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Crisis as Reconfiguration of the Economic Complex Adaptive System

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Abstract

"Top-bottom" (MSP) technique of Complex Adaptive Systems (CAS) Modelling (Pushnoi 2003, 2004a, 2004b; Pushnoi and Bonser 2008) is applied for the exploration of macroscopic properties of the economic systems. MSP-Model of Economic CAS is considered according to which two global feedbacks determine dynamics of Economic CAS at utmost abstract level. Positive feedback determines the change of the temporary equilibrium state of the system whereas the negative feedback stabilizes one. The interplay of these feedbacks engenders very complex macroscopic dynamics with catastrophic jumps and discontinuous cycles.

Introduction.

Many surprising properties of the Economic Systems (such as sudden crises, jumps of macro-indices, catastrophe-like changes of the system) can be understood deeper on the basis of complex adaptive systems (CAS) paradigm. Complex Adaptive Systems consist of many interacting adaptive agents. Stephan Wallis (2008) found 20 concise definitions/descriptions of "CAS theory" in the current scientific literature. Despite the diversity of CAS-definitions most authors agree that the Complex Adaptive System can be represented as a multitude of "agents" interacting with each other in line with certain rules of adaptive behavior. Multi-agent modeling (MAM) is used in CAS-modeling.

Very dissimilar MAM-models display often the same set of macroscopic (so-called emergent) properties: (1) self-organized instability, (2) self-organized criticality (SOC), (3) episodic sudden reconfigurations of the system, (4) sharp jumps of macro-indices, (5) discontinuous cycles, (6) formation of hierarchical fractal-like structure. These emergent properties were discovered in many realistic multi-agent models of the real CAS-s such as ecosystems, societies, markets, organizations and so on. The enormous literature exists which is devoted to emergent properties of MAM-models. Let's mark only some references: 1) models which demonstrate self-organized instability and SOC - Bak, Tang and Wiesenfeld 1987, Henley 1989, Drossel and Schwabl 1992, Bak and Sneppen 1993, Sole, Bascompte and Manrubia 1996, Sole, Alonso and McKane 2002, di Collobiano 2002; 2) the models with sudden reconfigurations of the system and jumps of macro-indices – Kauffman and Johnsen 1991, Sole and Manrubia 1996, Hommes 2002, Kephart 2002, Sornette 2002, Allen and Holling 2008; 3) the models with discontinuous cycles – Epstein 2002, Gunderson and Holling 2002, Hommes 2002, Kephart 2002, Allen and Holling 2008; Paperin and Sadedin 2009; 4) the models with formation of fractal-like structure – Warnecke 1993, di Collobiano 2002, Fisher, Schillo and Siekmann 2004.

These common properties of MAM-models do not depend on internal structure of the concrete System or on specific features of the "agent's" behavioral rules in a specific model. Rather these macroscopic properties of MAM-models are inherent in CAS as a holistic System. Multi-agent modeling is based on "down-up" methodology, starting from the interaction of a multitude of "agents" to revealing the emergent properties of the integral system. Within the framework of MAM-platform above-listed universal properties of CAS emerge as unpredictable aggregated macroscopic effects of interaction of "agents".

Here we use so-called Method of Systems Potential (MSP) according to which above listed macroscopic emergent properties of CAS can be interpreted as "thermodynamic" properties of ensemble consisting of interacting adaptive agents.

MAM-MSP interrelation is similar to interrelation between statistical molecular physics and thermodynamics**.** Both MAM and MSP describe one and the same reality – Complex Adaptive Systems (CAS). MAM attempts to explain how peculiarities of inner microscopic structure of the System (properties of agents and behavioural rules) generate the system's macroscopic properties. MSP attempts to find some general regularity in macroscopic properties and dynamics of ensembles consisting of inter-acting agents. As inter-molecular interaction and motion of molecules in statistical physics produce some macroscopic properties of matter which can be described in thermodynamic terms just-as-inter-agent interaction and behaviour of agents produce some regularity in macroscopic properties of the CAS as a whole (Pushnoi and Bonser, 2008, p. 35).

MSP postulates that two fundamental feedbacks form the basis of CAS-dynamics: (1) the reinforcing feedback process changes the current stationary state (short-run equilibrium) of the System; (2) the regulating feedback stabilizes this state. Interaction of these mechanisms produces very complex dynamics of the System with cycles and catastrophic jumps. Given paper discusses properties of Economic System from point of view MSP-platform of CAS-modeling.

The paper is structured as follows. The second section contains short introduction into MSP-modeling. MSP-model of the Economic CAS is formulated in the third section. Theoretical conclusions of this model are verified on stylized data (Solow 1957, Kendrick 1961 and Giussani 2005) in the fourth section of the paper.

MSP-Technique of CAS-Modeling.

MSP-model of CAS postulates the existence of some macroscopic variables which play the role of "thermodynamic potentials" in the System consisting of interacting adaptive agents:

(1) "**Adaptive potential** of the System" - the aggregated ability of CAS to adequately respond to the challenges of the external world,
(2) "**Conditions for realisation** of adaptive potential" - the aggregate factors contributing to (or preventing) the exploitation (employment) of the "adaptive potential",
(3) "**Efficiency of CAS**" - the relationship between the exploited *"adaptive potential" and the accumulated one.* (Pushnoi and Bonser, 2008, p. 29).

