Supposing a Control Law of Primary Income Distribution for the Modern US Economy[1]

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Abstract. This paper defines a hypothetical Law (HL) of capital accumulation that includes a growth rate of supply of labour force as a non-linear function of capital intensity. The main state variables are the labour productivity, relative wage, employment ratio, and capital-output ratio. An application of an extended Kalman filtering to the US macroeconomic data 1969–2002 exhibits long wave as a viable pattern generated by capital accumulation.

Applying the Structural Control Theory the present paper reveals closed loop control over a fractional growth rate of total profit and its advantages in comparison with an open loop control. The supposed control law of primary distribution of income for the macroeconomic oscillatory system is derived as a substantial modification of the initial HL.

It is shown that the US state and business leadership has been pursuing pro-growth stabilization policy with a focus on primary income distribution at least since 2001.

Introduction

The widely held view of social science is that oscillatory macroeconomic systems are usually undesirable because of the ups and downs they bring into the system components. Smoothing or eradicating oscillations requires more structural than numerical changes. Still after the Second World War, the American economy probably passed peaks of the Kondratiev cycles twice (Figure 1a) if judged by the

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employment ratio: 1969 and 2000–2001[2]. The subsequent 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 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).

Correspondingly to this assertion on the Kondratiev downswing, the paper (Ryzhenkov 2004) has presented two non-equilibrium scenarios of the American economic evolution in 2003–2034, based on a system dynamics model of capital accumulation with an exogenous growth of labour supply. A comprehensive Phillips equation for a rate of change of real wage, which is allowing for additional payment for skilled labour, belongs to main factors determining primary distribution of income. A continuation of business as usual has been named Scenario 1, and the development path with the more aggressive substitution of labour by man-made capital has been named Scenario 2.

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 ratio and rate of economic growth. 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 and mean profitability is higher in the Scenario 2 than in the Scenario 1. The Kondratiev recession of the US economy could not be mitigated by more aggressive substitution of living labour by man-made capital alone (Ryzhenkov 2004).

These both scenarios have been compared with equilibrium projections of the US Board of Trustees of the Federal Old-Age and Survivors Insurance and Disability Insurance Trust Funds. 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. The employment ratio and growth rate of labour productivity do not change in the remaining part of the projection period (2035–2080) in the trustees' projections (Board of Trustees 2004).

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[2] Figure 15 (below) demonstrates that the peak of the general profit rate in the past long wave was achieved in 1998, the preceding peak (not shown) in 1966. The lead-time of the general profit rate in relation to the employment ratio in the previous long wave was about 3 years (Ryzhenkov 2004). The basal period 1969-2002 includes almost the whole period of the previous downturn 1966–1982 for the general profit rate and the all years of that downturn for the employment ratio.

In the author's both scenarios, mentioned above, after the onset of the structural crises in 1998–2001 the long-term business upturn will not happen until 2013 or even 2015 if evaluated by the employment ratio (*v*). It will proceed thereafter up to the beginning of the next long-term downturn in 2030–2032 (Fig. 1b).

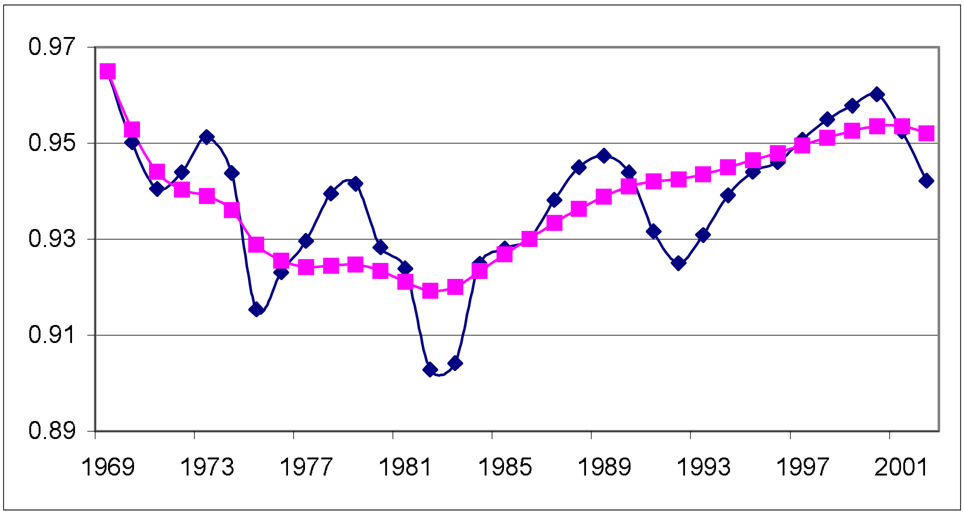

Figure 1a. The employment ratio (*v*) in the basal period, 1969–2002 (real – blue curve, smoothed – violet curve)[3]

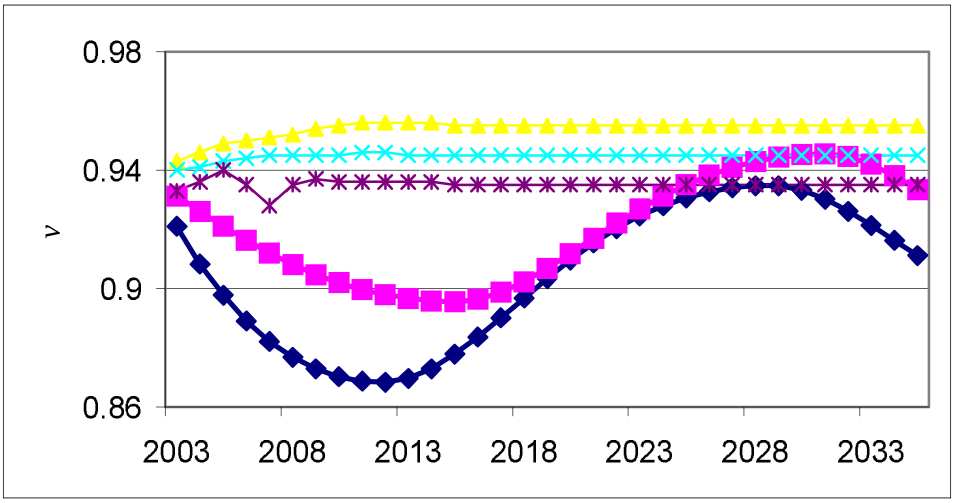

Figure 1b. The employment ratio (*v*) in the two scenarios (Scenario 1 – violet curve, Scenario 2 – blue curve) compared with trustees' projections (low cost – yellow curve, intermediate – aqua curve, and high cost – purple curve), 2003–2035

The author must admit that the real development has shown so far more similarity with the trustee's projections than with his both scenarios. The current unemployment ratio (about 5.2 per cent) is

[3] See Section 2.

substantially lower than in the Scenarios 1 and 2 in 2005 (7.9 and 10.2 per cent, respectively) being in the trustees' range for the same year (5.1–6.0 per cent). This is important evidence that the author has not taken into account some important factors. One of them is a pro-growth stabilization policy[4].

It seems that a pro-growth stabilization policy has been rather effective in combating economic deceleration and decline in employment. This policy is usually characterised by governmental measures to provide American families with tax relief to keep more of their own money and to guarantee new businesses incentives to invest and create jobs. One of the tasks of the present paper is to uncover deeper facets of this policy than in the given characteristic.

This paper develops further *the hypothetic law of capital accumulation* (HL) for uncovering structural changes in the US economy that have enabled in particular shortening the crisis phase of the current Kondratiev cycle. The focus of research is on pro-growth stabilization policy that brings about shifts in primary income distribution between two main social classes[5]. A further advance also necessitates building a system dynamic model of capital accumulation with endogenous growth of labour supply, especially in view of the expected substantially slower growth of labour force in the current century than in 1946–2000.

As shown in (Franco 1990), design of effective policies to control oscillations is a problem that goes beyond the Classical Optimal Control Theory of non-linear systems, and it belongs to the Structural Control Theory. Its application and development allows conceiving a policy of primarily income distribution that stabilizes the oscillatory dynamics of the main macroeconomic variables, maintaining total profit and employment.

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[4] President G. Bush has written: "The unemployment rate is now 5.2 percent, which is lower than the average of each of the past three decades and the lowest since the attacks of September 11, 2001. Our pro-growth policies are taking us in the right direction. As I start my second term, we must take action to keep our economy growing" (Economic Report of the President 2005: 5).

[5] Different types of property income payable out of the value added created by production (profit before taxes, interest, resource rent) belong to primary income of owners of capital (capitalists). Primary income of labour consists mainly of wages and salaries of employees, employers' social contribution and imputed labour income of self-employed. See for details (Eurostat et al., 1993: 157–182).

Only net value added created by production is considered in this paper. The primary income of government is not treated separately, having been included in property income on this stage of research.

The present author agrees with a view: “Policy Support Systems should work as a kind of "transitional object" that allows experimentation, development and the analysis of different scenarios into the future. They should lead to a better understanding of the structure and the behaviour of complex business organizations” (Milling 1990: 33).

This paper elaborates and compares two pro-growth policies mitigating the tendency of general profit rate to fall and enabling to overcome within several years the downturn in the Kondratiev cycle that, probably, started at the end of the previous decade. Open loop control produces the first policy, more sophisticated closed loop control gives birth to the second policy.

The rest of this paper reports on the modelling process gone through key stages in System Dynamics including specification of structure, decision rules, estimation of parameters, behavioural relationships, and initial conditions, testing the model, finally policy design and evaluation (Sterman 2000: 86–87). In the presentation given below, analytical methods and simulation runs reveal complex net of interactions under the political-economy surface, helping to achieve better scientific understanding and social control over economic growth cycles. Defining a control law of primary income distribution that may govern capital accumulation in the modern US economy is the ultimate goal of the present paper.

1. The Hypothetic Law (HL) of Capital Accumulation and Endogenous Labour Supply

The HL upgrades models developed in (Ryzhenkov 2000, 2003, 2004). The advanced capital does not include variable capital since workers are paid at the end of each completed circulation process. The HL abstracts from capital of circulation. Natural capital and resource rent are not taken into explicit account, therefore magnitudes of general profit rate are biased.

