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Profitability, Productivity and Employment in a Model of the U.S. Long Waves

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Abstract

This paper elaborates the notion of viable quasi-periodic motion bounded in the phase space that generalises stationary growth and stationary cyclical growth. Simulation experiments, based on real and estimated statistical data, support the original hypothetical law (HL) of capital accumulation formulated in the previous publications of the author.

This paper contributes to finding the general law of motion of the modern economic system that is characterised by resilience and fragility. It gives an additional ground for a positive answer to the question: 'Are there macroeconomic laws?' It is shown in particular, that Okun's law and some other prominent empirical regularities are, likely, the manifestation of this HL.

The application of the HL with exogenous growth of labour force to the U.S. economy reveals and explains a trade-off between long-term improvements in profitability against lower employment ratio and larger volatility of economic-ecological reproduction. A focus of this work is on possible adverse social consequences of a more aggressive substitution of living labour by man-made capital during the current Kondratiev quasi-cycle, or long wave.

Two disequilibrium scenarios of the American economic evolution, based on the HL, are compared with equilibrium projections of the U.S. Board of Trustees of the Federal Old-Age and Survivors Insurance and Disability Insurance Trust Funds. Achilles' heel of these projections, as demonstrated, is the neo-classical conjecture on economic growth.

Key words: profitability, productivity, employment, volatility, long waves, modelling

Introduction

The books (Ryzhenkov 2000a, 2003b) and papers (Ryzhenkov 2000b, 2001, 2002a, 2003a) have defined and refined *the hypothetical law of advancing capitalism* (HL). A system of non–linear ordinary differential equations establishes a deterministic form of this law. The state variables are the relative wage, employment ratio, unit gross rent, man-made capital–output ratio, natural capital–output ratio, indicated natural capital–output ratio and unit depletion and degradation of the natural capital.

The HL, presented as a generic system dynamics model in the intensive form, reflects the dialectical interaction between factors that tend to lower the average rate of profit and those that counteract this tendency. Conversion of profit into capital and sustained expansion for a number of years eventually result in a tight labour market, rising real wages, and in an acceleration of capital–labour substitution. As this process tends to raise the capital–labour ratio, it also tends to lower the average rate of profit. When the latter tendency outweighs the counteracting tendencies, a recession abruptly follows the expansion.

After the Second World War, the American economy probably passed peaks of the Kondratiev cycles twice: 1966, 1997 for the gross (biased) profit rate and 1969, 2000 for the employment ratio (Figure 1 and Figure 2).[1] The current downswing in the long wave has manifested itself in the growing produced capital–output ratio and unit wage, declining profitability and employment ratio. There has been a secular profit squeeze and deceleration of economic growth in spite of the steady reduction of the eco–intensity and labour productivity growth. Worsening profits have affected the growth in productivity that inhibits profits, in turn. Excessive capital accumulation (overinvestment) that developed in the late 1990s has created structural imbalances, which need considerable time for resolving (Economic Report of the President 2004: 32–36).

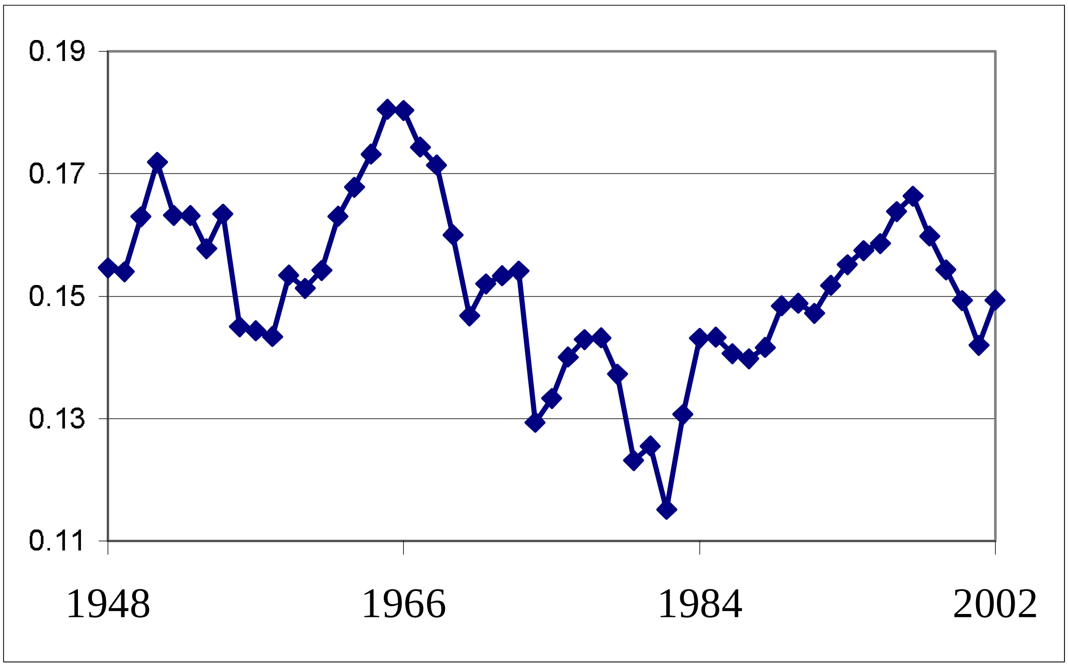

Figure 1 The gross (biased) profit rate $(1 - u)/s$ in the USA, 1948–2002

[1] Based on data on man-made capital from the Survey of Current Business, May 2004, and other relevant macroeconomic data from www.economagic.com downloaded on May 30, 2004. Exact definitions and explanations for mathematical notations are given below (section 1.2). The global maximum of employment ratio observed in 1953 did not constitute a peak of the Kondratiev cycle. It was brought about by the Korean war (1950–1953), by the boom in the middle-term business cycle and other factors. Consideration of these factors goes beyond the scope of the present paper.

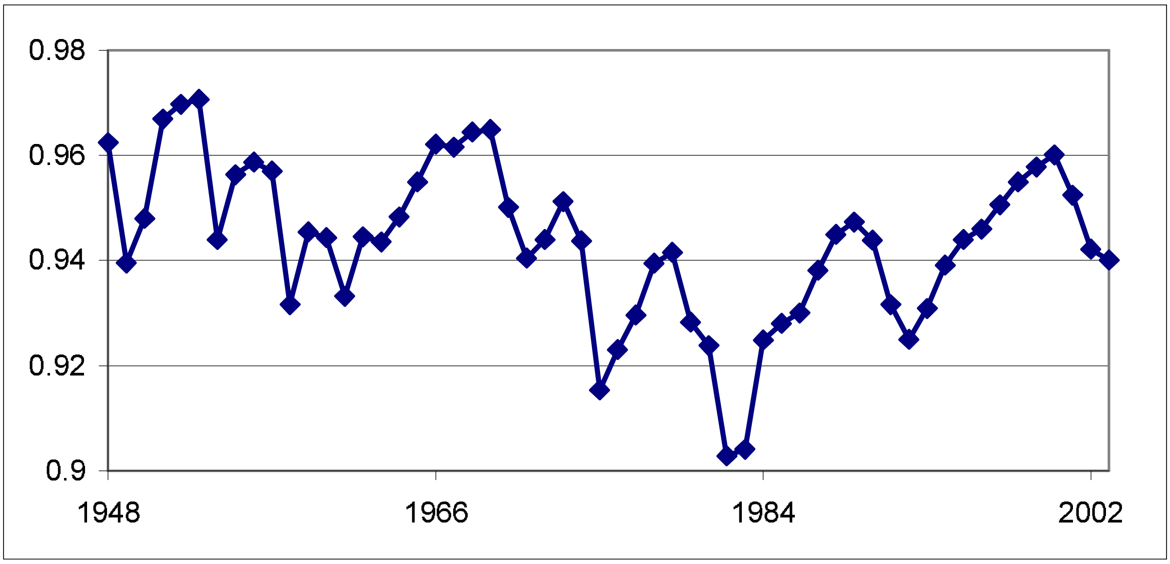

Figure 2 The employment ratio (v) in the USA, 1948–2003

The lead time of the gross (biased) profit rate is about three years against the employment ratio. This real property is in agreement with the HL. A modern neo-classical model of cyclical growth erroneously exaggerates this lead time by positing it at about ¼ of the period of a cycle (Zhang 1988).

The HL explains not only the long-term quasi-periodic fluctuations of the average profit rate, of the employment ratio and of other macro economic variables. It sheds light on a secular tendency of the average profit rate to fall that has been typical for the U.S. economy at least from the middle 1960-s (Ryzhenkov 2002a, 2003). This secular tendency is absent in the modern neo-classical model of cyclical growth (Zhang 1988) unlike the earlier neo-classical model of non-cyclical growth (Solow 1956).

The post second war growth of the U.S. economy is marked by a positive economy of scale. A growth rate of the employment ratio has been remarkably positively correlated with a growth rate of net output per worker over the long term (Figure 3). There seems to be a violation of this regularity in some years, particularly, in the year 2002. This regularity will be considered more closely below.

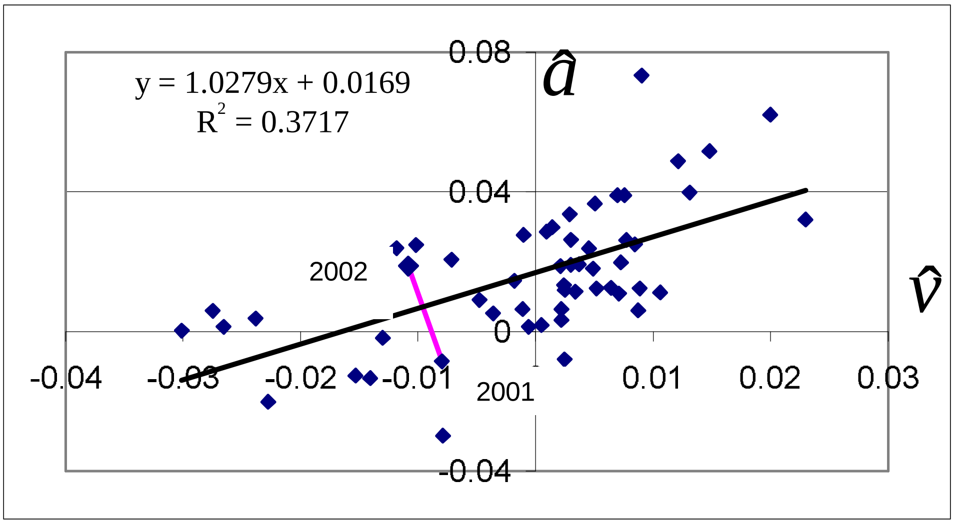

Figure 3 Economy of scale in the U.S. economy, 1949–2002

The present downturn in the long wave is not only a regularly recurrent phase of the long wave. Its additional pains are characteristic of childbirth of the natural capitalism. The 'old' industrial capitalism is experiencing a dialectical negation, or creative destruction. The system dynamics approach could be helpful for shortening and lessening disorder and distress of this major global transformation.[2]

The HL has been tested against facts and has undergone numerous laboratory experiments. The non-linear feedback relationships, measurement errors violate the maintained hypotheses of most single–equation econometric techniques. However, the Powell hill climbing algorithm and Kalman filtering could be applied for identification of unobservable elements of the HL in its probabilistic form (Ryzhenkov 2001, 2002a). The simulation software Vensim developed by Ventana Systems, Inc. allows applying these techniques.

This paper elaborates the notion of viable quasi-periodic motion bounded in the phase space that generalises stationary growth and stationary cyclical growth. This elaboration has been supported by the simulation experiments, based on the original hypothetical law (HL) of capital accumulation, and by statistical data.

