

CONFERENCES AND SYMPOSIA

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Econophysics and evolutionary economics
(Scientific session of the Physical Sciences Division of the Russian Academy of Sciences, 2 November 2010)

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The scientific session "Econophysics and evolutionary economics" of the Division of Physical Sciences of the Russian Academy of Sciences (RAS) took place on 2 November 2010 in the conference hall of the Lebedev Physical Institute, Russian Academy of Sciences.

The session agenda announced on the website www.gpad.ac.ru of the RAS Physical Sciences Division listed the following reports:

(1) **Maevsky V I** (Institute of Economics, RAS, Moscow) "The transition from simple reproduction to economic growth";

(2) **Yudanov A Yu** (Financial University of the Government of the Russian Federation, Moscow) "Experimental data on the development of fast-growing innovative companies in Russia";

(3) **Pospelov I G** (Dorodnitsyn Computation Center, RAS, Moscow) "Why is it sometimes possible to successfully model an economy?"

(4) **Chernyavskii D S** (Lebedev Physical Institute, RAS, Moscow) "Theoretical economics";

(5) **Romanovskii M Yu** (Prokhorov Institute of General Physics, RAS, Moscow) "Nonclassical random walks and the phenomenology of fluctuations of the yield of securities in the securities market";

(6) **Dubovikov M M, Starchenko N V** (INTRAST Management Company, Moscow Engineering Physics Institute, Moscow) "Fractal analysis of financial time series and the prediction problem."

Papers written on the basis of these reports are published below.

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The transition from simple reproduction to economic growth

V I Maevsky, S Yu Malkov

1. Introduction. Representation of the macro economy by a population of macroeconomic subsystems

At the current stage, the theory of economics offers a large number of models of the economy achieving static market equilibrium (see, e.g., [1]) as well as models describing how a macro system reaches the trajectory of stable, steady economic growth [2]. But there are no models showing how growth emerges at the macro level from an equilibrium situation.

It seems that the reason for this lacuna is of a fundamental, methodological nature: by virtue of a well-rooted tradition, the macro level is regarded as a complete entity in which the behavior of each element is identical to the behavior of any other part. Because any economy engages simultaneously in the production of consumer goods and investments in fixed capital and current assets, the tradition is to implicitly assume that every part of the macro economy is capable of conducting these two sorts of activities simultaneously (the *coproduction* mode). In our opinion, this well-established view on the macro level should not be treated as absolute, i.e., regarded as the only one acceptable. Another approach is possible, associated with the so-called *cycled* production–reproduction mode. To better understand the essential features of this approach, we consider some of the peculiarities of the machine-building industrial complex.

We assume that this complex includes a full set of subbranches of the machine-building industry capable of creating the active part of fixed capital (machine tools, machinery, equipment, instruments, and so on) both for itself and for the 'rest' of the economy. In terms of the tradition of coproduction, this complex is perceived as an aggregate unit in which all elements are operating simulta-

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neously for the unit and for the 'rest' of the economy. But it is possible to argue differently.

All branches of the machine-building complex are composed of plants for which the ages of fixed capital in a year t are different. If we break down the set of plants in the year t into age groups, we obtain a set of subsystems; in the current year, the oldest among them needs to undertake the reproduction of its fixed capital, while the other subsystems are busy providing the growth in the rest of the economy. In the year $t+1$, the 'rejuvenated' subsystem of plants of the complex switches to providing the growth in the rest of the economy and another subsystem of plants, the oldest in year $t+1$, works on self-reproduction of its fixed capital. We can therefore say that acting within the machine-building complex is a population of machine-building subsystems distributed nonuniformly according to the age of fixed capital and hence also in efficiency, each of which is characterized by a cycled production–reproduction mode.

Because the operation of a machine-building complex predetermines the development of the economy as a whole, we decided to extend the production–reproduction mode to the macro level of the economy. For us, the macro level is not the traditional mono-unit but a population of macroeconomic subsystems (nonidentical in age and in the degree of efficiency); each subsystem operates in a year t either in the mode of self-reproduction of fixed capital or in the production of consumer goods, but not the two simultaneously.

