Part 2. Knowledge and human development

Chapter 5. Accumulation of knowledge by mankind

5.1. Knowledge turnover cycle

The role of a certain factor in a system depends on what system it is an element of and what functions it fulfills in it. Figure 2.2 represents the system diagram of knowledge-based human development. To draw attention directly to the knowledge turnover cycle, this diagram is transformed into the one represented in figure 5.1. It surely gives far from all the links. For example, very important are links between R&D and industry or between industry and learning, however this figure represents just major flows of knowledge and investments (dotted lines).

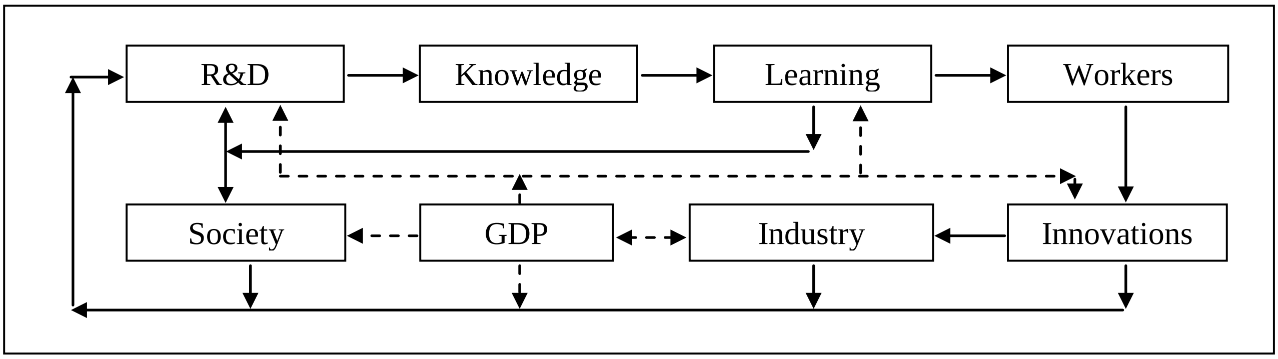

Fig. 5.1. Knowledge turnover cycle

In chapter 3, I considered interrelation between the global population and GDP per capita. Now I want to investigate whether there is interrelation between population growth and knowledge or another related to knowledge factor such as state of technology as suggested by some authors.

However usefulness of such a factor as the state of technology is questionable since it is not directly measurable and can be assessed solely through its effect, for example lower death rate or GDP per capita (G/N). The way such ratios are introduced is far from evident. The G/N ratio is used because it is a common parameter to describe economic development of mankind. And it depends heavily on the market situation, i.e. demand, international competition and price level.

As it is evident from the above (see fig. 4.4), intensity of innovation activity depends heavily on the stage of a technology revolution whereas global population and GDP evolve quite monotonely (within a middle-term period of about decades). So it would be helpful to identify a more monotone indicator of activity intensity for the cycle shown in figure 5.1. And it is essential to detect information that affects human development as an integrated system and feeds innovation, industry, science and higher standard of life. Also important is that knowledge should be easily shared across the world and generate increase in global output. So it is reasonable to focus on codified information.

5.2. Knowledge accumulation over time

Prior to the demographic transition, information was mainly stored in hard copies so the amount of knowledge accumulated in that period is normally assessed by the amount of books published. Only information that explicitly contributes to improving global GDP will be considered. I suggest using data on the amount of books, booklets and newspapers in the Library of Congress[121, 122, 123] as three reference points; in 1960 this amount was about 14.5 mn books and booklets, in 2000 – 30 mn and in 2012 – 35.8 mn (Table 5.1).

Table 5.1. Collection of the Library of Congress

Item, mn	**1960**	**2000**	**2012**
Books and booklets	14.5	30	35.8
Volumes of backed newspapers	1.32	> 1	
Handwritten materials	29	58	68
US Government publications		> 1	
Music books and literature	3.3		6.6
Geographic maps	3	4.8	5.5
Photos		12	
Audio records		2.7	3.4
Microfilms		0.5	16.7
Totally items		130	155
Length of shelves, km		850	
Digitized amount, gig		18,000	

Evidently, the Library of Congress stores global knowledge not in full, however it is the today's largest repository of knowledge. Furthermore, it keeps duplications. So its collection may to a certain extent be deemed to represent the total human knowledge. To measure knowledge I will use the term of a conditional book (c.b.) introduced in section 2.2. In c.b. terms, the total collection of the Library of Congress (see Table 5.1) equals: 18 mn c.b. in 2000, in 1960 – twice as little, i.e. 9 mn c.b., and 21.5 mn c.b. in 2012.

My forth reference point will be the Alexandrian Library which was established in about 300 B.C. and its collection comprised from 100,000 to 700,000 scrolls[124]. Noting the assumed content per a scroll, the amount of knowledge per scroll is estimated to be 1/5 c.b. The Alexandrian Library surely did not contain the total human knowledge, however its collection was close to this, so let's take that it stored the total human knowledge of that time that is ~ 80,000 c.b.

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[121] Ушаков К. Хранилище вечности // CIO. – 2007. – №7.
[122] Библиотека конгресса. – Википедия, 2012. http://ru.wikipedia.org/wiki.
[123] General Information – About the Library (Library of Congress). 2012. http://www.loc.gov/about/general-information
[124] Советский энциклопедический словарь. – М., 1987.

And the final reference point will be the origin time of mankind that is dated back to 1.6 mn years ago when population numbered about 100,000. Since people were not separated by professions that time, total human knowledge may be estimated by the amount of neuronal memory of an individual who is developed better than a chimpanzee and worse than a modern individual, i.e. ~ 20 c.b.[125]. The proposed estimation of the amount of knowledge and its interrelation with population growth is represented in Table 5.2.

Table 5.2. Amount of human knowledge

Assessed object (library)	Year of CE	Global population, mn	Knowledge, ths. c.b.	Knowledge in c.b. per ths. of people
Library of Congress	2012	7,000	21,500	3.07
Library of Congress	2000	6,000	18,000	3.00
Library of Congress	1960	3,077	9,000	2.92
Alexandrian Library	–300	86	80	0.93
Originating mankind	–1,600,000	0.1	0.02	0.20

Table 5.2 shows the amount of knowledge per person changes relatively slow in time. So population is the key parameter affecting the amount of human knowledge **Z**, i.e. **Z ~ N.** Hence global knowledge may be approximated a hyperbola-type formula[126]

$$\mathbf{Z \approx 1{,}5 \cdot 10^9 / (2025 - T)^{1{,}25}}. \qquad (5.1)$$

Formula (5.1) is true for the period of the hyperbolic population growth (up to 1960 and to some extent to 1975). Noting formula (1.1), the correct expression for the amount of knowledge covering the period of the demographic transition will be as follows[127],

$$\mathbf{Z \approx Z_0 \cdot (N/N_0)^{1{,}25} = 20 \cdot (N/N_0)^{1{,}25}} \qquad (5.2)$$

(here $\mathbf{N_0}$ = 100,000 is a conditional figure for the initial population[128]). Approximation error of formula (5.2) as to the human knowledge from Table 5.2 is less than 10% for the last hundred years and is less than 16% for the year 300 B.C. (Table 5.3).

Figure 5.2 represents, in double logarithmic scale, the relationship between human knowledge in c.b. according to formulas (5.1) and (5.2) and technology revolution dates according to formula (4.1).

