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MATHEMATICS

A Mathematical Model for Predictive Computations of the Synergy Effect of NBIC Technologies and the Evaluation of Its Influence on the Economic Growth in the First Half of the 21st Century

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In 2013, for the first time after the 2008–2009 financial and economic crisis, revival began in the economies of a number of developed countries. In the first economy of the world—the US economy—the rate of growth is expected to be approximately 2.8–2.9% in 2014 and up to 3% in 2015, as compared with 1.9% in 2013. Investments return in the economy of the eurozone and it also begins to recover due to the growth of internal demand. The locomotive of the eurozone—the economy of Germany—increases stably and in 2014 is expected to grow by 1.8% as compared to 0.4% in 2013. In the East, in the largest Japanese economy, after many years of stagnation, the growth rate of 1.5% has been observed over the last two years in succession and 1.7–1.8% is expected in 2014.

This revival of the world economy is a prelude to stable growth, which will begin according to our predictions in approximately 2017–2018 and will continue up to 2040 unless global catastrophes or wars intervene. As early as 2009, immediately after the global financial and economic crisis began, it was predicted in [1] that the crisis would be accompanied by a long depression characteristic of a period of change in Kondratieff long waves and a change in techno-economic paradigms [2] and that the recession would reach its bottom in 2013–2014 and then a revival would begin, which would develop into stable long-term economic growth in 2017–2018 with the beginning of a upward wave of the sixth Kondratieff long wave (sixth KLW, 2018–2050).

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Note that the present revival began in the economies of developed countries and it is associated with the beginning of manufacturing innovation products based on NBIC technologies (nano, bio, information, and cognitive technologies), which will become the core of the future sixth techno-economic paradigm. Thus, we see that the principle "innovations overcome depression" [3] formulated by the outstanding German economist G. Mensch during the 1970s global economic crisis works without fail. Therefore, the locomotives of an upward wave in the sixth KLW in the world economy development will become the most developed countries—the US, EU, and Japan, which are recognized leaders in the study and development of NBIC technologies.

The features of NBIC technologies generated by intensive interpenetration and mutual influence of nano, bio, information, and cognitive sciences and technologies were described in detail in [4]. Recently noted by researchers, this phenomenon is known as NBIC convergence [5]. Due to convergence, NBIC technologies produce a considerable synergy effect. Judging by the expected scale of future socioeconomic transformations, NBIC convergences are estimated as revolutionary [6]. The synergy effect caused by NBIC convergence or, in other words, by their combined cooperative action can appear so strong that its contribution to the rise of cumulative efficiency of factors will become decisive and the growth rate of the world economy will again approach its record values (4.9% per year on average) reached during the 4th KLW (1948–1973), thus disrupting the tendency of decelerating economic growth having been observed since the 1970s. The question arises as to how to estimate the synergy effect of NBIC technologies and its influence on the economic growth within the sixth KLW. In this paper, the simplest mathematical model is offered for this purpose for the first time.

Consider a neoclassical model of economic growth with physical and human capital as proposed by Mankiw, Romer, and Weil [7]:

$$Y(t) = K^{\alpha}(t)H^{\beta}(t)[A(t)L(t)]^{1-\alpha-\beta}, \quad (1)$$

where $Y(t)$ is the current amount of the national income (GDP), $K(t)$ is physical capital, $H(t)$ is human capital, $L(t)$ is the number of people occupied in the economy, $A(t)$ is technical progress, and α and β are parameters of the production function. An empirical analysis has shown that $\alpha = 0.14$ and $\beta = 0.37$ for developed countries of the Organization of Economic Cooperation and Development (OECD), while $\alpha = 0.31$ and $\beta = 0.28$ for developing countries not related to oil extraction [7, p. 420]. In rate form, Eq. (1) becomes

$$q_Y = \alpha q_K + \beta q_H + (1-\alpha-\beta)(q_A + q_L), \quad (2)$$

where $q_Y = \frac{\dot{Y}}{Y}$; $q_K = \frac{\dot{K}}{K}$; $q_H = \frac{\dot{H}}{H}$; $q_L = \frac{\dot{L}}{L}$; $q_A = \frac{\dot{A}}{A}$.

Since the "cumulative factor efficiency" can be interpreted as a characteristic of synergy effects of the cooperative contribution of the labor and capital factors to the economic growth [8], Eq. (2) implies the following estimated formula for the growth rate caused by the synergy effect:

$$q_Y^{\text{syn}} = (1-\alpha-\beta)q_A. \quad (3)$$

Thus, this estimated formula becomes $q_{Y_{\text{HD}}}^{\text{syn}} \cong 0.49q_A$ for OECD countries and $q_{Y_{\text{LD}}}^{\text{syn}} \cong 0.41q_A$ for developing countries.

