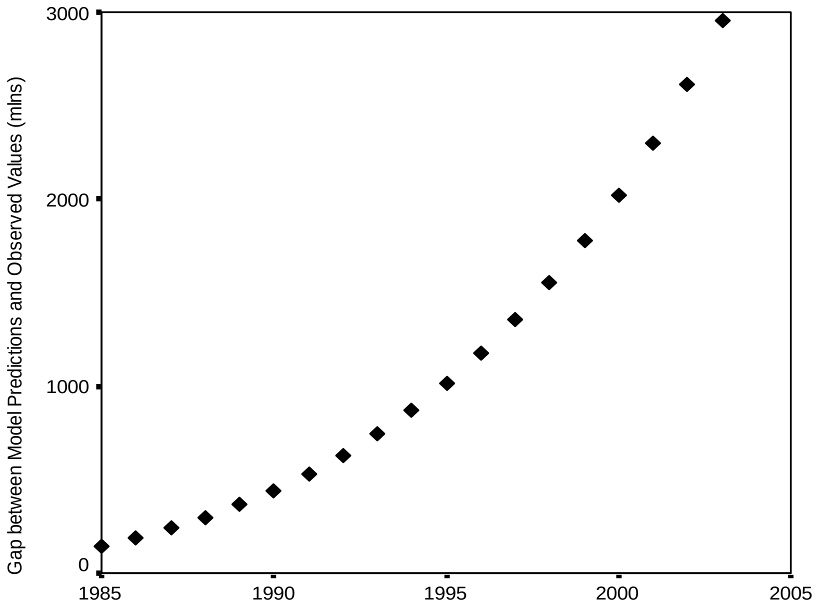
Introduction to Social Macrodynamics. Compact Macromodels of the World System Growth by Andrey Korotayev , Artemy Malkov, and Daria Khaltourina. Moscow: Editorial URSS, 2006. Pp. 67–80.

Chapter 4

A General Extended Macromodel of World Economic, Cultural, and Demographic Growth

One problem with the compact macromodels is that they do not account for the post-1962 world population growth pattern. Take, for example, our simulation with the first macromodel starting in 1650, which produced an almost perfect fit with the observed data for 1650–1962. After 1962 (and especially after 1985) the gap between the predictions generated by the compact macromodel and observed values of the world population starts growing in a literally hyperbolic way (see Diagram 4.1):

Diagram 4.1. Growth of the Gap between Predicted and Observed Values, 1985–2003



Our general extended macromodel of the world's economic, cultural, and demographic growth is conceived to capture both of its two salient features: [1] hyperbolic growth trend in the pre-1962 era, and [2] increasing decline of the world population growth rates afterwards.

Earlier researchers differ significantly in their analytical attempts to integrate into one model the model of hyperbolic growth and the model of global demographic transition. Kapitza (1992, 1999) connects the cause of the transition with the limited nature of the characteristic times of the human development and the humankind development.[1] Kremer (1993) considers the cause to be the decline of fertility in wealthy families. There are also differences in the levels of their approach: Kremer tries to describe the actual mechanism of transition, whereas Kapitza does not look for the actual mechanism of fertility reduction; he rather looks for the cause of the change of the regime in the global development of humankind. Kapitza tries to explain why the current state is exceptional, why the global demographic transition is taking place just now within a period of time that is microscopic on the historical scale, and just on the level of development that has been achieved at the moment.

In the model suggested by us below we aim at accounting both for the transition micromechanism and for the causes of the uniqueness of this phenomenon. The first thing which should be defined is the time period within which the respective model could claim to describe reality.

We have world population estimates starting from 1 million BP, and this is the period for which the population growth is analyzed by Kapitza and Kremer. Despite all the attractiveness of such global theories, we will consciously restrict the scale of our analysis. As in addition to population we use other indices (in particular the world GDP), the field of our model applicability is naturally restricted by the field of available statistical data. This does not mean that the model is not applicable to earlier times, but in any case to corroborate this one would need more data than is available at present.