These macroscopic variables describe the ensemble of interacting adaptive "agents" as holistic system. Values of macroscopic variables depend on structure of fitness landscapes and on positions of adaptive agents in landscapes. The details of MAM-MSP interrelation are considered in Pushnoi and Bonser 2008, pp. 35-41.

Evolution of the system consisting of interacting adaptive agents can be modeled (at utmost abstract level) by means of MSP-variables: "adaptive potential" (Φ), "conditions for realization of adaptive potential" (U) and "realized part of adaptive potential" (Φ_R).

Aggregative adaptive activity of agents within CAS and destructive influence of random factors (influence of entropy) determine the change of MSP-variables. The adaptive activity of agents is larger; the employed potential (Φ_R) is larger. The following nonlinear dynamical model describes the behaviour of MSP-variables:

$$\dot{\Phi} + d \cdot \Phi = (a + d) \cdot \Phi_R \qquad (1)$$

$$\dot{U} + \Lambda \cdot U = \nu \cdot \Phi_R \qquad (2)$$

$$\dot{\Phi}_R = a \cdot \Phi_R \qquad (3)$$ [1]

The second term in the left part in equations (1)-(2) describes the influence of entropy whereas the right part of these equations describes the increment of MSP-variables on account of adaptive activity of the system. Values $a; d; \Lambda; \nu$ are positive "evolutionary parameters" of MSP-model. System of equations (1)-(3) can be transformed into the system for two new variables:

1) Efficiency of system (rate of exploitation of accumulated adaptive potential)

$$R = \frac{\Phi_R}{\Phi} \qquad (4)$$

2) Density of "conditions" in the system (the quantity of "conditions" per unit of "potential")

$$Z = \frac{U}{\Phi} \qquad (5)$$

The following two equations follow from (1)-(5):

$$\frac{\dot{R}}{R} = (a + d) \cdot (1 - R) \qquad (6)$$

$$\frac{\dot{Z}}{Z} = \left(\frac{\nu}{Z} - (a + d) \right) \cdot R + (d - \Lambda) \qquad (7)$$

Equation (6) indicates that the efficiency of the system R grows with time accordingly to the logistic law.

Consider the plane $(Z; R)$ at which formulas (6)-(7) determine the curve satisfying to the following equation:

$$R'_Z = \frac{(a + d) \cdot R \cdot (1 - R)}{\left[(\nu - (a + d) \cdot Z) \cdot R + (d - \Lambda) \cdot Z \right]} \qquad (8)$$

Solution of this equation subject to the constant evolutionary parameters describe the possible positions of the system at the plane $(Z; R)$. Solution of equation (8) consists of two "branches":

"Upper" evolutionary branch subject to $Z < Z_0 \cdot R$

$$Z^{(U)} = Z_0 \cdot R - C^{(-)} \cdot R^{-\chi} \cdot (1 - R)^{1+\chi} \qquad (9)$$

"Lower" evolutionary branch subject to $Z > Z_0 \cdot R$

$$Z^{(L)} = Z_0 \cdot R + C^{(+)} \cdot R^{-\chi} \cdot (1 - R)^{1+\chi} \qquad (10)$$

The following designations are taken:

$$Z_0 = \frac{\nu}{a + \Lambda} \qquad (11)$$

$$\chi = \frac{\Lambda - d}{a + d} \qquad (12)$$

Values $C^{(-)}$ and $C^{(+)}$ are some positive constants.

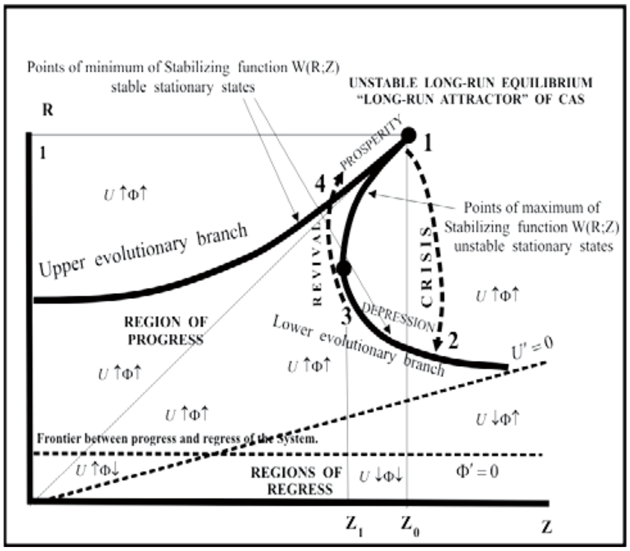
Consider the case $\chi > 0$. The evolutionary branches are depicted in Fig.1.