Let us transform model (1) according to [9] with the use of Kaldor's empirical with

$$K = c_K Y,\ \ H = c_H Y;\ \ c_K = \text{const},\ \ c_H = \text{const}. \quad (4)$$

Assume also that the number L of people occupied in the economy is related to the total population number N as

$$L = c_L N; \quad c_L = c_L(t). \quad (5)$$

Substituting relations (4) and (5) into the original model (1) yields a rather simple approximate model for computing the dynamics of GDP:

$$Y = \gamma A N; \quad (6)$$

$\gamma = \gamma(t)$ in the general case.

It follows that, if $\gamma = \text{const}$, then

$$q_Y = q_A + q_N. \quad (7)$$

Thus, the estimate synergy effect or, more precisely, its contribution to the economic growth rate is reduced to computing the growth rate of technical progress q_A (3). In [10] the simplest mathematical model for computing the growth rate of the average technological level $A(t)$ over the entire economy depending on the relative economic efficiency of newly introduced basis innovation technologies $a(t)$ was proposed in the form of the differential equation

$$\frac{dA}{dt} + s\xi A = s\xi a(t), \quad (8)$$

where $s(t)$ is the rate of saving ($s = \frac{I}{Y}$, I is bulk investments, Y is GDP) and $\xi(t)$ is capital productivity ratio ($\xi = \frac{Y}{K}$, K is physical capital). The rate of saving $s(t)$ is rather stable, so it can be regarded in the first approximation as a constant: $s(t) = s_0$. In a long-term period, the averaged capital productivity ratio $\xi(t)$ is also nearly a constant if we consider a period of duration of a single KLW. However, within a KLW, it differs considerably from its trend and oscillates almost simultaneously with the KLW, increasing with the upswing phase of the KLW and decreasing during recession periods. For example, for the US economy, $\xi(t)$ can be well approximated by a sine function [10]:

$$\xi(t) = \xi_0 + \xi_1 \sin\omega(t-1987), \quad (9)$$

where $\xi_0 = 0.34$; $\xi_1 = 0.03$, and $\omega = \frac{\pi}{15}$. For the US economy, $s_0 = 0.187$.

The diffusion of future basis innovations $a(t)$ on the right-hand side of Eq. (8), whose core is represented by NBIC technologies, is described by the logistic law written as

$$a = \frac{a_0(1+c)}{1 + c\exp[-d(t-T_0)]}. \quad (10)$$

Here, a_0, c, d, and T_0 are constants parameters, which were determined in [10]. Moreover, c is specified as the normalization condition for the intensity of the cluster of new basis technologies: $c = \frac{a_{\max}}{a_{\min}}$. Usually, it is specified as $c = 9$ [11]. Next, the parameter d is determined using the life cycle of the new techno-economic paradigm: $d = \frac{2\ln c}{\Delta T_f}$. For NBIC technologies, it was found that $\Delta T_f = 70$ years [10]. The date of the origin of basis technologies of the new techno-economic paradigm (T_0) and the date of beginning their intensive introduction (T_{i}) are related by the equation $T_0 = T_{\text{i}} - \frac{0.877}{d}$. Relying on Hirooka's innovation paradigm [11], it was shown in [10] that T_{i} coincides with 2018 (the beginning of the sixth KLW), i.e., $T_{\text{i}} = 2018$. The initial intensity a_0 of basis technologies of the new techno-economic paradigm is given by the formula $a_0 = \frac{a_{\text{i}}}{1+c}\{1 + c\exp[-d(T_{\text{i}} - T_0)]\}$, which follows directly from Eq. (10) at $t = T_{\text{i}}$. Here, we use the important concept of the relative efficiency of new basis technologies $\rho = \frac{a_{\text{i}}}{A_{\text{i}}}$, which is determined using the formula $\rho = 1 + \frac{q_{A_{\text{i}}}}{s_0\xi_{\text{i}}}$, where $q_{A_{\text{i}}}$ is the rate of technical progress in the economy at the beginning of the upswing phase

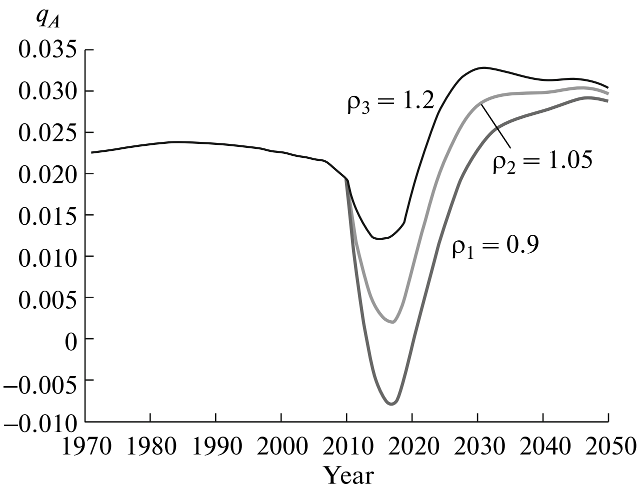

Fig. 1. Dynamics of the growth rate of technical progress (q_A) in the fifth and sixth KLWs (prediction).