This interpretation of the macro level already deserves attention because it helps pinpoint the competition between the older, less efficient, and the newer, more efficient, macroeconomic subsystems. Newer subsystems, like Glaz'ev's technological structures [3], are capable of forcing out older subsystems from the economic space. The processes activated in this case are those of merger and of absorption of capital, while the number of bankruptcies increases. A different scenario is possible, however: older subsystems succeed in modernizing themselves, without 'help' from new subsystems. Then the evolution unfolds in a quieter mode.

Before modeling the process of development, we must consider the behavior of a population of macroeconomic subsystems in an equilibrium situation in which the efficiency of fixed capital does not increase and the simple reproduction mode is established.

2. Simple reproduction model

Before we tackle the building of a model of simple reproduction in a population of macroeconomic subsystems, we note that the first economist who created a numerical macroeconomic model of simple reproduction was the French physiocrat François Quesnay [4]. Karl Marx [5] followed him with his model of simple reproduction. However, neither Quesnay nor Marx, nor their numerous followers, were interested in the phenomenon of a cycled production–reproduction mode, and they did not regard the macro level as a population of macroeconomic subsystems. We were the first to suggest a simple model of this type in 1980 [6]. We now consider this model.

Let $T_{\text{fixed cap}}$ be the average service life of capital assets; we assume that in the economy of a country, it is only three years ($T_{\text{fixed cap}} = 3$), and let T_{repr} be the average time of reproduction of fixed capital, equal to one year ($T_{\text{repr}} = 1$). We also assume that the distribution of the fixed capital in the economy over age is uniform. In this case, we can single out three specific macroeconomic subsystems of the economy,

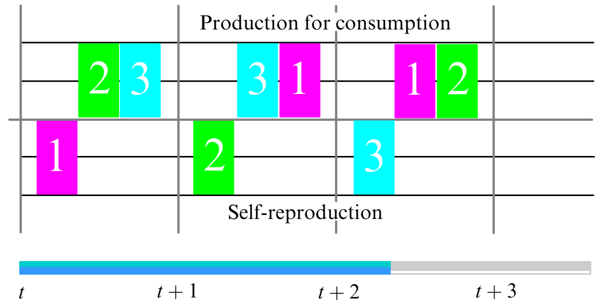

Figure 1. Subsystems 1, 2, 3 operating in the production–reproduction mode in years t, $t+1$, $t+2$.

each of which is capable of reproducing its fixed capital (Program A) and producing consumer goods (Program B) in the cycled production–reproduction mode. The execution of programs A and B by the subsystems of the macro level is accompanied by accumulation and expenditure of monetary funds, i.e., of 'depreciation' money. The subsystems differ from each other only in the age of fixed capital by the beginning of year t. The contractors of the subsystems are households (which supply the workforce to all three subsystems and are consumers of their products), and the bank plays an intermediary role. Finally, we note that all indicators of macroeconomic subsystems are measured in *current* prices, and hence the gross domestic product (GDP) produced by their combined effort is the *nominal* GDP.

The first subsystem is the oldest, and the age of its fixed capital at the beginning of year t is two years. By that time, it has accumulated the necessary depreciation savings and is to reproduce its fixed capital during year t (Program A). The age of the fixed capital of the second subsystem at the beginning of year t is 1 year; its tasks are to produce and sell consumer goods to households and accumulate savings (Program B). The third subsystem is the newest: its age is 0 years; it behaves during year t exactly as the second subsystem (Program B).

The following year, subsystems swap places in the process of operation: the first subsystem becomes the newest after the renewal of fixed capital, the third becomes a year older, and the second becomes the oldest and begins to renew its capital (Fig. 1).