The points of curve (9)-(10) correspond to "temporal macroscopic equilibrium states" ("stationary states") of the System. CAS moves along the evolutionary branches. This

[1] Sign "dot" means time derivative and sign "touch" means derivative respect to some variable.

is very slow process. System tends to the point 1 of maximal efficiency. This point is the long-run attractor of the System. Permanent random disturbances take away the System from its current "stationary state" (disposed on the "evolutionary branch"). Consequently some short-run adjustment process must exist in order to ensure the long-term development of the System along evolutionary branch.

Figure 1. Evolutionary Cycle of Complex Adaptive System.



Short-run adjustment can be represented as attraction of actual state to corresponding "stationary state" localized on the evolutionary branch.

The simplest mathematical representation of stabilizing feedback is anti-gradient dynamical which can be formulated by means of so-called "stabilizing function" of the System $W(Z;R)$:

$$\dot{R} = -\frac{\partial W}{\partial R} \qquad (13)$$

Stabilizing function $W(R)$ has two minimum points (stable equilibrium states) and one maximum point (unstable equilibrium state) in the range $Z_1 < Z < Z_0$. Minimum points lie on the "upper" (region 4 → 1) and on the "lower" (region 2 → 3) evolutionary branches. The stability of System diminishes during its motion along the evolutionary branches. Two catastrophic jumps take place in vicinity of points 3 and 1. At points 1 and 3 the System, under the influence of the stabilising feedback, "rolls" into a new the temporal equilibrium state.

The System displays complex dynamics of discontinuous cycles (see Fig. 2 - 3) with two catastrophic jumps in each cycle. Efficiency of the System changes step-wisely during the cycle. Evolution of the System along "upper" evolutionary branch (stage of "prosperity" 4→1) describes the behaviour (motion) of adaptive agents towards the current attractive peaks in its fitness landscapes (maximization of gain). Downward leap of efficiency (stage of "crisis" 1→2) corresponds to avalanche-like reorientations of agents onto a new attractive peak in fitness landscapes. Evolution of the System along the "lower" evolutionary branch (stage of "depression" 2 → 3) describes the transition of agents into the region of landscape with a new attractive peak. Upward jump of efficiency (stage of "revival" 3→4) is the start of new phase of "prosperity". There are 6 different alternatives of CAS-development which correspond to different bundles of signs of derivatives in triad $(\dot{U};\dot{\Phi};\dot{Z})$. Positive (negative) sign of derivative means the increase ↑ (the decrease ↓) of value under consideration. Each "option of development" corresponds to definite "region of development" in the plane $(Z;R)$ - Fig. 1 Trend of long-run growth of "potential" and "conditions" corresponds to "progress" of the System. Long-term decrease of these values point to "regress" of the System – Fig. 2 and 3. One may expect that these common properties of complex adaptive systems are inherent to the economic complex adaptive systems. MSP-modelling of CAS gives new analytical tools for quantitative analysis of the Economic System. Let's attempt to interpret the basic MSP-notions and statements in the economic terms.

Figure 2. The progressive evolution of CAS.

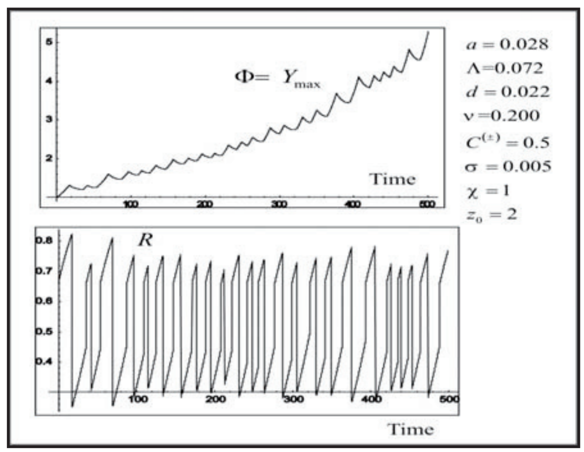
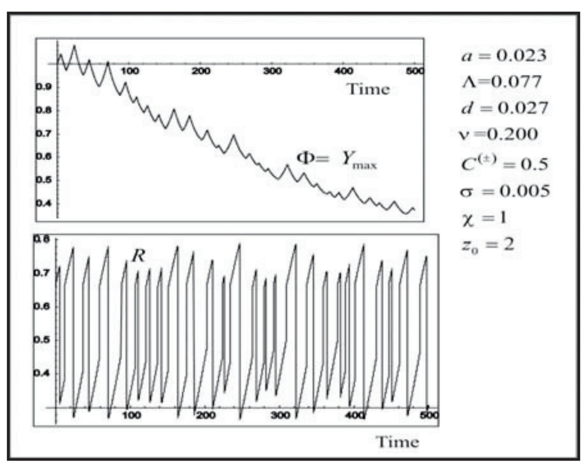


Figure 3. The regressive evolution of CAS.



MSP-Model of the Economic CAS.