This paper develops the economic theory of long waves via the system dynamics approach. Causality provides a key tool in this search for universal laws within a coherent theoretical system. Causal explanations allow, in particular, unobservable relations in formulating causal explanations of economic-ecological reproduction. The author tries to find additional points of contact between the HL and reality showing that statistical relations should not serve as substitutes for causal relations. In behavioural testing of the HL this paper pushes the background model beyond recent historical ranges of behaviour (cf. Bell, Senge 1980).

The deceleration of labour force growth challenges U.S. sustainable development in the XXI century. The application of the HL with exogenous growth of labour force to the American economy has shown that the moderation of the secular tendency of the average profit rate to fall is conditioned by the society's investment strategies (Ryzhenkov 2003a).

Ceteris paribus, the slower is the growth of the labour supply, the higher should be the overt incremental increases in the unit gross rent to secure accumulation of man-made *and* natural

[2] "Because it [natural capitalism] is both necessary and profitable, it will subsume traditional industrialism within a new economy and new paradigm of production, just as industrialism previously subsumed agrarianism" (Lovins et al. 1999: 158).

capital together. The reason is that due to the slower growth of the labour supply and labour productivity, economic growth and accumulation of capital decelerate. With the general economic slowdown the absolute rate of decline of the unit depletion and degradation of the natural capital (*e*) becomes smaller, therefore greater environmental investment is required for strongly sustainable development.

A practical focus of this work is on possible adverse social consequences of a more aggressive substitution of living labour by man-made capital during the current Kondratiev quasi-cycle, or long wave. This paper presents two exploratory scenarios of the current Kondratiev quasi-cycle in the USA in the contemporary period up to 2034 (and beyond). Building models and inventing policies, a modeller is to remember that preventing the real and potential class conflicts over distribution of income from escalating is one of the major policy concerns in business practice.

1 The original model of sustainable development

The necessity of linking both components — growth and long waves — empirically as well theoretically is as an important topic. The original system dynamics model of cyclical growth includes the stocks and flows, multiple non–linear feedback processes, and other elements of dynamic complexity. This model reflects the impact of economic activities upon natural environmental conditions. These conditions, in their turn, influence the growth rates of labour productivity and capital intensity. Policies, based on a perception of resource scarcity and pollution levels, are also reflected.

1.1 The model assumptions

A capitalist economy is restricted by natural resources. Produced capital is an embodiment of knowledge and, similarly, natural capital is a stock of information. Some conversion factors are needed for aggregating information content of different constituents. Fixed assets, labour and natural assets are essentially complementary to each other and are also substitutes to some degree depending on relative prices.

The other most important premises are such:

(1) two social classes (capitalists and workers); the State enforces the property rights, yet the cost of such an enforcement is not treated explicitly;

(2) three factors of production — labour force, man–made fixed capital, natural capital — are homogenous and non–specific;

(3) only one aggregated good is produced for consumption, investment and circulation, its price is identically one;

(4) production (supply) equals effective demand;

(5) productive capacities can be partially idle;

(6) all wages consumed, the resource rent and a part of profits saved and invested;

(7) steady growth in the labour force that is necessarily not fully employed;

(8) a growth rate of a unit real wage rises in the neighbourhood of full employment;

(9) a change in capital intensity and technical progress are not separable due to a flow of invention and innovation over time;

(10) a qualification of the labour force corresponds to technological requirements.

The product–money identity and the supply–demand equivalence stated in the third and fourth assumptions do not contradict the two–fold character of labour embodied in commodities. This model mirrors the twofold nature of labour power, the unity and contradiction of its value and use–value. The creative functions of labour market as an instrument for transmitting impulses to economic change are the focal point.

The model does not describe the formation of real income of the unemployed persons. It is assumed that a part of wages and salaries covers indirectly the needs of the unemployed. The latter do not play an active role in the model economy. Social security contributions and benefits are not shown unambiguously.

The model assumes supremacy of production over final demand. This assumption abstracts from the relative independence of final demand. It is more acceptable for the long run as for the short–run: although in the shorter run aggregate demand influences output, in the very long run output dominates over demand. Capital adapts the output to the scale of production.

The model abstracts from over–production of commodities inherent in over–production of capital during certain phases of industrial cycles. The assumption (6) simplifies definitions of the investment, saving and profit rates. It may be a key to explanation of the fact that the rate of profit on capital of order of 12 or 15 per cent per annum is compatible with a rate of economic growth of two or three and half per cent per annum.

The assumption (5) reflects the existence of excessive productive capacities. It is important for interpreting an equation for a rate of change of labour productivity (below). The assumption (7) means that the labour force grows exponentially over time. This assumption has been substituted by a more realistic hypothesis of an exogenous uneven growth of labour force in (Ryzhenkov 2003a). The assumption (6) corresponds to the immediate aim of profit–oriented capitalist production.

1.2 The equations of the original deterministic model

The model is formulated in continuous time. Time derivatives are denoted by a dot, while growth rates will be indicated by a hat. A listing of variables is given in the Appendix. This model consists of the following equations:

$$P = K/s; \qquad (1.1)$$

$$a = P/L; \qquad (1.2a)$$

$$a_S = P / L_S, \text{ where } L_S = LH; \qquad (1.2b)$$

$$u = w/a = w_S / a_S; \qquad (1.3)$$

$$\hat{a}_S = m_1 + m_2 \widehat{K/L_S} + m_3 \psi(\hat{v}) + m_5 \widehat{F/L_S}, \qquad (1.4)$$

$$\psi(\hat{v}) = SIGN(\hat{v}) ABS(\hat{v}) \wedge j,\ m_1 \geq 0,\ 1 \geq m_2 \geq 0,\ m_3 \geq 0,\ 1 \geq m_5 \geq 0,\ 1 \geq j > 0;$$

$$\widehat{K/L_S} = n_1 + n_2 u + n_3(v - v_c) + n_5(Z/P), \qquad (1.5)$$

$$n_2 \geq 0, \quad n_3 \geq 0, \quad n_5 \geq 0, \quad 1 > v_c > 0;$$

$$v = L/N; \qquad (1.6)$$

$$n = \hat{N} + \hat{H} = const; \qquad (1.7)$$

$$\hat{w}_S = -g + rv + b\,\widehat{K/L_S} + q\,\widehat{F/L_S},\ g \geq 0,\ r > 0; \qquad (1.8)$$

$$P = C + \dot{K} + Y = w_S L_S + (1 - k)M + \dot{K} + Y; \qquad (1.9)$$

$$\dot{F} = Y - Z; \qquad (1.10)$$

$$Z = eP,\ 0 < e < 1; \qquad (1.11)$$

$$y = Y/P \geq 0; \qquad (1.12)$$

$$\hat{X} = i; \qquad (1.13)$$

$$f = F/P; \qquad (1.14)$$

$$c = X/P; \qquad (1.15)$$

$$\hat{e} = \hat{P}(e_1 / e - 1),\ e \geq e_1 > 0; \qquad (1.16)$$

$$\dot{K} = kM = k[(1 - w/a)P - Y] = k[(1 - u)P - Y], \quad 0 < k \leq 1; \qquad (1.17)$$

$$\dot{y} = (o_1(c - f) + o_2 \hat{f})y. \qquad (1.18)$$

Equation (1.1) postulates a technical relation between the capital stock (K) and net output (P). The variable s is called capital–output ratio. Equation (1.2a) relates net output per worker (a), net output (P) and employment (L). Equation (1.2b) is a similar equation for labour productivity (a_S) that equals net output divided by labour input (L_S) as a product of the employment (L) and average annual hours worked (H). Equation (1.3) describes the shares of labour in net output (u).

Equation (1.4) is an extended technical progress function. It includes: the rate of change of produced capital intensity, K / L_S, the direct scale effect, $m_3\psi(\hat{v})$, and the rate of change of natural capital intensity, F / L_S. $ABS(x)$ is absolute value of x that is non–negative, x^j is x raised to the j-th power, $SIGN(x)$ is a sign of x, so $\mathrm{SIGN}(\hat{v}) = -1$ for $\hat{v} < 0$ and $\mathrm{SIGN}(\hat{v}) = 1$ for $\hat{v} \geq 0$.

The reader may notice that the equation (1.4) generalises a Kaldorian linear technical progress function that explains a rate of change of labour productivity by rate of change of produced capital intensity (Kaldor 1957). The similar relationship is a property of the Solow neo-classical model of economic growth (Solow 1956).

Due to the non-linear component $m_3\psi(\hat{v})$, this generalised technical progress function (1.4) is not analytical for $\hat{v} = 0$ if $m_3 > 0$ and $1 > j > 0$ as supposed throughout the rest of this paper. Because the function $\psi(\hat{v})$ is not analytical everywhere, the model is able to reflect the sudden and steep decline of the average profit rate during a crisis in a big cycle of conjuncture. This valuable property is beyond reach for many modern studies of endogenous economic cycles that use the Andronov – Hopf bifurcation as a common tool for presentation of stable cyclical growth, implying smooth analytical functional relationships that strongly idealise the capitalist reality.

An important assumption behind the equation (1.4) is that labour productivity is related to the (un)employment rate (cf. Okun 1983: 148). The non-linear element of the equation (1.4) is a reflection of Okun's observation that "a reduction in unemployment, measured as percentage of the labour force, has a much larger than proportionate effect on output" (ibid.: 153). In particular, " periods of movement toward full employment yield considerably above-average productivity gains" (ibid.: 155). Although depressed levels of activity will stimulate productivity through pressure on management to cut costs, 'the empirical record demonstrates that they are swamped by other forces working in the opposite direction" (ibid.: 156).

Equation (1.6) outlines the rate of employment (v) as a result of the buying and selling of labour–power. The exogenous growth rate of labour supply (n) is the sum of exogenous growth rates of labour force ($\hat{N}$) and averaged annual hours worked ($\hat{H}$) in (1.7). In the equation (1.8), the rate of change of the unit real wage ($\hat{w}_S$) depends on the employment rate (v), as in the usual Phillips relation, and on the rates of change of capital intensity (K / L_S) and (F / L_S), additionally. The capital intensity (K / L_S) is a proxy for qualification. It is assumed here and in the next sections that the growth rate of average hours worked is a component of the growth rate of the worker's real wage: $\hat{w} = \hat{w}_S + \hat{H}$. Correspondingly, $wL = w_S LH$.

In the equation (1.9), the sum of net export, final private and public consumption is $C = P[u + (1- k)(1- u - y)]$. The net formation of produced fixed capital is $\dot{K} = kM$. The gross accumulation of natural assets Y equals the gross resource rent in monetary (or information value) terms. Equations (1.9) and (1.17) show that profit ($M = (1- u - y)P$) and incremental man–made capital ($\dot{K}$) are not equal in monetary (or information value) terms if the investment share $k < 1$.

In the equation (1.10), $\dot{F}$ is a net accumulation (loss) of the natural capital (F). Z is the net environmental damage in the equation (1.11), i.e., depletion and degradation of non–produced natural assets (land, soil, landscape, eco–systems) due to economic uses above the regeneration rate.[3] The resource use or pollution has a fixed relationship to output. The linearity of this rela-

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[3] The rate of regeneration is given by a function $Q(F, Y)$, satisfying $Q(0, Y) = 0$, $\partial Q/\partial Y > 0$ (at least for F above a certain minimal level of F) in a more detailed model of sustainable develop-

tionship constitutes a particular case (e = *const*). A non–linear relationship (1.16) was firstly introduced in (Ryzhenkov 2001).