Squares in figure 5.2 mark the reference points used for estimating the amount of knowledge (see Table 5.2). Note that the point for year 2012 is conditional since dates of technology revolutions after 1978 are calculated at low accuracy.

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125 Анисимов В.А. О законе возрастания сложности эволюционирующих систем, или Что день грядущий нам готовит. www.yugzone.ru/articles/438, 2006.

126 Орехов В. Д. Знания в системе развития общества // Бизнес-образование, РАБО. – 2010. – №28. – С. 77.

127 Орехов В. Д. Прогнозирование в сложном окружении // XIV-й всеросс. симпоз.: «Стратегическое планирование и развитие предприятий». – М., 2013. – №5. – С. 108.

128 Капица С. П. Парадоксы роста: законы глобального развития человечества. – М., 2012. – С. 42.

Table 5.3. Human knowledge approximation

Assessed object (library)	Year	Z, ths. c.b.	Z, ths. c.b., acc. to f-a (5.1)	Error of (5.1)	Pop., mn	Z, ths. c.b. acc. to f-a (5.2)	Error of (5.2)
Congress	2012	21,500			7,000	22,772	6%
Congress	2000	18,000	26,833	49%	6,073	19,067	6%
Congress	1960	9,000	8,127	-10%	3,039	8,025	–11%
Alexandrian	–300	80	93	16%	86	93	16%
Originating mankind	–1,600,000	0.02	0.026	32%	0.1	0.020	0%

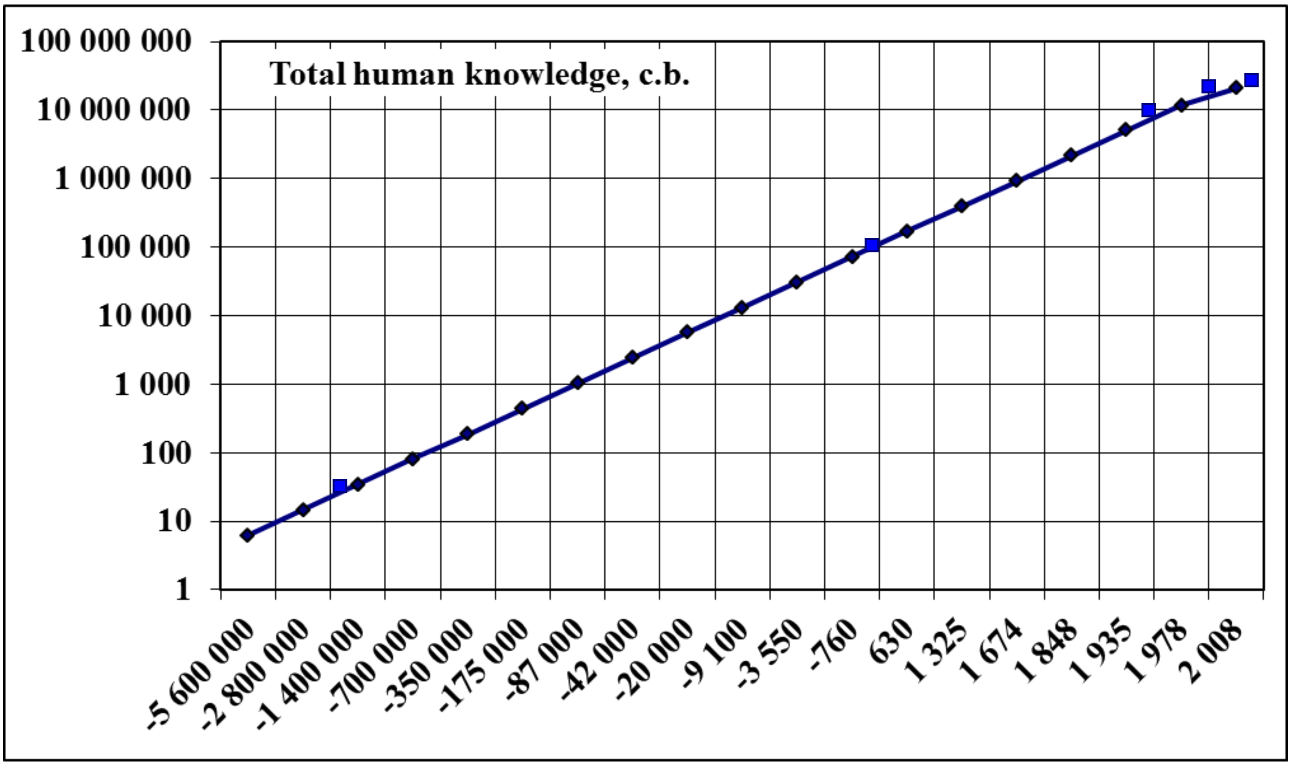

Fig. 5.2. Human knowledge in different technology epochs

In the double logarithmic scale the hyperbola (5.1) is a straight line and fixed with minimum two points it goes through. There are three reference points in the hyperbolic growth area and they fit well this line; this proves the data on knowledge in different periods are consistent. Amount of knowledge in previous epochs is calculated at rather low accuracy, however noting that the function is represented by a straight line in the double logarithmic scale an error of about 100% affects little the equation of the straight line with the hyperbola coefficient depending on all the reference points used and this reduces the error of calculations.

The derived formulas for the amount of human knowledge (5.1) and (5.2) provide an estimation of magnitude, nevertheless they prove that the amount of knowledge depends mainly on population number and correspondingly on the certain time in the period of the hyperbolic growth.

Also there is a coefficient which links accumulation of knowledge with human brain improvement. Formula (5.2) shows knowledge enriches not proportionally to population growth but more rapidly – to the power 1.25. This index raised by **0.25** represents the pace at which human mental abilities and relevant available tools are enriched in time. According to formula (1.1) global population grew by 70,000 since its origin whereas human mental abilities to generate knowledge increased by about the fourth root of this number, i.e. by 16 times. The size of human brain roughly doubled over this period while the part of brain responsible for higher mental and thinking functions enlarged much more. Moreover, its efficiency including its tools such as verbal and writing abilities also improved. Obviously information technology may further improve human efficiency as a knowledge generator, however many authors doubt this.

This result differs essentially from the ideas put forward by M. Kremer and other authors who believe mental productivity of people who create technology is proportional to the current technology level, i.e. varies over time noticeably.

5.3. Why knowledge amount is proportional to population

The derived function (5.2) reflects close interrelation between knowledge and population amounts, the fact that is far from evident and it is important to understand reasons behind this relationship. Let's consider some hypotheses.

1. O*wners of knowledge*. According to UNESCO[129], the number of scientists (specialists involved in R&D) in the world in 2007 equaled to 7,100,000 people. Knowledge amount that time, according to formula (5.2), equaled to ~ 21,000,000 c.b. that means about three conditional books of knowledge per scientist. To estimate the order of magnitude, let's assume that a scientist has a good command of and applies during his/her fruitful years the knowledge contained in about 50 c.b. half of which is popular universal knowledge and 25 c.b. contain unique knowledge, hence each book of unique knowledge is used by about eight scientists. Noting that scientists speak different languages, let's introduce a language barrier index which equals to ~ 4 (conditionally: English, Chinese, Spanish and one of the European). So there are only about two scientists and authors not separated by a huge language barrier per book of knowledge. Evidently it is precious insufficient.

