Schumpeterian modelling

Witold Kwasnicki
Institute of Economic Sciences
Wroclaw University, Poland
e-mail: kwasnicki@prawo.uni.wroc.pl
http:/www.prawo.uni.wroc.pl/~kwasnicki

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Schumpeterian models of economic growth and industrial dynamics can be called also an evolutionary ones. By using the term 'evolution' or 'evolutionary' neo-Schumpeterians indicate the importance of long-term changes and crucial role of innovation for economic development.

In spite of general agreement on evolutionary character of Schumpeter's theory there is discussion whether 'theory of economic development of Joseph Alois Schumpeter can be considered as evolutionary'? Two important voices in this debate are Geoffrey M. Hodgson (1997) and Matthias Kelm (1997). Ulrich Witt (2002) clearly states that question in the title of his paper: "*How evolutionary is Schumpeter's theory of economic development?*". Putting aside all that controversies it seems justifiable to separate two notions, namely meaning of Schumpeter's original ideas and that how Schumpeter's work is reread in modern times. It seems that revival of Schumpeter's ideas, as observed in last decades, is fully based on evolutionary interpretation of his original ideas. One of the founder of modern evolutionary economics, Richard Nelson (1995) says directly that "the evolutionary theories of economic growth ... all draw inspiration form Joseph Schumpeter".

What are the main features of evolutionary, schumpeterian models? First of all, the models are **dynamical** ones (it corresponds with frequently mentioned words of Sidney Winter "*Dynamics first*"). According to this school, the evolutionary process is a dynamical, spontaneous, historical process in which macroeconomic characteristics are the effects of activity of economic agents observed at the micro-level. Next, to be called 'schumpeterian', a model ought to be are focused on **far-from-equilibrium analysis**. The other features which seem to be crucial to call a model an evolutionary one are: **diversity and heterogeneity of economic agents and their behaviour**,[1] **search for innovation based on a concept of hereditary information (knowledge)**, and **selection process** which leads to diversified rate of growth. Schumpeter stressed the importance of entrepreneur in the economic process, therefore one of the important question in that context is 'how decisions are made?' **Decision making procedures** are present in almost all neo-Schumpeterian models.

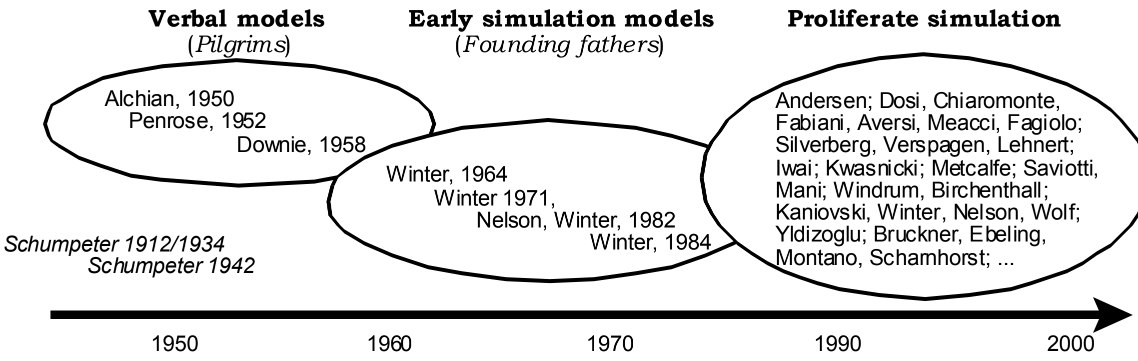

Fig. 1. Three stages of schumpeterian modelling

Development of 'schumpeterian modelling' has its own history. In that historical process we can distinguish three stages (Fig. 1). The early stage (*'Pilgrims',* mainly in 1950s) is dominated by verbal models, three of them seems to be representative, namely Alchian (1950), Penrose (1952) and Downie (1958). The second stage, 1960s and 1970s, can be called early simulation models ('*Founding fathers*'), and here the representative models are Winter (1964, 1971, 1984), and Nelson and Winter (1982). Nelson and Winter book of 1982 can be considered as culmination of this stage and can be treated as initiating the third stage, which can be called 'schumpeterian modelling proliferation'.