1.1 An Extensive Deterministic Form of the HL

Time is viewed as a continuous variable. So the appropriate measure for the rate of change of a variable x is the derivative of x with respect to time ($\dot{x} = \frac{dx}{dt}$), while its fractional rate of change is $\hat{x} = \frac{\dot{x}}{x} = \frac{dx}{xdt}$. For simplicity, the expression ‘growth rate of a variable x’ is used below instead of ‘fractional growth rate of a variable x’. The same convention is appropriate for all variables.

A deterministic model consists of the following equations:

$$P = K/s,\ s > 0; \quad (1)$$

$$L = P/a; \quad (2)$$

$$u = w/a,\ 0 < u < 1; \quad (3)$$

$$\hat{a} = m_1 + m_2(K\hat{/}L) + m_3\psi(\hat{v}), \quad (4)$$

$$\psi(\hat{v}) = sign(\hat{v})|\hat{v}|^j,\ \ m_1 > 0,\ \ 1 > m_2 > 0,\ \ m_3 > 0,\ 1 > j > 0;$$

$$K\hat{/}L = n_1 + n_2u + n_3(v - v_c), \quad (5)$$

$$n_2 > 0,\ n_3 > 0,\ \ 1 > v_c > 0;$$

$$v = L/N,\ 1 > v > 0; \quad (6)$$

$$n = p_1 e_1^{-M_1|K/L - K_c/L_c|^{i_1}} \text{ for } 0 < K/L < K_c/L_c, M_1 = 1; \quad (7a)$$

$$n = p_1 e_2^{-M_2(K/L - K_c/L_c)^{i_2}} \text{ for } K/L \geq K_c/L_c,\ M_2 = 1,\ \ p_1 > 0; \quad (7b)$$

$$\hat{w} = -g + rv + b(K\hat{/}L),\ \ g > 0,\ r > 0; \quad (8)$$

$$P = Q + \dot{K} = wL + (1 - k)M + \dot{K}; \quad (9)$$

$$\dot{K} = k[(1 - u)P] = kM,\ 0 < k < 1. \quad (10)$$

Equation (1) postulates a technical-economic relation connecting the advanced constant capital (*K*), net output (*P*) and capital–output ratio (*s*). Equation (2) relates labour productivity (*a*), net output (*P*) and labour input, or employment (*L*). Equation (3) describes the relative wage, or unit value of labour power (*u*), as a ratio of real wage (*w*) to labour productivity[6]. Equation (4) is an extended technical progress function. It includes: the rate of change of capital intensity, *K*/*L*, and direct scale effect, $m_3\psi(\hat{v})$; $|x| \geq 0$ is an absolute value of *x*; $sign(x) = -1$ for $x < 0$, $sign(x) = 1$ for $x \geq 0$.

The non-linear continuous function $\psi(\hat{v})$ is analytical except at singular points with $\hat{v} = 0$ where its positive first derivative ($\psi'(\hat{v}) = j|\hat{v}|^{j-1}$) becomes infinite. The derivatives of the function $\psi(\hat{v})$ of higher orders go to plus or minus infinity at the vicinity of $\hat{v} = 0$. These properties do not allow direct

[6] The equity $u = 1$ is not compatible with capitalist production relations as the use value of labour power ceases to exist for capitalists when they get no surplus value at all. The equity $u = 0$ would exclude the specific premise of capitalist production relations, namely, market supply of labour force. Therefore $0 < u < 1$. See also footnote 8 below.

application of Classical Optimal Control Theory for finding a control law of capital accumulation and distribution of income.

Equation (6) outlines the rate of employment (v) as a result of the buying and selling of labour–power. In the equation (8), the rate of change of the real wage rate (w) depends on the employment rate (v), as in the usual Phillips relation, and on the rate of change of capital intensity (K/L) additionally. The capital intensity (K/L) is a proxy for qualification. The equivalent form of this equation is given by an extended relation that the author calls a comprehensive Phillips equation

$$
\begin{aligned}
\hat{w} &= -g + rv + b(\widehat{P/L} + \widehat{K/P}) \\
&= -g + rv + b(\hat{a} + \hat{s}), \quad b > 0,\ g > 0,\ r > 0. \qquad \text{(8a)}
\end{aligned}
$$

It will be compared with new equations of the growth rate of real wage for open loop control (section 3.2, equation 8′) and closed loop control (section 4.2, equation 17) over total profit.

Mechanisation (automation) manifests itself in a growing capital intensity. The rate of change of capital intensity (K/L) in the equation (5) is a function of the relative wage (u), difference between the real employment ratio (v) and some base magnitude (v_c) that is lower than quasi-stationary employment ratio (v_a) defined below. A high relative wage and high employment ratio promote mechanization (automation) that shapes the labour supply.

Following reasoning stays behind a *hypothetical partial law for the labour supply*. Before reaching a critical magnitude, mechanisation (automation) pushes new demographic groups (children, women, aged, immigrants from less developed countries) into a labouring population (as far as qualification really or potentially satisfies technological requirements) thus chiefly accelerating the growth of supply of labour force. Afterwards mechanisation (automation) becomes mainly a decelerating factor for the growth of supply of labour force because a substantial part of working-age population does not possess adequate qualification for being hired or self-employed.

Accordingly, the equations (7a) and (7b) determine the growth rate of supply of labour force (N) as a non-linear continuous function of capital intensity. The growth rate of supply of labour force is monotonically increasing for $K/L \le K_c/L_c$, reaching an absolute maximum $n_{\max} = p_1$ at the point $K/L = K_c/L_c$; this rate is monotonically decreasing for $K/L \ge K_c/L_c$. Time evolution of supply of labour force (N) is typically S-shaped.

In the equations (9) and (10), the net formation of constant capital is $\dot{K}$, Q sums net export, final private and public consumption, $M = (1 - u)P$ is the total profit in real terms.

1.2 An Intensive Deterministic Form of the HL

The deterministic model in an intensive form, derived from the equations (1) – (10), consists of four non-linear ordinary differential equations (11) – (14):

$$\dot{a} = (m_1 + m_2 (n_1 + n_2 u + n_3(v - v_c)) + m_3 \psi(\hat{v}))a, \tag{11}$$

$$\dot{s} = (-m_1 + (1 - m_2)(n_1 + n_2 u + n_3(v - v_c)) - m_3 \psi(\hat{v}))s, \tag{12}$$

$$\dot{v} = (k\frac{1-u}{s} - (n_1 + n_2 u + n_3(v - v_c)) - n(sa))v, \tag{13}$$

$$\dot{u} = (-g + rv - m_1 + (b - m_2)(n_1 + n_2 u + n_3(v - v_c)) - m_3 \psi(\hat{v}))u. \tag{14}$$

For finding stationary states of the system (11) – (14), it is necessary to equate each of the expressions on the right to zero. As $\dot{a} = 0$ is not true (for $a > 0$), this system does not possess a stationary state.

It is reasonable substitute the equation (7b) by equations (7b′) and (7c), keeping the equation (7a) intact

$$n = p_1 e_2^{-M_2(K/L - K_c/L_c)^{i_2}} \text{ for } K_m / L_m > K / L \geq K_c / L_c, \tag{7b′}$$

$$n = 0 \text{ for } K / L \geq K_m / L_m. \tag{7c}$$

Respectively, for $K / L \geq K_m / L_m$ the partial derivatives $\frac{\partial n}{\partial s} = 0$ and $\frac{\partial n}{\partial a} = 0$. This redefinition of the partial dynamic law of labour supply, being not harmful from the economic point of view, enables to have solutions with a constant labour force.

Assume that the system (11) – (14) includes n defined by the equations (7a), (7b′) and (7c). Then there is a single non-trivial stationary state in the subsystem (12) – (14), defined as

$$E_a = (s_a, v_a, u_a), \tag{15}$$

where $s_a = k\frac{1-u_a}{i}$, $v_a = (g + (1 - b)i)/r$, $u_a = (i - n_1 - n_3(v_a - v_c))/n_2$.

The stationary growth rate of constant capital, net output, real wage, labour productivity and capital intensities is the same: $\hat{K}_a = \hat{P}_a = \hat{w} = \hat{a} = K\hat{/}L = i = \frac{m_1}{1-m_2}$. At this stationary state, the value of constant capital, employment and labour force are fixed, i.e., $K_a \hat{/} a_a = \hat{L}_a = n_a = 0$. The stationary general profit rate is $(1 - u_a)/s_a = i/k$.

This stationary state E_a is dynamically unstable because $\psi'(\hat{v}) = j|\hat{v}|^{j-1}$ goes to positive infinity for $\hat{v} \to 0$. This substantial singularity explains why the growth rate of labour productivity changes stepwise at local extrema of the employment ratio. Abruptness of economic crises follows from this essential singularity too if a closed loop control over total profit is not enforced (see section 4).

1.3 A Probabilistic Form of the HL

For estimating probable states of the economy and for identifying unobserved parameters in the basal period the deterministic model (11) – (14) has been transformed in a stochastic model, taking into account measurement errors and an impact of factors neglected in the model assumptions[7]. This makes implicit allowances for short-term and middle-term economic fluctuations by specification of the random components. The latter model includes state equations and measurement equations for discrete moments of time

$$\mathbf{x}(\tau) = \mathbf{f}\,[\mathbf{x}(\tau - 1)] + \mathbf{w}(\tau),$$

$$\mathbf{z}(\tau) = \mathbf{H}\mathbf{x}(\tau) + \mathbf{v}(\tau),$$

where $\tau = 1, 2,\ldots, T$ is an index of data samples, $\mathbf{x}(0)$ – a vector of an initial state of the system, $\mathbf{w}(\tau)$ – a vector of equations errors (driving noise), $\mathbf{v}(\tau)$ – a vector of measurement errors. The deterministic part $\mathbf{x}(\tau) = \mathbf{f}[\mathbf{x}(\tau - 1)]$ corresponds to the system (11) – (14). The symbol $\mathbf{H}$ is for a rectangular matrix. The residuals are not due entirely, or largely, to pure random influences. On the contrary, these residuals contain highly systematic, non-random components.

This paper applies a simplified version of an extended Kalman filtering (EKF), realised in the Vensim software developed by Ventana Systems, Inc. This software has enabled to estimate the unobservable components of the compact model (11) – (14) by a procedure of maximum likelihood.