Nevertheless the current proportion between R&D specialists and global population which in 2007 equaled to about 0.11% is an objective figure featuring the system of creation and application of human knowledge. Therefore it is only increased population that could raise the amount of knowledge. Surely in the past epochs, R&D specialists were not

[129] Пресс-коммюнике ЮНЕСКО № 2009-139. – Стат. ин-т ЮНЕСКО (ISU), 2009.

distinguished so evidently; anyway the number of people who then contributed to knowledge was also very little.

2. *Financing R&D.* Financing research and development is limited. In 2002-2007, just 1.71 – 1.74% of global GDP was allocated to R&D[130]. So about 16 people work to provide financing one scientist and to change this index globally is a challenging task. Hence it is increased population that could raise financing R&D.

3. *Generating knowledge (number of scientists).* Capacity to generate knowledge also depends on the number of scientists and correspondingly on population. For example, Scopus database[131] registered 1,070,000 publications in 2007, i.e. 0.15 publications per R&D specialist. Assuming that a publication comprises 15 pages (~15% of c.b.), the publication activity of an average scientist will be $\Delta P_{S1} \approx 2.26\%$ of c.b. per annum and totally $\Delta P_S \approx 90\%$ of c.b. throughout their fruitful life (about 40 years). The total amount of knowledge generated by a scientist will be $\Delta Z_{S1} \approx 6.8\%$ per annum or $\Delta Z_S \approx 2.7$ c.b. throughout their work life. Within their life-span, the today's corps of scientists will produce about $\Delta P \approx 6{,}400{,}000$ c.b. registered in Scopus and about $\Delta Z \approx 19{,}000{,}000$ c.b. of total knowledge. So the today's scientists' productivity in generating knowledge is close to the currently available knowledge (note that I do not consider the knowledge obsolescence factor and decommission of this knowledge that is acceptable when estimating the order of magnitude under rapid knowledge accumulation though it should be involved in fact). Anyway, the factor of productivity of a knowledge generating system obviously may noticeably affect the ratio between knowledge and population.

4. *Number of professions*. To implement globally the newly acquired knowledge, professional communities should be established in each field. The author[132] puts forward a hypothesis that the number of such professions ($\mathbf{N_P}$) in the world equals to the number of people divided by the conditional initial population $\mathbf{N_0}$ = 100,000.

$$\mathbf{N_P = N/N_0.} \qquad (5.3)$$

According to this hypothesis, currently there are about 70,000 professions in the world and the amount of knowledge per profession equals to 325 c.b. It is an approximate amount of knowledge an individual is able to keep in their professional view but not to know in details.

The indicated number of professions is close to reality. For example, in 1994 the All-Russian Occupational Classification[133] comprised about 10,000 professions, however it

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130 Ibid.

131 Scopus abstract database

132 Анисимов В.А. О законе возрастания сложности эволюционирующих систем, или Что день грядущий нам готовит. – 2006.

133 Общероссийский классификатор профессий рабочих, должностей служащих и тарифных разрядов // Госстандарт России. – 1994. – №367.

included most knowledge intensive IT and biotechnology ones at minimum. It is because professions are included to the Classification with time delay and far from everyone science fields are developed in Russia.

Noting this classification of professions, each of them involves about 100 R&D specialists with 25 of them per language group mentioned above. Probably, it is the requirement to the number of R&D specialists per creative group that actually determines the size of a professional group being as large as 100,000 people.

5. *Number of inventors and innovators*. Some authors (J.A. Schumpeter, A.V. Podlazov, M. Kremer) believe progress in technology (P) depends on developments made by lucky and quick-witted people number of which is the larger the larger population (1.6). Since community considers essential and adopts the knowledge that is actually used in true innovations and output of public goods, the amount of knowledge and the amount of people should be interrelated.

Thus there should be a range of factors that relate the amount of knowledge with the amount of people (see Table 4.5). They may be taken as hypotheses as yet, however this does not belittle significance of the derived above empiric result on the interrelation between the amounts of knowledge and people.

Table 5.4. Hypotheses about reasons behind interrelation between amounts of knowledge and people

Reason	Start point	Essential parameter
1. Proportion between 'owners of knowledge' and population	In 2007, there were 21 mn c.b. per 7.1 mn involved in R&D	Each book of knowledge is in possession of about two R&D specialists not separated by language barrier.
2. Financing R&D is proportional to population	In 2002–2007, R&D financing accounted for an average of 1.71 – 1.74% of global GDP	About 16 people work to provide for financing of one researcher.
3. Number of scientists is proportional to the global population	In 2007, 7.1 mn people were involved in R&D with 0.15 publications in Scopus per person that means ~ 2.2% of c.b.	R&D specialists account for ~ 0.11% of population
4. Number of professions required to implement knowledge globally is proportional to population	There are ~ 70,000 professions in the world; amount of knowledge per profession equals to 325 c.b.	Number of R&D specialists per profession is ~ 25 people not separated by language barrier
5. Number of innovations is proportional to population	According to some authors (J.A. Schumpeter, A.V. Podlazov, M. Kremer), progress in technology (P) depends on developments made by lucky and quick-witted people number of which is the larger the larger population: $dP/dT = PN/C$ (1.6)	

Reasons 1, 3 and 4 seem to be more important (numbers of knowledge owners, knowledge generators and professions) however other factors also matter as their advocates attest.

5.4. Interrelation between amount of knowledge and publication activity

Despite its somewhat inaccuracy, the approach to counting human knowledge described above (see Table 5.1) allows to view the whole picture of how people accumulated knowledge throughout the history of mankind and to avoid the effect of applying IT to knowledge estimation. Anyway the amount of knowledge stored in the Library of Congress in 2012 fits well the general law though IT was widely applied that time. It is not improbable that a noticeable amount of knowledge was not counted in 2012. Now more accurate data on the knowledge enrichment are available that might be used to detail the picture as a whole.

The annual knowledge augmentation ΔZ may be estimated with formulas (5.1) and (5.2) and by the annual amount of publications and patents registered globally ΔP as well. The latter items do not comprise a comprehensive source of knowledge but provide a source of knowledge which is carefully fixed and is not duplicated. Figure 1.11 shows the time dependence of the number of publications in the world and figure 5.3, of the number of patents registered annually[134] (in millions). To avoid duplication, the figure gives the number of patents granted to solely residents.