The equation (1.5) is a generalization of a linear mechanization function in a model of cyclical growth offered in (Glombowski, Krüger 1984) that relies on relative wage as the single endogenous factor for the rate of change of capital intensity. The rate of change of capital intensity (K/L) in the equation (1.5) is a function of the relative wage (u), difference between real employment ratio and some base ('natural') magnitude ($v - v_c$), depletion/degradation of natural capital in relation to net output (Z/P). The rate of growth of capital intensity depends on the environmental damage per unit of output (an application of the principle 'a pollution prevention pays'), in particular. A high wage share and high employment ratio promote mechanization (automation).

The parameter v_c plays a central role in this paper. The lower its magnitude, the more aggressive is substitution of living labour (L_S) by man-made fixed capital (K). The present author surmises that lowering this control parameter magnitude has gained a key role at the present recession phase of the Kondratiev cycle in the USA. The focus of this paper is on the probable short-term and longer-term consequences of a respective policy (see section 3).

The indicated natural capital, X, may remain constant, decrease or increase exponentially in the equation (1.13). In (1.12), the unit gross rent y is the investment ratio for the natural capital at the same time.

This model does not treat explicitly a stock of environmental assets. The natural capital–output ratios – real, f, and indicated, c, in the equations (1.14) and (1.15) – belong to the state variables of the model.

We assume that the unit depletion (degradation) of the natural capital asymptotically declines due to substitution and structural change as in (1.16) where for $\hat{P} > 0$ and $e > e_1$, $\hat{e} < 0$. The higher the rate of economic growth, the faster is the reduction of eco–intensity (or the promotion of eco–efficiency in the narrow sense). The equation (1.16) is, likely, a better approximation than $e = const > 0$. An approximation of a higher order can be easily implemented in the future work.

All growth rates in this model are in real terms. The flow variables P, C, M, Y, and Z are measured in monetary units per year, the stock variables K and F are measured in monetary units. Respectively, these variables could be measured in bits per year and bits as well. Methods of an evaluation of their informational content need a special elaboration that goes beyond the scope of this paper.

The equation (1.18) defines an investment policy that is aimed to develop the natural capital in accordance with the indicated natural capital. A combination of proportional and derivative control over the investment in natural capital is attainable hereby if the first parameter is positive ($o_1 > 0$), whereas the second parameter in this equation is negative ($o_2 < 0$). It is likely that such a wishful combination of the negative (i.e., control) feed-back loops has been absent in the reality. We will return to this issue in section 3.

The next peculiarity of the model is that it has only implicit delays. Due to them, the model gets rid of instantaneous adjustment to an equilibrium with full employment of labour force used by the earlier neo–classical theories of economic growth. An explicit investment delay is still set aside.

Three profit rates are defined for this economy. The first is the *average* rate of return to man–made capital $(1- u - y)/s$. The second is a *general* one, it measures a ratio of the economic surplus to the total value of produced and natural capital $(1 - u - e)/(s + f)$. The third is a *gross* (bi-

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ment. There is a perceived social need of directing technological progress to the development of material resources with a shorter regeneration time after the epoch of the increasing aggregate regeneration time of the resource package in use (Saeed 1994: 124–130). These aspects are skipped in this paper.

ased) profit rate $(1-u)/s$ that is more easily calculated based on the statistics with incomplete data on the natural resources.

The rate of net rent is the ratio of net unit rent to natural capital – output ratio, $(y-e)/f$. The general rate of profit is a weighted average of the rate of return to man–made capital and the rate of net rent: $(1-u-e)/(s+f) = [s/(s+f)](1-u-y)/s + [f/(s+f)](y-e)/f$.

The average rate of profit can grow because of a rise in the capital share $(1-u-y)$, a decline in the capital–output ratio (s), or decline in the relative price of capital goods (p/p_K). The ratio p/p_K is identically one in this one–product model.

Through a transformation of $\widehat{K/L_S} = \hat{K} - \hat{L}_S$, it is easy to derive a generalization of the fundamental equation of neo-classical economic growth (FENEG):

$$\dot{\overline{K/L_S}} = \hat{K}(K/L_S) - \hat{L}_S(K/L_S) = \dot{K}/L_S - \hat{L}_S(K/L_S) = k(1-u-y)a_S - \hat{L}_S(K/L_S).$$

The FENEG is a particular case of this equation for $k(1-u-y) = const$ and $\hat{L}_S = \hat{N} + \hat{H} = n$.

The model in an intensive form originates in (Ryzhenkov 2001, 2002a). It consists of seven differential equations (1.19) – (1.25) that define *a deterministic form of the hypothetical law of capital accumulation*:

$$\dot{s} = -\frac{1}{(1-m_5)}(m_1 + (m_2 + m_5 - 1)(n_1 + n_2u + n_3(v - v_c) + n_5e) + m_3\psi(\hat{v}) + m_5\hat{f})s; \tag{1.19}$$

$$\dot{v} = (k\frac{1-u-y}{s} - (n_1 + n_2u + n_3(v - v_c) + n_5e) - n)v; \tag{1.20}$$

$$\dot{u} = (-g + rv - m_1 + (b + q - m_2 - m_5)(n_1 + n_2u + n_3(v - v_c) + n_5e) - m_3\psi(\hat{v}) + (q - m_5)(\hat{f} - \hat{s}))u; \tag{1.21}$$

$$\dot{f} = ((1-m_5)\frac{(y-e)}{f} - m_1 - m_2(n_1 + n_2u + n_3(v - v_c) + n_5e) - m_3\psi(\hat{v}) - (1-m_5)(\hat{v} + n))f; \tag{1.22}$$

$$\dot{c} = (i - k\frac{1-u-y}{s} + \hat{s})c; \tag{1.23}$$

$$\dot{y} = (o_1(c-f) + o_2\hat{f})y; \tag{1.24}$$

$$\dot{e} = (k\frac{1-u-y}{s} + m_1 + (m_2 + m_5 - 1)(n_1 + n_2u + n_3(v - v_c) + n_5e) + m_3\psi(\hat{v}) + m_5(\hat{f} - \hat{s}))(e_1 - e). \tag{1.25}$$

It is helpful to repeat that the state variables are, respectively, the man–made capital–output ratio, employment ratio, unit wage, natural capital–output ratio, indicated natural capital–output ratio, unit gross rent, and unit depletion and degradation of the natural capital. The requirement for the denominators to be positive is omitted. If $\dot{K} > 0$, $\dot{F} > 0$ at each instant of time, the system (1.19) – (1.25) defines *a strongly sustainable development*.

An element of a continuum of non–trivial stationary states of the system (1.19) – (1.25) is defined as

$$E_a = (s_a, v_a, u_a, f_a, c_a, y_a, e_a), \tag{1.26}$$

where

$$s_a = s_0,$$
$$v_a = (g + (1-b-q)(d-n))/r,$$
$$u_a = (d - n - n_1 - n_3(v_a - v_c) - e_an_5)/n_2,$$
$$f_a = (1 - u_a - e_a)/d - s_a/k,$$
$$c_a = f_a,$$

$$y_a = e_a + df_a,$$
$$e_a = e_1,$$
$$i = d.$$

At this stationary state, a growth rate of produced fixed capital, indicated natural capital, real natural capital, net output is the same: $\hat{K}_a = \hat{X}_a = \hat{F}_a = \hat{P}_a = d = \dfrac{m_1}{1 - m_2 - m_5} + n$. The stationary average profit rate is $(1 - u_a - y_a)/s_a = d/k$. The stationary rate of growth of real wage, labour productivity and capital intensities is $\hat{w}_{s_a} = \hat{a}_{s_a} = \widehat{K_a / L_{s_a}} = \widehat{F_a / L_{s_a}} = d - n$.

Kaldor's stylized facts on economic growth in industrialized capitalist economies are valid for this stationary state (Kaldor 1957). The requirements of the FENEG are also satisfied:

$$\dot{\overline{K_a / L_{s_a}}} = k(1 - u_a - y_a)\, a_{s_a} - n\, K_a / L_{s_a}.$$

The higher the growth of labour supply (n), the higher are the stationary rates of economic growth, stationary average profit rate and the faster is capital accumulation, like in the neo–classical model (Solow 1956). Thus, the importance of the rate of growth of labour supply is the shared view in different streams of economic thought.

The form of the technical progress function (1.4) deserves more attention. It has a special element, the function $\psi(\hat{v})$, that reflects the economy of scale. For $\hat{v} = 0$ and [ABS $(\hat{v})$^ j]' = j[ABS $(\hat{v})$^ (j – 1)], partial derivatives of the function $\psi(\hat{v})$ go to infinity, if $0 < j < 1$. The system (1.19) – (1.25) cannot be linearly approximated at the stationary state $E_a = (s_a, v_a, u_a, f_a, c_a, y_a, e_a)$ because partial derivatives of a Jacobian matrix evaluated at this non–trivial stationary state go to infinity ($+\infty$) due to the same reason. As a rule, the stationary state E_a is not locally stable unlike the neo–classical stationary state. So the real economy cannot be observed in this state. Although the economy does not move asymptotically to E_a, it is possible to have periodic or quasi–periodic solutions of the system (1.19) – (1.25) that are bounded in the phase space. The movement toward the long-range sustainable growth path, taking place in the Solow (1956) neo-classical model, requires assumptions that cannot be maintained (Ryzhenkov 2000b, 2004).

With constant returns to scale, the marginal productivity of capital (profit rate) depends in Solow's model only on the capital-output ratio *K/P* and capital share in the net output, and does not depend on any scale quantity. The factor markets in his model work perfectly since the unit wage and profit rate adjust smoothly and instantaneously to changing circumstances. The rate of profit, being a reflection of how scarce capital in relation to the labour force, has not any independent significance for the growth rate.

This textbook neo-classical model consists of one positive and one negative feedback loops (Figures 1.1 and 1.2) that determine asymptotical convergence to steady state without fluctuations if exogenous shocks are disregarded (Figures 1.3 and 1.4).

$$\widehat{K/L_s} \xrightarrow{+} \hat{s} \xrightarrow{+} \dot{s} \xrightarrow{+} s \xrightarrow{+} \widehat{K/L_s}$$

Figure 1.1 The positive feedback in the Solow model

$$\widehat{K/L_s} \xrightarrow{+} \hat{a}_s \xrightarrow{-} \hat{s} \xrightarrow{+} \dot{s} \xrightarrow{+} s \xrightarrow{+} \widehat{K/L_s}$$