More or less grounded estimates of the world GDP are available now for the period since 1 CE (Maddison 1995, 2001). Since 1950 they are known at a rather high level of accuracy for every year (Maddison 2001; World Bank 2005). Thus our model only describes demographic and techno-economic growth from 1 CE until the present. The prognostic potential of the model is also restricted by time of the order of one century, which will be discussed specially below.

The uniqueness of the current sharp decrease of the world population growth rates consists in the fact that for the first time in the world history it is connected with the global decline of fertility rates. All the previous decreases took place because of increases in the rate of mortality due to famines, epidemics, warfare *etc.* In the framework of the global demographic process just this appears to constitute the uniqueness of the present time, for which Kapitza tried to ac-

[1] For more detail see Appendix 3.

count. Indeed, in comparison with all the previous development of humankind, it is precisely our time that marks the transition to a new demographic regime.

Thus, the model involving the global demographic transition should detect factors causing this transition, and first of all the factors of sharp fertility reduction.

Kremer attempted to account for fertility decline through the introduction of the function of dependence of fertility on income (Diagram 3.1). However such an explanation is not sufficient and rather indicates a mediated relationship. Thus, the drop in per capita incomes in the countries of the former Communist block in the late 1980s and 1990s did not lead to sharp rise of fertility rates, as one would expect from Kremer's model; in fact we observe the exact reverse (see, *e.g.*, Korotayev, Malkov, and Khaltourina 2005: 255–81). In addition to this, the introduction of additional nonlinear functions including several parameters, each of which is poorly measured in historical perspective, significantly decreases the possibility to use the model for the description of actual data.

To determine the main factors and predictors of fertility reduction it makes sense to address the empirical data. Analyses of large amounts of empirical data suggest that one of the major factors of fertility reduction (in addition to, *e.g.*, the development of health care, or social security subsystems) is the growth of education (especially, female education) (*e.g.*, Hollingsworth 1996; McMichael 2001; Bongaarts 2003 *etc.*).

The literacy rate (that is, the proportion of literate people in the adult population) turns out to be a good integral indicator of the education level. Note that it has been shown that female literacy turns out to be a rather strong negative predictor of fertility (*e.g.*, Bongaarts 2003).

Our own cross-national test of fertility factors with stepwise multiple regression has confirmed this conclusion (see Table 4.1):

Table 4.1. Regression Model of Fertility Factors in the World in 1995

Model	Nonstadardized Coefficients		Standardized Coefficient	*t*	*p*
	B	Standard Error	*β*		
Constant	6.955	0.467		14.899	4×10^{-16}
Female Literacy, %	- 0.038	0.007	- 0.600	- 5.139	0.00001
Number of Physicians per 1000	- 0.253	0.117	- 0.239	- 2.155	0.036
Urbanization (% of population, leaving in cities)	- 0.006	0.007	- 0.087	- 0.866	0.391

NOTE: $R = 0.837$; $R^2 = 0.701$; $p = 2 \times 10^{-11}$. DATA SOURCE: SPSS 2005.

This three-factor model accounts for more than 70% of all the variation of fertility rates in 1995. This multiple regression analysis confirms that female literacy is a major factor in fertility reduction in the course of modernization (let us note here that – as we shall see below – female, male and overall literacy are very strongly interconnected variables).

Our regression analysis of the World Bank (2005) and US Bureau of the Census (2005) data on the female literacy and world population growth rates has produced the following results (see Tables 4.2 and 4.3):

Table 4.2. World Population and Female Literacy, 1990–1999

Year	*World Population Growth Rate (%)*	*World Literacy Rate, adult female (% of females, ages 15 and above)*
1990	1.58	61.61
1991	1.56	62.38
1992	1.49	63.13
1993	1.44	63.90
1994	1.43	64.66
1995	1.38	65.44
1996	1.37	66.56
1997	1.32	67.71
1998	1.29	68.60
1999	1.25	69.50

Table 4.3. Correlation between World Population Size and Female Literacy, 1990–1999 (regression analysis)

	Unstandardized Coefficients		**Standardized Coefficients**	**t**	**Sig.**
Model	**B**	**Std. Error**	**Beta**		
(Constant)	4.054	0.162		25.003	0.00000001
Literacy rate, adult female (% of females, ages 15 and above)	-0.04044	0.002	-0.985	-16.312	0.0000002
Dependent Variable: **World Population Annual Growth Rate** (%)					

$\boldsymbol{R} = \mathbf{0.971}$, $\boldsymbol{R}^{2} = \mathbf{0.967}$

As we see, we do observe an extremely strong and significant correlation in the predicted direction. In fact, this regression analysis suggests that 96.7% of all the world macrodemographic variation in 1990–1999 is described by the following equation:

$$r = 4.05 - 0.0404F,$$

where *F* is world female literacy (%), and *r* is the annual population growth rate (%).