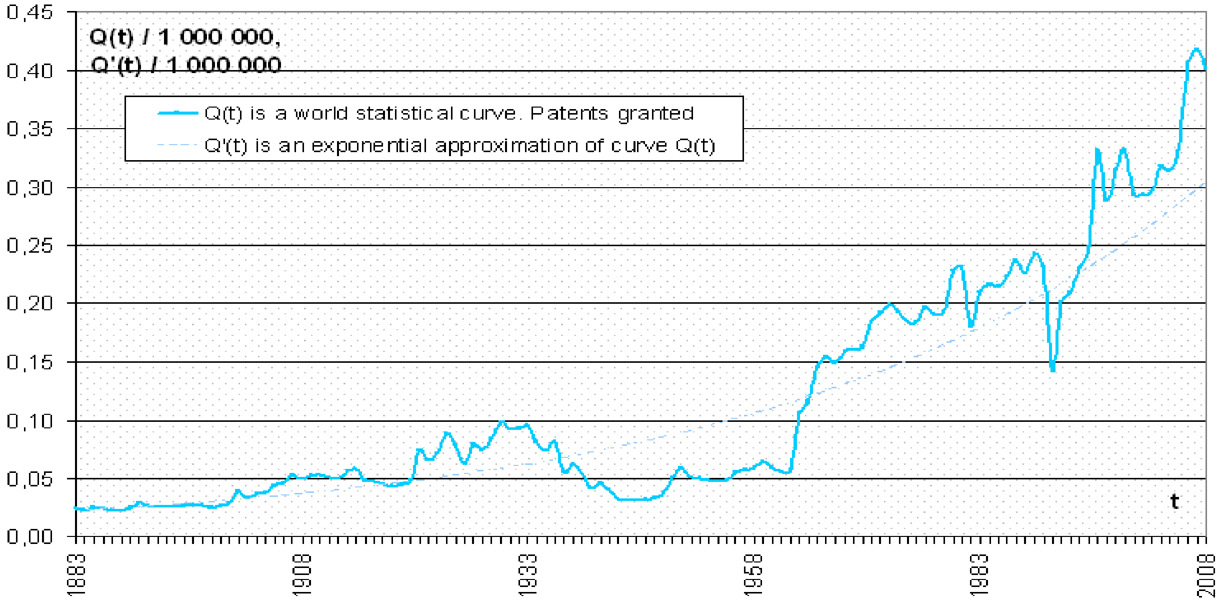

Figure 5.3. Number of patents granted in the world annually (mn/year)

Dynamics of publishing activity and granting patents (fig. 5.4) prove their numbers depend on time differently. Up to 1946, the number of patents is more than of publications whereas later the number of publications is two-three times as many as the number of patents. It may be because patents started to be registered accurately earlier than other types of publications.

[134] Cited from: Немцов Э. Ф. Человечество становится всё изобретательнее. – 2011.

At the same time Scopus presents about 25,000,000 patents[135]. Starting from 1949 when Scopus observed a sharp rise of publications, about 28,000,000 patents have been granted in the world. So up to this date patents seem to be included on Scopus in a limited way and afterwards, quite comprehensively. That is why estimation of the total augmentation of publications and patents ΔP(T) prior to 1949 sums up data on the number of publications and patents from Scopus and starting from 1949, uses data from Scopus solely.

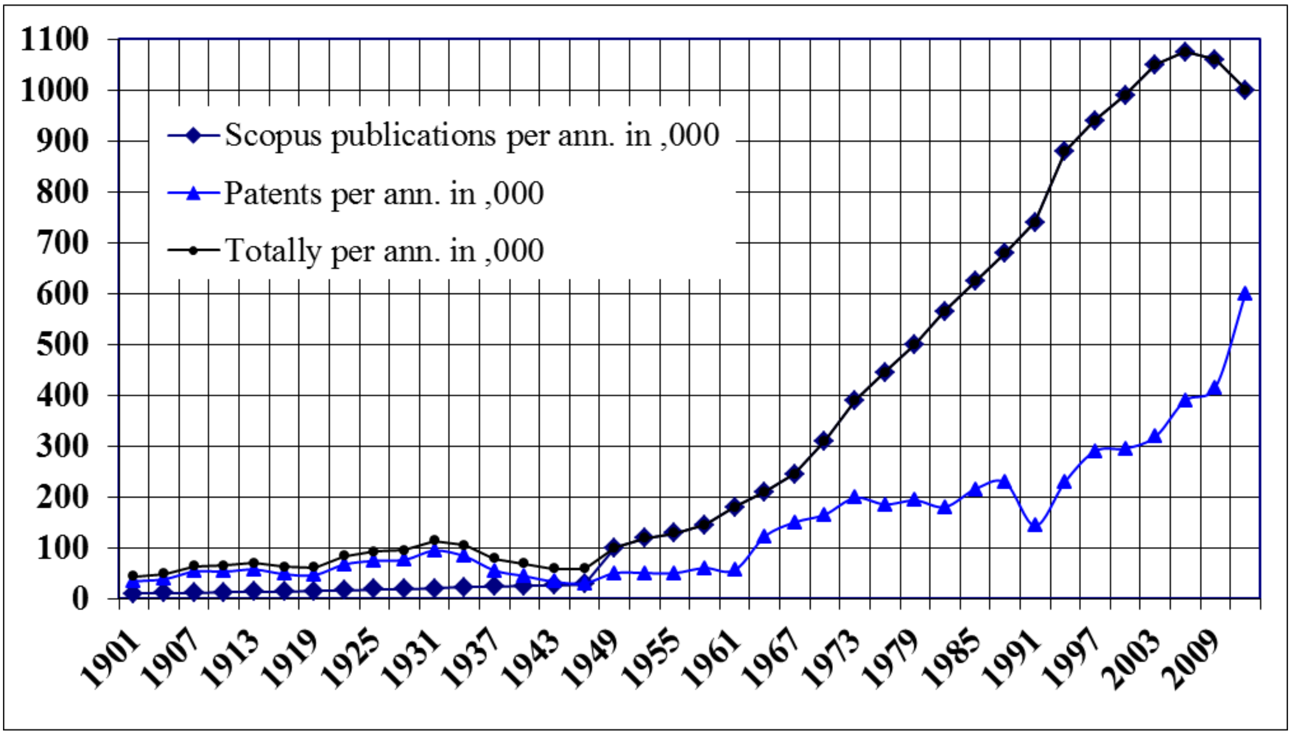

Figure 5.4. Annual augmentation of patent and publication numbers in the world

To allow comparison of functions ΔZ(T) and ΔP(T), I assume that any publication from Scopus (see fig. 1.11) or any patent (see fig. 5.3) comprises 15% of c.b. To calculate knowledge augmentation ΔZ up to 1975 I use the hyperbolic formula (5.1) and in the later period, formula (5.2) and statistic data on global population from S.P. Kapitsa's work[136] with linear interpolation between these figures.

Figure 5.5 compares human knowledge augmentation ΔZ(T) calculated with formulas (5.1) and (5.2) and publication and patent augmentation ΔP(T). The number of publications and patents is evidently less than a half of the calculated amount of knowledge. Both curves come to a plateau though there is a time shift of about 25 – 30 years between the calculated curve and Scopus data on publications. This means that formulas (5.1) and (5.2) should engage a time delay between augmentations of knowledge and population.

135 Scopus abstract database
136 Капица С. П. Парадоксы роста: законы глобального развития человечества. – М., 2012. – С. 69.