An Appendix is a source of the relevant technical information. Table A–1 lists the real data; Table A–2 posts estimations of the probable states. Vensim EKF optimisation control and pay-off definition files as well the file with identified magnitudes of the model parameters are also presented there. For the reader's convenience, there is also a listing of the main variables (at the very end).

2. An Inertia Scenario for the US Economy Based on the HL

An application of the EKF to the US macroeconomic data for the basal period 1969–2002 has identified unobservable components of the above stochastic model: $b \approx 0.540$, $e_1 \approx 2.5$, $e_2 \approx 100$, $i_1 \approx 0.2$,

[7] It is not possible to check whether the given deterministic model is able to replicate behavior and create understanding of the observable economic behavior without estimating parameters that usually require construction of a stochastic model. Direct inference on parameters' values is hardly possible in macroeconomic modeling, including this particular study.

$i_2 \approx 0.4$, $g \approx 0.046$, $j \approx 0.342$, $k \approx 0.203$, $K_c / L_c \approx 0.098$, $m_1 \approx 0.0067$, $m_2 \approx 0.2357$, $m_3 \approx 0.015$, $n_1 \approx -0.246$, $n_2 \approx 0.347$, $n_3 \approx 0.6$, $p_1 \approx 0.03$, $r \approx 0.053$, $i \approx 0.009$. The simulation, started at the magnitudes of the phase variables observed in 1969 ($a_0 \approx 0.0422$, $s_0 \approx 1.826$, $v_0 \approx 0.965$, $u_0 \approx 0.710$), has calculated the most probable (still sub-optimal) magnitudes of these four and other variables in the subsequent years.

The main variables have the following units of measurement: *a* [millions of chained 1996 dollars per worker per year], *u*, *v* [dimensionless], *s* [years]. Calculations of *u* and *s* are done with the nominators and denominators measured in current prices. The employment ratio *v* is for the civil labour force (without accounting hidden unemployment). Private and governmental produced non-residential fixed assets represent the constant capital (*K*).

2.1 A Historical Fit of the HL in the Basal Period 1969–2002

The HL has passed behaviour reproduction tests. In particular, estimating its historical fit (Table 1), the Theil inequality statistics have been used (Theil 1966).

Table 1. Decomposition of errors of the retrospective forecast for 1969–2002

Variable	RMSPE (%)	U^M	U^S	U^C
a	0.81	0.049	0.076	0.875
s	3.31	0.002	0.315	0.683
v	0.92	0.000	0.080	0.920
u	1.56	0.088	0.000	0.912
$(1 – u)/s$	4.36	0.076	0.087	0.838

The rather small root-mean-square percent errors (RMSPE) and prevailing non-systematic errors of incomplete co-variation (U^C) over bias (U^M) and over difference in variation (U^S) show that this probabilistic model tracks the major variables observed in the basal period agreeably. Figures 1a, 2, 3a and 3b support this conclusion by demonstrating a certain likeness of simulated and realised trajectories.

A long wave has been a viable pattern of the US capital accumulation in the basal period with local maximum (minimum) of the employment ratio, *v*, in 2001 (1982) and local maximum (minimum) of the general profit rate, $(1 - u_a)/s$, in 1998 (1982). The maximal magnitudes of the both variables are lower than their magnitudes in 1969. Moreover, the previous local maximum of the profit rate (higher than that in 1969) was observed in 1966 before the basal period (Figure 3a).

The uncovered tendency of the profit rate to fall is unfavourable for the employment ratio in the long-term. A shortage of labour supply is detrimental for capital accumulation. Understanding these linkages is a step in conceiving pro-growth stabilization policies in sections 3 and 4.

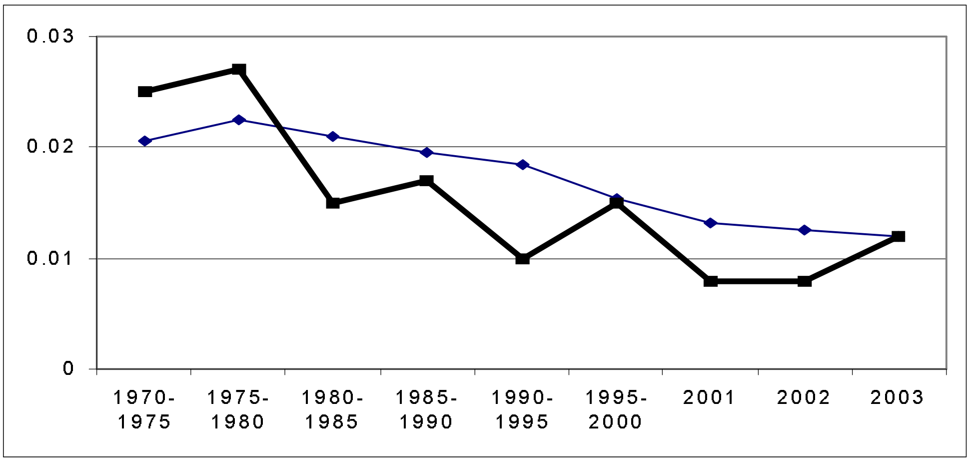

Figure 2. The realised (solid broken line) (Board of Trustees 2004: Table V.B2) and simulated (thin one) growth rates of labour force (n) in the USA, 1970–2003

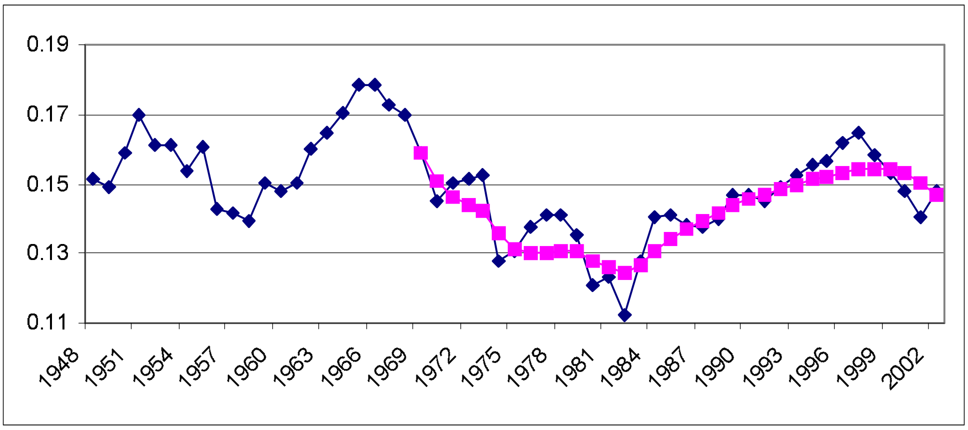

Figure 3a. The gross profit rate: realised (violet curve), 1948–2002, and simulated (blue curve) in the basal period, 1969–2002

2.2 A Long-term Extrapolation of the Tendency of General Profit Rate to Fall

An extrapolation of the retrospective forecast, based on the deterministic model (1) – (10) with the parameters values given above, is called the inertia scenario. The tendency of the employment ratio, rate of profit and rate of surplus value to fall during the first quasi-cycle of the 21st century lasts until the end of 2030-s mainly because the growth rate of the real wage exceeds the growth rate of labour productivity. Only when the latter surpasses the former the long wave starts to move upwards.

Profit in real terms grows uninterruptedly in spite of the fall in the profit rate in 2001–2038 (Fig. 3b and Fig. 4). Still this variable almost comes to a standstill when the profit rate declines.

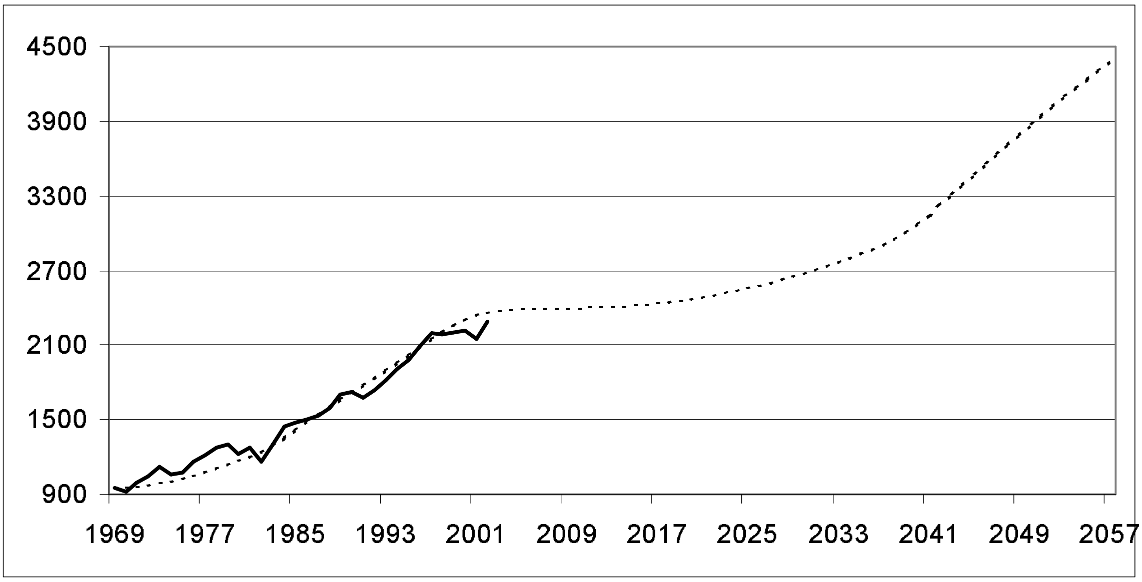

Figure 3b. The profit *M* (milliards 1996 dollar a year): realised (solid curve), 1969–2002, and simulated (dotted curve) in the inertia scenario, 1969–2057