Note that this model predicts that when the world population literacy becomes 100% (which by definition implies 100% female literacy), the world population growth rate will be 0.01% (4.05 – 0.0404 × 100), which is extremely close to the one of the main assumptions of our model below.

Thus, there are definite grounds to consider literacy as a good integral index of those modernization processes that could be considered as fertility reduction factors. The fertility decline in connection with the growing literacy rate is free from the defects of Kremer's explanation connecting the declining fertility directly with growing incomes. Our explanation has no problem with the above cited case of the decreasing incomes not being accompanied by increasing fertility in the post-Communist countries (in the late 1980s and early 1990s). On the other hand, the suggested explanation is wider than Kremer's in the sense that literate people tend to earn more than the illiterate ones. Thus, Kremer's explanation only works in the periods of stability, whereas our explanation works both for stable and crisis periods.

We would like to stress that in no way are we going to claim that the literacy growth is the only factor in the demographic transition. We do not deny important roles played by such factors as the development of medical care, or social security subsystems (*e.g.*, Chesnais 1992). Note that these variables together with literacy can be regarded as different parameters of one integrative variable – the human capital development index (*e.g.*, Denison 1962; Schultz 1963; Lucas 1988; Scholing and Timmermann 1988; Meliantsev 1996, 2003, 2004a, 2004b). On the other hand, both of these variables display a very strong correlation with literacy.[2] In general, if we know that in country A the proportion of literate population is 95%, and in country B this proportion is 25%, we can be perfectly sure that the health care and social security subsystems in country A are about an order of magnitude more developed than in country B. Note also that the modern medical care development is connected in the most direct way with the development of the education subsystem. The development and diffusion of new medical technologies (including, naturally, the family planning ones) is very strongly connected with the development of education. *E.g.*, the

[2] For example, our cross-national analysis of *World Development Indicators* database for the year 1975 shows that there is a strong and significant correlation between total literacy rate and the percentage of birth attended by skilled personnel (R = 0,83; p < 0,0001, similar results were obtained for other years) (World Bank 2005). On the other hand, our analysis of the data for the year 1995 indicates that literacy rate below 30% predicts with the maximum possible value (Gamma = 1.0) social security taxes being below 5% of current revenue, and literacy rate below 75% predicts in the same way security taxes being below 15% of current revenue. We have also found that the number of physicians per 1,000 correlates exponentially with the total literacy rate for the same year (R = 0.844) (In this case the data on literacy are from World95 database [SPSS 2005]; the data on other parameters are from *World Development Indicators* Database [World Bank 2005]).

medical specialists are produced by the education system, the education facilitates the spread of medical information (including the information on family planning means and practices), and so on.

Thus, literacy rate turns out to be a very strong predictor of the development of both medical care and social security subsystems.

Hence, literacy has turned out to be a rather sensitive indicator of human capital development level, which has made it possible to avoid including its other parameters as separate variables in our model.

Note that the overall adult literacy turns out to be an extremely strong predictor of both male and female literacy (see Table 4.4):

Table 4.4. Correlations between World Overall, Female, and Male Literacy Rates, 1970–1999

		Literacy rate, adult total (% of people ages 15 and above)	**Literacy rate, adult female (% of females ages 15 and above)**	**Literacy rate, adult male (% of males ages 15 and above)**
Literacy rate, adult total (% of people ages 15 and above)	Pearson Correlation		0.99984	0.99977
	Sig. (2-tailed)		<<0.0001	<<0.0001
	N		30	30
Literacy rate, adult female (% of females ages 15 and above)	Pearson Correlation	0.99984		0.99923
	Sig. (2-tailed)	<<0.0001		<<0.0001
	N	30		30
Literacy rate, adult male (% of males ages 15 and above)	Pearson Correlation	0.99977	0.99923	
	Sig. (2-tailed)	<<0.0001	<<0.0001	
	N	30	30	

Correlations of such a level could, of course, hardly be regarded as anything but extremely strong, even notwithstanding the fact that here we are dealing with an evident autocorrelation component. That is why, though the effects of male and female literacy on demographic dynamics are rather different, it has turned out to be possible to avoid including them as separate variables in model.