Figure 1.2 The negative feedback in the Solow model

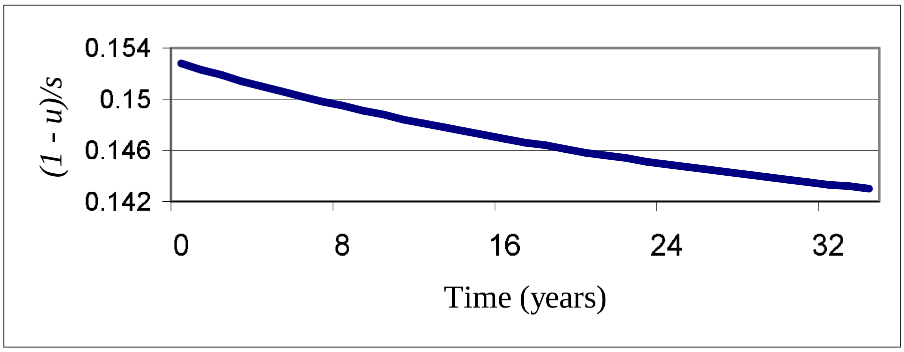

Figure 1.3 The secular tendency of the profit rate to fall in the Solow model

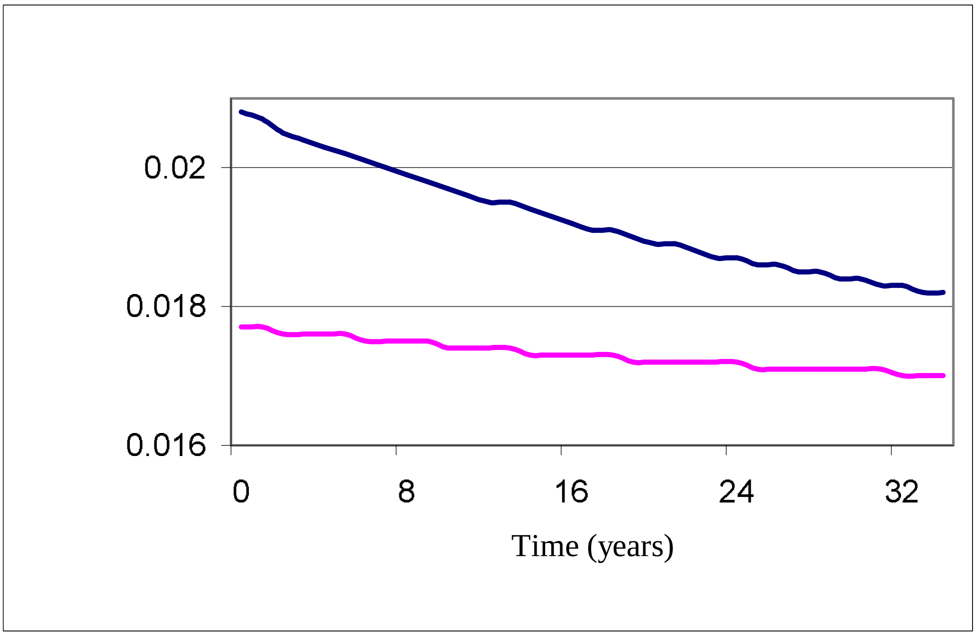

Figure 1.4 The declining growth rates of capital intensity $K\hat{/}L$ (blue curve) and labour productivity $\hat{a}_S$ (violet curve) in the Solow model

The reader may notice that Solow's neoclassical model contains no feedback loops involving the employment ratio, *v*, and average profit rate, (1 – *u*)/*s*. Therefore this model is abstracting from the most essential production relations of capitalism.

The HL encloses multiple feedback loops absent in the Solow's model. Figures 1.5 and 1.6 display only several feedback loops of the HL. The natural capital and respective variables are set thereby aside to avoid going into too much details. The reader, supported by the sets of the equations (1.1) – (1.25), may explore additional linkages freely and draw them. As demonstrated (Ryzhenkov 2004), the Solow's model is a particular (less realistic) case of the HL.

$$\hat{a}_S \xrightarrow{-} \hat{s} \xrightarrow{+} \dot{s} \xrightarrow{+} s \xrightarrow{-} \frac{1-u}{s} \xrightarrow{+} \hat{v} \xrightarrow{+} \hat{a}_S$$

$$\hat{a}_S \xrightarrow{-} \hat{s} \xrightarrow{+} \dot{s} \xrightarrow{+} s \xrightarrow{-} \frac{1-u}{s} \xrightarrow{+} \hat{v} \xrightarrow{+} \dot{v} \xrightarrow{+} v \xrightarrow{+} K\hat{/}L_S \xrightarrow{+} \hat{a}_S$$

$$\hat{a}_S \xrightarrow{-} \hat{s} \xrightarrow{+} \dot{s} \xrightarrow{+} s \xrightarrow{-} \frac{1-u}{s} \xrightarrow{+} \hat{v} \xrightarrow{+} \dot{v} \xrightarrow{+} v \xrightarrow{+} \hat{w} \xrightarrow{+}$$

continued on the next line

$$\hat{u} \xrightarrow{+} \dot{u} \xrightarrow{+} u \xrightarrow{+} K\hat{/}L_S \xrightarrow{+} \hat{a}$$

Figure 1.5 Three examples of the positive feedback loops in the HL

$$K\hat{/}L_S \xrightarrow{-} \hat{v} \xrightarrow{+} \dot{v} \xrightarrow{+} v \xrightarrow{+} K\hat{/}L_S$$

$$\hat{a}_S \xrightarrow{-} \hat{u} \xrightarrow{+} \dot{u} \xrightarrow{+} u \xrightarrow{+} K\hat{/}L_S \xrightarrow{+} \hat{a}_S$$

$$K\hat{/}L_S \xrightarrow{+} \hat{s} \xrightarrow{+} \dot{s} \xrightarrow{+} s \xrightarrow{-} \frac{1-u}{s} \xrightarrow{+} \hat{v} \xrightarrow{+} \dot{v} \xrightarrow{+} v \xrightarrow{+} K\hat{/}L_S$$

$$\frac{1-u}{s} \xrightarrow{+} \hat{v} \xrightarrow{+} \dot{v} \xrightarrow{+} v \xrightarrow{+} \hat{w}_S \xrightarrow{+} \hat{u} \xrightarrow{+} \dot{u} \xrightarrow{+} u \xrightarrow{-} \frac{1-u}{s}$$

Figure 1.6 Four examples of the negative feedback loops in the HL

1.3 A stochastic form of the original model (HL)

For taking into account measurement errors and an impact of factors neglected in the model assumptions, the deterministic model (1.19) – (1.25) has been transformed in a stochastic model. It was assumed for simplicity that $\hat{a}_S = \hat{a}$ and $\hat{L}_S = \hat{L} = n$. Whereas the model (1.19) – (1.25) abstracts in particular from short-term and middle-term economic fluctuations, this stochastic model makes implicit allowances for them by specification of the random components. The latter model includes state equations and measurement equations

$$\mathbf{x}(n) = \mathbf{f}\,[\mathbf{x}(n–1)] + \mathbf{w}(n),$$
$$\mathbf{z}(n) = \mathbf{H}\mathbf{x}(n) + \mathbf{v}(n),$$

where $n = 1, 2,\dots N$ is an index of data samples, $\mathbf{x}(0)$ – a vector of an initial state of the system, $\mathbf{w}(n)$ – a vector of equations errors (driving noise), $\mathbf{v}(n)$ – a vector of measurement errors. The deterministic part $\mathbf{x}(n) = \mathbf{f}[\mathbf{x}(n-1)]$ corresponds to the system (1.19) – (1.25) and an additional integral equation for net output per worker a = INTEGRAL($\dot{a}$, a_0). The symbol $\mathbf{H}$ is for a rectangular matrix.

A simplified version of an extended Kalman filtering (EKF) applied assumes that all the multivariate moments of the second order equal zero. It assumes additionally that each of the random vectors $\mathbf{x}(0)$, $\mathbf{w}(n)$, $\mathbf{v}(n)$ has a constant mathematical expectation and dispersion. The covariance matrices (Ψ, $\mathbf{Q}$, $\mathbf{R}$) of these vectors are diagonal and invariable. Each element on the main diagonal is the dispersion of the respective stochastic component, all other matrix elements equal zero. To some extent, these simplifications contribute to a theoretical idealising of growth cycles.

An application of the EKF to the U.S. macroeconomic data 1958–1991 has identified unobservable components of this stochastic model (Ryzhenkov 2001, 2002a). It has been shown that long wave is a dominant non–equilibrium quasi–periodic behavioral pattern of the U.S. capital accumulation. Evaluating the historical fit through appropriate summary statistics and long–range forecasting has strengthened confidence in this model. In an exploratory scenario, a spiral of accumulation is almost periodically arrested by the relative shortage of labour. A quasi–period of fluctuations is about 29–33 years.[4]

This duration is shorter than earlier estimations of the period of long wave (Forrester 1992; Sterman 1985, 1986, 1990). The reduction of the long wave's period may be explained by shortened product life cycles, resource intensive R&D and some other factors, analysed in (Milling 2002).[5] In the region of relative structural stability, the quasi-period of fluctuations is the longer, the lower is the growth rate of labour force (here n).[6]

In order to create additional points of contact between the HL and reality, the next section confronts this law with important empirical regularities uncovered by other researchers independently of the present paper. This confrontation may lead to refutation of this law and/or prompt revising the background model structure. In fact, it strengthens the confidence in the HL as a relative objective truth.

2 Properties of the smoothed economic time series

An application of the HL of capital accumulation to an analysis of the U.S. economic time series for 1958–1991 enables to reveal and explain a number of empirical regularities. Simplified version of the extended Kalman filtering (EKF), mentioned in the previous section, allows not only getting the estimates of the all model parameters but obtaining smoothed time series for the generic model variables in the basal period as well. These time series are probable (theoretical) estimates of the actual data that could be not measured in practice without a statistical error or even cannot be observed at all like the indicated natural capital (X). The probable magnitudes of the state and other variables for the basal period (1958–1991) used below are from (Ryzhenkov 2001, 2002a). For avoiding confusion, it is necessary to note that the rate of growth of net output per worker ($\hat{a}$) equals the rate of growth of labour productivity ($\hat{a}_S$) in the initial model (1.1) – (1.18) and in the compact model (1.19) – (1.25) as well throughout this section, since it was assumed that $n = \hat{N}$ and $\hat{H} = 0$ for 1958–1991.

Known regularities explained/generalised by the HL

1. There was a positive correlation between growth rates of output and labour productivity (Nikitin 1982: 23). Accelerating economic growth was accompanied by accelerating growth of labour productivity, decelerating economic growth – by decelerating productivity (Figure 2.1).

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[4] Roughly the same estimations for the period of the economic long wave in the USA are given in the books (Chizhov 1977: 110–124), (Gerster 1988) and paper (Kiefer 1996).

[5] A review *Innovation in Industry* works out that the economic long waves are shortening from 50–60 years to around 30–40 years. See: *The Economist*, February 20th 1999, 350 (8107): 8. Numbered 1–5, these long waves correspond to the industrial revolutions.

[6] Accumulation of man-made capital and natural capital facilitates the growth of population and labour force that, in turn, reinforces the economic-ecological reproduction. An explicit modelling of this positive feed-back requires a treatment of the growth rate of labour force as endogenous variable in a subsequent research.

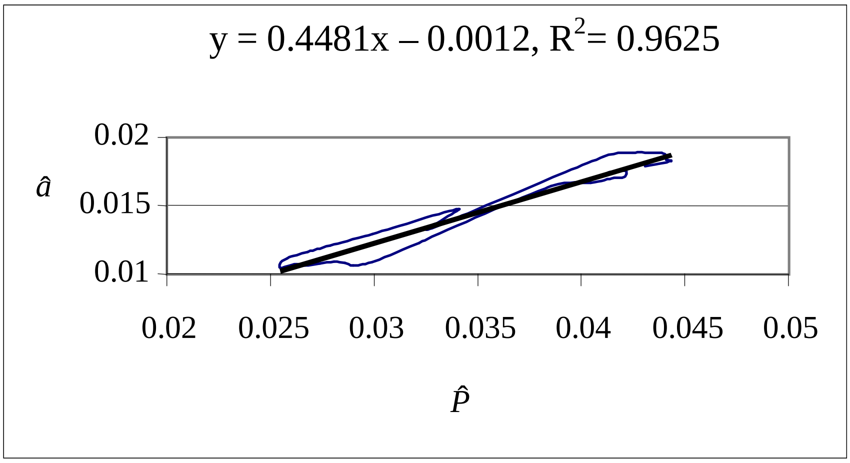

Figure 2.1 The growth rates of NNP ($\hat{P}$) and labour productivity ($\hat{a}$) in the USA, 1960–1991. Counter-clockwise

2. According to (Izumov 1983), the profit rate grew in periods, when the growth rate of labour productivity, $\hat{a}$, was higher than the growth rate of capital intensity, $\widehat{K/L}$, and higher than the growth rate of real unit wage, $\hat{w}$ (Figures 2.2 and 2.3).