The quarter-by-quarter sequence of events in year t unfolds as follows. At the beginning of the first quarter of year t, subsystems 1 and 2 have depreciation funds accumulated earlier and kept in the bank. One part of these funds is used up by subsystem 1 over the quarters of year t to pay wages to its employees who this year renew the fixed capital of subsystem 1. These workers take their earnings home. In this way, the money reach households (families) 1 that concentrate around subsystem 1. The other part of the depreciation funds 1 and 2 (kept in the bank) is used as credit serving to form the working capital of subsystems 2 and 3. It is assumed that by the beginning of year t, subsystems 1 and 2 have sold all their output produced by the end of year $t-1$ (warehouses are empty): the goods are bought up by households 1, 2, 3, which finance purchases with the money earned at the end of year $t-1$ (Fig. 2).

During the first quarter, the money from subsystems 1, 2, 3 flows to households 1, 2, 3 as wages, warehouses fill up with finished products, and households consume the products stored earlier. Having received their wages, households start buying consumer goods produced by subsystems 2 and 3,

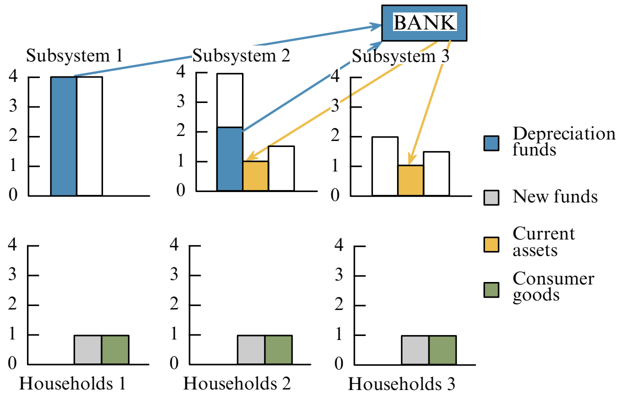

Figure 2. The status of the economic system at the beginning of the first quarter of year t.

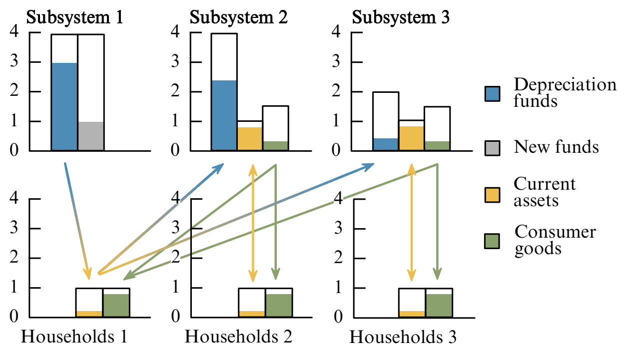

Figure 3. Functioning of the economic system in the first quarter of year t.

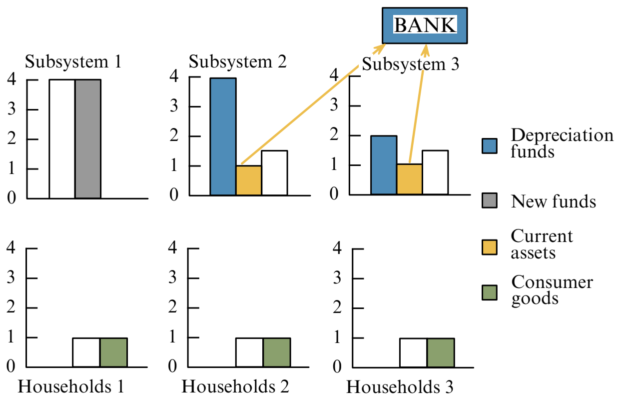

Figure 4. The status of the economic system at the end of year t.

company warehouses empty, and the money returns to the businesses of subsystems 2 and 3, which thus replenish their current assets and partly pour it into the depreciation fund (the corresponding flows of goods and money are shown in Fig. 3).

The circulation of goods and floating funds continues similarly in the second, third, and fourth quarters of year t. As a result, the first subsystem replenishes its fixed capital, and its depreciation funds are 'pumped out' to the depreciation funds of subsystems 2 and 3 (Fig. 4).

At the end of year t, subsystems 2 and 3 repay the bank for the loans received early in the year to support ongoing activities and the economic systems return to their original status (see Fig. 2), except that the subsystems have swapped places: the place of the first subsystem is now occupied by the second, that of the second by the third, and the place of the third by the first, with updated fixed capital (see Fig. 1).