Let's consider the economy as the Complex Adaptive System (CAS) consisting of many interacting adaptive agents: firms, organizations, and individuals. We can explore the properties of this system by means of multi-agent modelling. It is notable that many realistic MAM-models of economy (for example Kephart 2002; Hommes 2002)) demonstrate the similar macroscopic properties - such as sudden jumps of macro-indices, discontinuous cycles, self-organized instability and criticality. Pushnoi and Bonser 2008 conjectured that these general macroscopic properties of MAM-models originate from some common laws acting at the level of integral system:

"Potential of the Economic CAS" and "conditions for realization of the economic potential" are two constituents of the "useful experience" accumulated (installed) within the economic system. "Useful experience" consists of the "economic potential" (available resources and know-how incorporated in technologies, organizations, management rules, and human capital) and "conditions for realization of economic potential" (available capital, investment conditions, rules of agent-agents interactions, social routines, and institutions). Both the "potential" of the System and the "conditions for realization of the potential" within the System are the result of productive activity of the economic agents. Gain in the Economic System is achieved owing to the growth of complexity of the System. Complexity of the economic CAS depends on embodied knowledge installed within the System. New technologies of production, new methods of distribution, new forms of organization and of management, and new configuration of networks all together increase the complexity of the Economic System. The growth of complexity gives raises the new possibilities for the growth of welfare. On the other hand the growth of complexity undermines the stability of the System. The loss of stability is a sort of "payment" for prosperity and welfare. Economic CAS spontaneously tends to unstable equilibrium state $(Z_0; R = 1)$ which triggers the dramatic process of System's reconfiguration.

The macroscopic dynamics of the Economic Complex Adaptive System is superposition of three processes: (1) the increment in "useful experience" on account of adaptive activity of agents within the System; (2) the decrement in "useful experience" on account of destructive influence of entropy; (3) stabilization of the macroscopic stationary state of the System owing to operation of stabilizing feedback.

There are two points 1 and 3 (Fig. 1) at which the stationary state of the Economic System becomes unstable. Any small perturbation (deviation from the current stationary state) can trigger sudden jump of the System into a new equilibrium state when the System is disposed in a small neighborhood of these points. The System makes a leap from one evolutionary branch to another. Stabilizing feedback takes away the System from the old equilibrium (stationary) state as only the System leaves the basin of attraction of this state. Dynamics of the System is a sequence of discontinuous cycles.

Each evolutionary cycle, 1→2→3→4 , consists of two catastrophic jumps and two stages of the gradual changes of the System: 1) jump downwards - "crisis", 2) jump upwards - "revival", 3) gradual development of the System along the lower evolutionary branch - "depression", and 4) gradual development of the System along the upper evolutionary branch – "prosperity" – Fig. 1.

Evolutionary cycle is accompanied by deep qualitative changes in the structure of the System. New rules of agent-agent interactions, new networks, new technologies, new forms of organization, and management arise within the System during the evolutionary cycle. The process of System's reconfiguration produces a new more robust structure.

Let us identify the "economic potential" (capacity of the economic system) with maximal (or potential) output of the economic system. Maximal output (Y_m) is the output of the Economic System subject to the full utilization and optimal allocation of available production factors (technologies, forms of management, human capital, and so on) and optimal cost-minimizing factor prices.

Consider the model of the economy with three production factors: 1) the capital K , 2) the labor force L and 3) the total factor productivity (TFP) A . TFP describes the influence of technological progress on the productivity of labor and capital. The economic potential is realized through productive activity of the economic agents. The "gross output" (GNP) characterizes the realized economic potential of a System.

Factual (real) output Y is lesser than "potential output" of the system. Efficiency of the Economic CAS is the "real output" per "potential output" ratio:

"Conditions of realization of the economic potential" in the Economic CAS depend on economic factors which influence on the utilization rate of available factors of production. The capital is the main force that stimulates exploitation of the labor, land, plant, and knowledge in the modern economy. It is evident that some capital must be advanced in order to combine (and to transform) the potential forces of the labor, machines, land, and technologies into the real production. Therefore the store of capital in national economy characterizes the ability of economy to realize the available resources in production.

Fernando de Soto 2000 established that capital is functioning both as production factor (plant, buildings, land and etc.) and as financial instrument (condition) for exploitation of production factors. The capital stock (as tool for exploitation of resources) is the necessary condition for successful realization of economic potential of market economy. Therefore the "stock of capital" can be used as the quantitative measure of "conditions of realization of the economic potential" in the Economic CAS.

So, MSP-model of the Economic CAS uses three basic economic variables: 1) "gross output" Y, 2) "maximal (potential) output" Y_m, and 3) "stock of capital" K.

The maximal (potential) gross output is quantitative measure of the economic potential:

$$\Phi \rightarrow Y_m; \tag{14}$$

The gross output is quantitative measure of employed economic potential:

$$\Phi_R \rightarrow Y; \tag{15}$$

Actual per maximal output ratio is the efficiency of the Economic CAS:

$$R = \frac{Y}{Y_m} \tag{16}$$

The stock of capital K characterizes the 'conditions of realization of potential' in the Economic CAS:

$$U \rightarrow K \tag{17}$$

The equations of MSP-model (1) can be rewritten in the economic terms as follows:

1) Equation for the constant rate of growth of output:

$$\dot{Y} = aY \tag{18}$$

2) Equation for the accumulation of capital stock:

$$\dot{K} + \Lambda K = \nu Y \tag{19}$$

3) Long-run dynamics of maximal output:

$$\frac{d(Y_m - Y)}{dt} = -d \cdot (Y_m - Y). \tag{20}$$

Parameters $a; \Lambda; \nu; d$ describe the properties of the Economic System:

a - the rate of growth of output;
Λ - the depreciation rate;
ν - the share of gross investment in GNP;
d - adjustment coefficient.