An important additional factor that led us to choose literacy rather than any other fertility reducing parameter of the human capital development index is that this seems to be the only such parameter for which it appears possible to obtain long-term global historical data.

As a result, in order to account for the global demographic transition, model (3.7)-(3.10) should be extended to take into account the development of human capital level (measured through literacy rate) as a factor of fertility decrease. As a result of this modification, model (3.7)-(3.10) looks as follows:

$$\frac{dN}{dt} = aNS \ (1 - L) \ , \tag{4.1}$$

$$\frac{dS}{dt} = bNS \ , \tag{3.10}$$

$$\frac{dL}{dt} = cLS \ (1 - L) \ , \tag{4.2}$$

where *L* is proportion of literate population and *a*, *b*, and *c* are constants. The influence of world literacy on the global demographic transition is expressed through the addition to (3.7) of the multiplier (1 – *L*), which results in equation (4.1). Such a modification implies that the growth of literacy affects negatively fertility rates even in the absence of any resource limitations. As regards the fact that the death rates also decline with modernization, equation (4.1) takes this fact into account too, since the natural population growth rate (which tends to zero when the literacy approaches to 100%) is, by definition, the difference between the fertility rate and the death rate.

The introduced additional equation for the literacy growth (4.2) has the following sense: the literacy growth rate is proportional to the proportion of literate people in the whole population *L* (potential teachers), to the proportion of illiterate people in the whole population (1 – *L*) (potential pupils), and the presence of surplus *S*, which can be used for educational purposes (in addition to this, *S* is connected with the technological level *T*, including the level of educational technologies that accelerate the spread of education). From the mathematical point of view equation (4.2) is analogous to logistic equation (0.2), because within equation (4.2) the saturation is achieved with literacy level *L* = 1, whereas *S* accounts for the speed with which the saturation level is reached.

Notwithstanding the fact that this modification of the model is generally quite logical, its version (4.1) – (3.10) – (4.2) needs additional justification. As it is evident that with the same logical conclusions on the dependence of population growth rate on the literacy rate (or, on the dependence of literacy growth rate on the growth rate of the number of potential teachers *etc.*) the same model may be presented as:

$$\frac{dN}{dt} = aN^{\varphi_1} S^{\varphi_2} (1 - L)^{\varphi_3} ,$$
$$\frac{dS}{dt} = bN^{\varphi_4} S^{\varphi_5} ,$$
$$\frac{dL}{dt} = cL^{\varphi_6} S^{\varphi_7} (1 - L)^{\varphi_8} ,$$

where φ_1, φ_2, φ_3, φ_4, φ_5, φ_6, φ_7, φ_8 are some positive values that are not necessarily equal to one.

As regards coefficients φ_1, φ_2, φ_4, φ_5, the following suggests that they could be considered to be equal to one: in the area, which is removed from the zone of the second phase of the global demographic transition, such coefficients describe satisfactorily the hyperbolic growth and fit the empirical data very well (see Chapter 3). As regards values of the other coefficients, they should be also determined on the basis of empirical data.