With simple reproduction, cycles of this type follow one another indefinitely long and the population of macroeconomic subsystems persists in dynamic equilibrium. Incidentally, the presence of an intermediary bank makes the 'depreciation' fund sufficient for servicing all exchange operations in a given economy, while the depreciation fund itself completes the turnaround: this money transforms in its flow into 'consumer' money, with the consumer money again transforming into the depreciation fund.[1]

3. Transition to economic growth

We now assume that in year t, the macroeconomic subsystem 1 implemented the self-reproduction of fixed capital and introduced new technologies, thus creating a more efficient fixed capital. Then in year $t+1$ it can produce more consumer goods (at *current* prices) than the third subsystem, which also produces consumer goods in year $t+1$. Accordingly, the aggregate supply of consumer goods in year $t+1$ increases. Is this a sufficient condition for ensuring the resulting economic growth? Generally speaking, no: the additional product would not be bought if the amount of money at the disposal of households did not increase. Additional output leads to economic growth under the condition that the aggregate solvent demand increases simultaneously.

The aggregate solvent demand can only increase if the monetary supply and consumer preferences of households also increase. In turn, the availability of monetary supply depends on the monetary policy of the financial authorities. The following three scenarios of monetary policy are then possible.

First scenario. The amount of money issued supports an increment in aggregate demand from households equal to the increment in the aggregate supply of consumer goods: the result is noninflationary growth.

Second scenario. The amount of money issued generates demand that exceeds the growth in the aggregate supply of consumer goods: economic growth is accompanied by inflation.

Third scenario. Zero monetary emission: growth is impossible, and the crisis of overproduction of consumer goods sets in. Because the first subsystem succeeded in achieving higher productivity and became more competitive, it either economically strangles the third subsystem or absorbs its capital with time. The process of strangling inevitably leads to increasing unemployment and a decrease in the aggregate consumer demand, which is accompanied by economic recession and growing social tensions.[2]

To summarize, the innovations introduced in macroeconomic subsystem 1 in year t generated a *bifurcation state* in the

[1] By our estimate, by the end of 2007, the aggregate depreciation fund in the USA reached approximately \$17 trillion. This is nearly 2.5 times the USA M2 (the amount of cash in circulation, term deposits, checks, demand deposits), which in 2007 was \$7.4 trillion, and is considerably higher than the annual GDP of \$13.8 trillion.

[2] Historically, the third scenario has repeatedly manifested itself in the form of social explosions (e.g., the Luddite revolt at the beginning of the 19th century). Later, a practice was adopted of retraining redundant workers (e.g., for work in the services industry). It was the field of services which in the 20th century grew into the macroeconomic subsystem that absorbed the labor force released as a result of innovations.

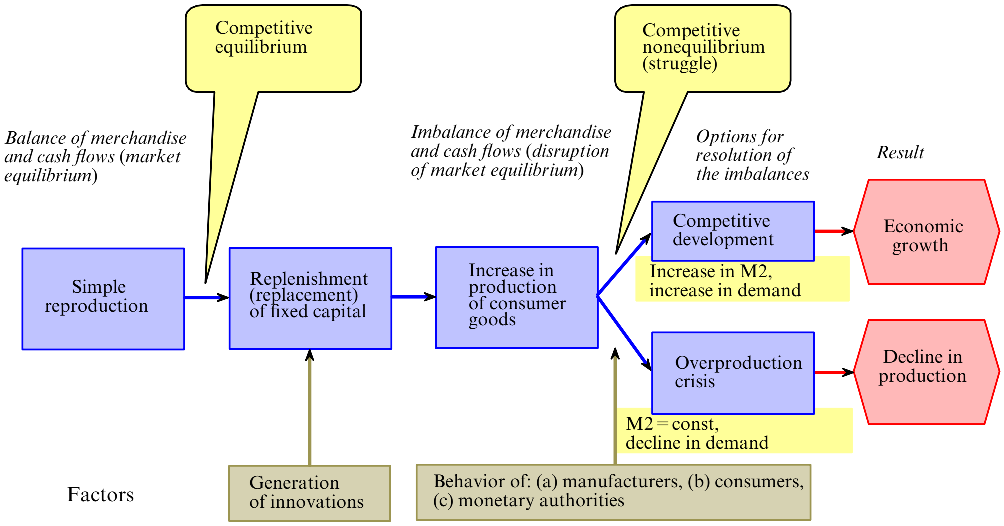

Figure 5. Diagram of the transition from simple reproduction to economic growth.