The rest of the paper is organised as follows. In section 2 Schumpeter's ideas are outlined. That section is followed by short description of the models of Alchian and Downi. In the fourth section brief report on current neo-schumpeterian models is presented. The paper ends with short description of a separate stream of modelling efforts in evolutionary economics, namely *Agent-based Computational Economics* (ACE). What we observe in the last decade is a convergence process of formerly separate streams of modelling, i.e. neo-schumpeterians and

[1] therefore it is frequently said that schumpeterian models are based on an idea of 'population concept', i.e., the modelled process is observed within a population of agents (e.g. firms).

ACE. Within a broad research efforts called sometime 'Artificial life' (*A-life*) Lane (1993a, 1993b) distinguishes 'artificial worlds in economics'. Some models rooted in schumpeterian tradition can also be classified as ACE models, two last examples are (Fagiolo, Dosi, 2002) and (Silverberg, Verspagen, 2002). To what extend this convergence process will be continued and will give interesting results is still open question but it seems to be interesting to point that possibility in this short paper.

Schumpeterian ideas on economic development

Schumpeter formulated and presented fully matured (although still far from any formal approach and without applying any mathematical models) proposition of principles and goals of economic analysis in evolutionary spirit. As it is frequently mentioned in this book, he did it in 1912 in his *Theory of Economic Development* and in later publications, e.g., (Schumpeter 1928, 1935, 1939, 1942, 1947). In the mariginalist theory, predominating in the beginning of the 20th century, the causes of development were searched in factors exogenous to economic process. One of the founders of the mariginalist school, J.B. Clark (*The Distribution of Wealth*, 1894) treated population growth, changes in consumers attitudes, changes of production methods as such exogenous factors. This view was challenged by Schumpeter who correctly pointed out that such factors ought to be searched in the economic process itself. In his opinion, capitalism can never be perceived as the process at equilibrium state and never can be treated as a stationary process. The essential element of his theory is the concept of recurring structural changes, what he called *gales of creative destruction*, followed by waves of expansion and rapid growth; "evolution is lopsided, discontinuous, disharmonious by nature ... evolution is a disturbance of existing structures and more like a series of explosion than a gentle, though incessant, transformation"(Schumpeter, 1939, vol. 1, s. 102). Persons responsible for those gales of creative destruction are, introducing radical innovations, pioneering entrepreneurs. Entrepreneurs search for new productive and trade combinations (innovations in the understanding of Schumpeter) to gain greater profit. The entrepreneurs profit flows from, what Schumpeter used to call, temporary monopoly position. Profit emerges in the situation of economic growth, in other words in dynamic economy. In opinion of Schumpeter profit is not always the primary motivation for entrepreneurs, frequently such motivation comes from entrepreneur will for artistic creation, outlet for his temperament, wish to show his possibilities, or just initiation of novel actions.

Schumpeter was so convinced of evolutionary character of capitalistic economy that in 1942 he wrote: "The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process. It may seem strange that anyone can fail to see so obvious a fact which morever was long ago emphasized by Karl Marks." (Schumpeter, 1942, p. 82). But it is necessary to mention that Schumpeter's understanding the adjective 'evolutionary' is slightly different than those of Darwinian or Lamarckian. Economic development, as all evolutionary processes, is historical one in which future development is determined by the past pathway of changes as well as by the current state of this process. "Every concrete process of development finally rests upon preceding development ... Every process of development creates the prerequisites for the following" (Schumpeter, 1934, p. 64). Innovations in economic process, as mutations in biological evolution, are essential element of development. In 1939 he wrote that economic evolution is equivalent to "changes in the economic process brought about by innovation, together with all their effects, and the responses to them by economic system" (Schumpeter, 1939, vol. 1 s. 86). In opinion of Schumpeter, those changes "illustrate the same process of industrial mutation – if I may use that biological term – that incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, creating a new one. This process of Creative Destruction is the essential fact about capitalism" (Schumpeter, 1942, p. 84).[2]

We can find elements of selection and search for innovations in those statements, i.e. the most essential mechanisms of evolutionary processes. But in his later works his understanding of evolutionary process is different than that in his early works. "The term evolution may be used in a wider and in a narrower sense. In the wider sense it comprises all the phenomena that make an economic process non-stationary. In the narrower sense it comprises these phenomena minus those that may be described in terms of continuous variations of rates within an unchanging framework of institutions, tastes, or technological horizons, and will be included in the concept of growth" (Schumpeter, 1954, s. 964). It means that for Schumpeter 'evolution' in wider sense is almost the same as 'change' and in the narrower sense is equivalent to economic growth.