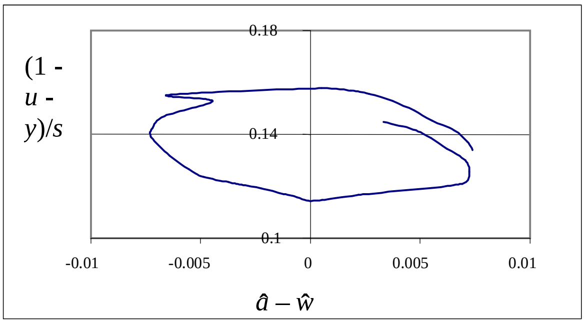

Figure 2.2 A difference of growth rates of labour productivity and unit real wage ($\hat{a} - \hat{w}$) versus average profit rate $(1 - u - y)/s$ in the USA, 1960–1991. Counter-clockwise

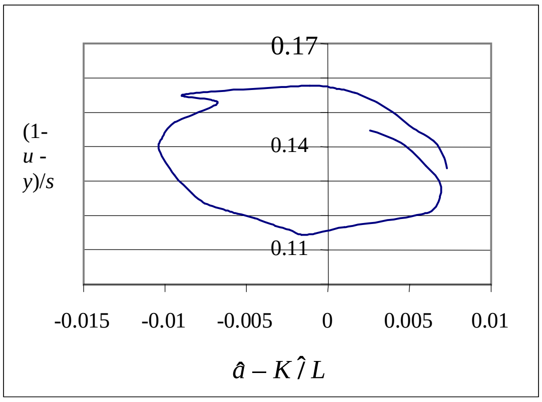

Figure 2.3 A difference of growth rates of labour productivity and capital intensity ($\hat{a} - \widehat{K/L}$) versus average profit rate $(1 - u - y)/s$ in the USA, 1960–1991. Counter-clockwise

3. As observed (Valtukh 2001: 552–553), there was a high positive correlation of the growth rate of non-residential investments and incremental capital productivity (respec-

tively, $\hat{I}=\hat{K}=\hat{k}+(-\dot{u}-\dot{y})/(1-u-y)+\hat{P}=(-\dot{u}-\dot{y})/(1-u-y)+\hat{P}$ and $\dot{P}/I$; see Figure 2.4) .

4. The growth rate of labour productivity was weakly correlated with the growth rate of capital intensity in the USA in 1973–1993. If this correlation is considered significant, it is negative (Valtukh 2001: 627).

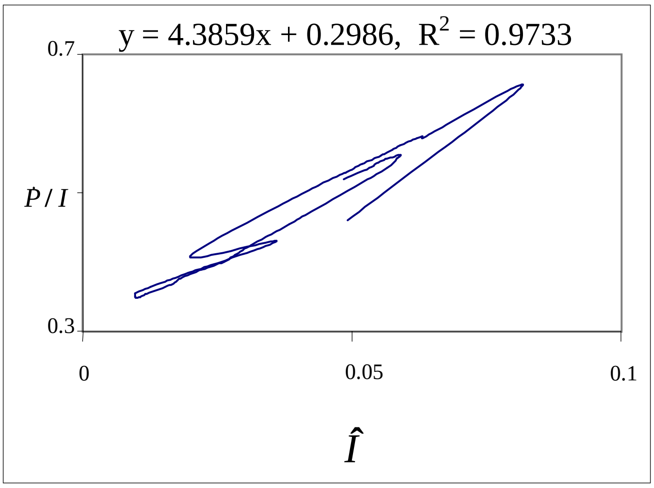

Figure 2.4 The growth rate of non-residential investment ($\hat{I}$) and incremental capital productivity ($\dot{P}/I$) in the USA, 1958–1991

The empirical regularity 4 seems to refute the applied model since it questions the technical progress function (1.4) that assumes a positive causal relationship between rates of change of capital intensity and labour productivity. This apparent contradiction between the model and reality is spurious because the model relationship in question reflects only the effect of the growth rate of capital intensity on the growth rate of labour productivity, whereas the observed correlation of the growth rates of capital intensity and capital intensity reflects the combined effects of *all* variables affecting the growth rate of labour productivity. When all variables affecting this variable in the model are allowed to vary in simulation, the model generates the same negative correlation between the growth rates of labour productivity and capital intensity seen in the data.

This result has been confirmed both for the whole base period 1958–1991 and for its part 1973–1991 (Figures 2.5 and 2.6). The author calls again the reader's attention to the principal difference between correlation and causal relationships. The apparent contradiction of these relationships has been solved by the HL of capital accumulation. It is clear that correlation methods are a subordinate pattern recognition tool for the complex macroeconomic behaviour.

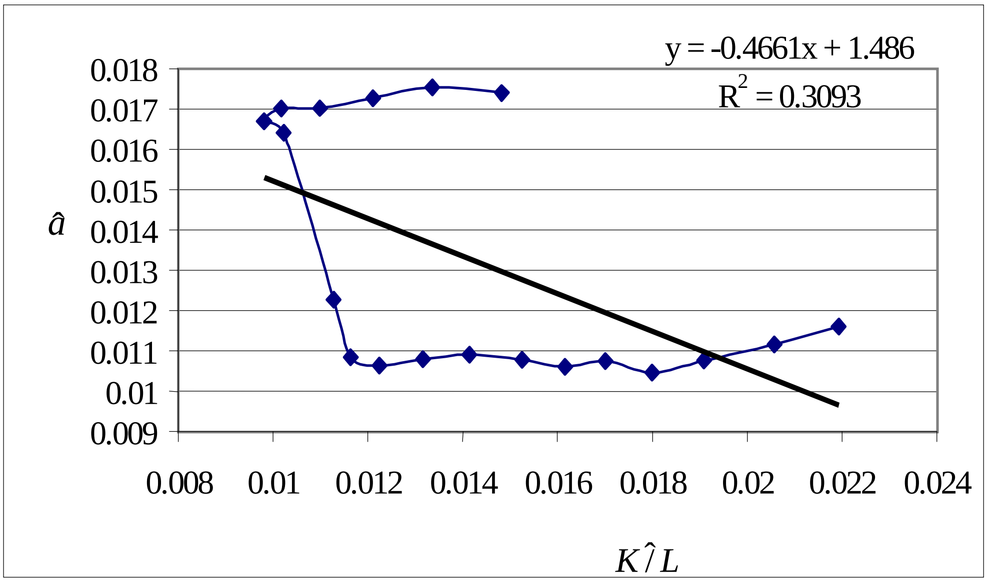

Figure 2.5 The growth rates of capital intensity ($\widehat{K/L}$) and labour productivity ($\hat{a}$) in the USA, 1973–1991. Clockwise

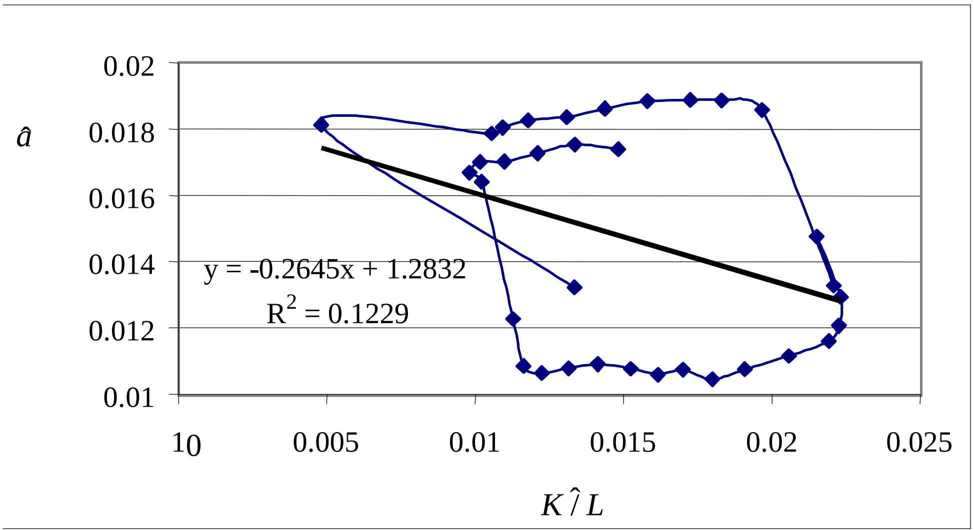

Figure 2.6 The growth rates of capital intensity ($\widehat{K/L}$) and labour productivity ($\hat{a}$) in the USA, 1958–1991. Clockwise

5. Okun's Law

The Okun law explains movements of unemployment by co-movement in output (Okun 1962). It states a positive relationship between economic growth, measured by real net output, and the employment ratio.

Okun's particularly important assumption in the context of the present investigation is that labour productivity is related to the unemployment ratio (Okun 1983: 148). This idea has helped to formulate the modified technical progress function (1.4) as already noticed above.

In periods, from which this relationship was obtained, the unemployment ratio varied from about 3 to 7.5 per cent. This "relation is not meant to be extrapolated outside this range" (Okun 1962: 150). It is well known that a real range of fluctuations of the unemployment ratio is substantially broader than this interval.

For Kondratiev's quasi-cycles, Okun's law is likely only partially true. Figure 2.7 demonstrates that usually two different levels of the employment ratio correspond to each magnitude of the rate of economic growth and vice versa.

Statistical analysis based on the HL has shown that the Okun's analysis could be deepened and extended. Accelerated economic growth can be accompanied by constant, growing or declining employment ratio depending on a particular phase of the long wave (Figure 2.7). In particular, the rate of economic growth and employment ratio increase simultaneously during the recovery phase of the Kondratiev quasi-cycle.

The present paper will utilize the Okun idea that measuring potential labour input in man-hours is more perfect than measuring it by a number of members of the labour force although "economy-wide data on average hours are notoriously poor" (ibid.: 154–155). The reader may notice that changes of working hours have not been taken into account explicitly in the identification of the generic model parameters in (Ryzhenkov 2001, 2002a).

Behavioural testing of the above generic system dynamics model should push the model beyond recent historical ranges of behaviour. We will test, in particular, the possible long-term consequences of the more aggressive substitution of living labour by dead labour (i.e., man-made fixed assets), that is supported by ample evidence in the current business press, in the next section.

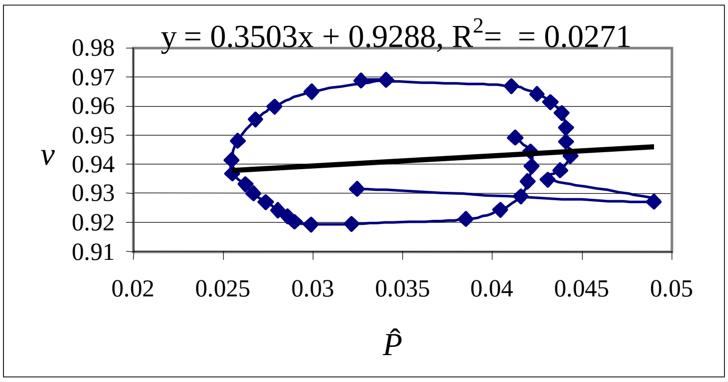

Figure 2.7 The growth rate of the NNP ($\hat{P}$) and employment ratio (*v*) in the USA, 1958–1991. Counter-clockwise

6. The economy of scale

The Economist (1995, vol. 337 (7942): 21–22) observed: "… rapid productivity growth tends to go hand in hand with rapid output growth. In 1960s, when productivity in OECD economies grew more than twice as fast as it has over the past decade, unemployment remained low. Only in 1970s, when the growth in productivity (and in output) slumped, did unemployment rise." The positive correlation between productivity growth and output growth has been already considered. Now we turn our attention to a positive correlation between productivity growth and growth of the employment ratio (Figure 2.8).