It is easy to notice that if $\varphi_1 = \varphi_6 = 1$, $\varphi_2 = \varphi_7$, $\varphi_3 = \varphi_8$, through the dividing of the first equation by the third we arrive at the following equation:

$$\frac{dN}{dL} = \frac{a}{c}\frac{N}{L}.$$

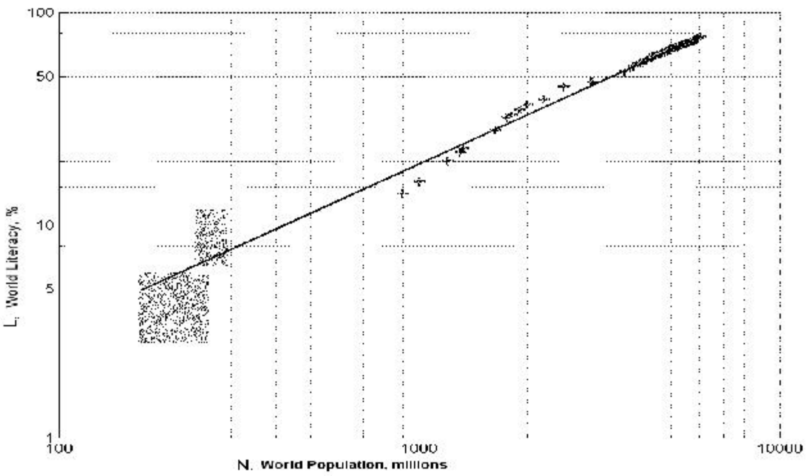
Its solution defines the relationship between L and N in the following way:

$$L = a N^{\frac{c}{a}}, \qquad (4.3)$$

where λ is a constant.

Let us test this hypothesis with historical data. Diagram 4.2 presents data on the simultaneous growth of world literacy and world population in double logarithmic scale:

Diagram 4.2. World Literacy (%) and World Population (millions)



NOTE: Rectangles correspond to 1 and 1000 CE, for which we have large dispersions of estimates. Estimates of the world population are by Kremer (1993), Maddison (2001) and US Bureau of the Census (2005). World literacy = proportion of literate adult population, calculated on the basis of Meliantsev's (1996, 2003, 2004a, 2004b) estimates and UNESCO/World Bank (2005) data for post-1970 period.

Within such a scale a straight line corresponds to a power-law dependence. The diagram suggests that power-law dependence (4.3) fits the available data rather well.

Thus, the available data (see Diagram 4.2) suggest the validity of relation (4.3), and thus argue in favor of the statement that $\varphi_1 = \varphi_6 = 1$, $\varphi_2 = \varphi_7$, $\varphi_3 = \varphi_8$, which, in view of our earlier estimate of the power of φ_2 as 1.0, may be written as: $\varphi_1 = \varphi_6 = \varphi_2 = \varphi_7 = 1$, $\varphi_3 = \varphi_8$. As regards the equality of φ_3 to 1.0, what supports this is the good fit (see Diagrams 4.3–8) of the observed data with the values generated by model (4.1)-(3.10)-(4.2). Of course, a finer "tuning" of the model using parameters $\varphi_{1\ldots8}$ could enhance the fit, however, due to the high error margins for existing data such a "fine tuning" does not make much sense, as we do not know for sure the exact coordinates of the points to which the solution should be tuned. In any case, within such a general model one should strive to decrease the number of those parameters that do not enhance the solution at a qualitative level.