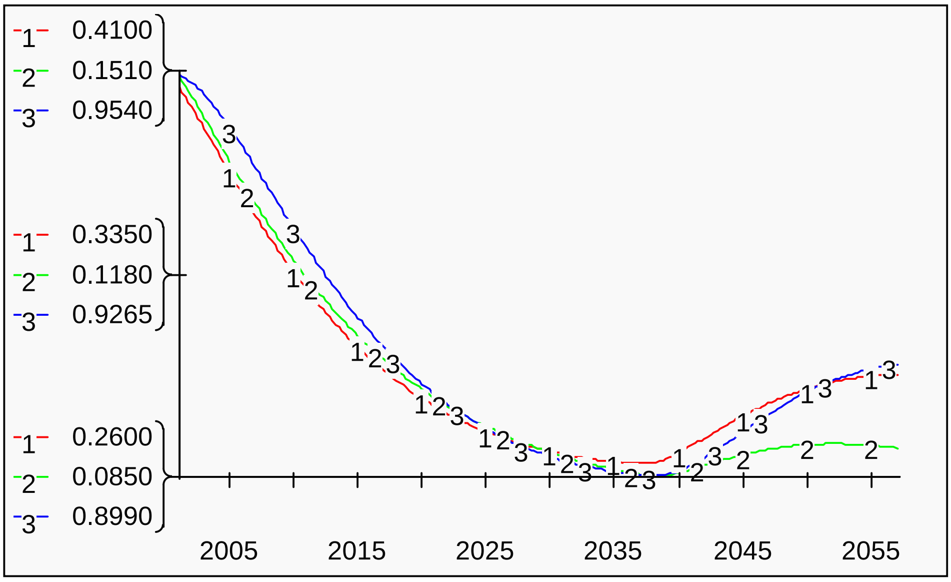

Figure 4. The rate of surplus value $(1 - u)/u$ (1), rate of profit $(1 - u)/s$ (2) and employment ratio *v* (3), 2001–2057, in the inertia scenario

Computer simulations reveal that phase variables (*s*, *v*, *u*), gross profit rate, growth rates of labour productivity and real wage as well as some other variables fluctuate. The duration of fluctuations is 58–63 years. The periods of fluctuations are shorter at the beginning for higher values of the growth rate of labour supply (n). For example, the first complete quasi-cycle of the employment ratio (v) in the 21st century encompasses 2001–2058. More than four hundred years later, this variable starts to oscillate about the stationary value (v_a) with a period 62–63 years for $n \approx 0$.

The growth rate of the material substance of the constant capital (K) and growth rate of its labour value ($K \hat{/} a$) as well as growth rate of the labour input ($\hat{L}$) experience the long-term anharmonic fluctuations. These growth rates, together with the general profit rate, tend to decline at the transient to the closed orbits around the stationary values (Fig. 5).

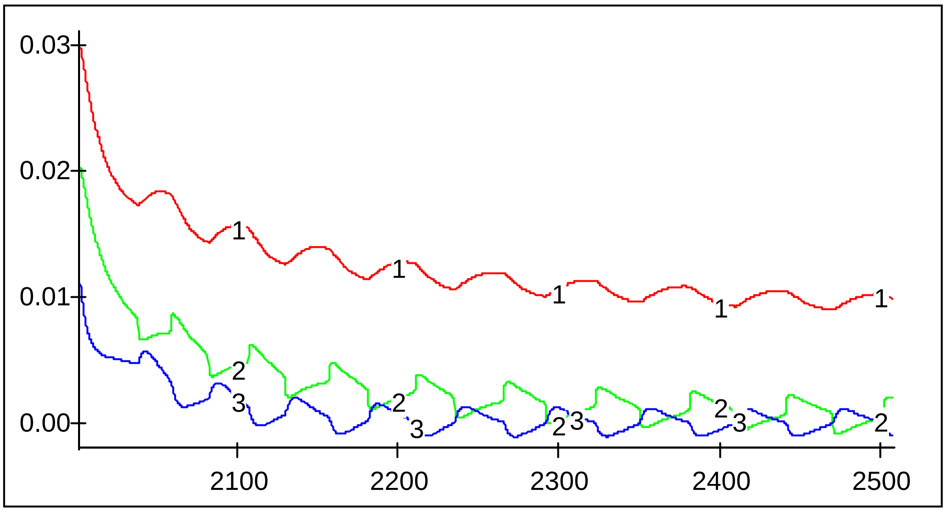

Figure 5. The growth rates of the constant capital $\hat{K}$ (1), of its labour value $K \hat{/} a$ (2) and of labour input $\hat{L}$ (3) in the inertia scenario, 2001–2507

3. Explaining a Contemporary Development of the US Economy by a Modified HL

3.1. A Dialectical Negation of the Inertia Scenario

The inertia scenario above may lead to a wrong fatalistic conclusion that the general profit rate has inevitably to decline uninterruptedly in 1999–2038 and that the total profit is to be nearly constant in 2000–2010. The official middle-term macroeconomic projection in January 2001, based on information as of November 2000, carried traits of this pessimistic vision: the full amount of corporate profits (before taxes) in the year 2010 deflated by CPI was projected only 4 per cent higher than that in 2000 (Executive Office of the President 2001: Table II-1). The same official middle-term projection envisioned that the ratio of the full amount of nominal corporate profits (before taxes) to wages and salaries would have to decline from 0.196 in 2000 to 0.153 in 2010 (ibid.). The analogous rate of surplus value declines (Fig. 4) during these years in the inertia scenario too.

The US state and business leadership has rejected a policy of passive adaptation to the long-term decline. They have been carrying out a pro-growth stabilization policy at least since the beginning of 2001. The terrorist attack of the September 11, 2001 has served as a new powerful catalyst for this policy. Cheapening elements of constant capital, foreign trade and outsourcing belong to additional counteracting factors beyond the scope of the present analysis.

An official middle-term projection based on information available in November 2001 has aimed at substantially higher growth of corporate profits in real terms and considerably higher ratio of nominal corporate profits to nominal wages and salaries than those in the previous official projection: in 2010 the first indicator would have to stand higher by 23.1 per cent than in 2000, while the second would be 0.169 in 2010 (CBO 2001: Table 2-1).

Output per hour worked grew since the fourth 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). Yet workers' compensation has consistently lagged productivity growth over this period. Total labour compensation has experienced the slowest growth in any recovery since World War II (Bivens 2004). As a result, the profit share (ratio of property and entrepreneurial income to GDP) has recently reached its previous peak of 1997 – 7 per cent above its average for 1981–2003 (BIS 2004: 15, 24). This is the highest growth rate of profit in a recovery since World War II.

3.2 A Synthesis of the HL and Historical Contingency

The inertia scenario above and facts from the previous section contradict each other like thesis and antithesis. Synthesis necessitates breaking the closeness of the initial causal system by saving a great part of its essence and allowing for pro-growth stabilization policy. A working assumption is that the growth rate of real wage is not higher in the middle-term 2001–2010 than the stationary magnitude, defined by the equation (15): $\hat{w} \leq \hat{w}_i \leq i$. The deliberately chosen magnitude $\hat{w}_i = 0.007$ is plausible. The modified equation for the rate of growth of real wage (8′) substitutes the equation (8)

$$\hat{w} = \min[\hat{w}_i, -g + rv + b(\widehat{K/L})],\ 0 \leq \hat{w}_i \leq i \approx 0.009,\ g \geq 0,\ r > 0. \qquad (8')$$

All other equations, the starting point for 2001, and parameters values remain the same. This equation represents an open loop control since the fixed growth rate of real wage is not dependent on endogenous variables of the modified model. Multiple feedback loops of the initial model (1) – (10) containing $\hat{w}$ die down after imposing the open loop control by the equation (8′).

Table 2 reports on results of the simulation run based on the modified model. The outcomes of this pro-growth stabilization policy do not contradict qualitatively the above latest data on growth and distribution. They are compared with outcomes of the inertia scenario. For capital, the mobilising scenario conditioned by the current war is superior to the inertia scenario in the chosen middle-term period.

In particular, the total profit in the mobilising scenario will be 42.9 per cent higher in 2010 than in 2001 (in the inertia scenario only 2.6 per cent higher). A recent official projection expects the 68.9 per cent increment of corporate profits (before taxes) deflated by CPI in 2001–2010 (CBO 2004: Table C-1).

According to the simulation run, the American economy will crash into the upper limit of full employment ($v \approx 0.978$) at the end of the projection period or even before 2010 in the mobilising scenario. This creates the necessary condition for a new crisis.

Table 2. Increments (per cent) in the two scenarios of the US economic development, 2001–2010 (2001 = 100)

Variable	Scenario	
	Inertia	Mobilising
Labour productivity (a)	8.8	12.2
Real wage (w)	14.4	6.5
Rate of surplus value ($(1 - u)/u$)	−16.9	18.5
Profit rate ($(1 - u)/s$)	−19.8	7.5
Employment (L)	7.9	13.2
Labour force (N)	10.2	10.4
Surplus value ($(1 - u)L$)	−5.7	27.4
Constant capital (K)	27.9	32.9
Value of constant capital (K/a)	17.5	18.5
Net output (P)	17.4	27.0
Profit (M)	2.6	42.9

A shortcoming of the open loop control policy supporting profitability manifests itself in an excessive employment that is detrimental for capitalist reproduction on the increasing scale. The Economic Report of the President (2005: 47) projects in its own way that the unemployment rate is to stabilize at 5.1 per cent (i.e., $v = 0.949$). The capital share in the net output is expected to fall from its currently high level before plateauing near its historical average (ibid: 48) due to a higher employment ratio in the coming years then in 2001–2003.

4. Designing a Control Law of Primary Income Distribution for the Modern US Economy

4.1 Particular Forms of Closed Loop Control over Primary Income Distribution

The present research is aimed at finding robust sub-optimal control for achieving higher levels of total profit, profitability and employment ratio then in the inertia scenario. Open loop control is clearly unreliable and inefficient for extended periods of economic evolution. As the previous section shows, such a control may lead to over-shooting.

The Structural Control Theory is to be applied as a main tool for conceiving efficient and robust stabilization policy aimed at pro-growth shifts in primary distribution of income. The Classical Optimal Control Theory and modal methods, although useful and efficient for particular tasks, do not suffice in the present case for the following reasons.

In an optimal control problem, an objective function is usually expressed in a form of an integral over a time period, and a system of first-order differential equation governs evolution of state variables. The essential singularity of the HL in the vicinity of $\hat{v} = 0$ mentioned in section 1.1 does not allow application of the Classical Optimal Control Theory that assumes that the functions comprising a dynamic law are continuously differentiable for all variables (Pontryagin 1976).

In the modal methods (Mohapatra and Sharma 1985), a closed loop control is designed by moving the eigenvalues of a linearized model and is expressed as a function of the level variables. As the HL cannot be linearized in the vicinity of $\hat{v} = 0$ the modal methods are not directly applicable too.