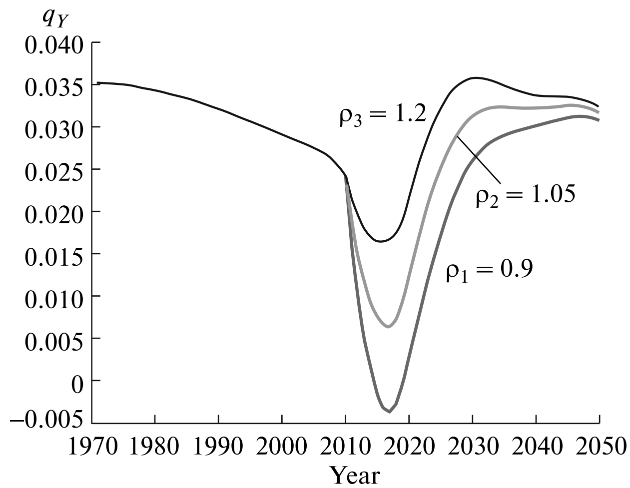

Fig. 2. Dynamics of the economic growth rate (q_Y) in the fifth and the sixth KLWs (prediction).

of the current KLW. For example, for the US economy, q_{A_i} was estimated by experts as equal to 1.3%, i.e., $q_{A_i} = 0.013$. In this case, $\rho = 1.2$.

Thus, substituting (9) and (10) into the original equation (8), we obtain the following linear differential equation for computing the average rate of technical progress $A(t)$ over the entire economic system:

$$\frac{dA}{dt} + s_0[\xi_0 + \xi_1 \sin\omega(t - 1987)]A = \frac{s_0 a_0 (1 + c)[\xi_0 + \xi_1 \sin\omega(t - 1987)]}{1 + c\exp[-d(t - T_0)]}. \tag{11}$$

This equation was solved numerically with various values of ρ ($\rho_1 = 0.9$; $\rho_2 = 1.05$; $\rho_3 = 1.2$). The numerical results obtained for the growth rate of technical progress are presented in Fig. 1. The coefficient of efficiency of NBIC technologies was estimated above: $\rho = 1.2$. For comparison purposes, the technical progress was calculated for lower efficiency of NBIC technologies ($\rho = 0.9$). However, the predicted growth rate curves (Fig. 1) show that, even in this case, they exceed the rate of technical progress in the fifth KLW, which is the exclusive consequence of a considerable increase in synergy effects.

Thus, the powerful cooperative action of NBIC technologies gives rise to a substantial synergy effect that accelerates the rate of technical progress up to 3.3% by 2030 (see Fig. 1), which is much higher than in the period from 1980 to 2009—in the upswing phase of the fifth KLW. Figure 2 presents the expected growth rate of the US economy up to 2050 as calculated using formula (7). It can be seen from the figure that, with an expected coefficient of efficiency of NBIC technologies $\rho = 1.2$, the growth rate of the US economy will reach the level of the successful 1990s as early as 2020 and then will grow steadily at a rate of approximately 3.4% annually up to 2050. The same growth rates in the US economy were observed in the 1980s in the upswing phase of the fifth KLW, but then there was a considerable contribution associated with the high rate of arrival of fresh qualified labor ($q_Y = q_A + q_N$). The US reaped the fruits of the postwar sharp rise in the birth rate. The contribution of q_N to the sixth KLW will be insignificant. This is well seen by comparing the plots of q_Y and q_A in Fig. 3, which shows the dynamics of the growth rates of all three variables: q_A, q_Y, and q_Y^{syn}.

Figure 4 illustrates the contribution of the synergy effects for various possible values of the efficiency coefficient of NBIC technologies as compared with the basis technologies of the fifth techno-economic paradigm. An analysis of the plots in this figure shows that the contribution of the synergy effects during the sixth KLW will increase considerably in comparison with the fifth KLW (by approximately 1.4 times) at the expected efficiency coefficient $\rho = 1.2$. Note that, even with a lower efficiency of NBIC technologies ($\rho = 0.9$) as compared with basis technologies of the fifth techno-economic paradigm, the contribution of the synergy effect of NBIC technologies in 2030 will considerably exceed the corresponding contribution of the basis technologies of the fifth techno-economic paradigm (see Fig. 4).