The results of computer simulation with (4.1)-(3.10)-(4.2) with parameters

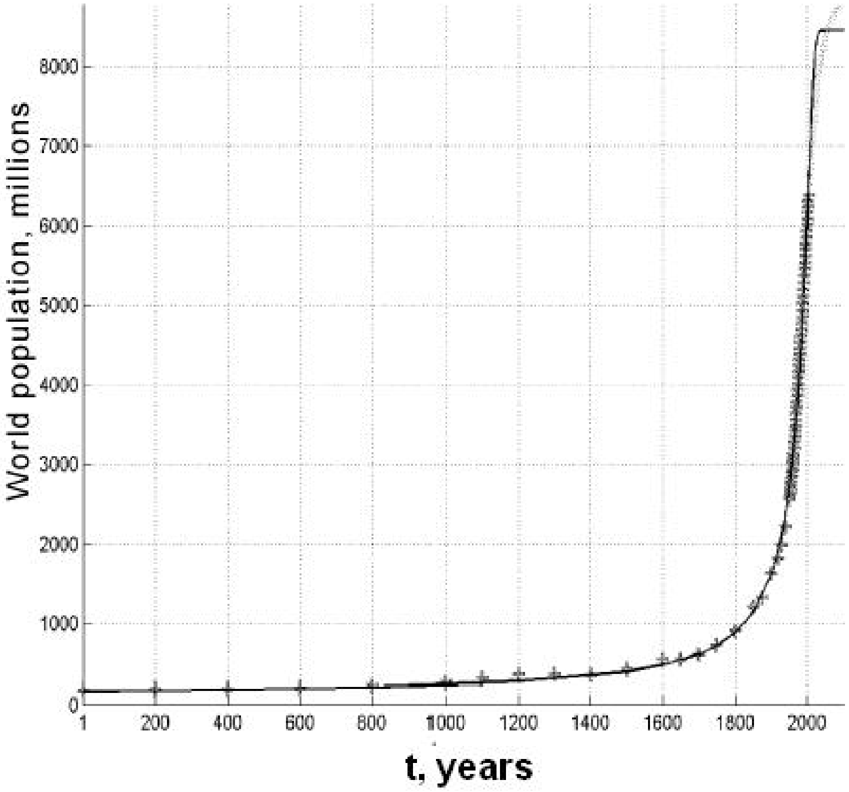
$a = 1.085 \cdot 10^{-5}$ (\$ · year)$^{-1}$;
$b = 6.51 \cdot 10^{-12}$ (person · year)$^{-1}$;
$c = 8.2 \cdot 10^{-6}$ (\$ · year)$^{-1}$;
$\tilde{m}$ ("necessary product per person") = 420 \$

and initial conditions for 1 CE:

$N_0 = 170000000$;
$S_0 = 17.47$ \$;
$L_0 = 0.052$,

where L is a dimensionless quantity (ranging from 0 to 1), sign \$ corresponds to 1995 international dollar (PPP), are displayed at Diagrams 4.3–8:

Diagram 4.3. World Population Growth

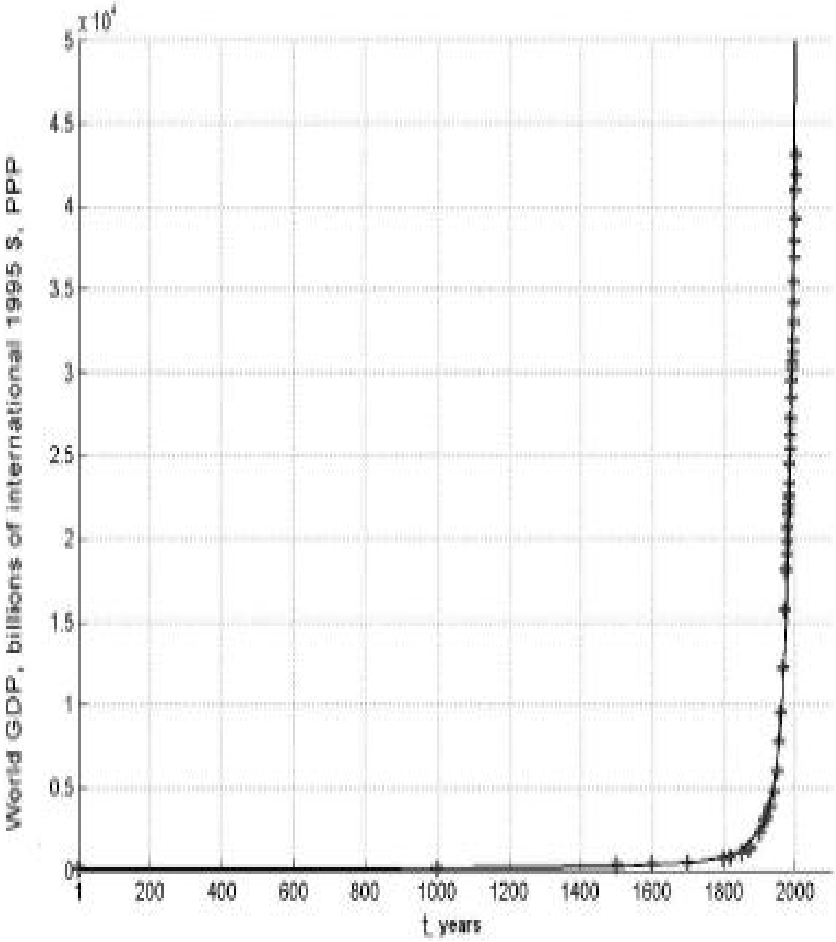


Values generated by the model (solid line) for the world population describe well both the pre-1962 hyperbolic growth and the global demographic transition by the present (the observed values are indicated with grey crosses). With regards to the future, the model suggests a scenario a bit different from the intermediate UN forecast (light grey markers). The model suggests that at the final phases the global demographic tradition will proceed in a less smooth way than is implied by the UN forecasts.