next year $(t+1)$; the output from the fork depends on the policies of the monetary authorities and on the evolution of consumer preferences. In this situation, the economy cannot be described as in the case of the simple reproduction model. The main difference is that the intermediary bank not engaged in issuing money needs to be replaced by a bank issuing new money or, to quote Schumpeter, a bank creating new purchasing power [7]. At the macro level, this function is fulfilled by the central bank, and the main method of delivering the new money emitted by the central bank and of placing it at the disposal of households is typically (at least in modern industrialized countries) the mechanism of raising public debt and, respectively, the budget deficit.

The general diagram illustrating the transition from simple reproduction to economic growth is shown in Fig. 5.

The transition from competitive equilibrium (in the case of simple reproduction) to intensified competitive wars (in the case of imbalance in the economic system), which may lead to economic growth but may also result in an economic crisis (see Fig. 5), can be illustrated by the growth model of two competing macroeconomic subsystems. We assume that the following logic diagram reflects the dynamics of the production of goods by each of these subsystems: *the change in production output equals the increase in the output under conditions of no resource constraints*[3] *minus a correction taking the resource constraints into account, minus a correction taking the effect of the competitor subsystem into account*.

Mathematically, this logic reduces to the basic model of competition that is widely used in studies of social systems [8, 9]:

$$\frac{\mathrm{d}x_1}{\mathrm{d}t} = a_1 x_1 - b_1 x_1^2 - c_1 x_1 x_2 \,, \tag{1}$$

$$\frac{\mathrm{d}x_2}{\mathrm{d}t} = a_2 x_2 - b_2 x_2^2 - c_2 x_1 x_2 \,, \tag{2}$$

where x_i is the total output of the ith subsystem $(i = 1, 2)$.

[3] Here, we interpret the 'resources' in a broad sense: they include raw materials, manpower, monetary resources, solvent demand of the production output, etc.

The first two terms in the right-hand sides of Eqns (1) and (2) characterize the process of autonomous development of the subsystems under resource constraints, but without taking competition into account. The third terms in the right-hand sides of (1) and (2) take competition into account. They enter with the minus sign, which indicates that the emergence of competitors obviously worsens the economic situation of the subsystem in question and may even threaten its existence. A threat to their existence pressurizes the competing subsystems into intensification of their activities (into increasing a_i, in terms of the model), and the higher the level of threat from the competitors is, the more active the efforts need to be to build up the subsystem capabilities. In view of this, we can write

$$\begin{aligned} \frac{\mathrm{d}x_1}{\mathrm{d}t} &= a_1(1 + h_1 x_2)x_1 - b_1 x_1^2 - c_1 x_1 x_2 \\ &= a_1 x_1 - b_1 x_1^2 + (h_1 a_1 - c_1) x_1 x_2 \,, \end{aligned} \tag{3}$$

$$\begin{aligned} \frac{\mathrm{d}x_2}{\mathrm{d}t} &= a_2(1 + h_2 x_1)x_2 - b_2 x_2^2 - c_2 x_1 x_2 \\ &= a_2 x_2 - b_2 x_2^2 + (h_2 a_2 - c_2) x_1 x_2 \,. \end{aligned} \tag{4}$$

We see that in contrast to Eqns (1) and (2), Eqns (3) and (4) can describe both economy in recession (if $h_1 a_1 - c_1 < 0$) and economic growth (if $h_i a_i - c_i > 0$). The quantity $h_i a_i - c_i$ is the bifurcation parameter that determines the characteristics of system dynamics. The quantity $h_i a_i - c_i$, in turn, is a function of the parameter h_i, whose value is affected by a number of factors: availability of credit, cheap raw materials, skilled labor, modern technologies, and market demand for manufactured products. The bifurcation parameter takes different values depending on specific combinations of the above factors, and these also determine the type of dynamics of the economic system (growth, decline, or stagnation).