Based on the analyses of the US business and governmental policies in the previous sections, the author will hypothesize different forms of closed loop control over income distribution. They should provide a synthesis of efficiency and robustness. As written by R.M. Goodwin, "…there must be a successful policy of forcing or persuading employers and trade unions to forgo raising real wages in consequence of tightness of the labour market, in exchange for high and stable employment along with rising output" (Goodwin 1990: 110). In view of the present author, successful policy requires strengthening elements of feed-forward control over capital accumulation and primary income distribution. Feed-forward control, as known, changes variables according to expected future states of the economy.

Rate of profit is the well-known key instrument of business control that does not require explanation in this paper. Still an important aspect deserves attention.

It is reasonable to add a new negative feedback loop (Fig. 6), containing only one level variable, namely unit labour cost (u), to the structure comprising the initial HL. This additional loop provides stronger grip over the profit rate. The rate of change of unit labour cost becomes positively dependent on the rate of change of employment ratio, which is a leading macroeconomic indicator. This dependence represents already mentioned readiness “to forgo raising real wages in consequence of tightness of the labour market, in exchange for high and stable employment along with rising output” advised by R. M. Goodwin.

Notice total profit $M = (1 - u)P$ is already a part of the initial HL entering the equations (9) and (10). Still total profit has been subsumed by other variables of the intensive form (11) – (14) of this HL. The analysis in section 3 suggests differently that a rate of change of total profit is more important in reality than assumed at the very beginning.

Figures 7–13 display the rate of growth of total profit as the surmised pivotal element of control over primary distribution of income. Controlling relies thereby not only on negative feedback loops (Figures 7–10) but on positive feedback loops (Figures 11–13) as well. The positive feedback loops are instrumental for the pro-growth stabilization policy that would be hardly possible without them.

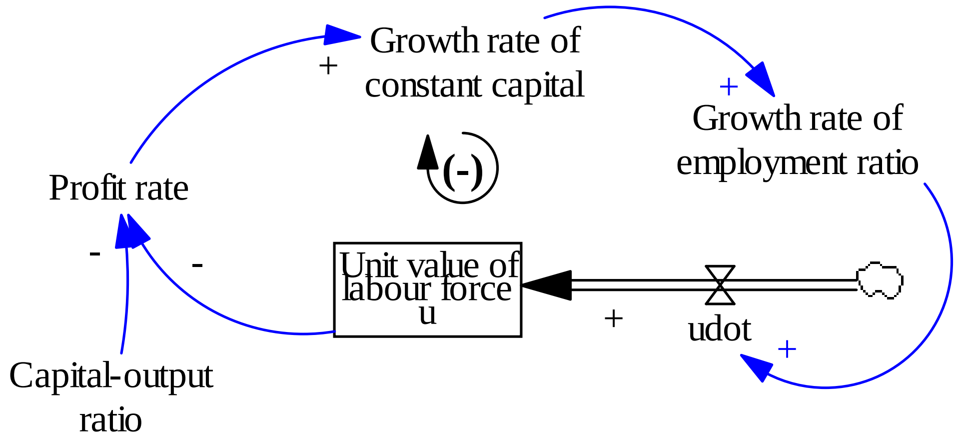

Figure 6. The first negative feedback loop controlling profitability via a single level variable (unit labour cost)

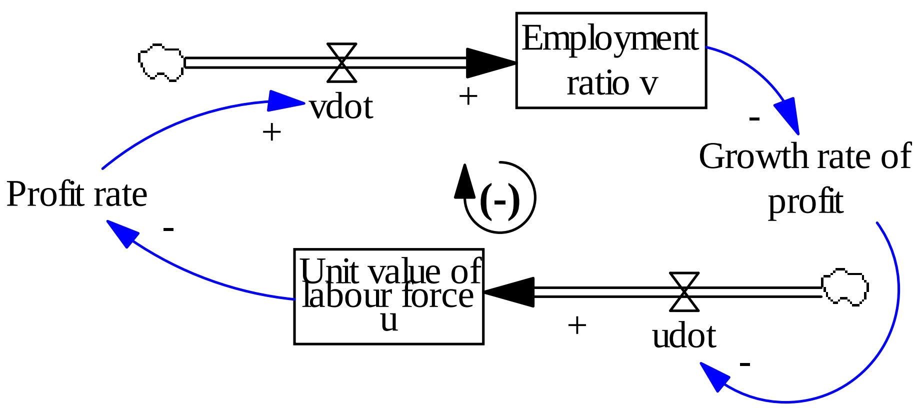

Figure 7. The second negative feedback loop controlling profitability and total profit via two level variables (employment ratio and unit labour cost)

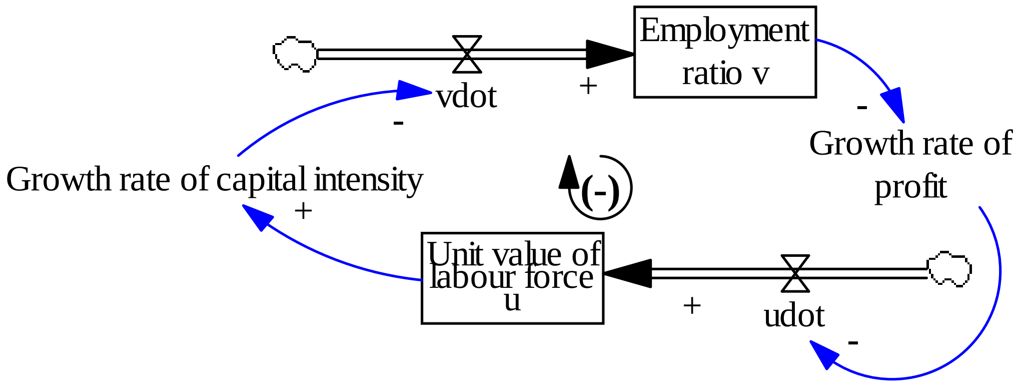

Figure 8. The third negative feedback loop controlling total profit via two level variables (employment ratio and unit labour cost)

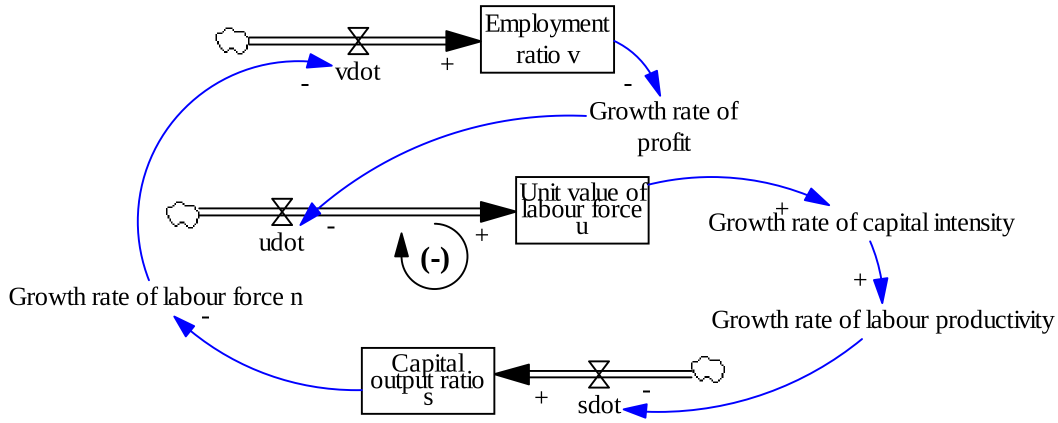

Figure 9. The fourth negative feedback loop controlling total profit via three level variables (employment ratio, unit labour cost and capital-output ratio)

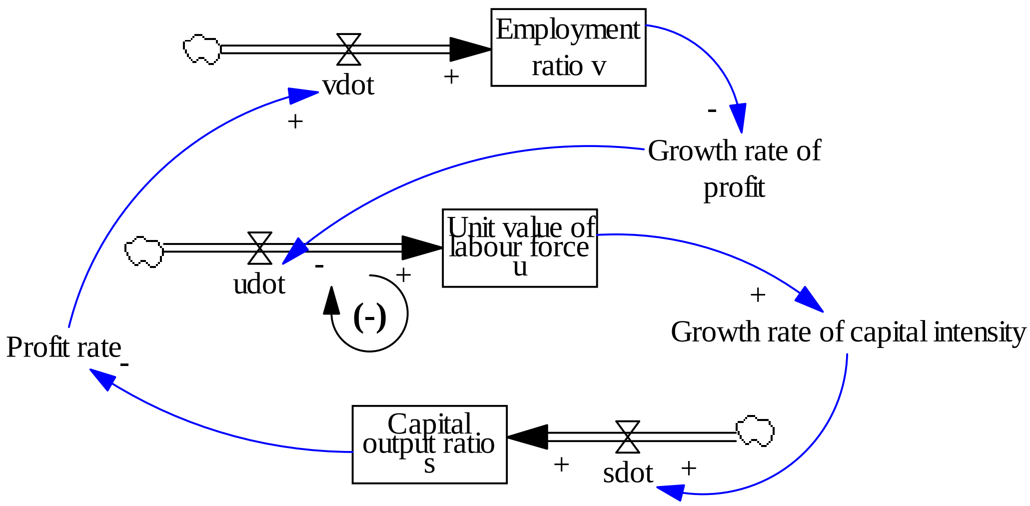

Figure 10. The fifth negative feedback loop controlling profitability and total profit via three level variables (employment ratio, unit labour cost and capital-output ratio)

