 1500–1850.* New York, NY: McGraw-Hill.

Goldstone J. A. 2012. Divergence in Cultural Trajectories: The Power of the Traditional within the Early Modern. *Comparative Early Modernities 1100–1800* / Ed. by D. Porter, pp. 165–192. New York: Palgrave-Macmillan.

Grinin L. E. 2006. *The Productive Forces and Historical Process.* Moscow: KomKniga. *In Russian* (Гринин Л. Е. *Производительные силы и исторический процесс.* Москва: КомКнига).

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

Grinin L. E. 2011. *State and Historical Process. The Epoch of the State Formation.* Moscow: Izdatelstvo LKI. *In Russian* (Гринин Л. Е. *Государство и исторический процесс. Эпоха формирования государства. Общий контекст социальной эволюции при образовании государства.* Изд. 2-е. М.: Изд-во ЛКИ).

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

Grinin L. E., and Grinin A. L. 2015. *From Bifaces to Nanorobots. The World on the Path to the Epoch of Self-Regulating Systems (History of Technologies and Description of Their*

Future). Moscow: Uchitel. *In Russian* (Гринин Л. Е., Гринин А. Л. *От рубил до нанороботов: мир на пути к эпохе самоуправляемых систем (история технологий и описание их будущего).* Москва: Учитель.

Grinin L. E., and Grinin A. L. 2016. *The Cybernetic Revolution and the Forthcoming Epoch of Self-Regulating Systems.* Volgograd: Uchitel.

Grinin L. E., and Korotayev A. V. 2006. Political Development of the World System: A Formal Quantitative Analysis. *History & Mathematics: Historical Dynamics and Development of Complex Societies* / Ed. by P. Turchin, L. Grinin, V. de Munck, and A. Korotayev, pp. 63–114. Moscow: KomKniga.

Grinin L. E., and Korotayev A. V. 2015. *Great Divergence and Great Convergence. A Global Perspective*. New York, NY: Springer.

Hale J. 1993. *The Civilization of Europe in the Renaissance*. London: Harper Collins.

Haustein H. D., and Neuwirth E. 1982. Long Waves in World Industrial Production, Energy Consumption, Innovations, Inventions, and Patents, and their Identification by Spectral Analysis. *Technological Forecasting and Social Change* 22(1): 53–89.

Hellemans A., and Bunch B. 1988. *The Timetables of Science*. New York, NY: Simon and Schuster.

Hill Ch. 1955. *The English Revolution, 1640.* 3rd ed. London: Lawrence & Wishart.

Huang P. C. C. 2002. Development or Involution in Eighteenth-Century Britain and China? A Review of Kenneth Pomeranz's 'The Great Divergence: China, Europe, and the Making of the Modern World Economy'. *The Journal of Asian Studies* 61(2): 501–538.

Israel J. I. 1995. *The Dutch Republic, Its Rise, Greatness, and Fall. 1477–1806.* Oxford: Clarendon Press.

Johnson A. H. 1955. *Europe in the Sixteenth Century: 1494–1598*. London: Rivingtons.

Jones J. R. 1996. *The Anglo-Dutch Wars of the Seventeenth Century*. London; New York, NY: Longman.

Kondratieff N. D. 1926. Die langen Wellen der Konjunktur. *Archiv für Sozialwissenschaft und Sozialpolitik* 56(3): 573–609.

Kondratieff N. D. 1935. The Long Waves in Economic Life. *Review of Economic Statistics* 17(6): 105–115.

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

Korotayev A. V. 2006. The World System Urbanization Dynamics: A Quantitative Analysis. *History & Mathematics: Historical Dynamics and Development of Complex Societies* / Ed. by P. Turchin, L. Grinin, A. Korotayev, and V. C. de Munck, pp. 44–62. Moscow: KomKniga/URSS.

Korotayev A. V., Malkov A. S., and Khaltourina D. A. 2006. *Introduction to Social Macrodynamics: Compact Macromodels of the World System Growth.* Moscow: KomKniga/URSS.

Landes D. S. 2006. Why Europe and the West? Why Not China? *Journal of Economic Perspectives* 20(2): 3–22.

Li Chen, and Ugurlu Soylu. 2004. Innovations in the Chinese History of Science: Compiled from Joseph Needham's Science and Civilization in China. *Political Competition, Innovation and Growth in the History of Asian Civilizations* / Ed. by P. Bernholz, and R. Vaubel, pp. 91–95. Cheltenham, UK: Edward Elgar.

Lilley S. 1976. Technological Progress and the Industrial Revolution, 1700–1914. *The Industrial Revolution, 1700–1914. The Fontana Economic History of Europe.* Vol. 3 / Ed. by C. M. Cipolla, pp. 187–254. New York, NY: The Harvest Press Limited; Barnes & Noble.

Lucas A. R. 2005. Industrial Milling in the Ancient and Medieval Worlds. A Survey of the Evidence for an Industrial Revolution in Medieval Europe. *Technology and Culture* 46(1): 1–30.

Maddison A. 1991. *Dynamic Forces in Capitalist Development.* New York, NY: Oxford University Press.