Notion that economic changes comes 'from within', not exogenously for economic process, seems to be one of the most important contributions of Schumpeter's theory. This notion shaped future development of evolutionary approach to economic analysis.

[2] Few decades earlier Schumpeter (1912 (1934)) expressed it as follows: "By 'development' ... we shell understand only changes in economic life as are not forced upon it from without but arise by its own initiative, from within." (p. 63) „Development in our sense is a distinct phenomenon, entirely foreign to what may be observed in the circular flow or in the tendency toward equilibrium. It is spontaneous and discontinuous change in the channels of flow, disturbance of equilibrium, which forever alters and displaces the equilibrium state previously existing. " (p. 64)

Schumpeter's approach to economic analysis stresses qualitative changes as much more important. Although it is very difficult to encompass them in mathematical models or by any formal approach. Qualitative changes and generation of economic diversity are the central categories of long-term perspective of economic changes. Therefore for Schumpeter the most interesting are those changes "which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps. Add successively as many mail coaches as you please, you will never get a railway thereby" (Schumpeter, 1912 (1934) p. 64).

In 1947 he related innovation to historical and non-reversible changes, repeating the phrase of 1912 he wrote: "This historic and irreversible change in the way of doing things we call 'innovation' and we define: innovations are changes in production function which cannot be decomposed into infinitesimal steps. Add as many mail-coaches as you please, you will never get a railroad by so doing" (Schumpeter, 1947).

Schumpeter pointed out very essential feature of capitalistic economy, feature being in fact general for all evolutionary processes, namely that effective development strongly depends on diversity and that diversity is the basic source of innovation and can be named evolutionary engine. Diversity leads to diminishing current quality of systems performance, therefore from the short-term perspective is disadvantageous. But it is beneficial in the long-term perspective. As Schumpeter wrote (1942, p. 83): "A system ... that at *every* point in time fully utilizes its possibilities to its best advantage may yet in the long run be inferior to a system that does so at *no* given point in time, because the latter's failure to do so may be a condition for a level or speed of long-run performance."

Schumpeter is considered as one of the founder of evolutionary approach to economic analysis, and in such a way are re-read his works in the last decades. But Schumpeter commenting the possibility of using biological analogies to analysis economic phenomenon wrote that "no appeal to biology would be of the slightest use" (Schumpeter, 1954, p. 789). And this opinion seems to be stable in his thinking. To excuse Schumpeter we can suppose that this opinion was based on very specific, seemingly wrong, understanding of transmission of biological ideas to economic analysis, and from very personal Schumpeter's attitude to some streams of economic analysis at the beginning of the 20th century. At the beginning of the chapter on *The fundamental phenomenon of economic development* he wrote:

> Closely connected with the metaphysical preconception ... is every search for a "meaning" of history. The same is true of the postulate that a notion, a civilization, or even the whole of mankind, must such a matter-of-fact mind as Roscher assumed and as the innumerable philosophers and theorists of history in the long brilliant line from Vico to Lambrecht took and still take for granted.

Here, too, belong all kinds of evolutionary thought that centre in Darwin – at least if this means no more than reasoning by analogy – and also the psychological prejudice which consists in seeking more in motives and acts of violation than a reflex of the social process. But the evolutionary idea is now discredited in our field, especially with historians and ethologists, for still another reason. To the reproach of unscientific and extra-scientific mysticism that now surrounds the "evolutionary" ideas, is added that of dilettantism. With all the hasty generalisations in which the word "evolution" plays a part, many of us have lost patience. (Schumpeter, 1912 (1934), s. 57-8).