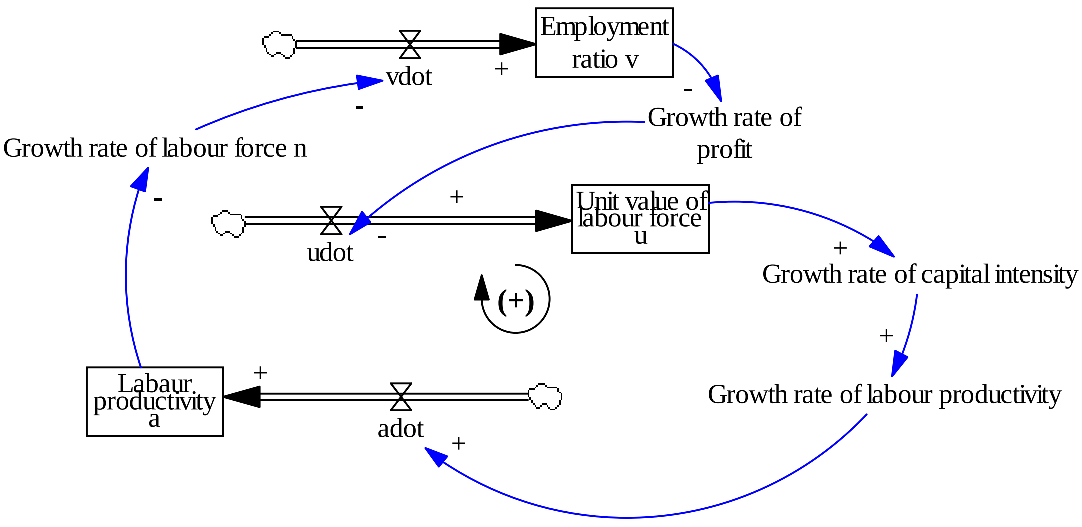

Figure 11. The first positive feedback loop controlling total profit

via three level variables (employment ratio, unit labour cost and labour productivity)

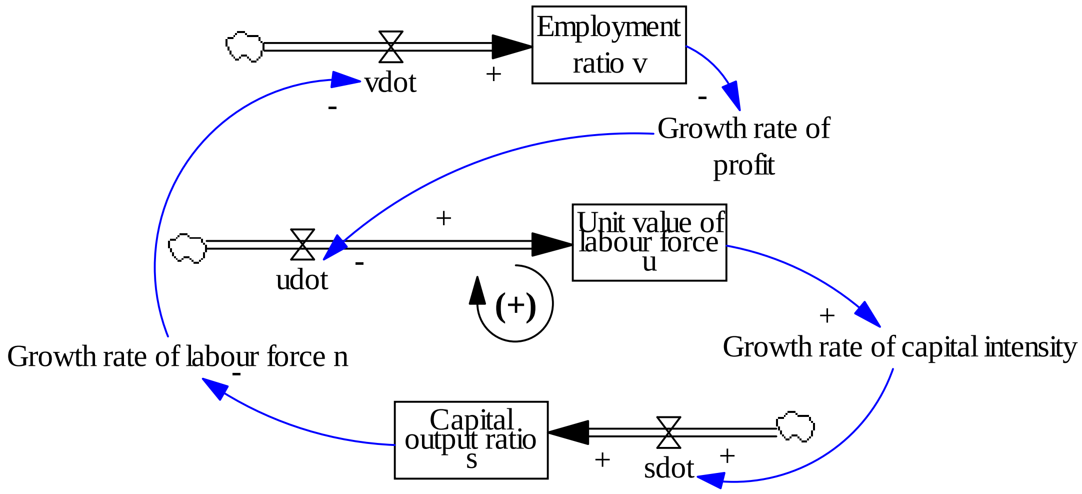

Figure 12. The second positive feedback loop controlling total profit

via three level variables (employment ratio, unit labour cost and capital-output ratio)

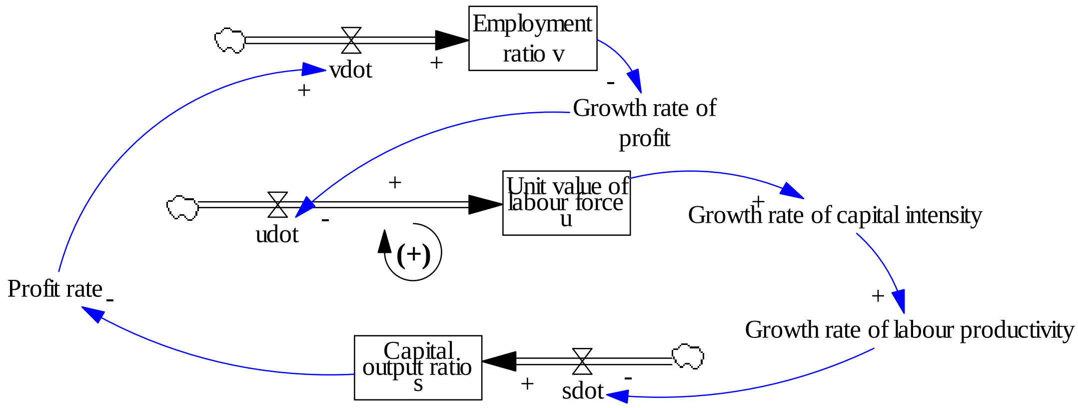

Figure 13. The third positive feedback loop controlling profitability and total profit via three level variables (employment ratio, unit labour cost and capital-output ratio)

4.2 Equations for Closed Loop Control over Total Profit

The feedback loops presented in the previous section prompted the formalization, which, in turn, gives a proper ground for them. Remembering that total profit $M = (1 - u)P$, let us assume that the decision-makers (the State officials, owners of capital, labourers) set a desirable growth rate of total profit depending on a difference between an indicated and current employment ratios:

$$\hat{M} = \frac{-\dot{u}}{1-u} + \hat{P} = c_1 + c_2(X - v), \qquad (16)$$

where $v < X$ is typical for recessions and depressions; it is assumed that $c_1 = 0$ for simplicity .

When $c_2 < 0$ the negative feedback loop displayed by Fig. 6 turns into a positive (destabilizing) feedback loop

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

As computer simulations have shown, u becomes negative, and v exceeds 1. So it is assumed realistically below that the parameter c_2 is positive.

A new equation for a growth rate of real wage follows from the equation (16):

$$\hat{w} = \hat{u} + \hat{a} = (\hat{P} - \hat{M})\frac{1-u}{u} + \hat{a} = (\hat{a} + \hat{v} + n - \hat{M})\frac{1-u}{u} + \hat{a} =$$

$$= \frac{\hat{a}}{u} + (\hat{v} + n - \hat{M})\frac{1-u}{u}$$

$$= \frac{\hat{a}}{u} + \hat{L}\frac{1-u}{u} - c_2 X\frac{1-u}{u} + c_2\frac{1-u}{u}v. \qquad (17)$$

The equation (17) is structurally different from the initial equation (8) and its equivalent form (8b) written as

$$\begin{aligned}\hat{w} &= -g + rv + b(\widehat{K/L}) \\ &= -g + rv + b(\hat{a}+\hat{s}),\ \ b > 0,\ g > 0,\ r > 0. \qquad (8b)\end{aligned}$$

The equation (17) is structurally different from the modified equation (8′) of the open loop control in section 3.2 too. Table 3 outlines the structural differences of the equations (8b) and (17) in detail.

Table 3. Partial derivatives of the rate of change of real wage

Partial derivatives	The initial equation (8b)	The modified equation (17)
$\frac{\partial \hat{w}}{\partial \hat{s}}$	$b > 0$	…
$\frac{\partial \hat{w}}{\partial v}$	$r > 0$	$c_2 \frac{1-u}{u} > 0$
$\frac{\partial \hat{w}}{\partial \hat{a}}$	$b > 0$	$\frac{1}{u} > 0$
$\frac{\partial \hat{w}}{\partial \hat{L}}$	…	$\frac{1-u}{u} > 0$
$\frac{\partial \hat{w}}{\partial \frac{1-u}{u}}$	…	$\hat{L} - c_2(X - v)$

According to the equation (17) and Table 3, the former constant g has been transformed into a product $c_2 X \frac{1-u}{u}$ of the two new constants (c_2, X) and of rate of surplus value $(\frac{1-u}{u})$; the impact of the growth rate of labour productivity on $\hat{w}$ has become dependent on the inverse of labour share in net output $(\frac{1}{u})$; non-linear positive dependence of $\hat{w}$ on the rate of change of the employment $(\hat{L})$ has substituted its former positive linear dependence on the rate of change of capital-output ratio $(\hat{s})$. As both $\frac{\partial \hat{w}}{\partial n} > 0$ and $\frac{\partial \hat{w}}{\partial v} > 0$, decelerating growth of employment ratio and declining growth rate of labour supply are detrimental for growth of real wage if the all other conditions remain the same.

A new partial dynamic law for the unit value of labour power is derived correspondingly from the equations (3) and (16):

$$\dot{u} = (\hat{P} - \hat{M})(1-u) = (\hat{a} + \hat{v} + n - \hat{M})(1-u)$$

$$= (\frac{k(1-u)}{s} - (K\hat{/}L + n) + P\hat{/}L + n - \hat{M})(1-u)$$

$$= (\frac{k(1-u)}{s} - \hat{s} - \hat{M})(1-u)$$

$$= (\frac{k(1-u)}{s} - \hat{s} + c_2(v - X))(1-u)\,. \qquad (18)$$

The HL has been buried in its initial form. This law will be now resurrected as a control law of primary income distribution in a new form. An intensive deterministic form of the control law of primary income distribution consists of the initial equations (11) – (13) and the new equation (18) that substitutes the initial equation (14).

If the equations (7a), (7b′) and (7c) for the growth rate of labour force are applied again, then the subsystem of the equations (12), (13) and (18) has a single non-trivial stationary state

$E_a = (s_a, v_a, u_a)$, where (19)

$$s_a = k\frac{1-u_a}{i},\ v_a = X - i/c_2,\ u_a = \frac{i - n_1 - n_3(v_a - v_c)}{n_2},\ i = \frac{m_1}{1-m_2}.$$

At this stationary state, the value of constant capital, employment and labour force are fixed, i.e., $K_a\hat{/}a_a = \hat{L}_a = n_a = 0$. The stationary general profit rate is $(1 - u_a)/s_a = i/k$[8].

Unlike the unstable stationary state defined by the equation (15) of the initial subsystem (12) – (14), this one seems to be globally or at least locally stable for the subsystem (12), (13) and (18). A formal proof of the property of global or at least local stability of the non-trivial stationary state (19) requires a substantial additional effort beyond the scope of this paper.