Maddison A. 2001. *Monitoring the World Economy: A Millennial Perspective.* Paris: OECD.

Maddison A. 2010. *World Population, GDP and per Capita GDP, A.D. 1–2008*. URL: http://www.ggdc.net/maddison.

McEvedy C., and Jones R. 1978. *Atlas of Population History.* London.

Melyantsev V. A. 1996. The *East and the West in the Second Millennium: Economy, History, and Modernity*. Moscow: Moscow State University. *In Russian* (Мельянцев В. А. *Восток и Запад во втором тысячелетии: экономика, история и современность*. М.: Московский государственный университет).

Milskaya L. T., and Rutenburg V. I. 1991. *History of Europe*. In 8 vols. Vol. 3. *From the Middle Ages to New Age (From the End of the Fifteenth to the Early Seventeenth Centuries)*. Moscow: Nauka. *In Russian* (Мильская Л. Т., Рутенбург В. И. *Исто-рия Европы*: в 8 т. Т. 3. *От средневековья к новому времени (конец XV – первая половина XVII в.).* М.: Наука).

Modelski G. 1987. *Long Cycles in World Politics.* Seattle: University of Washington Press.

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

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

Mumford L. 1934. *Technics and Civilization.* New York, NY: Harcourt, Brace & Co.

Pirenne H. 1920–1932. *Histoire de Belgique.* Vols. 1–7. Bruxelles: H. Lamertin.

Pomeranz K. 2000. *The Great Divergence: China, Europe, and the Making of the Modern World Economy*. Princeton, NJ: Princeton University Press.

Porter D. (Ed.) 2012. *Comparative Early Modernities 1100–1800*. New York: Palgrave-Macmillan.

Postan M. 1987. The Trade of Medieval Europe: The North. *The Cambridge Economic History of Europe.* Vol. 2. *Trade and Industry in the Middle Ages* / Ed. by M. M. Postan, and E. Miller, pp. 168–305. Cambridge: Cambridge University Press.

Rayner R. M. 1964. *European History 1648–1789.* New York: David McKay Company, Inc.

Reinert E. S. 2007. *How Rich Countries Got Rich and Why Poor Countries Stay Poor*. London: Constable.

Rietbergen P. J. A. N. 2002. *A Short History of the Netherlands. From Prehistory to the Present Day*. 5th ed. Amersfoort: Bekking.

Ryzhov K. V. 1999. *One Hundred Great Inventions.* M.: Veche. *In Russian* (Рыжов К. В. *100 великих изобретений*. М.: Вече).

Saliba G. 2007. *Islamic Science and the Making of the European Renaissance*. Cambridge, MA. London: MIT Press.

Silverberg G., and Verspagen B. 2003. Breaking the Waves: A Poisson Regression Approach to Schumpeterian Clustering of Basic Innovations. *Cambridge Journal of Economics* 27(5): 671–693.

Singer C. 1941. *A Short History of Science to the Nineteenth Century*. Oxford: Oxford University Press.

Snooks G. D. 1997. *The Ephemeral Civilization. Exploding the Myth of Social Evolution*. London; New York, NY: Routledge.

Usher A. P. 1954. *A History of Mechanical Inventions*. Cambridge, MA: Harvard University Press.

Vanina E. Yu. 1991. *Medieval Urban Craft of India in the 13th – 18th Centuries.* Moscow: Nauka. *In Russian* (Ванина Е. Ю. *Средневековое городское ремесло Индии 13–18 вв.* М.: Наука).

Vries P. 2013. *Escaping Poverty: The Origins of Modern Economic Growth*. Vienna: W&R Unipress.

Vries J. de, and Woude A. van der. 1997. *The First Modern Economy. Success, Failure, and Perseverance of the Dutch Economy, 1500–1815.* Cambridge: Cambridge University Press.

Wallerstein I. 1974, 1980, 1988. *The Modern World-System*. 3 vols. New York, NY: Academic Press.

White L. Jr. 1978. *Medieval Religion and Technology: Collected Essays.* Berkeley, CA: University of California Press.

Wigelsworth J. R. 2006. *Science and Technology in Medieval European Life*. Westport, CT: Greenwood Publishing Group.

Yastrebitskaya A. L. 1993. *The Material Culture and Life Mode in Europe at the End of Middle Ages. History of Europe*. In 8 vols. Vol. 3. *From the Middle Ages to New Age (From the End of the Fifteenth to the Early Seventeenth Centuries)* / Ed. by L. T. Milskaya, and V. I. Rutenburg, pp. 16–40. Moscow: Nauka. *In Russian* (Ястребицкая А. Л. *Материальная культура и образ жизни в Европе на исходе средневековья. История Европы*: в 8 т. Т. 3. *От средневековья к новому времени (конец XV – первая половина XVII в.*) / Ред. Л. Т. Мильская, В. И. Рутенбург, с. 16–40. М.: Наука).

Zhao Wenlin and Xie Shujun-zhu. 1988. *History of Chinese Population*. Peking: People's Publisher (in Chinese).