Pilgrims

Armen A. Alchian was the first who directly has based model of economic development on evolutionary ideas. Alchian searched for the way to replace neoclassical maximisation principle by biological concept of natural selection. Possibility of application of 'natural selection' idea to describe firm's behaviour was discussed by Alchian in 1950 and by Penrose two years later (Alchian, 1950; Penrose, 1952). As Alchian argued, competition is not described by the motive of profit maximisation but by "adaptive, imitative, and trial-and-error behaviour in search for profit" and therefore "those who realize *positive profit* are the survivors; those who suffer losses disappear". Alchian vision is clearly concordant with the Darwinian proposition (Alchian, 1950, s. 211-3). The work of Alchian was the first very important step toward building mathematical models of economic development on the basis of evolutionary metaphors. In one place he states that "[t]he economic counterparts of genetic heredity, mutations, and natural selection are imitation, innovation, and positive profits" (Alchian, 1950, s. 220). In very suggestive way he presents the way of analysing firms' behaviour in competitive environment.

A useful, but unreal, example in which individuals act without any foresight indicates the type of analysis available to the economist and also the ability of the system to "direct" resources despite individual ignorance. Assume that thousands of travelers set out from Chicago, selecting their roads completely at random and without foresight. Only our "economist" knows that on but one road are there gasoline stations. He can state categorically that travelers will *continue* to travel only on that road; those on other roads will soon run out gas. Even thought each one selected his route at random, we might have called those travelers who were so fortunate as have picked that road wise, efficient, foresighted, etc. Of course, we would consider them the lucky ones. (Alchian, 1950, p. 214)

Alchian has not considered one very important element of firms' behaviour, namely the searching processes of competing firms for technological innovation. In similar neoclassical fashion Alchian treated technological changes as coming from outside. It seems that the main aim of Alchian's article was not to show virtues of evolutionary approach but to point out some consequences of using maximisation principle treated as the primary motive of economic agent's actions.

Although there are no evidences that Jack Downie has been influenced by Alichan work, we can consider his model presented in *The Competitive Process* (1958) as an extension of Alchian one. Two papers of Nightingale (1997 and 1998) give good overview of Downie's model. In the first paper, Nightingale states that Downie's work was "anticipating Nelson and Winter".

In his population oriented model Downie considers an industry producing a homogeneous product. One of an evolutionary and schumpeterian feature of the model is heterogeneity of firms. Production technique selected by each individual firm influences a unique level of cost of that firm. A firm's unique character flows from the property that differences between techniques are cumulative in a sense that depends on past investments in production capacity and proprietary elements of knowledge accumulated within the firm (Downie, 1958,, 81-90). Individual firm's development is a stochastic process being a result of past mistakes and also random influences. Therefore we can say that specific process leading to uniqueness of each firm resembles evolutionary principle of variation. This production technique uniqueness of each firm is transmitted from year to year but in a course of firms development the technique can be modified. Growth is a main goal of each firm thus profit is re-invested in production capacity. The production capacity is equal to sales what is assured by price mechanism, namely price is set by each firm to keep sales at the production capacity level over time (Downie, 1958,, 63-67). Through so-called *Transfer Mechanism* firms experience different levels of efficiency. Each firm's profit depends on production costs, therefore firms having lower costs of production gain larger profit and are able to develop much quicker then their competitors. Therefore the share each firm changes accordingly to firm's specific sales growth. We can say that the average firm had the average growth rate and firms with above (below) average cost have above (below) average growth rate. Less efficient firms are withdraw from the market and concurrently more efficient firms dominate on the market. Due to this process, in a course of time, the industry average efficiency increases. Naturally this selection process leads to a monopoly of the most efficient firm. Te monopolisation occurs in a case of no innovation but, as Downie notes, a loss of a marked by a less efficient firm acts as the firm's stimulus. Firms still profitable, but whose growth rate is below that of the most efficient will attempt to improve their production techniques by some form of innovation. This process Dawnie calls the *Innovation Mechanism*. Search for innovation is a random process and not all firms succeed in finding better techniques but some of them make it and in that case we can say that some successful firms create new best practice levels of efficiency. Therefore we can say that we observe turbulence in shares of firms because it may happen that former losers gain advantageous techniques and re-gain its market position (Downie, 1958, 91-94). In Dwnie's theory firms do not maximise profit but are "able to take over the business of another and. . . conduct it reasonably effectively" (Downie, 1958, 30).