"Density of conditions" Z is the "capital coefficient" of the economy subject to full employment of all production factors. This value depends on productivity of the capital stock P:

$$Z = \frac{U}{\Phi} = \frac{K}{Y_m} = \frac{R}{P} \tag{21}$$

$$P = \frac{Y}{K} \tag{22}$$

Equation (20) evidences that factual output tends to maximal output in long-run. Point of maximal efficiency is the point of unstable equilibrium state. The System displays the picture of "self-organized instability". As soon as trajectory of development of the Economic System (upper or lower evolutionary branch) enters into a small neighborhood of unstable equilibrium points 1 and 3 (Fig.1), any small perturbation of the System can trigger catastrophic jump in capacity utilization of the Economic System ("crisis" or "revival" phase of evolutionary cycle).

The productivity of the capital satisfies to logistic equation:

$$\dot{P} = \nu \cdot P \cdot (P_0 - P) \tag{23}$$

$$P_0 = \frac{1}{Z_0} = \frac{a + \Lambda}{\nu} \tag{24}$$

Value P_0 is productivity of the capital in the point 1. Aulin 1997 proposed the model of economic growth in which the productivity of employed capital increases by logistic law. This regularity is confirmed by Solow' 1957 data for the U.S. non-farm industry during the Great Depression – Fig.5.

Stabilizing feedback describes short-run adjustment of the System. Adjustment equation (13) can be rewritten in the economic terms as follows:

$$\dot{Y} = -Y_m^2 \cdot \frac{\partial W(Y;K)}{\partial Y} \tag{25}$$

Short-run adjustment in the Economic CAS is the process of demand-supply (or investment-saving) regulation. Kaldor 1940 assumed that short-run adjustment can be modeled as follows:

$$\dot{Y} = -\alpha \cdot [S(Y;K) - I(Y;K)] \qquad \alpha > 0 \tag{26}$$

$I(Y;K)$ - is the S-shape investment function;
$S(Y;K)$ - is the S-shape saving function.

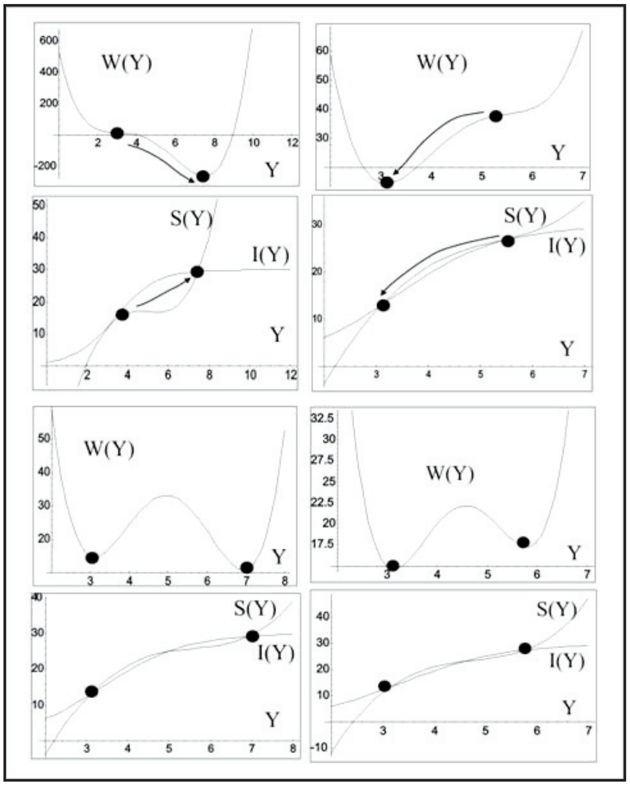
Trade cycle in Kaldor' 1940 model consists of two stages of gradual development and two catastrophic jumps. There are three equilibrium points (two of them stable and one unstable) during the prosperous and depression phases of Kaldor' cycle. The saving and investment functions are shifting relatively each other when the capital stock increases. "Excess saving function" $S(Y;C) - I(Y;C)$ is proportional to derivative of "stabilizing function".

$$S(Y;K) - I(Y;K) = \frac{Y_m^2}{\alpha} \cdot \frac{\partial W(Y;K)}{\partial Y} \tag{27}$$

The simple model of Kaldor' 1940) cycle is depicted in Figure 4. Cyclical dynamics in Kaldor' model can be interpreted in terms of MSP-model. The long-term dynamics in Kaldor's model are regulated by relative position of "saving" and "investment" functions. There are two stable states when these functions have three points of intersection. Catastrophic leap into the new equilibrium state takes place when two points of intersection coincide. Such dynamics can be described in terms of stabilizing function as it is depicted in Figure 4.