CONCLUSIONS

NBIC technologies, due to the powerful synergy effect generated by the convergence of nano, bio, info, and cognitive technologies, will lead to a strong acceleration of technical progress, which will exceed the rates reached in the upswing phase of the fifth KLW (1982–2006). Thus, the tendency of decelerating the rate of the world economy development, which was

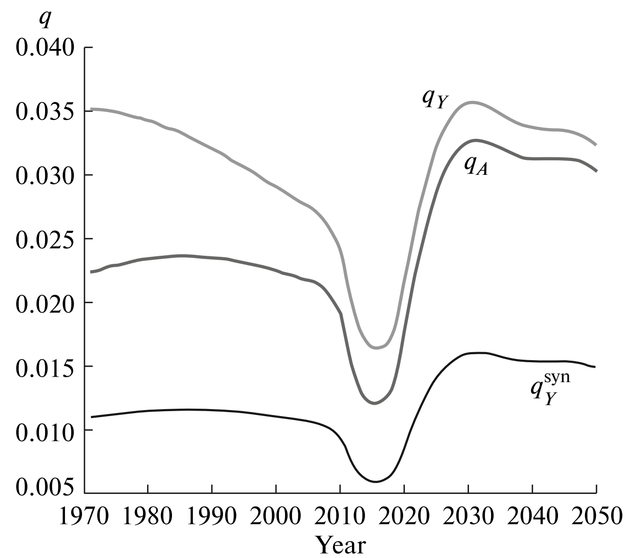

Fig. 3. Predicted growth rate of the US economy (q_Y) to the year 2050, technical progress (q_A), and the contribution of synergy effects (q_Y^{syn}) for $\rho = 1.2$.

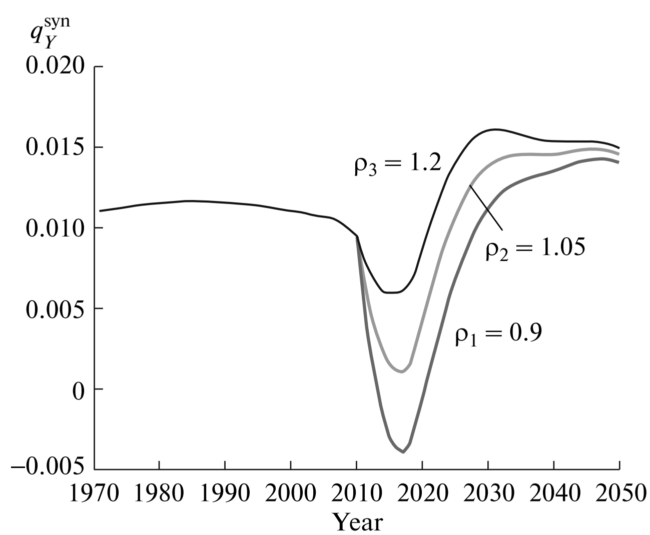

Fig. 4. Predicted curves of the contribution of synergy effects of NBIC technologies to the growth rate of the US economy during the sixth KLW (2018–2050).

observed over the entire fifth KLW (1982–2013), will be replaced an upward tendency. The example of the US economy was used to show that the rate of technical progress will increase from 2.3% in the 1980s to 3.4% in the 2020–2030s, while the economic growth rate will reach 3.3–3.7%.

REFERENCES

1. A. A. Akaev, V. I. Pantin, and A. E. Aivazov, *Proceedings of the First Russian Congress of Economists* (Mosk. Gos. Univ., Moscow, 2009).
2. S. Yu. Glaz'ev, *A Strategy of Russia's Outpacing Development Amid a Global Crisis* (Ekonomika, Moscow, 2010) [in Russian].
3. G. Mensh, *Stalemate in Technology—Innovation Overcame the Depression* (Ballinger, New York, 1979), pp. 142–146.
4. A. A. Akaev and A. I. Rudskoi, *World Dynamics: Patterns, Trends, and Prospects* (Librokom, Moscow, 2013) [in Russian].
5. M. Roko and W. S. Bainbridge, *Converging Technologies for Improving Human Performance* (WTEC, Los Angeles, 2003).
6. W. S. Bainbridge and M. Roko, in *Converging Technologies in Society* (Springer, Dordrecht, 2006), pp. 337–345.
7. G. Mankiw, D. Romer, and D. Weil, Quart. J. Econ. **107** (2), 407–437 (1992).
8. D. Jorgenson and K. Stiroh, Am. Econ. Rev. May **89** (2), 109–115 (1999).
9. A. A. Akaev, V. A. Sadovnichii, and I. E. Anufriev, in *World Dynamics* (KRASAND, Moscow, 2014), pp. 15–50 [in Russian].
10. A. A. Akaev and A. I. Rudskoi, Ekon. Politika, No. 2, 25–46 (2014).
11. M. Hirooka, *Innovation Dynamism and Economic Growth: A Nonlinear Perspective* (Edward Elgar, Cheltenham, UK, 2006).

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