A smoother transition could be achieved through the introduction of $\varphi_3 = \varphi_8 \neq 1$; however, the UN forecast is just one of many possible forecasts that rely on their own models. On the other hand, the available historical data are not sufficiently exact to support the hypothesis $\varphi_3 = \varphi_8 \neq 1$.

Naturally, with appearance of new data the model could be corrected.

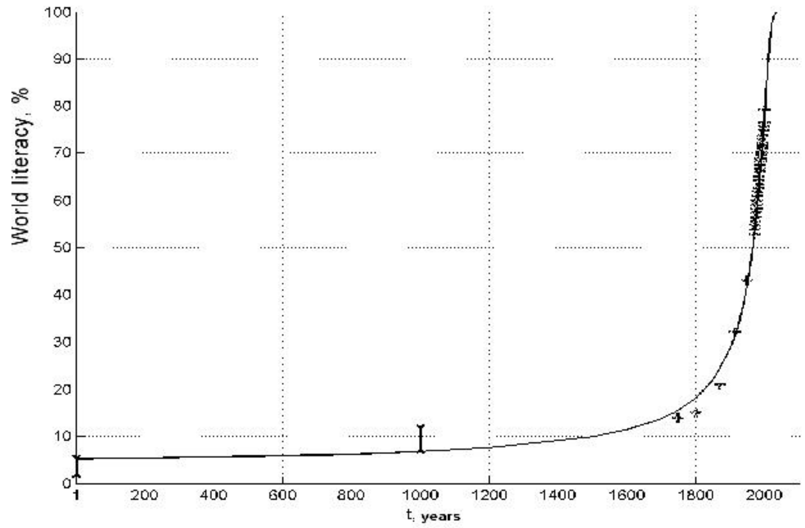
Diagram 4.4. World GDP Growth



The world GDP grew even more steeply than the world population and can be described mathematically with equation (3.11). Notwithstanding the fact that GDP is not included explicitly in the system of equations, in this diagram the respective points are calculated on the basis of equations (3.10) and (4.1).

Finally, consider the diagram displaying the relationship between the world literacy growth dynamics generated by the model and the observed values of the respective variable (see Diagram 4.5):

Diagram 4.5. World Literacy Growth (%%)



Diagrams in double logarithmic scale hide the visual component of hyperbolic growth and make the results more visible, though the deviations also look more saliently in this scale (Diagrams 4.6–8):