There are many models with catastrophic jumps and discontinuous cycles in the modern economic literature. Many economists emphasize the alternation the stages of gradual evolution and sudden leaps in dynamics of macro-economic indices. Large and small crashes and collapses occur perpetually in the modern life. Jumps in the economic dynamics can be interpreted as manifestation of self-organized instability of the economic CAS. Reconfiguration (renewal) of the Economic CAS is the result of the complex process consisting of many large and small cycles of irregular duration. Cycle arises either in overall economic system or in some sub-system of the economy. Set of such cycles superimposed one another can produce very complex macroscopic behavior of the Economic CAS. We consider in this paper only the simplest case under which overall Economic System displays four-phase discontinuous evolutionary cycle.

Figure 4. Interrelation of Kaldor's model and MSP-model of the business cycle.



Each crisis phase of the cycle initiates the active search and adoption of innovations. Deep qualitative changes in configuration of the Economic System emerge in course of time. New quality (new configuration) of the System creates the base for new, higher level of potential productivity. The business cycle ("crisis – depression – revival – prosperity") can be interpreted as "evolutionary cycle" of the Economic CAS. According to Eis 1969 and Nelson 1959 picks in merges and acquisitions of firms correspond to crisis and depression phases of the business cycle. Schumpeter 1939 especially emphasized the role of innovations in recovery from recession. Qualitative renewal of economy after each crisis is well-established fact. Technologies, rules of management and forms of organizations change radically during each evolutionary cycle. Impulses (or clusters) of innovations were discovered independently by some scientists (Mensch 1979; Hochgraf 1983; van Duijn 1983; Kleinknecht 1984).

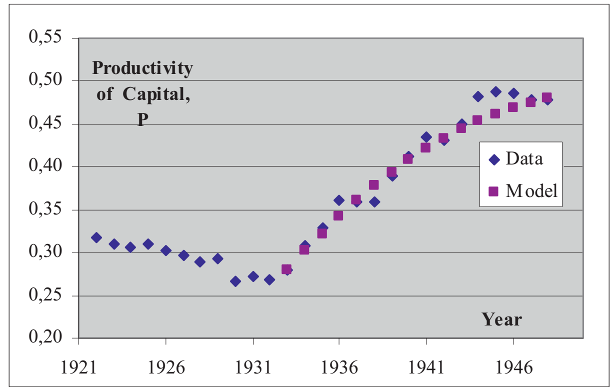
Some non-trivial interrelations between economic variables can be deduced from MSP-model of the Economic CAS. Consider the Economic System with Cobb-Douglas production function:

$$Y(t) = A(t) \cdot K^{\beta} \cdot L^{1-\beta}; \; 0 < \beta < 1 \qquad (28)$$

The productivity of the capital equals to the tangent of angle of inclination of the radius-vector drawn in the plane $(Z; R)$:

$$P = \frac{R}{Z} = \frac{Y}{K} \qquad (29)$$

Figure 5. Productivity of capital in non-farm industry of the U.S. Economy (data from Solow' 1957 paper).



Stylized facts indicate that productivity of the capital is almost constant value (with very slow decrease) during the prosperous phase of the business cycle (Fig 5). This property follows from MSP-model. The prosperous stage of the business cycle corresponds to position of the Economic CAS on the "upper evolutionary branch" where productivity of the capital almost constant and it decreases very slowly during this period.

The next formula for the "productivity of the capital" follows from (9), (10), (24) and (29):

$$P = \frac{P_0}{1 \pm C^{(\pm)} \cdot P_0 \cdot \left(\frac{Y_m}{Y} - 1 \right)^{1+\chi}} \qquad (30)$$

Efficiency of the Economic System (rate of "capacity utilization") depends on productivity of capital as follows:

$$R = \frac{1}{1 + \left(\frac{|P - P_0|}{C^{(\pm)} \cdot PP_0} \right)^{\frac{1}{1+\chi}}}; \qquad (31)$$

Let us introduce the following designations:

$k = \frac{K}{L}$ - is the capital intensity, (32)

$y = \frac{Y}{L}$ - is the productivity of labor, (33)

f - is the rate of utilization of capital and labor,

$A(t)$ - is the total factor productivity,

$k_0 = \left(\frac{\beta}{1-\beta} \right) \cdot \frac{w}{r}$ - is optimal capital intensity (34)

Optimal capital intensity depends on wage rate w and interest rate r. Value k_0 is the solution of output maximization (cost minimization) problem subject to given costs (given output). Let $L_0; K_0$ is maximal available stock of labor and capital subject to optimal capital intensity.