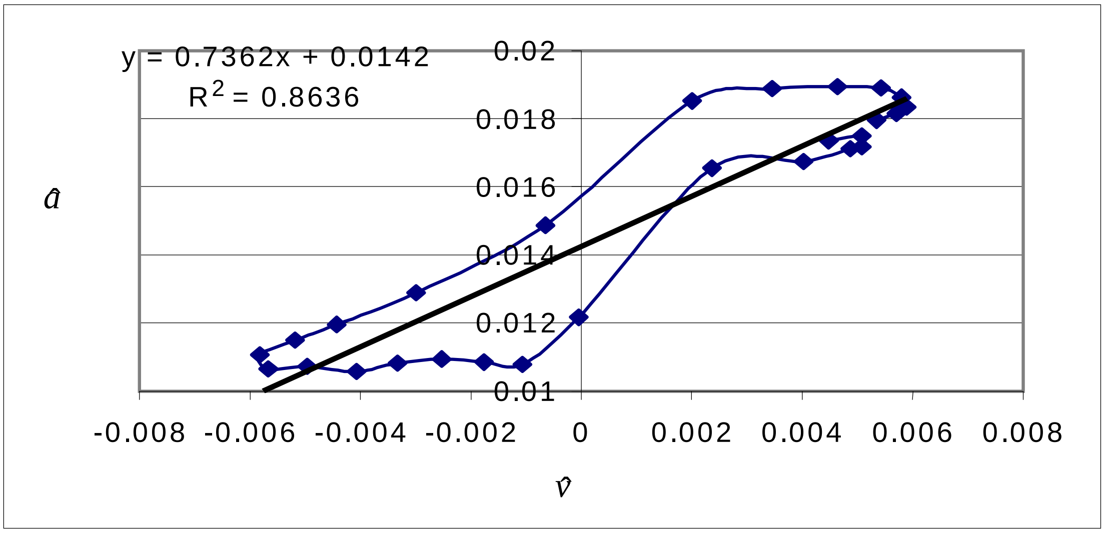

Figure 2.8 The growth rates of the employment ratio ($\hat{v}$) and labour productivity ($\hat{a}$) in the USA, 1960–1991. Counter-clockwise

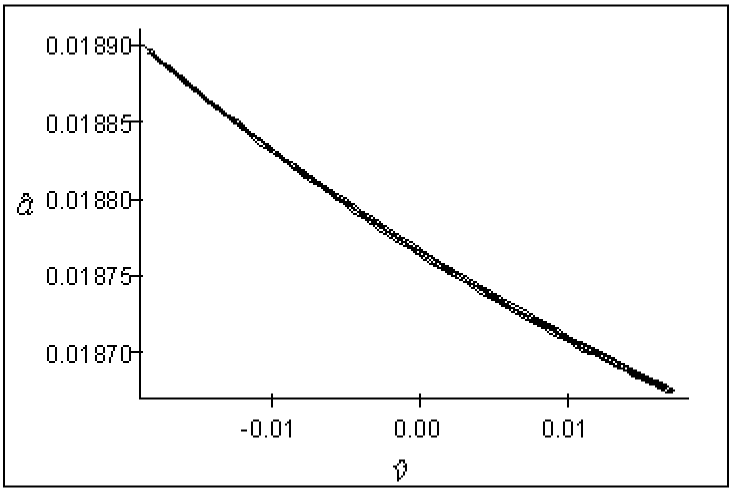

Figure 2.9 The diseconomy of scale in the modern neoclassical model of cyclical growth, according to the author's calculations based on (Zhang 1988)

The modern neoclassical model of cyclical growth substitutes incorrectly this positive association, based on revealed causal relationship in the equation (1.4), by negative one as shown on Figure 2.9. It is demonstrated that such an incorrect negative association is also a property of the Solow (1956) model if the strong assumption of full employment (or constant employment ratio), stated in this neo-classical model, is relaxed (Ryzhenkov 2004).

3 Two scenarios of the current long wave in the USA

In this section, the growth rate of net output per worker is different from the growth rate of labour productivity. Thus the related simplification of the previous section is relaxed here. The growth rate of employment ($\hat{L}$) is now also different from the growth rate of the total hours worked in the economy. The latter is defined as $\hat{L}_S = \hat{L} + \hat{H}$. The growth rate of net output per worker is, at this point of this presentation, equal to the sum of growth rate of labour productivity and growth rate of the average hours worked ($\hat{a} = \hat{a}_S + \hat{H}$).

The economists have witnessed a fast growth of productivity since the 4th quarter of 2000 up to the beginning of 2004 at an exceptional annual rate of more than 4 per cent per year (Economic Report of the President 2004: 46). There is growing empirical evidence in the literature that American firms have been adjusting their employment more drastically after the beginning of the recession in the business cycle in the fourth quarter of 2000.[7] Ruthless elimination of the least-efficient plants and companies has enabled labour productivity to bound by 4.8 per cent in 2002, which has been the best performance since 1950 (Samuelson 2003).

The first question is why this achievement did not signal a robust recovery? The second question: what are quantitative characteristics of a trade-off in a greater aggressiveness in substituting living labour by machines? This trade-off is between a higher economic volatility, lower employment, on the on hand, and higher profitability and shorter downward phases of the Kondratiev quasi-cycle.

The following magnitudes of the model parameters have been estimated with a help of EKF for 1958–1991 (assuming the annual growth rate of averaged hours worked is roughly zero, i.e., $\hat{H} \equiv 0$): $b \approx 0.621$, $g \approx 0.053$, $i \approx 0.037$, $j \approx 0.211$, $k \approx 0.267$, $m_1 \approx 0.015$, $m_2 \approx 0.1$, $m_3 \approx 0.011$, $m_5 \approx 0.089$, $n = 0.02$, $n_1 \approx -0.242$, $n_2 \approx 0.353$, $n_3 \approx 0.5$, $n_5 \approx 0.011$, $o_1 \approx -0.030$, $o_2 \approx -9.934$, $q \approx -0.008$, $r \approx 0.061$, $v_c \approx 0.925$ (Ryzhenkov 2001, 2002a).

The magnitudes of the state variables in 1991 are also the EKF estimations. All these (except the unobserved indicated ratio *c*) are compared with realized magnitudes of the same state variables, based on raw statistical data, in the Table 3.1.

Table 3.1 The author's estimates for the U.S. real macro economic data based on the official American statistics for 1991

	f	u	s	v	a	y	e	c
Simulated	0.109	0.694	2.052	0.947	0.051	0.008	0.008	13.980
Realised	0.119	0.711	1.960	0.931	0.050	0.005	0.008	…

Source: Ryzhenkov 2001. Units of measurement: *u*, *v*, *e* and *y* [dimensionless], *c*, *f* and *s* [years], *a* [billions of chained 1996 dollars per 1000 civil persons employed per year]. Constant 1987 dollars are used for the nominators and denominators calculating *y* and *e*; constant 1996 dollars are used for the nominators and denominators calculating *f* and *a*; calculations of *u* and *s* are done with the nominators and denominators valued in current prices. The employment ratio *v* is for the civil labor force.

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[7] According to the web site of the Bureau of Labor Statistics http://www.bls.gov/cps/home.htm (August 17, 2004), the registered unemployment ratio (not seasonally adjusted) in the USA has increased to 6.0 per cent in 2003 from 4 per cent in 2000. The unemployment level was 8,774,000 for 2003. The seasonally adjusted unemployment ratio has been at 5.5 per cent in July 2004.

Table 3.2 The growth rates (geometrical averages) of civil labour force, employment and hours worked in the USA, 1992–2000*

Growth rates of				
labour force ($\hat{N}$)	employment ($\hat{L}$) *	total hours worked in the economy ($\hat{L}+\hat{H}$) **	hours worked annually per person employed ($\hat{H}$)***	labour supply ($\hat{N}+\hat{H}$)
(1)	(2)	(3)	(4) = (3) – (2)	(5) = (1) + (4)
0.0135	0.0169	0.0198	0.0029	0.0164

* Based on data downloaded from http://www.economagic.com on May 30, 2004. ** Including hours of the military personnel. Based on the unpublished BLS data delivered to the author by e-mail on May 30, 2004.
*** Disregarding the military personnel.

In two exploratory forecasts for 1991–2034 below, the EKF estimates of the state variables are also used in the computer simulations. Still instead of the EKF estimate $n \approx 0.02$ for 1958–1991, $n \approx 0.016$ is used (Table 3.2) unchanged for the whole period 1991–2034 for simplicity. It takes into account that the growth of the number of members of the American labour force ($\hat{N}$) has decelerated, whereas the hours worked annually on the average have increased ($\hat{H} > 0$) . The sum $\hat{N}+\hat{H}$ measures the growth rate of the labour supply.

Table 3.3 The annual growth rates (%) of labour force, average annual hours worked and labour supply, the two scenarios compared with the trustees projections, 2003–2034

	Scenarios 1 & 2	Trustees projections*		
		low cost	intermediate	high cost
$\hat{N}$	1.35	0.7	0.55	0.4
$\hat{H}$	0.29	0.1	0	-.1
$\hat{N}_S$	1.64	0.8	0.55	0.33

* Source: Board of Trustees 2003, table V.B.1, p. 93–94 and table V.B.2, p. 99–100.

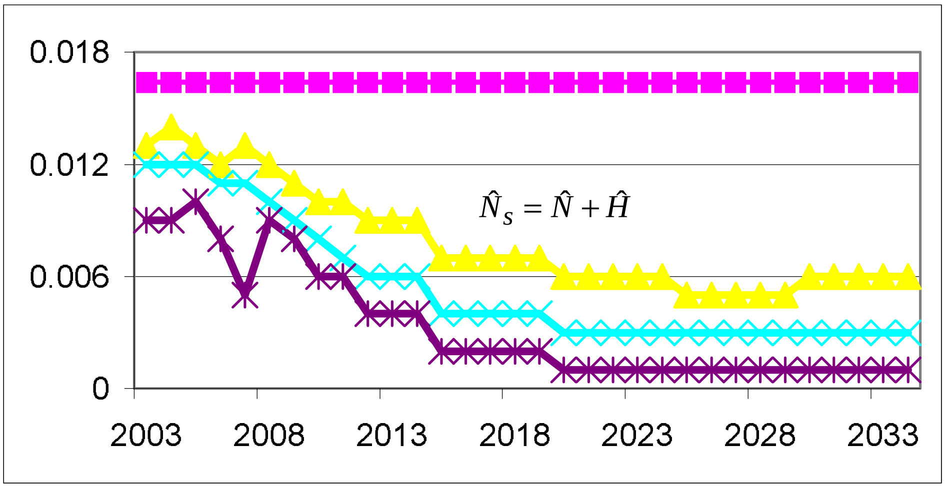

Figure 3.1 The growth rates of labour supply, two scenarios compared with trustees' projections, 2003–2034

For comparison, the Board of Trustees projects labour supply to taper down between 2004 and 2035 from 0.014 to 0.007 in the low cost projection, from 0.012 to 0.003 in the intermediate projection, and from 0.009 to 0.0 in the high cost projection (Table 3.3 and Figure 3.1).