4.3 Potential Efficiency and Robustness of the Pro-growth Stabilization Policy

It is known that the majority of dynamic systems in economics belongs to the class of dissipative systems. A characteristic property of a dissipative system implies that the 'volume' of an element of the phase space shrinks to zero as time progresses, when trajectories approach an attractor. Formally, this property can be examined with the help of the Lie derivative or the divergence defined as

$$\dot{V}/V = \mathrm{div}(f) = \frac{\partial \dot{a}}{\partial a} + \frac{\partial \dot{s}}{\partial s} + \frac{\partial \dot{v}}{\partial v} + \frac{\partial \dot{u}}{\partial u} \qquad (20)$$

where V is the "volume" and div(f) is the divergence of the vector-function $f\,(a, s, v, u)$.

For the initial model (11) – (14), the Lie derivative is calculated as follows:

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[8] It could be shown mathematically that the latter subsystem does not have a trivial stationary state where $u_b = 1$, $s_b > 0$ and $1 > v_b > 0$. Moreover, the equity $u_b = 1$ is not compatible with capitalist production relations, as explained above (see footnote 6).

$$\dot{V}/V = \frac{k(1-u)}{s} - n + \hat{u} - n_3 v + (b - m_2) n_2 u + m_3 \psi'(\hat{v})(\frac{k}{s} + n_2 u). \quad (21)$$

The Lie derivative is negative except vicinity of critical (singular) points: it moves to positive infinity since the sum of coefficients at $\psi'(\hat{v})$ is positive ($m_3(\frac{k}{s} + n_2 u) > 0$) and $\psi'(\hat{v}) \to +\infty$ for $\hat{v} \to 0$. So induced technical progress and economy of scale presented in particular by the compound positive element $m_3 \psi'(\hat{v})(\frac{k}{s} + n_2 u)$ are at least locally destabilizing in vicinity of the critical points in the initial model.

For our control law defined by the equations (11) – (13) and (18), the Lie derivative is given by:

$$\dot{V}/V = -n - n_3 v - (1 - m_2) n_2 (1-u) - m_3 n_2 \psi'(\hat{v})(1-u) - \frac{\dot{u}}{1-u} < 0. \quad (22)$$

Lie derivative is negative in this case. Its magnitude moves to negative infinity in vicinity of critical (singular) points since the sum of coefficients at $\psi'(\hat{v})$ is negative ($-m_3 n_2 (1-u) < 0$) and $\psi'(\hat{v}) \to +\infty$ for $\hat{v} \to 0$. Thus in this case induced technical progress and economy of scale presented in particular by the compound negative element $-m_3 n_2 \psi'(\hat{v})(1-u)$ are at least locally stabilizing in vicinity of the critical points.

As computer simulations have shown, the absolute magnitude of the negative Lie derivative in the modified model is higher than 0.5 as a rule for the given parameters values (Table 4). This means that the "volume" V shrinks more than 50 per cent a year and the model variables s, v and u moves rapidly to the their stationary magnitudes (s_a, v_a, u_a) defined by the equation (19) while n approaches 0. As the initial magnitudes v_0 and u_0 are closer to v_a and u_a then s_0 to s_a, the variable s is still far from its stationary magnitude, when the variables v and u are in vicinity of their stationary magnitudes.

Four simulation runs presented by Figures 14–19 below are based on the equations (11) – (13) and (18) of the control law. All of them, like the inertia scenario before, use the initial magnitudes of state variables for 2001 and relevant parameters' values estimated by the EKF based on data for 1969-2002 for the initial model. Parameters b, g and r from the comprehensive Phillips equation (8) are not applicable for the modified model.

The information from the initial model is preserved in the basal simulation run most of all. The new stationary magnitude of the employment ratio is defined in this run according to the estimate of the Council of Economic Advisers (Economic Report of the President 2005: 41). The other three simulation runs use estimations of the stationary employment ratio and stationary growth rate of output per worker from three trustees' projections known as low cost, intermediate and high cost scenarios of the American economy in the coming decades (Board of Trustees 2004), which have been mentioned in the Introduction of the present paper. The Table 4 provides the reader with the necessary peculiarities of the four simulation runs.

Table 4. Parameters of the simulation runs based on the modified model

Parameters of the modified model	Simulation runs				
	inertia scenario	basal	related to the trustees' scenarios		
			low cost	intermediate	high cost
	(0)	(1)	(2)	(3)	(4)
i	0.009	0.009	0.015	0.012	0.010
v_c	0.925	0.925	0.900	0.900	0.900
c_2	…	8.521	10.376	4.934	2.941
X	…	0.950	0.956	0.947	0.943
v_0	0.954	0.954	0.954	0.954	0.954
$\hat{M}_0$	0.014	-0.030	0.030	–0.030	–0.030
m_2	0.236	0.236	0.552	0.450	0.320
v_a	0.933	0.949	0.955	0.945	0.940
v_a that would be in the initial model	0.933	0.944	0.998	0.974	0.953
s_a	6.455	7.099	4.657	5.562	6.837
u_a	0.72	0.693	0.657	0.666	0.668

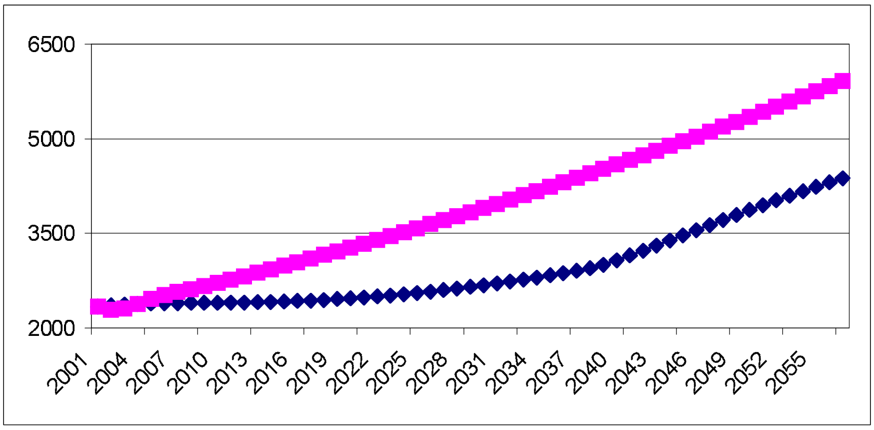

Figure 14. Total profit $(1 - u)P$ (billion 1996 dollars per year) in the basal run (violet curve) and in inertia scenario (blue curve), 2001–2057

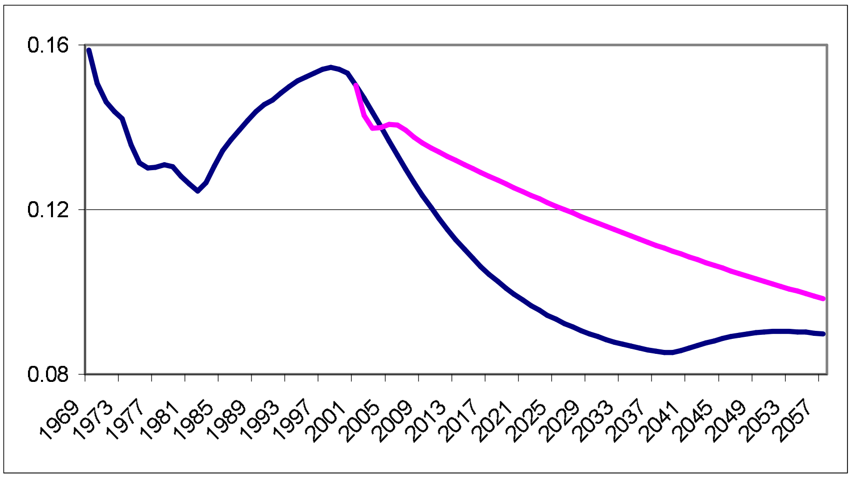

Figure 15 Profit rate $(1 - u)/s$ in the basal run (violet curve) 2001–2057 and in the inertia scenario (blue curve), 1969–2057

Table 5. Measures of economic efficiency: average magnitudes for 2001–2057

Variable	Simulation runs		Improvement by the closed loop control
	Inertia	Basal	
(1)	(2)	(3)	(4) = (3) – (2)
Profit, $(1 - u)P$ (billion 1996 \$ a year)	2,924	3,924	1,000
Employment, L (million)	166	171	5
Profitability, $(1 - u)/s$	0.101	0.119	0.018
Employment ratio, v	0.915	0.948	0.033

The total sum of profit over 2001–2057 is 34.2 per cent higher in real terms in the basal run than in the inertia scenario; improvement in the mean profitability is 1.8 per cent point; improvement in the mean employment ratio is 3.3 per cent point (Table 5). Ups and downs of the potential economic long waves are successfully smoothed in the basal and three other simulations runs presented.

The suggested pro-growth stabilization policy mitigates the tendency of general profit rate to fall in the simulation runs. Unlike the inertia scenario based on the initial HL, a relatively high employment ratio that is deliberately chosen is steadily maintained after a short transition period, although the tendency of general profit rate to fall remains in the mitigated form. These properties speak for prospective efficiency of this policy.

Figures 17–19 illustrate also prospective robustness of this pro-growth stabilization policy against exogenous shifts in parameters' values according to the simulation runs numbered in the Table 4. The choice of growth rate of net output ($\hat{P}$) must suffice since other variables evolve similarly.