The factual output is Cobb-Douglas production function of the employed capital K, exploited labor L and the total factor productivity A (Solow 1957):

$$Y = A \cdot K^{\beta} \cdot L^{1-\beta} = A \cdot f \cdot L_0 \cdot k_0^{\beta} \cdot \left(\frac{k}{k_0} \right)^{\beta} \quad (35)$$

$$y = A \cdot k^{\beta} \quad (36)$$

$$P = \frac{y}{k} = A \cdot k^{\beta - 1} \quad (37)$$

Total Factor Productivity (TFP) describes the progress in adoption of new knowledge via its installation in plant, management and the organization of the business activity subject to given capital and labor stocks. Maximal output Y_m is the output subject to optimal capital intensity and full utilization of production factors.

$$Y_m = A_m(t) \cdot L_0 \cdot k_0^{\beta} \quad (38)$$

$$y_m = A_m \cdot k_0^{\beta} \quad (39)$$

$$P_0 = \frac{y_m}{k_0} = A_m \cdot k_0^{\beta=1} \quad (40)$$

The efficiency of the Economic CAS equals to actual per maximal output ratio:

$$R = \frac{Y}{Y_m} = f \cdot \frac{A}{A_m} \cdot \left(\frac{k}{k_0} \right)^{\beta} = f \cdot \frac{P \cdot k}{P_0 \cdot k_0} = \frac{f \cdot y}{y_m} \quad (41)$$

Technological progress is described in MSP-model as the growth of actual and maximal total factor productivity. Let us consider the simplest case of exponential technological progress:

$$A_m(t) = A_m(0) \cdot Exp\{n \cdot t\}; \qquad n > 0 \quad (42)$$

According to formulas (41) and (31) the productivity of labor and capital intensity are functions of productivity of capital:

$$y(P) = P \cdot k = \frac{P_0 \cdot k_0}{f \cdot \left[1 + \left| \frac{P - P_0}{C^{(\pm)} \cdot PP_0} \right|^{\frac{1}{1+\chi}} \right]} \quad (43)$$

$$k(P) = \frac{y(P)}{P} \quad (44)$$

Formulas (43)-(44) determine parametrically function $y(k)$.

MSP-Model and Stylized Facts.

Consider the following stylized facts:

(1) Giussani' 2004 data for the capital intensity, productivity of the capital and productivity of labor in 118 countries during 1963-2000;

(2) Kendrick' 1961 data for the U.S. Economy during 1869-1957

(3) Solow' 1957 data for Nonfarm Industry in the USA during 1909-1949 years.

Giussani' 2004 data are represented in his paper as distributions of points in the planes $(y; k)$ (Giussani 2004; Fig.3, p.3) and $(y; P)$ (Giussani, 2004; Fig.4, p.4). These distributions demonstrate certain fundamental regularity. MSP-model explains why the points are disposed in such manner. Theoretical distributions $y(k)$ and $y(P)$ (formulas (43)-(44)) are depictured in Fig. 6 and 7**.** The different theoretical curves were calculated for the different values of capital intensity.

Figure 6. Productivity of labor – productivity of capital interrelation in MSP-Model of the Economic CAS.

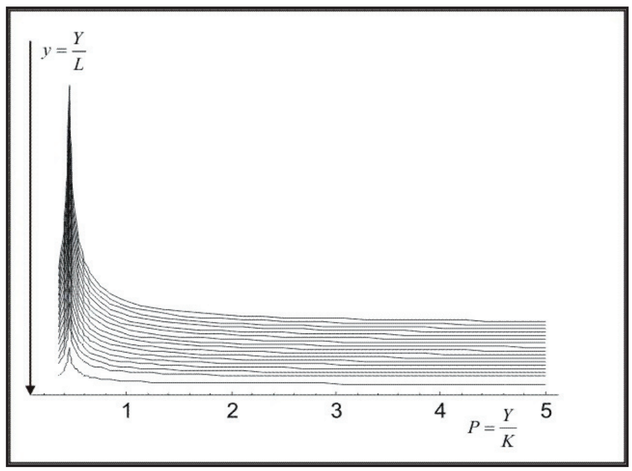
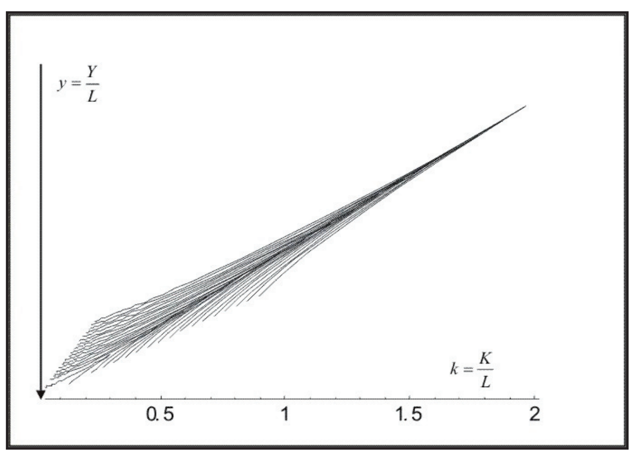


Figure 7. Productivity of labor – capital intensity interrelation in MSP-Model of the Economic CAS.



Solow' 1957 data contain implicitly valuable information about dramatic changes in the Economic CAS of the USA during 1909–1949 years. This information can be retrieved owing to MSP-model.

The U.S. Economic System changed qualitatively after the crisis 1929-1933. The basic economic parameters: the investment share in GDP ν; the rate of depreciation Λ and the rate of growth a changed after 1933 year. Our calculations indicate that long-run equilibrium point Z_0 left-shifted in the plane $(Z;R)$ after the crisis. As consequence the equilibrium productivity of the capital P_0 increased after 1933 year – Fig. 5.