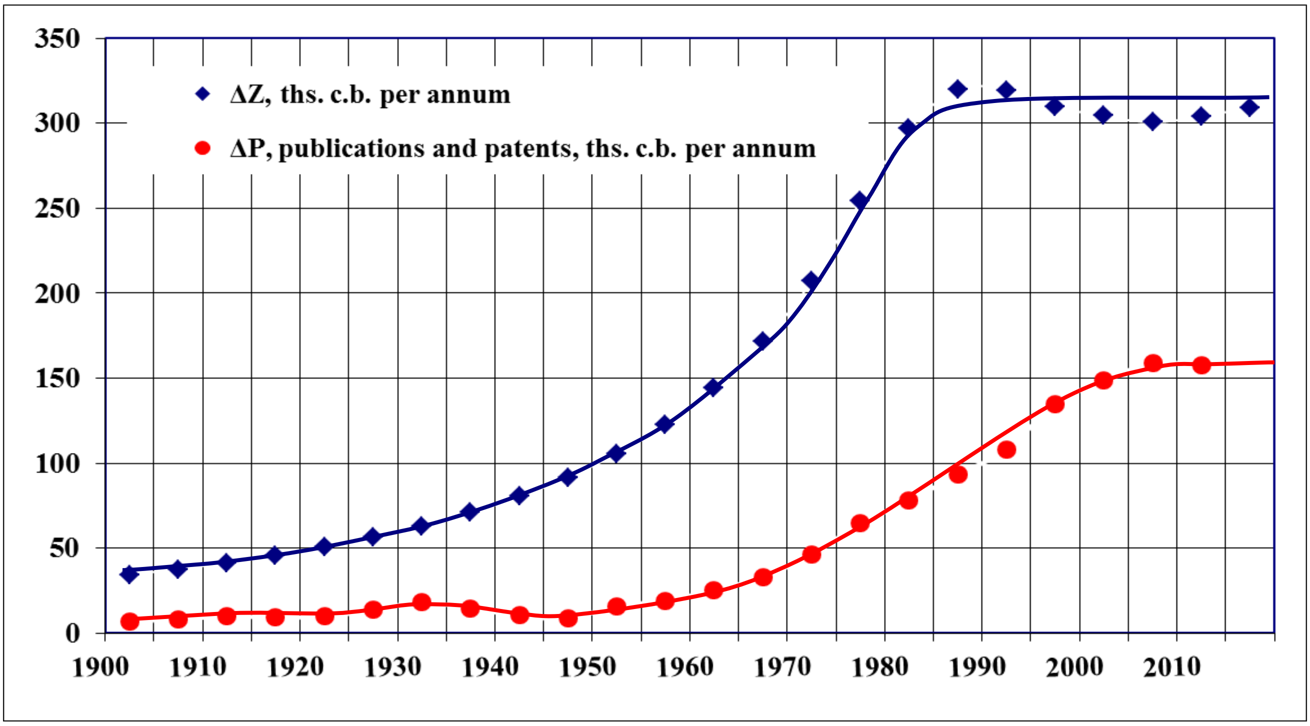

Figure 5.5.Annual augmentation of knowledge and publications and patents

To simplify calculations, formulas (5.1) and (5.2) may use population figures from the period that is 25 years earlier N(T–25) and the numerical coefficient increased by 1.5 correspondingly. Then these formulas will be as follows:

$$\mathbf{Z \approx 2{,}25 \cdot 10^{9} / (2050 - T)^{1{,}25};} \quad (5.4)$$

$$\mathbf{Z \approx 30 \cdot (N(T-25)/N_0)^{1{,}25}.} \quad (5.5)$$

Figure 5.6 compares approximation formulas (5.1) and (5.4) for the amount of knowledge, it also shows reference points from Table 5.2 for the last hundred years.

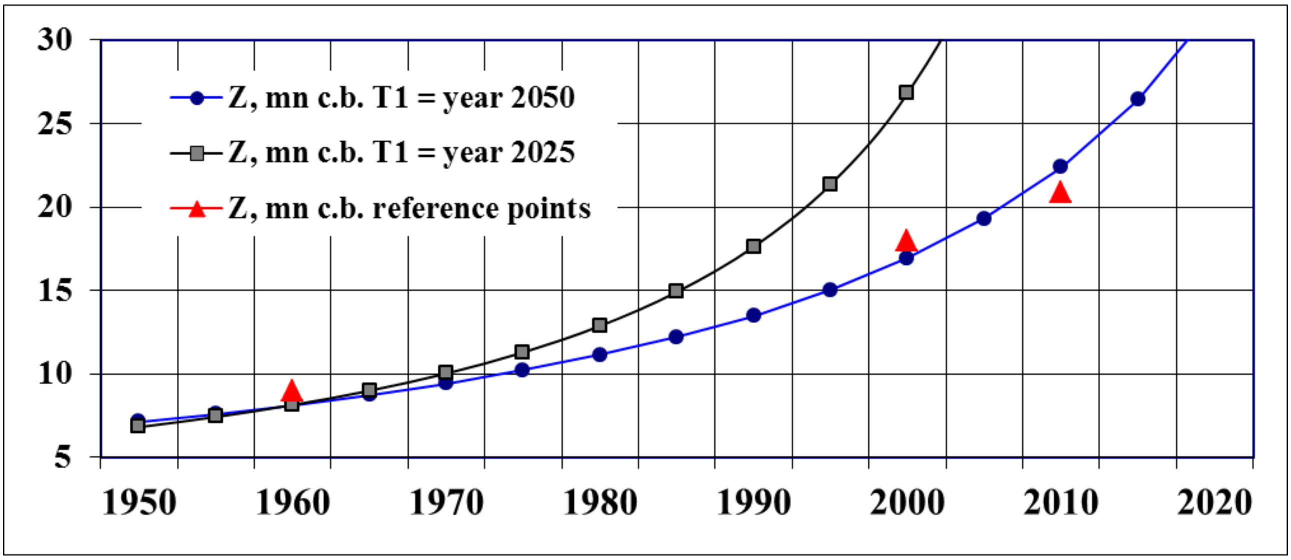

Figure 5.6. Comparison of approximation formulas (5.1) and (5.4)

Formula (5.4) approximates reference points in the demographic transition period evidently much better than formula (5.1). Note also that due to the 25-year time shift the hyperbolic area and hence the applicability scope of formula (5.4) spreads up to year 2000 and even further.

Table 5.5 represents error of formulas (5.4) and (5.5) in different periods. Formula (5.5) appears to approximate reference points better after 1960 and worse in far past periods (Table 5.5).

Table 5.5.Error of formulas for calculating the amount of human knowledge

Estimated object (library)	Year	Z, ths. c.b.	Z, ths. f-la (5.4)	Error, f-la (5.4)	Popul. (T–25), mn	Z, ths., f-la (5.5)	Error, f-la (5.5)
Congress	2012	21,500	23,848	11%	5,020	22,542	5%
Congress	2000	18,000	16,923	–6%	4,086	17,428	–3%
Congress	1960	9,000	8,117	–10%	2,157	7,842	–13%
Alexandrian	–300	80	138	72%	85	138	73%
Originating mankind	$-16 \cdot 10^5$	0.02	0.04	97%	0.1	0.03	50%

Should applicability of formula (5.4) be restricted, its accuracy in the period from 1950 to 2005 may be improved by raising its coefficient from 2.25 to 2.4. Such approach is valid because this formula is more simple than formula (5.5) and does not require population figures.

Figure 5.7 compares formulas (5.2) and (5.5) and proves that in this certain time period both of them approximate the reference points on the amount of knowledge much the same with formula (5.2) being even a bit more accurate near year 1960.