Diagram 4.6. World Population Growth in Double Logarithmic Scale

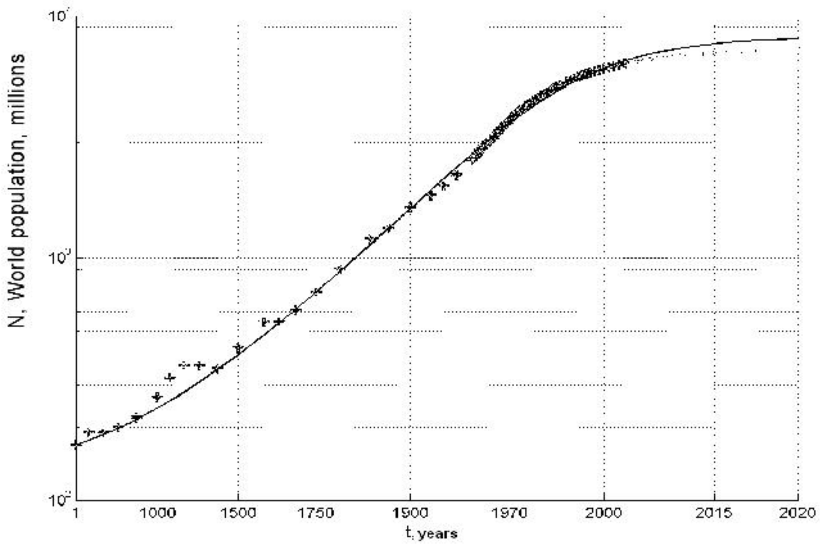


Diagram 4.7. World GDP Growth in Double Logarithmic Scale

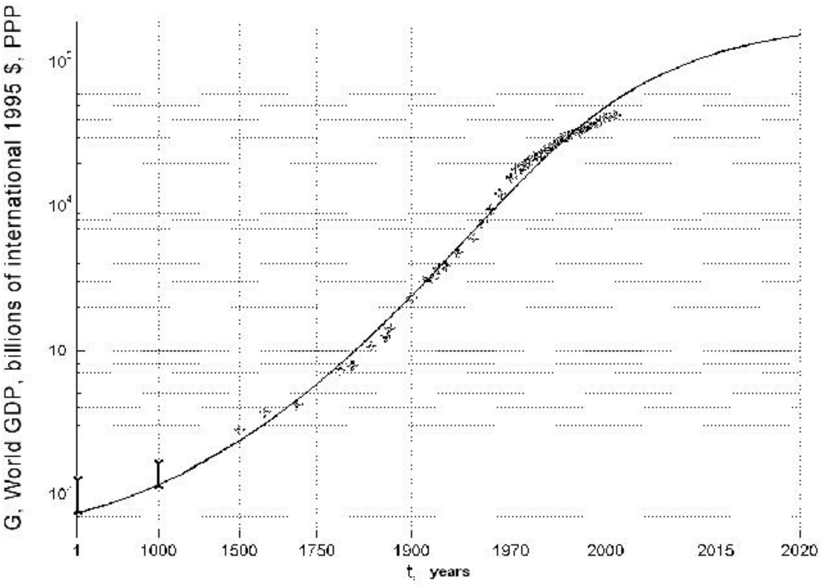
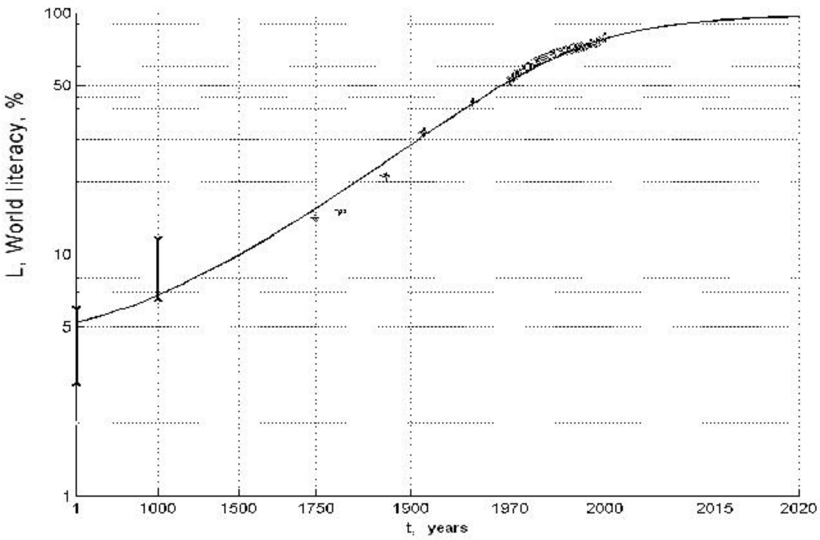


Diagram 4.8. World Literacy Growth in Double Logarithmic Scale



While commenting on these diagrams, it appears necessary to note that, notwithstanding local deviations, model (4.1)-(3.10)-(4.2) describes quite well the available empirical data, though the model only includes three coefficients. What is more, through normalization it appears possible to reduce two of them to 1.0 – in this case the model will only include one coefficient that is equal to the exponent in equation (4.3). Thus, notwithstanding the extreme simplicity of the model, it describes very successfully the joint dynamics of three major indicators of the global evolution of humankind.