Evolutionary Processes in Economics:
Multi-agent Model of Macrogenerations Dynamics

Kateryna KONONOVA[1], Maite LOPEZ-SANCHEZ[2]
[1]*V. N. Karazin Kharkiv National University (Ukraine), email: kateryna.kononova@gmail.com*
[2]*University of Barcelona (Spain), email: maite_lopez@ub.edu*

Abstract. A scientific paradigm of irreversible changes in the natural sciences has opened new prospects in economic researches. The modern school of evolutionism offers a wide variety of economic development models. However the evolutionary approach, rather successfully applied on the theory of company and innovation, has not received adequate development in the analysis of macroeconomic processes**.** So the objective of the study is to model macroeconomic growth as an evolutionary process.

Keywords. Economic growth, evolutionary theory, multi-agent based simulation.

Introduction

Evolutionary theory in economics sees economic development as an irreversible process of complexity, diversity and productivity increase due to recurrent changes of technologies and institutions. Since its initial definitions by Veblen [1] and Schumpeter [2], the modern school of evolutionism has offered a wide variety of economic models. From them, we may highlight Silverberg's school, which investigated not only Schumpeter's paradigm, but Kondratiev's theory [3].

At the macro level, scientists mostly deal with Kondratiev and Schumpeter's concepts [4]. Developing Kondratiev's ideas, Freeman [5] and then Glaziev [6] introduced the paradigm of techno-economic changes. Glaziev said that the new technological system appeared when the old one still dominated in economic structure. The redistribution of resources happened when the old technological system was beginning to exhaust its potential. However, Maevsky criticized Freeman and Glaziev's concepts for the complexity of practical application [4]. Thus, he introduced the concept of macrogenerations (MG) as subsystems that are born, live and eventually die like living creatures. Moreover, each MG produces a part of the gross national product (GNP) and the totality of simultaneously living macrogenerations produces the whole GNP [4].

Our study models the economic growth as an evolutionary process, where the term 'macrogeneration' describes a macroeconomic system that is based on a specific technology or combination of technologies and is involved in the production of national product. In this work, we have four different modeling assumptions [4]: i) The economy at the macro-level can be represented as a set of macrogenerations (MG); ii) Each MG is described by an embryonic phase and three phases of growth, saturation and decline; iii) A new MG is born when the current one reaches its limit; iv) The redistribution of resources between macrogenerations corresponds to the phases of their development.

Our research consists on, first, the MG identification based on the empirical data, and second, the simulation of the economic growth based on a multi-agent approach.

1. The MG Identification based on the US Data

We have used the Cobb–Douglas Production Function (CDPF) [7] to identify MGs: $Y = AK^{\alpha}L^{1-\alpha}$, where Y is the gross domestic product (GDP) [8], L is the labor input [9], K is the capital input [10], A is the productivity factor[1], α is the elasticity of capital[2]. A and α parameters have been estimated based on US statistics within the period of 1930-2011. As Figure 1 shows: 1) the dynamics of these CDPF parameters is cyclical; 2) α and A vary in antiphase; 3) in some intervals α becomes negative.

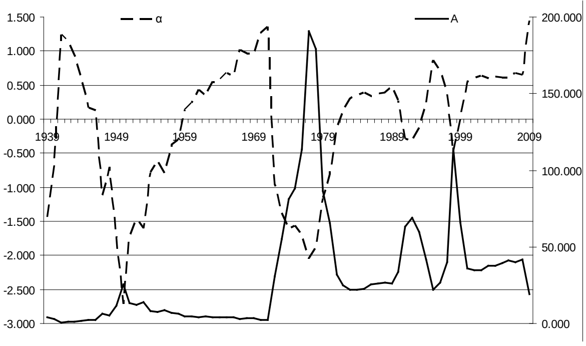

Figure 1. The α and A drift

To explain the results in terms of evolutionary theory, we have made the assumption that at those intervals where α becomes negative, there is a change of MG when the relationship between the capital and labor changes radically. It allows identifying five periods of MG appearance: the first MG should be born before 1930; the second one within the period from 1945 to 1950; the third one from 1970 to 1975, the fourth from 1985 to 1990; the fifth from 1995 to 2000. Then, to describe the macrogeneration life cycle we selected the log-normal function. The criterion was the minimization of squared deviations sum of model values from the real data:

$$z(\tau, M, \mu, \sigma) = \min\left\{ \sum_{t=1}^{80} \left(\sum_{i=1}^{5} \frac{M_i}{t-\tau_i} e^{\frac{-[\ln(t-\tau_i)-\mu_i]^2}{2\sigma_i^2}} - y_t^* \right)^2 \right\}$$

where τ sets the embryonic phase, μ and σ are the technological parameters; M is the potential of macrogeneration, y^* is US GDP for 80 years [8]. Analysis of the results (Fig. 2) shows that macrogenerations appear in the maximum of their predecessors' neighborhood and have all MG phases. The intervals between appearance and duration of macrogenerations are reduced. Drift analysis (Fig. 1) and the dynamics of macrogenerations (Fig. 2) show that: i) the MG growth phase corresponds to an increase of α; ii) saturation phase to an α local maximum; iii) the appearance of new MG to an α decrease; and 4) transition from one MG to the next to a local minimum of α [11].