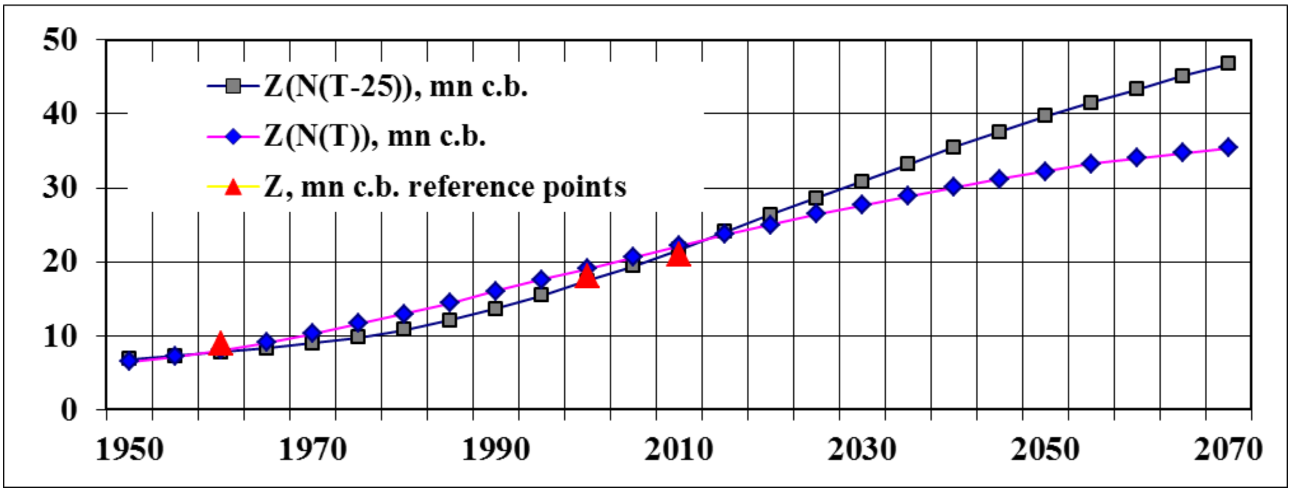

Figure 5.7. Comparison of approximation formulas (5.2) and (5.5)

According to formula (5.5), knowledge accumulates more slowly near 1975 that reflects reduced postwar population and respectively more rapid accumulation after 1990 that reflects postwar rapid population growth. Important is that formula (5.4) gives noticeably larger knowledge augmentation after 2015 than formula (5.2) does.

Figure 5.8 compares knowledge augmentation ΔZ(T) calculated with formulas (5.4) and (5.5) and publication augmentation including patents ΔP(T). For the purpose of convenience, here shown is the tripled ΔP(T).

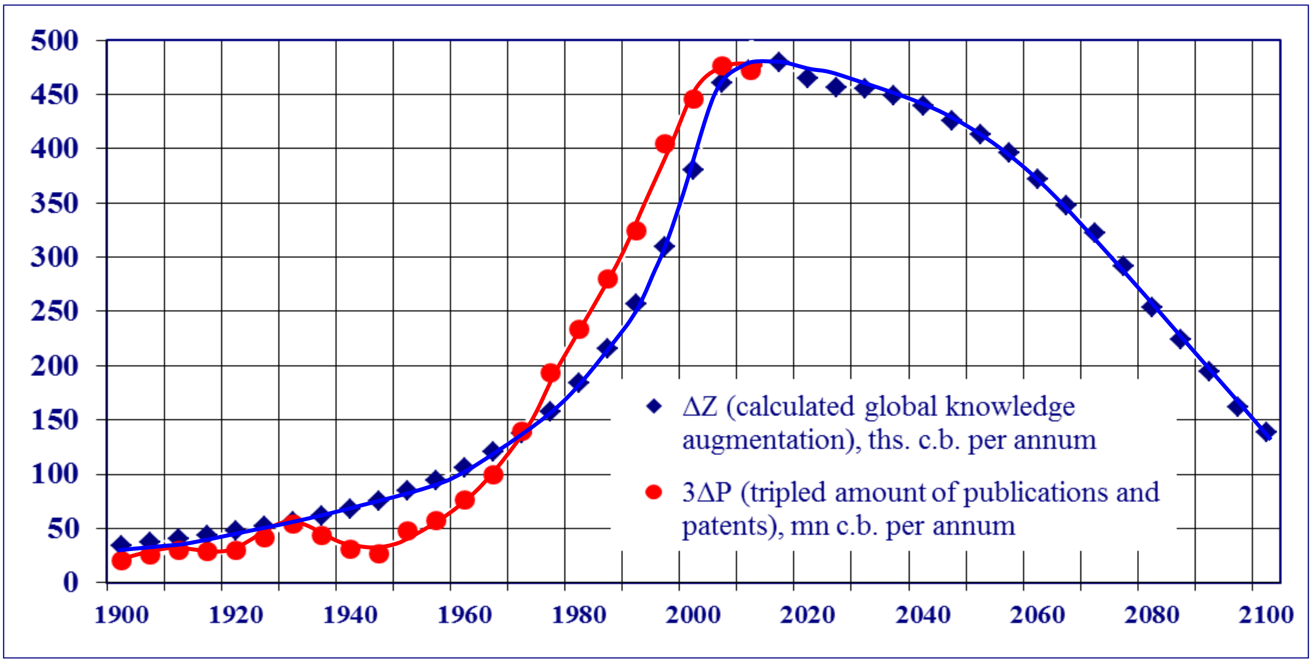

Figure 5.8.Comparison of estimate knowledge augmentation and amount of publications

Figure 5.8 shows curves ΔZ(T) and ΔP(T) are quite similar and they both reach their plateaus almost simultaneously. Amount of publications differs noticeably from the estimate knowledge augmentation during world wars, especially in 1940-1945. After 2020 knowledge augmentation decreases rather rapidly because of the demographic transition and slower global population growth.

Currently the following figures feature knowledge augmentation. In 2010 with population of about 6,800,000,000 and its augmentation ΔN ≈ 74 mn per annum according to formula (5.5) the amount of knowledge is Z ≈ 21.6 mn c.b. and the knowledge augmentation is ΔZ ≈ 470,000 c.b. Of the total amount of knowledge, 17,500,000 c.b. or 81% were published since the beginning of 20-th century. Nowadays the augmentation is 2.2% per annum.

In 2010, Scopus fixed 1,050,000 publications including 550,000 patents granted to residents[137]; this gives publication augmentation ΔP = 158,000 c.b. or 1/3 of knowledge augmentation ΔZ. Such a deviation between these data is quite acceptable since there is a lot

137 Scopus abstract database.

of other types of knowledge that are fixed less accurately than articles and patents. For example, Scopus keeps 376,000,000 research indexed web-pages[138].

So the initially applied approach to estimating human knowledge may be deemed appropriate as to the amount of publications including patents.

5.5. Links between technology revolutions and knowledge enrichment

Expressions presented above for estimating population N and the relevant amount of knowledge Z allow to estimate these values in different technology revolutions from Table 4.2 and discover laws governing their variations[139, 140]. Table 5.6 presents these data calculated using expressions (1.1), (5.1) and (5.2).

In the periods between technology revolutions population appears to grow by about 1.41 and the knowledge – by 1.54. Up to the demographic transition, a deviation from this pattern is no more than 0.01 with this error stemming from using years in integer values.

So there is an interesting and presumably a fundamental law that states that augmentations of knowledge and population between technology revolutions are governed by constant coefficients.