Our non-conventional assumption ($n \approx 0.016$) reflects the prevailing interest of capital in steady growth of labour supply over the long term. Still the reader should not forget that this assumption may alleviate the acute environmental strain in the model at this particular phase of theoretical consideration.

The other central working hypothesis is that the extraordinary high growth of labour productivity in 2002 and massive layoffs in the subsequent period have been brought about by a jump down by about 3 per cent of the initial magnitude of the control parameter v_c in the mechanization (automation) function (1.5). More specifically, the former coefficient $v_c = const$ is transformed into a new auxiliary variable

$$v_{step} = v_c - \text{STEP}(0.025, 2002). \tag{3.1}$$

It means that $v_{step} = v_c \approx 0.925$ for 1991–2001 and $v_{step} = v_c - 0.025 \approx 0.9$ for 2002–2034.

All other conditions in the simulations runs are the same. Results of simulations with the former and new definitions of this control parameter are compared below. We will give a name Scenario 1 for a continuation of business as usual, and name Scenario 2 – for the development path with the more aggressive substitution of labour by capital as in (3.1).

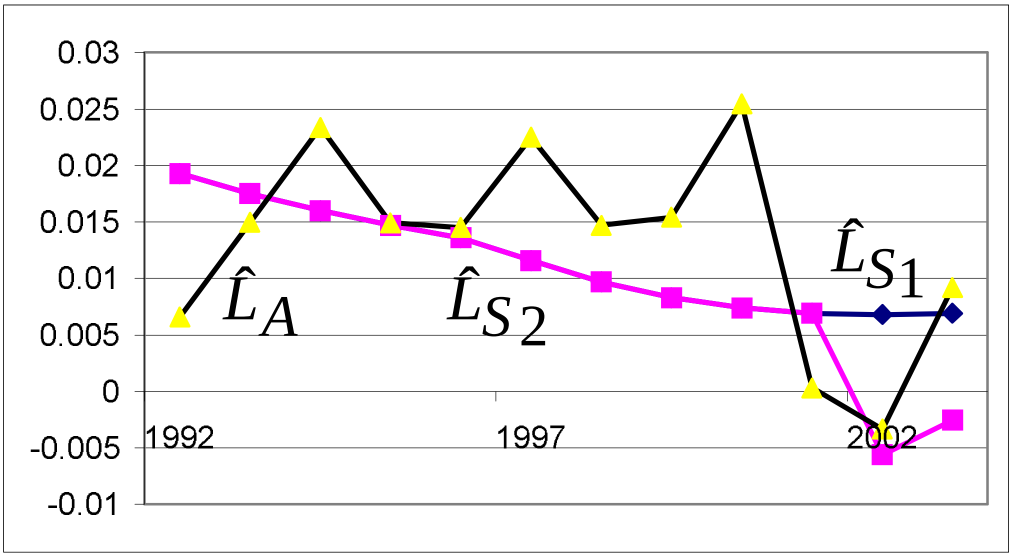

Figure 3.2 The growth rates of the employment in the two scenarios (respectively, $\hat{L}_{S_1}$ and $\hat{L}_{S_2}$) compared with its realized growth rates ($\hat{L}_A$), 1992–2003

The Board of Trustees foresees that the employment ratio and growth rate of labour productivity will move toward the ultimate assumed magnitudes as the economy progresses toward the supposed long-range sustainable growth paths, for the low cost, intermediate and high costs assumptions, respectively. These two variables do not change in the remaining part of the projection period (2035–2080) in these trustees projections. The total U.S. economy labour productivity is defined hereby as the ratio of real GDP to hours worked by all workers (civilian, military and the self-employed).

These trustees projections are methodologically akin to the equilibrium approach to economic growth in the Solow (1956) paper that does not accurately reflect factors disturbing equilibrium

(Ryzhenkov 2000b, 2004). The 2003 Annual Report of the Board of Trustees does not discuss, in particular, whether the slower growth of labour supply complicates achieving strongly sustainable development or not. As shown in (Ryzhenkov 2003a), when the growth of labour supply decelerates, the model economy becomes less dynamically and structurally stable, therefore transiting to sustainable development (for lower *n*) is more dependent on a society's strategy to invest in natural capital.

In my simulations, the immediate social consequences of the stronger aggressiveness in the Scenario 2 are more painful than those in the Scenario 1. Although this higher aggressiveness spurs the growth rate of labour productivity, it diminishes the employment, employment ratio, profitability, and the rate of economic growth (Figures 3.3–3.7). The Kondratiev downturn is deeper in the Scenario 2 than in the Scenario 1. The total period of the Kondratiev quasi-cycle is 2–3 years shorter in the Scenario 2 than in the Scenario 1.

In view of this pain, what makes the stronger aggressiveness so attractive for practical realisation? The first advantage is a shorter decline: the length of the downturn is about three years shorter in the Scenario 2 than in the Scenario 1. The second advantage is higher profitability and productivity in the Scenario 2 than in the Scenario 1 on the average (Table 3.4).

In these scenarios, the long-term business upturn will not happen until 2013 or even 2015 if judged by the employment ratio (v). It will proceed thereafter up to the beginning of the next long-term downturn in 2030–2032.

In the Scenario 2 the mean values of the growth rates of labour productivity, unit real wage, and the profit rate are higher than the respective ones in the Scenario 1. In the Scenario 2 the mean values of the growth rate of NNP, labour force and of employment ratio are lower than the respective ones in the Scenario 1 (Table 3.3).

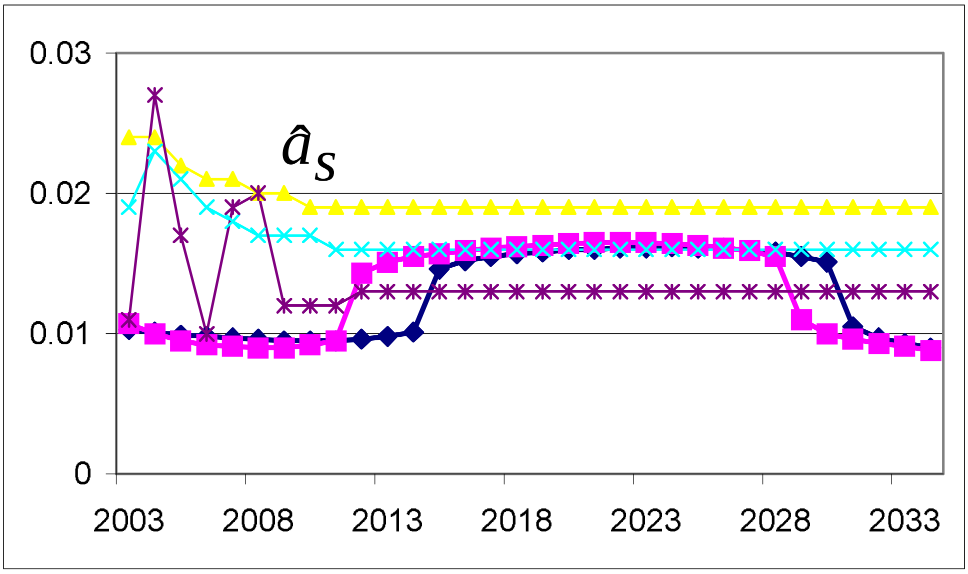

Figure 3.3 The growth rates of labour productivity in the two scenarios compared with trustees' projections, 2003–2034 (Scenario 1 – violet curve, Scenario 2 – blue curve)

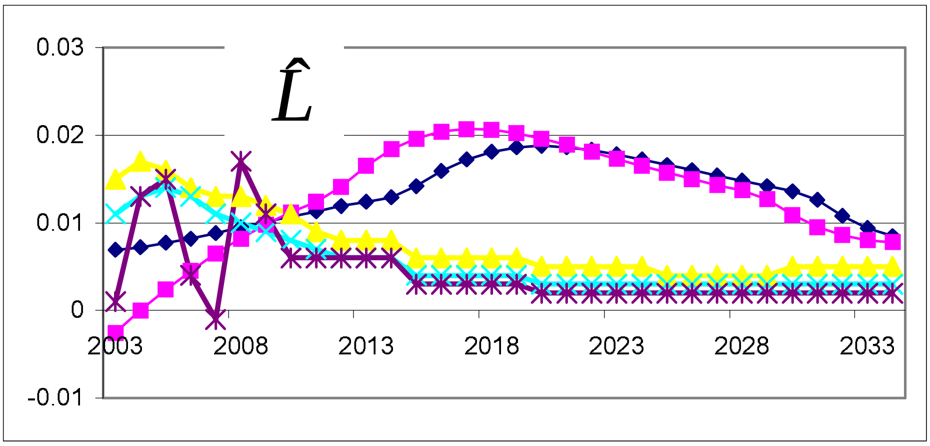

Figure 3.4 The growth rates of the employment, two scenarios compared with trustees' projections, 2003–2034 (Scenario 1 – violet curve, Scenario 2 – blue curve)

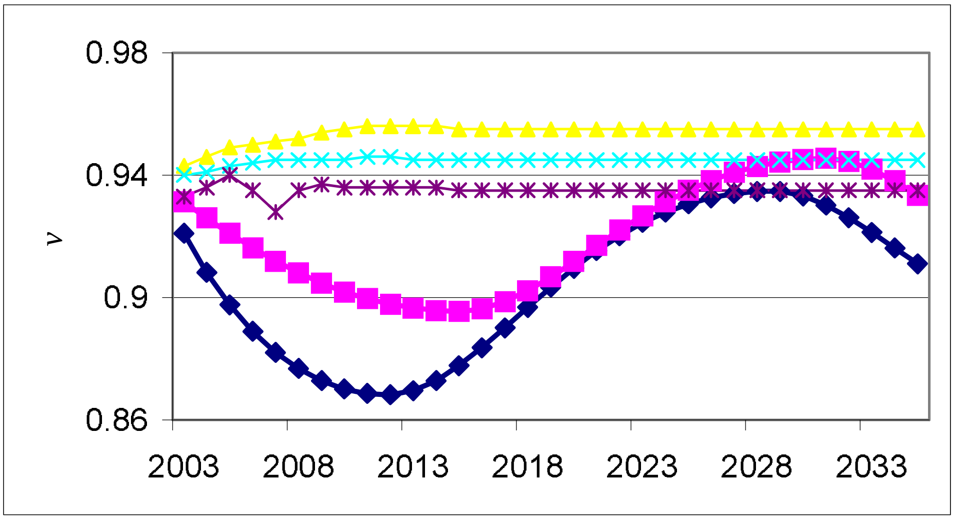

Figure 3.5 The employment ratio (*v*) in the two scenarios compared with trustees' projections, 2003–2035 (Scenario 1 – violet curve, Scenario 2 – blue curve)