Founding fathers

Schumpeterian models, to encompass an essence of evolutionary approach, ought to be nonlinear ones. In general, this requirement has not allowed for their analytical treatment. Thanks to development of computer technology in 1950s and 1960s and concurrent development of simualtion approach, it was possible to build and to analyse behaviour of evolutionary models.

The computer simulation may be considered as an alternative way of economic analysis. Discontinuities of development are natural phenomena observed in socio-economic processes, and in a sense, these discontinuities form the essence of socio-economic systems. The search for alternative approaches of economic analysis goes in different directions, for example, applications of chaos theory, fuzzy sets theory, catastrophe theory and game theory, to name only a few. Proper application of the simulation approach to economic analysis seems to be one of the most promising for further development and better understanding of socio-economic processes.

Out of three distinct evolutionary schools, namely Austrian, institutionalists and neo-schumpeterians, only neo-schumpeterians widely apply formal modelling and use the simulation approach to economic analysis. Institutionalists and the Austrians prefer verbal and graphical representations of economic phenomena. Therefore it is not surprise that some institutionalist call neo-Schumpeterians 'simulationists'.

The first simulation model within neo-schumpeterian tradition was that of Sidney Winter made in the begining of 1960s. Sidney Winter and Richard Neslon worked out in 1970s and 1980s different models and summarised their efforts in the well known book, sometime called 'bible of evolutionary economists' (Nelson, Winter, 1982). Nelson and Winter models suit frequently as a basis or a kind of pattern for inventing another evolutionary models. In the NW models and in almost all models of Schumpeterian tradition a firm is a basic unit of evolution. Nelson and Winter apply a population perspective and they postulate that it is possible to specify the space in which innovative search takes place.

The assumption of macroeconomic properties flowing from microeconomic behaviour of economic agents (i.e. firms) is basic reason for necessity of using simulation to investigate these models. The first model that will be shortly discussed is the one presented in Nelson and Winter (1982, ch. 9). This model can be seen also as the first evolutionary growth model.

The state of the evolutionary process of an industry at any moment *t* is described by the capital stock and the behavioural rules of each firm. The state in the next moment (*t*+1) is determined by the state in previous moment. In this growth model firms use production techniques which are characterised by fixed labour and capital coefficients. Firms manufacture homogeneous products, so the model describes only process innovation. It is assumed that firms produce using a Leontief production function, therefore substitution between labour and capital is not explicitly present in the model. Invention occurs as a result of firms' search activities. Firms search for new combinations of labour and capital coefficient. Changes of these both coefficients are not correlated, therefore a phenomenon that resembles substitution between labour and capital may be observed in the simulated process. Search activities are determined by satisfying behaviour, in a sense that a new technique is adopted only if the expected rate of return is higher than the firm's present rate of return. The search process may take two different forms: local search (mutation) or imitation. In the first case, firms search for new techniques, yet not present in the industrial practice. The term *local* search indicates that each undiscovered technique has a probability of being discovered which linearly declines with a suitably defined technological distance from the current technology. Imitation allows particular firm to find techniques currently employed by other firms but not yet used in its own production process. The probability of given technique imitation is proportional to its share in output. It is assumed that if a firm is engaged in search it can use only one type of the search. Selection of actually used type of search is a random event with a fixed probability for each type. An additional source of novelty in the economy is entry by new firms, which also search for innovation.

The rate of return on techniques is the main selection force in the NW model. A firm's investment in capital is equal to its profit diminished by a fixed fraction, which depends on paid dividends and capital depreciation. A firm's capital stock shrinks if profit of that firm is negative. Therefore we have second selection force which imposes withdrawing firms from the market if they do not pace of technological progress of its competitors.

To calibrate the above sketched model for the case of the Solow data on total factor productivity for the United States in the first half of the twentieth century it was assumed that firms produce homogenous product named GNP. Using that model, Nelson and Winter address the question whether these time series of the calibrated model correspond in a broad qualitative sense to the ones actually observed by Solow.