Table 5.6. Figures featuring technology epochs

Year	Technology revolution (epoch)	N, bil.	Z, mn c.b.	Growth of Z, by times	Growth of N, by times
52	Beginning of Christian epoch	0.10	0.11	1.54	1.41
630	**Feudal**	0.14	0.18	1.54	1.41
1038	Indicator of the Craft	0.20	0.27	1.54	1.41
1325	**The Craft** (proto-Renaissance)	0.29	0.42	1.54	1.41
1530	Renaissance	0.40	0.64	1.54	1.41
1674	**Classic science**	0.57	1.0	1.54	1.41
1776	First Industrial	0.80	1.5	1.54	1.41
1848	**Second Industrial**	1.13	2.3	1.53	1.41
1899	Indicator of S&T Revolution	1.59	3.6	1.53	1.40
1935	**The Science & Technology**	2.22	5.4	1.52	1.40
1961	Postindustrial	3.13	8.3	1.53	1.41
1979	**Cybernetic**	4.38	12.7	1.53	1.40
2005	Indicator of the Biotechnology	6.45	20.6	1.62	1.47
2040	**The Biotechnology**	8.74	30.0	1.46	1.35

To calculate dates of future technology revolutions more accurately, I will calculate relevant amounts of knowledge with formulas (5.4) and (5.5). I will assume also that

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138 Scopus. Content Coverage Guide, 2013. http://cdn.elsevier.com/assets/pdf_file/0019/148402/contentcoverageguide-jan-2013.pdf

139 Орехов В. Д. Знания в системе развития общества//Бизнес-образование, РАБО. – 2010. – №28 – С. 78.

140 Орехов В.Д. О парной взаимосвязи длинных волн: Тр. XV междунар. научн.-практ. конф. «Качество дистанционного образования: концепции, проблемы, решения». – М., 2013. – С. 165.

knowledge augments by a constant coefficient in the periods between two adjacent revolutions. The mean dates of technology revolutions from Table 4.1 will be reference points. The obtained sequence of dates of revolutions is shown in Table 5.7. For the purpose of comparison, the last column shows the averaged anticipated dates of technology revolutions from Table 4.1.

Table 5.7. More accurate figures featuring technology epochs in the 20-th - 21-st centuries

<table>
<tr><th>Year</th><th>Technology revolution (epoch)</th><th>N, bil.</th><th>Z, mn c.b.</th><th>Growth of Z, by times</th><th>Growth of N, by times</th><th>Year, table 4.1</th></tr>
<tr><td>1342</td><td>The CraftP (proto-Renaissance)</td><td>0.29</td><td>0.62</td><td>1.47</td><td>1.38</td><td>1330</td></tr>
<tr><td>1531</td><td>Renaissance</td><td>0.40</td><td>0.91</td><td>1.47</td><td>1.38</td><td>1500</td></tr>
<tr><td>1668</td><td>Classic science</td><td>0.56</td><td>1.33</td><td>1.47</td><td>1.38</td><td>1670</td></tr>
<tr><td>1770</td><td>First Industrial</td><td>0.78</td><td>1.96</td><td>1.47</td><td>1.40</td><td>1770</td></tr>
<tr><td>1844</td><td>Second Industrial</td><td>1.1</td><td>2.88</td><td>1.47</td><td>1.41</td><td>1845</td></tr>
<tr><td>1899</td><td>Indicator of S&T Revolution</td><td>1.59</td><td>4.25</td><td>1.47</td><td>1.44</td><td>1890</td></tr>
<tr><td>1939</td><td>The Science & Technology</td><td>2.33</td><td>6.24</td><td>1.47</td><td>1.47</td><td>1940</td></tr>
<tr><td>1968</td><td>Postindustrial</td><td>3.54</td><td>9.19</td><td>1.47</td><td>1.52</td><td rowspan="2">1980</td></tr>
<tr><td>1990</td><td>Cybernetic</td><td>5.25</td><td>13.5</td><td>1.47</td><td>1.48</td></tr>
<tr><td>2006</td><td>Indicator of the Biotechnology</td><td>6.53</td><td>19.8</td><td>1.47</td><td>1.24</td><td>2010</td></tr>
<tr><td>2026</td><td>The Biotechnology</td><td>7.97</td><td>29.2</td><td>1.47</td><td>1.22</td><td rowspan="2">2045</td></tr>
<tr><td>2059</td><td>Indicator of the knowledge revolution</td><td>9.80</td><td>42.9</td><td>1.47</td><td>1.23</td></tr>
</table>

Compared with the results from the hyperbolic formulas (5.1) and (5.2) (see Table 5.6) the knowledge augmentation between revolutions explicitly decreases from 1.54 to 1.47, i.e. by about 10%. Revolution dates within the hyperbolic domain are quite close to those indicated in Table 4.1 and do not differ noticeably from those indicated in Table 5.6. The Cybernetic revolution date shifts from 1980 to 1990 that fits the reality better noting that the Cybernetic revolution is two-stage (indicator and principal).

The date of the Biotechnology revolution-indicator shifts to 2006 that fits the actual beginning of the last crisis with accuracy of two years.

Note the burst of population augmentation from 1.4 to 1.52 near 1968 that should have been to meet the requirement of a permanent knowledge augmentation between the dates of revolutions. This burst occurs because the global population augmentation achieves its maximum by the beginning of the demographic transition whereas knowledge is generated by a relatively small post-war generation that was born 25 years earlier.

The date of the biotechnology revolution from Table 5.6 is amended most noticeably and is shifted closer to nowadays (to 2026). The reason is that population grew fast in 1980-2000 and 25-30 years later this generation will enter their working and creative age and will contribute weighty to the fast knowledge augmentation and future human knowledge.

However implementation of biotechnological developments may be postponed because new pharmaceuticals must undergo long tests before their introduction; moreover, there arise ethic issues concerning implementation of some biotechnological developments and their interfering with traditional law norms. Mass use of biotechnology also raises reasonable apprehension as to whether it would be safe that also may postpone its introduction to business practice.

Another problem is that mass use of biotechnology requires a lot of specialists in relevant fields to be trained however education seems to be unconscious of this. Furthermore, it is countries-leaders in biotechnology that the first should train such specialists, but these countries suffer lack of human resource available for such training. So a difficult decision should be adopted to transfer production based on old technology to developing countries with redundant human resource.

Here I would like to give an example of the aircraft industry in the USSR. Following the R&T revolution, aviation switched to turbojet vehicles and in some years, to the rocket ones. So many spheres in the aircraft industry should have been and were canceled with the aim to commission their specialists to the rocket-and-space industry. As a result a lot of knowledge was lost and in some years the USSR had to restore its aircraft industry.

Meanwhile it is essential to understand that it is innovation and technology rather than economic or financial[141] challenges that fundamentally underpin the persisting world crisis of 2008. None of attempts to resolve the depression would provide any positive result until the transition to biotechnological mode of production is completed. It is the conclusion the author comes to in this work. This finding surely needs testing. And the author feels the marketing research tools will be relevant.

The adopted approach to forecasting allows to anticipate the date of another revolution that may be treated as a ‘knowledge revolution indicator’ and occur somewhat around 2059. To anticipate this date is crucial because this revolution may appear the last in human history due to the demographic transition and the following global population stabilization.

However new knowledge-generating technology presumably to be developed by the cybernetic and biotechnology revolutions and the knowledge revolution-indicator reassures that further knowledge enrichment is feasible regardless whether population will grow or not and thus next technology revolutions are contemplated. Anyway a revolution in generating knowledge is extremely desirable.