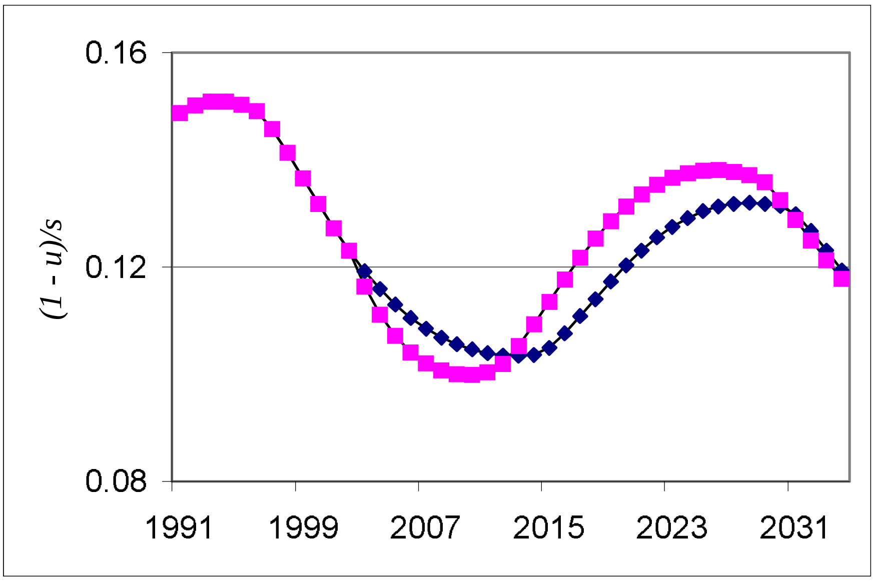

Figure 3.6 The biased profit rate (1 – u)/s in the two scenarios
(Scenario 1 – violet curve, Scenario 2 – blue curve)

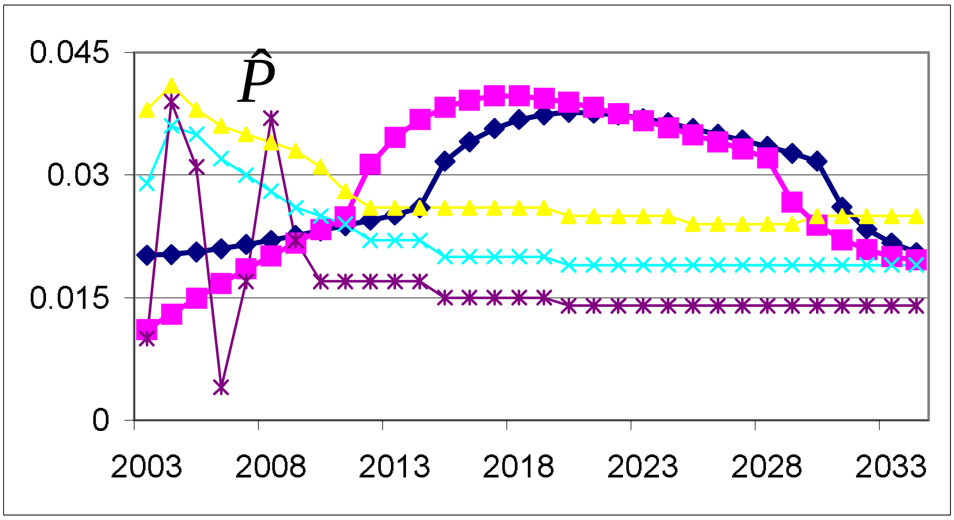

Figure 3.7 The growth rate of NNP ($\hat{P}$) in the two scenarios compared with the growth rate of real GDP in trustees' projections, 2003–2034
(Scenario 1 – violet curve, Scenario 2 – blue curve)

Table 3.4 Statistics on the model variables in
the two scenarios of U.S. economic development, 2002–2034

	Scenario	Min.	Max.	Mean	Variation*, %
$\hat{a}_s$	1	0.009	0.016	0.013	23.5
	2	0.009	0.017	0.013	24.7
$\hat{P}$	1	0.020	0.038	0.029	23.3
	2	0.009	0.040	0.028	33.7
$(1 - u)/s$	1	0.104	0.132	0.118	8.7
	2	0.100	0.138	0.121	11.3
v	1	0.900	0.949	0.925	1.9
	2	0.872	0.941	0.910	2.7

*Ratio of standard deviation to mean

Table 3.5 The average annual growth rates in
the two scenarios compared with the trustees projections, 2003–2034, %

	Scenario 1	Scenario 2	Trustees projections		
			low cost	inter-mediate	high cost
$\hat{P}$	2.90	2.87	2.79	2.24	1.66
$\hat{H}$	0.29	0.29	0.08	0.00	-0.10
$\hat{N}$	1.35	1.35	0.71	0.55	0.43
$\hat{a}$	1.56	1.58	2.04	1.67	1.27
$\hat{L}$	1.33	1.28	0.76	0.56	0.42
$\hat{a}_s$	1.27	1.29	1.96	1.67	1.37
$\hat{L}_s$	1.62	1.57	0.85	0.56	0.32

Cui bono?

Evidently, the Scenario 2 satisfies better the long term interests of capital than the Scenario 1 that would be favoured by labour (including unemployed). The social layers that are interested in milder volatility of economic evolution would favour the Scenario 1, characterised by a lower normalised standard deviation of each indicator than that in the Scenario 2. The potential risk of this latter scenario is more difficult prevention of real and potential class conflicts over distribution of income from escalating.

The slower growth rate of labour supply in reality than the deliberately chosen magnitude ($n \approx 0.016$) affects actual distributional conflicts. For strongly sustainable development, a more robust social consensus on distributional issues is needed than achieved so far. The author guesses that if the main social classes mitigate the distributional conflicts over income distribution, they will discover and carry out easier a policy for environmentally sustainable development. The system dynamics approach outlined in this paper could be helpful in determining societal policies and strategies for this end.

Let us return to the equation (1.18) for the time derivative of the unit gross rent. According to a statistical estimation in (Ryzhenkov 2001, 2002a), the second parameter in this equation is negative as expected ($o_2 < 0$), whereas the first parameter is paradoxically negative ($o_1 < 0$) too. Therefore the wishful combination of the negative (i.e., control) feed-back loops has been probably absent in the reality. Figure 3.8 illustrates that the real natural capital (F) becomes a negligible fraction of the indicated natural capital (X) as the ratio $X/F = c/f$ grows fast in the extended projection period.

The observable excessive depletion and degradation of natural capital supports empirically this formal result. In particular, there are positive feed-back loops that foster the mentioned gap between the indicated and actual natural capital and destabilizes the U.S. economy as a result. It is likely that voluminous imports of goods and services, produced abroad with a high direct or total input of natural resources (such as oil, gas, minerals), offset this destabilizing tendency only partially.

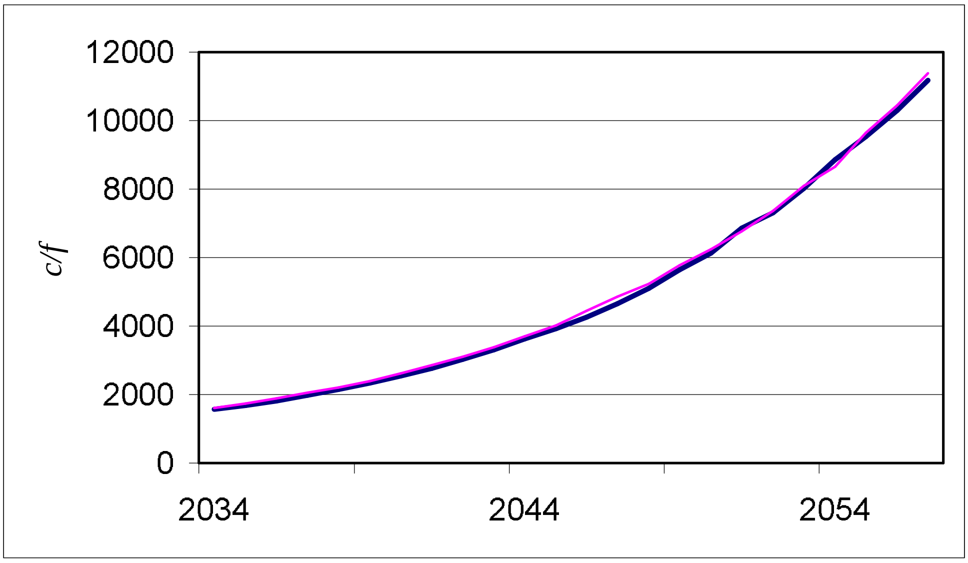

Figure 3.8 The ratio c/f in the exploratory scenarios of the U. S. economic development, 2034–2057 (Scenario 1 – violet curve, Scenario 2 – blue curve)

In spite of these imports, the excessive depletion and degradation of natural capital counteract tendencies to a stable stationary growth or to stably oscillating cyclical motion. The idealizations of point attractor or periodic attractor (limit cycle) are not sufficiently accurate for reflecting main tendencies of the real complex socio-technical system, characterized by bounded rationality of economic actors. The economic fluctuations can surpass viable boundaries if multiple positive feed-back loops, involving natural capital, continue to run unchecked. The conscious element of the HL may play a decisive role in providing better governance of the ecological–economic reproduction on the increasing scale when ecology remains one of the major political issues.

Conclusion

This paper elaborates the notion of viable quasi-periodic motion bounded in the phase space that generalises stationary growth and stationary cyclical growth. Simulation experiments, based on real and estimated statistical data, support the original hypothetical law (HL) of capital accumulation formulated in the previous publications of the author.

The application of the HL with exogenous growth of labour supply to the U.S. economy reveals and explains the trade-off between long-term improvements in profitability against lower employment ratio and larger volatility of economic-ecological reproduction.

The unusually high growth of labour productivity and massive layoffs in 2002 have been explained by a drop by about 3 per cent of the initial magnitude of the control parameter v_c in the mechanization (automation) function. The former coefficient $v_c = const$ (Scenario 1) is transformed into a new auxiliary variable (Scenario 2).

The more aggressive substitution of living labour by man-made capital will not mitigate the Kondratiev recession of the U.S. economy. The paper gives a strong support to the following view (Samuelson 2003): “Over the long run, productivity signifies higher living standards through new products, technologies and management methods. …The present productivity surge reflects bad news more than good: layoffs and bankruptcies. The ruthless elimination of the least-efficient plants and companies may improve productivity. But it does not necessarily signal a robust recovery… If economy stagnates, productivity may someday follow.”

This paper contributes to finding the general law of motion of the modern economic system that is characterised by resilience and fragility. It gives an additional ground for a positive answer to the question: ‘Are there macroeconomic laws?’ It is shown in particular, that Okun’s law and some other prominent empirical regularities are, likely, the manifestation of this HL.

This paper compares the two scenarios, based on the HL, with the Board of trustees projections for 2003–2034. The non-equilibrium long waves are the pattern of evolution in the both scenarios that these equilibrium projections overlook. The earlier neo-classical growth models that have not been theoretically and empirically warranted also mostly neglect this disequilibrium pattern.

A real development of the U.S. economy will differ not only from the trustees projections but from the both deterministic scenarios as well. The functional forms and parameters of the HL are to be updated regularly with a help of the EKF by tracking the observable evolution.

A further advance of the current theory necessitates, in particular, building a model of capital accumulation with endogenous growth of labour supply. Exploring consequences of the increases in average annual hours worked without parallel increases in the workers real wages would be also worthwhile.

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The Appendix

The variables of the Hypothetical Law

- K – the man-made capital (net fixed assets)
- F – the natural capital
- X – indicated natural capital
- N – the labour force
- H – the average annual hours per worker
- $N_S = NH$ – the labour supply
- L – the employment
- $L_S = LH$ – the total hours worked annually
- P – NNP
- $s = K/P$ – the man-made capital-output ratio
- $f = F/P$ – the natural capital-output ratio
- $c = X/P$ – the indicated natural capital-output ratio
- $v = L_S / N_S = L/N$ – the employment ratio
- w – the worker's real wage
- w_S – the unit real wage
- $a = P/L$ – the net output per worker
- K/L – the (produced) capital intensity
- F/L – the natural capital intensity
- $a_s = P/L_s$ – the labour productivity
- $u = w/a$ – the relative wage
- y – the unit gross rent
- e – the unit depletion and degradation of natural capital

Back to the Top