We need to remember that the parameters a_i, b_i, c_i, and h_i of the set of equations (3), (4) are not constant but are in fact functions of time. First, their values are affected by external circumstances, e.g., changes in resource costs in the markets of labor, raw materials, and capital. Second, they depend on the institutional features of the economic system under consideration and on the previous history of the processes occurring in it. Third, the competing subsystems may influence, to a certain extent, the values of the current parameters (e.g., by enhancing the innovative activity or by increasing pressure on the competitor). The situation is therefore shifting, and each imbalance in the economic system can generate a variety of diverging outcomes.

It is important that dynamic models of competition such as (3), (4) allow taking this diversity into account and can be the basis for a mathematical description of nonequilibrium situations that arise as a result of the presence of cycled production–reproduction modes in the economy.

4. Conclusion

As a rule, *mainstream* mathematical models analyze either 'pointlike' states of market equilibrium or the resulting trends of sustained economic growth. These models *do not solve* the problem as we have formulated it, of simulating the transition from simple reproduction to growth. They are difficult to use as a tool for supporting decision making on economic policies. We believe that one cause of this state of affairs is that economic theorists still perceive the macro economy as a system exclusively implementing the reproduction of itself in the mode of *coproduction* and the production of consumer goods. Economic theorists do not consider the alternative approach to the macro economy as a population of macroeconomic subsystems performing the same functions but in the *cycled production–reproduction* mode.

In our opinion, it is precisely this approach that offers good prospects for creating fundamentally new economic models, describing:

— competitive interaction at the macro level;

— macroeconomic bifurcation states;

— states of dynamic inequilibrium of merchandise and cash flows in the implementation of innovations and subsequent changes in the behavior of producers, consumers, and monetary authorities.

The important feature of the proposed approach is that it does not focus on seeking a trend of sustained growth. On the contrary, it shows how the economy now enters the trajectory of economic growth, now falls into recession, now stagnates, now resumes growth again, all of it as a result of systematic transitions from one bifurcation state to another (Fig. 6).

With this interpretation of the macro economy, the center of gravity of research in economic theory shifts toward the analysis of the conflict of interest, which becomes acute every time radical innovations are introduced. As regards research in mathematical simulation, the following fields for advancing mathematical methods are pressing and important in this case:

— simulation of nonstationary and nonsynchronous modes of the functioning of economic systems;

— simulation of the interaction between merchandise and cash flow under nonstationary conditions;

— modeling the effects of positive feedback (effects of positive returns) on economic systems;

— simulation of bifurcation in economic systems, and determination of critical values of economic parameters that define the transition from one mode of operation to another.

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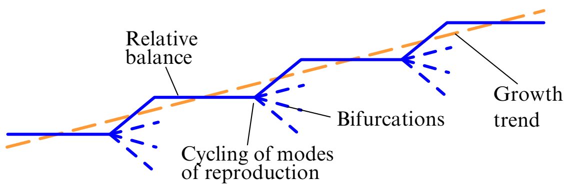

Figure 6. Sequence of bifurcations used to simulate economic growth.

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High-growth firms in Russia: experimental data and prospects for the econophysical simulation of economic modernization

A Yu Yudanov

1. Introduction

The concept of the 'high-growth firm' or 'gazelle' was introduced in the 1980s by David Birch. It was established that the majority of both large and small companies grow slowly and contribute minimally to increasing employment and the gross domestic product (GDP) [1, 2]. But a small proportion of firms combine high dynamic stability and growth. Birch gave them the name gazelles to emphasize the similarity of these companies to the animal that is capable not only of reaching high speed but of sustaining it for a long time. In 1988–1992, by Birch's estimate, gazelles making up only 4% of the total number of firms created approximately 70% (!) of all new jobs in the U.S.

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