[141] Мировой экономический кризис (с 2008 года). – Википедия, 2015. https://ru.wikipedia.org/wiki

5.6. Reasons behind technology revolutions

As shown above, the amount of new knowledge generated between revolutions (including revolutions-indicators) accounts for about 50% of the total knowledge accumulated for all the previous technology epochs whereas population grew by 41% of the population by the end of the previous technology epoch. And knowledge augmentation is half as much the amount of knowledge generated in the previous technology epoch. This is important noting the need to change innovators and entrepreneurs' priorities since a relatively small part of entrepreneurs would change their thinking stereotypes should this amount be less.

Evidently, the world economy, economic and social patterns should be changed crucially in order to engage so many new employees and knowledge and involve them in creating further innovations and material assets. Anyway the sharply increased population should be employed that is trained in new professions required to implement new knowledge. As a result the quantitative increase of the amount of knowledge will transfer into a quantum leap which is implemented, as practice shows, through a dramatic economic crisis (a revolution).

Meanwhile the above analysis (see fig. 4.2 – 4.3) discovers no evident interrelation between the number of innovations and the dates of technology revolutions. Moreover, the patenting rate achieves its top figures (see fig. 4.4) in different ways in principal revolutions and in indicators. Significant inventions are typical for the end of a revolution-indicator and their amount decreases over a long period at the beginning of a principal one. Thus innovative activity hardly can activate a technology shift.

Growing population brings in the quantum leap solely because of its uneven growth across regions rather than due to its quantity. This offers a change potential to countries with higher population growth rate and increases economy load as well because of the need to ensure life standards for their new citizens. Thus just numerical growth hardly can activate technology revolutions.

It is knowledge enrichment that may be a key factor that initiates technology revolutions. Patterns discovered above allow to shape a new model of cyclic human development which is represented in figure 5.9.

The idea of the ‘knowledge wave’ model is the following: well-known is a knowledge turnover cycle (see fig. 2.1, 5.1) which comprises a series of interacting factors. They interact as follows:

1. According to equations (3.3), (3.10), increased GDP per capita (G/N) triggers population growth (N).
2. Increased population triggers human knowledge enrichment (Z).

3. Increased GDP per capita together with knowledge enrichment draws out new persisting human needs which business is not prepared to satisfy.
4. At a definite stage, knowledge enrichment exceeds a threshold level required for a technology revolution to start.
5. Exceeding the threshold together with principally new needs of people and growing demand brings in an innovation impetus.
6. The innovation impetus initiates investment choice among directions of the new technology revolution.
7. Mass investments into the chosen direction lead to restructuring economy, manufacturing, law, education and the entire global economy.
8. Restructured global economy gives impetus to GDP growth.

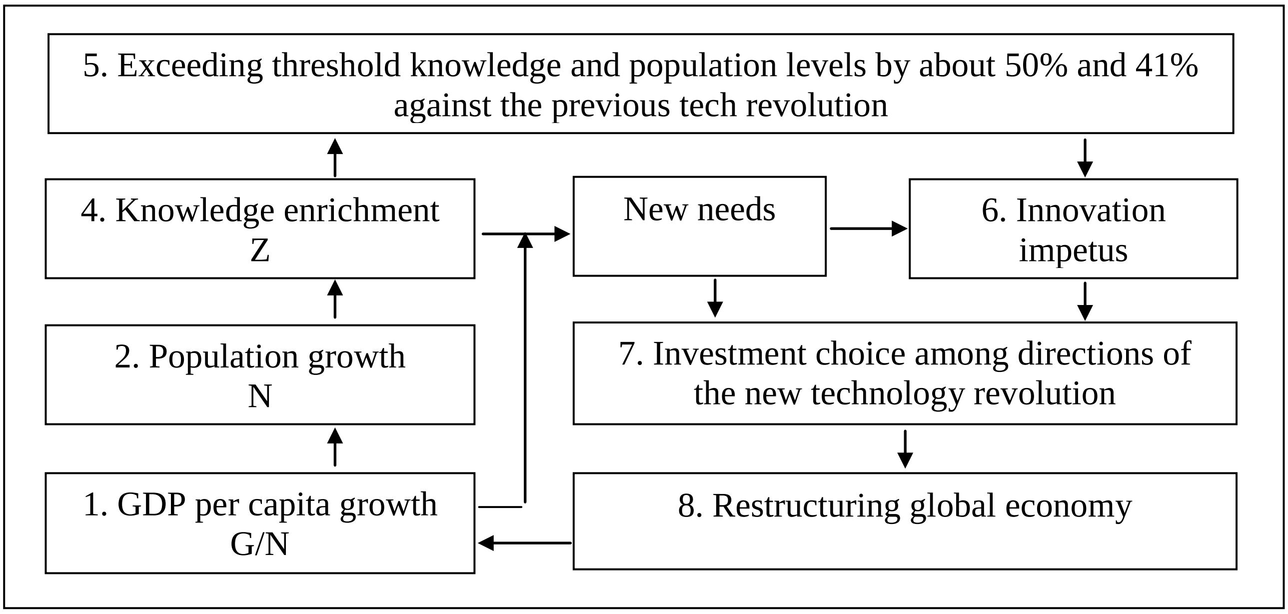

Fig. 5.9. 'Knowledge wave' model of cyclic human development

Table 5.8 gives a brief description of this model in comparison with similar models by N.D. Kondratiev and J.A. Schumpeter.

Table 5.8. Cyclic human development models

Kondratiev's waves	Schumpeter's cycle	Knowledge waves
Renewal of major capital amenities that stems from recovery in innovation	Driving force of prosperity is entrepreneurs' investments in capital assets that sustain implementation of innovations through constructive destruction	Knowledge enrichment cycle that comprises growing GDP per capita, population and global knowledge finally exceeds the knowledge threshold level and thus offers an innovation impetus which triggers a technology revolution

These models are obviously different in essence though innovation is their common principal component. But innovation in Schumpeter's and Kondratiev's models provides initial impetus whereas innovation in the 'knowledge wave' follows knowledge enrichment.

Main results of chapter 5

As to the period of the hyperbolic population growth, knowledge enrichment (Z) is represented by formula

$$\mathbf{Z \approx 2{,}25 \cdot 10^{9} / (2050 - T)^{1{,}25}.}$$

In the period of the demographic transition, knowledge amount may be determined as follows

$$\mathbf{Z \approx 20 \cdot (N/N_0)^{1{,}25}.}$$

About one third of knowledge enrichment calculated with expressions (5.4) and (5.2) are provided by publications including patents registered in Scopus abstract database.

Between technology revolutions, knowledge enriches half as much and global population grows by about 40% and this leads to crises and renewal of global economy.

The crisis of 2008 corresponds to a biotechnology revolution-indicator. This means that the crisis will come to its end only when the global economy transfers to a biotechnology mode of production.

Essential tasks to be completed during the transition to the new production mode are as follows:

- mass specialist training in biotechnology field;
- resolve the problem of the global lack of human resource;
- ensure law environment for the new production mode:
- reduce barriers for introduction of biotechnology;
- ensure safety and security for the new production mode;
- resolve the problem of people confidence in the new technology.

A more accurate forecast of dates of next technology revolutions: 2026 – biotechnology revolution; 2059 – knowledge revolution-indicator.