The left-shift of point Z_0 in the plane $(Z;R)$ is the clue to understanding of the Great Depression phenomenon.

Figure 8. Dynamics of the U.S. Economic CAS during the Great Depression.

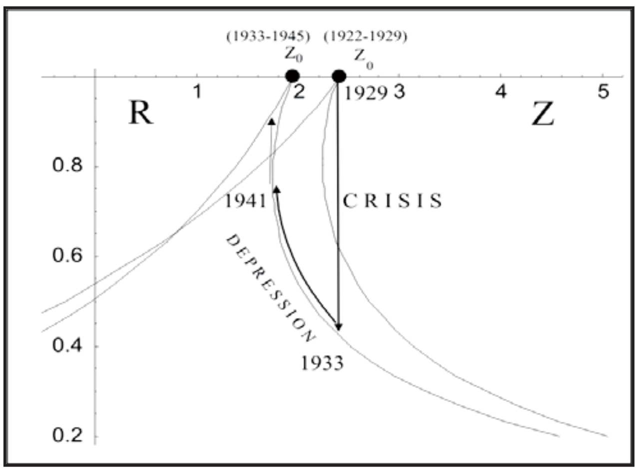
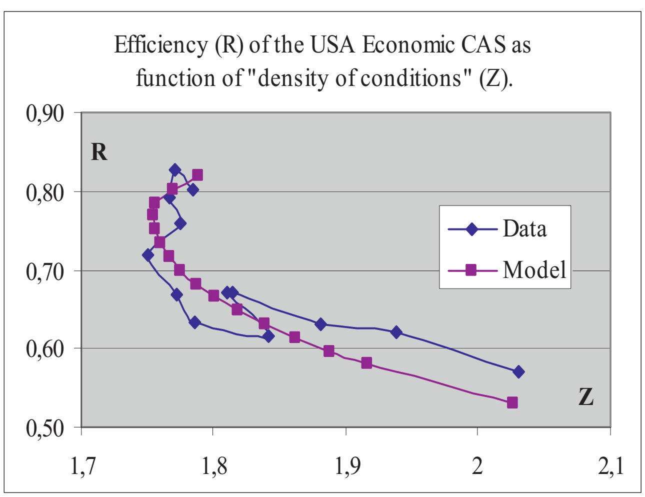


Figure 9. Efficiency of the U.S. Economic CAS during the Great Depression.



Parameters $a;\Lambda;\nu$ of MSP-Model were estimated on the basis of Kendrick' 1961 data. Least-square procedure for the equation (20) was used in order to estimate parameter d.

Period 1921-1928:

$a = 0.0513$; $\Lambda = 0.0296$; $\nu = 0.1950$; $Z_0 = 2.411$.

Period 1934-1948:

$a = 0.0517$; $\Lambda = 0.0343$; $\nu = 0.1677$; $Z_0 = 1.951$; $n = 0.0355$; $d = 0{,}002$; $A_m(0) = 0.73$; $k_0 = 2{,}63$; $\beta = 0{,}3435$; $\chi = 0{,}602$; $C^{(+)} = 2{,}27$.

The post-crisis dynamics of the U.S. Economic System can be interpreted as the search of a new long-term equilibrium state. The profundity and duration of Great Depression were expressly strengthened by shift of the long-run equilibrium point Z_0 (Fig. 8 and 9). Period of the Great Depression corresponds to development (motion) of the U.S. Economic CAS along the lower evolutionary branch (Fig. 9). The dynamics of the U.S. Economic System after 1933 year can be explained as attraction to a new long-term equilibrium state with higher level of productivity of capital stock. The productivity of capital increased owing to deep changes in the U.S. Economic System during 1930-s: adoption of innovations, technical progress, and "New Deal" policy. Alexpoulos 2006 makes numerous examples of radical modernization in the U.S. Economic System during 1930s.

Conclusion.

Comparison with stylized facts indicates that Economy indeed develops as Complex Adaptive System – the Economic CAS. Evolutionary cycle within Economic CAS manifests itself as the business cycle. "Top-bottom" technique of CAS-modelling (MSP) can be successfully used in the economic analysis. Remarkably, even simplest MSP-model of economy is consistent in general with stylized facts (Solow 1957; Kendrick 1961; Giussani 2004). MSP-model of Economic CAS reproduces most fundamental regularity of long-run dynamics.

Properties of MSP-variables reflect the aggregative outcome of agent-agent interactions. Variables in MSP-model describe "thermodynamic properties" of ensemble consisting of many interacting adaptive agents. MSP-model formulates these global properties as nonlinear dynamical system relatively MSP-variables ("potential", "conditions of realization", and "realized portion of potential").

MSP-modelling can be used in strategic planning and management. Evolutionary parameters determine the disposition of regions (in the plane "density of conditions" – "efficiency") in which "potential", "conditions of realization of potential" and "conditions per unit potential" will grow or fall. The System can develop (potential grows), or degenerate (potential falls) in long-run. Stability of current stationary state of the system, depth of crisis phase, and duration of depression phase depend on the disposition and shape of evolutionary branches.

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