2. Evolution of Macrogenerations: Multi-Agent Based Simulation

To solve the second task of our research we simulate US GDP dynamics within the period of 1930-2011[8] as a set of macrogenerations that appear as a result of autono-

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[1] Productivity factor can be taken as a measure of an economy's long-term technological change

[2] Elasticity measures the responsiveness of output to a change in levels of capital used in production

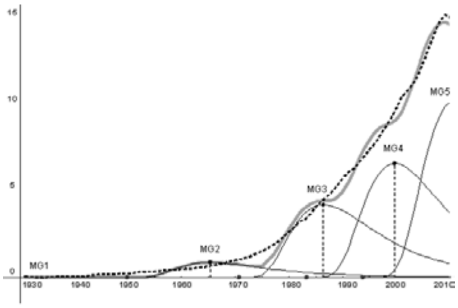

Figure 2. Approximation of GDP (billion $) by set of MGs: continuous thick line describes the model values; the dotted thick line is the real data, thin lines are the MGs, and the points mark their appearance)

mous agents' interaction. Previous analysis allows us to formulate the following assumptions of multi-agent model:

1. A world consists of a variable set of agents, which can be born and die depending on their efficiency (an agent dies if its capital $K < K_{min}$ and it produces an offspring if $K > K_{max}$, in this case, it gives it $K/4$). Agents follow previous Cobb–Douglas Production Function (CDPF) whose initial variables are uniformly distributed in a given range.

2. As we use the term 'macrogeneration' to describe the macroeconomic system that is based on a specific technology, the value of agents' productivity factor (A) could be used to specify the current macrogeneration, and the technological development could be represented as a result of the variation of A. According to Schumpeter [2] the innovation and technological change come from the entrepreneurs, large companies which have the resources and capital to invest in research and development. We have assumed that only 1% of agents are entrepreneurs and that their capital (K) shouldn't be less than half of a given K_{max}.

3. Agents just know their (8) neighbors' technologies. Moreover, each agent has a chance to buy the technology of one of them. The parameters of the agent's CDPF are changed according to the following assumptions:

a) The bigger neighbor's productivity factor the higher probability of purchasing. This corresponds to the assumption of evolutionary theory: 'if a random mutation increases the agent's fitness, it will spread with the higher probability' [12].

b) According to previous analysis, transition from one MG to the next corresponds to a local minimum of α, and its growth phase corresponds to an increase of α. Therefore with a new value of productivity factor (A) α falls to a minimum (a_0) and then increases (a_1) with each simulation step while the technology is not changed.

c) The cost of technology is proportional to the technological gap. The neighbor with higher A increases its K because the agent under consideration pays (i.e., reduces its K).

On the basis of these assumptions a multi-agent model has been built in NetLogo [13]. Analysis of the system evolution in Figure 3 shows that, with sufficiently good quality of approximation ($R^2 = 0.996$), a new macrogeneration is born when the current one reaches its maximum. Moreover, each MG is described by all the phases (see the trajectories of macrogenerations in Figure 3).

Conclusion

Our experimental results have confirmed the model assumptions about the appearance and dynamics of the MGs. We have shown that MGs appear in the maximum of

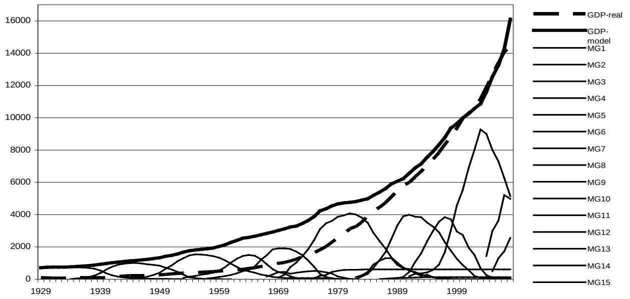

Figure 3. The dynamics of GDP (million $) as a set of macrogenerations – real and model data

their predecessors region and have the embryonic phase, and the phases of growth, saturation, and decline. The intervals between appearance and duration of macrogenerations are reduced. Additionally, the study of MGs phases confirmed the assumption that in those areas where the elasticity of capital became negative, macrogenerations were changed. In the growth phase MGs are filled with the capital.

The multi-agent model of MGs evolution which is developed in NetLogo shows the macro-effects that are not inherent to the individual agent behavior; the series of calculations have confirmed theoretical assumptions about the dynamics of the MGs. Finally, although the observed number of MGs is bigger than it was assumed, some of them are rather small, and some of them are very close to each other.

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