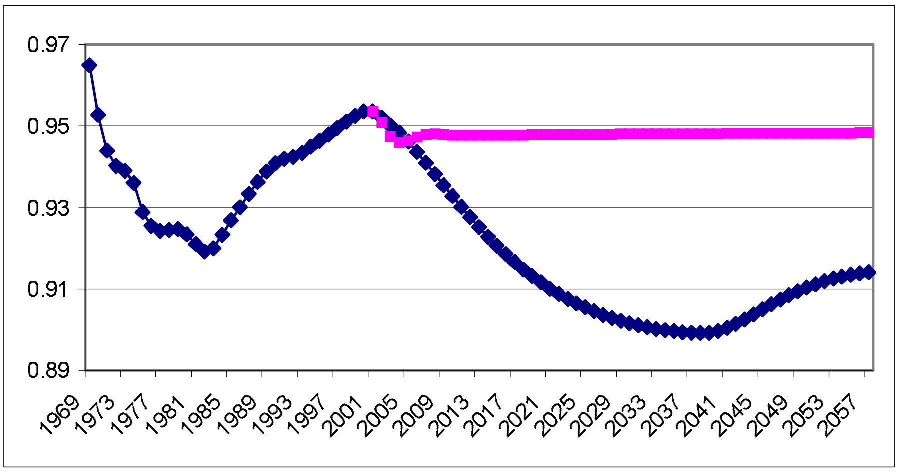

Figure 16. Employment ratio (v) in the basal run (violet curve) 2001–2057 and in inertia scenario (blue curve), 1969–2057

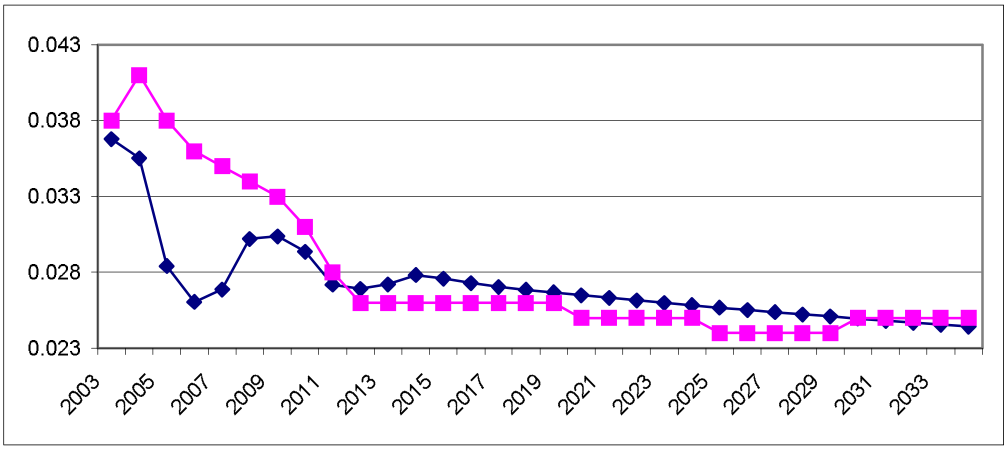

Figure 17. The growth rate of net output $\hat{P}$ (blue curve) in the first simulation run related to the growth rate of real GDP in trustees' low cost scenario (violet curve), 2003–2034

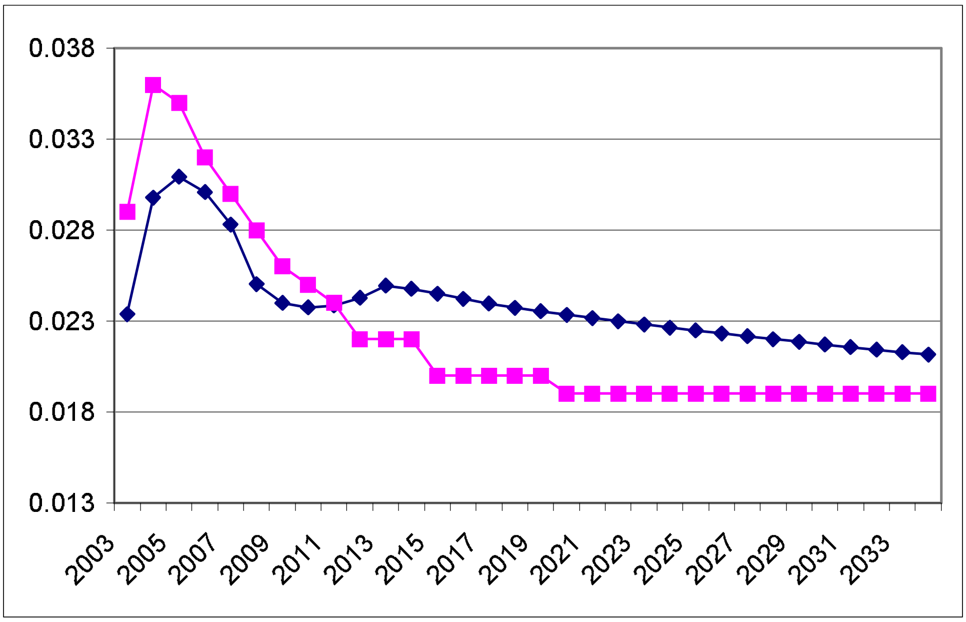

Figure 18. The growth rate of net output $\hat{P}$ (blue curve) in the second simulation run related to the growth rate of real GDP in trustees' intermediate scenario (violet curve), 2003–2034

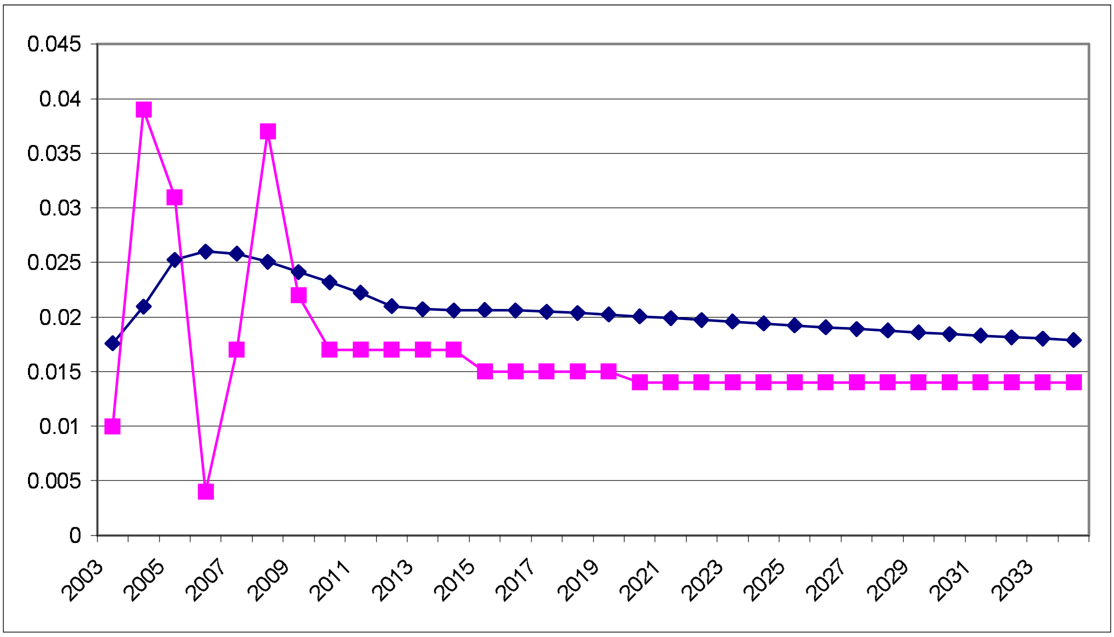

Figure 19. The growth rate of net output $\hat{P}$ (blue curve) in the third simulation run related to the growth rate of real GDP in trustees' high cost scenario (violet curve), 2003–2034

The designed closed loop control has successfully passed extreme conditions tests. For example, it avoids over-shooting even if the scale effect reflected by the equation (4) is much stronger or weaker (the coefficient m_3 can be multiplied by a positive factor and/or the coefficient j divided by a positive factor without creating a problem for control). This control remains effective for negative values of growth of labour supply (at least for $0 > n \geq -i$) if the equations (7a) and (7b) are modified.

Conclusion

This paper uncovers and explains the paradox that profit is the decisive factor of big economic cycles under capitalism and could be the key for smoothing them! It demonstrates that a more efficient social control over the oscillatory macroeconomic system requires a substantial reshaping of primary income distribution that takes into explicit account this dual characteristic of profit.

The modelling process, reflected in this paper, has went through key stages in System Dynamics including specification of structure, decision rules, estimation of parameters, behavioural relationships, and initial conditions, testing the model, finally policy design and evaluation. The Structural Control Theory has been mostly helpful during the policy design phase.

This paper defines a hypothetical Law (HL) of capital accumulation. The main state variables are the labour productivity, unit value of labour force, employment ratio, and capital-output ratio; a comprehensive Phillips equation governs a rate of growth of real wage. An application of an extended Kalman filtering to the US macroeconomic data 1969–2002 and computer simulation runs demonstrate that long wave resulted from the socio-economic relations has been a viable pattern generated by capital accumulation. The HL includes the hypothetical partial law for the labour supply as a non-linear function of capital intensity. Although this hypothetical law is not a necessary condition for Kondratiev cycles, it helps to portray them more accurately.

The characteristic of the inertia scenario based on the HL is a strengthening of the secular tendency of the general profit rate to fall. This is not accepted by the US state and business leadership pursuing a pro-growth stabilization policy.

The initial HL of capital accumulation and computer simulations based on the US official statistics have put in a nutshell how under conditions of the current war American workers have got to take freezing real wage to restore profitability and secure higher employment in coming years. The modified HL, that curtails the comprehensive Phillips equation, reflects moderation of real wage increases. This modified HL maintains the mobilising scenario with its open loop control over total profit. With all its benefits, especially for capital, over-shooting endangers capital accumulation in this scenario.

Applying the Structural Control Theory the present paper uncovers long-term advantages of the closed loop control over total profit in comparison with the open loop control. Based on examination of causal linkages, the supposed control law of primary distribution of income is derived as the more sophisticated modification of the initial HL. The new equation, representing feed-forward control, substitutes the comprehensive Phillips equation of the initial HL for the rate of change of real wage. The controlled transition to a non-trivial stationary state defined explicitly would alleviate the tendency of general profit rate to fall, maintain deliberately high steady employment ratio and uphold total profit.

The designed pro-growth stabilization policy for the macroeconomic oscillatory system is tested in original projections related to three scenarios of the US economic evolution in 2003–2034 (Board of Trustees, 2004). The comparison of the basal run with the inertia scenario demonstrates that the supposed closed loop control *could bring about, each year*, *additionally* 1 trillion 1996 dollars of profit and 5 million of jobs (on the average for 2001–2057). This paper shows robustness of the proposed closed loop control as well.

A question about its potential efficiency and robustness under rigid constrains of natural resources remains open. Figuring out whether the control law supposed in this paper really governs capital accumulation and primary income distribution in the modern US economy is another task for subsequent research.

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Errata

Figures 1 and 2 contain errors in (Ryzhenkov 2004: 10). The corrected figures follow.

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

Figure 1.1 The positive feedback in the Solow model

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

Figure 1.2 The negative feedback in the Solow model