The most developed and documented NW model which deals with the evolution of the production techniques and other behavioural rules of an industry producing a homogeneous product is frequently named as "Schumpeterian competition" (Nelson, Winter, 1982, ch. 12; Winter, 1984). As in the formerly sketched model, a number of firms produce single homogenous product. Techniques used by different firms differ in output per unit of capital, i.e. in capital productivity A. All other technique factors, as e.g. return to scale and input coefficient are assumed to be equal for all firms. Technical change (i.e., increase of the productivity of capital) takes the form of process innovations and process imitations. Each firm chooses a technique with the highest productivity out of the three possible techniques (i.e. currently used and found through innovative and imitative processes). Probability that firms innovate or imitate depends on R&D funds determined in proportion to the level of physical capital. Profit per unit of capital is calculated by including R&D costs as ordinary cost elements. The maximum investment of a firm depends on current profit plus loans from the banks (calculated in proportion to the profit). The firm's desired investment is determined by the unit costs, a mark-up factor influenced by the market share of the firm, and the rate of depreciation. The investment process has no time-lags. By multiplying the capital stock with the new level of productivity, we have the production capacity of the firms of the industry in next period. Products price is not firm specific but is equal to all firms and flows from the downward-sloping demand function to balance supply and demand. Investment decision of each firm is based on investment function, which depends on the firm's market share, price elasticity of the demand function, firm's unit profit and bank policy.

A firm grows (or shrinks, in terms of its market share and long-run performance index) accordingly to its profit (or loss) gained in each year (instant of time). A firm is withdrawn from the market if its capital falls below assumed minimal capital or if its long-run performance index falls below the assumed value. Firms can imitate and innovate. Improving productivity of capital is the main aim of innovative process.

Winter (1984) presents an interesting elaboration of search activity and entry. Firms are partitioned into two types: primarily innovative or imitative. It allows Winter to apply a notion of technological *regime* depending on whether the source of technical progress is external to the firm (e.g., from public scientific knowledge bases) or from firms' own accumulated technological capabilities. These two regimes are named as the *entrepreneurial* and the *routinized*. Specific parameters exogenously impose the type of investigated regime.

Proliferated simulation

Since publication of a seminal work by Richard Nelson and Sidney Winter in 1982 evolutionary models proliferated enormously. In this short paper we are not able to make review of neoschumpeterian models (reviews and surveys of evolutionary models can be found in Dosi *et al.* (1988), Saviotti, Metcalfe (1991), Nelson (1995), Silverberg, Verspagen (1995, revised version 2003)), also Kwasnicki (2001). Here will present only short remarks on general way of development as observed in last two decades.

The models are rather new ones, most of them were developed in 1990s. Looking into the history of Schumpterian tradition it seems possible to distinguish a few related but in some way independent streams of modelling efforts. The first is very closely associated with the work of Nelson and Winter (1982). To that tradition works of Winter (1984), Jonard, Yildizoglu (1998, 1999), Winter, Kaniovski, Dosi (2000), and Yildizoglu (2002) can be included. The other streams get inspirations from the work of Nelson and Winter but has essential distinguishing features.

The second stream of models can be called '*Silverberg-Verspagen models'*. One distinguished feature of SV models is that technological progress is embedded in vintage capital. In the model presented in Silverberg (1985) and Silverberg *et al.* (1988) firms are self-financing using their cash and liquid interest bearing reserves. Idea that firms rely on rather simple rules of thumb or routines rather than explicit optimisation procedures is applied in models developed by Silverberg, Lehnert and Verspagen (Silverberg and Lehnert, 1993, 1996; Silverberg, Verspagen, 1994, 1994a, 1994b, 1995a). These models can be seen as continuation of the work initiated by Gerald Silverberg in 1980s (Silverberg, 1985, Siverberg et al., 1988). The main difference between the Silverberg and Verspagen (1995) model and the ones presented in Silverberg (1985) and Silverberg and Lehnert (1993) is the way in which innovation is endogenized.

The third stream of models can be called '*Dosi et al. models'*, e.g., Chiaromonte and Dosi (1993), Dosi *et al.* (1993, 1994, 1995). Dosi *et al*. approach is highly bottom-up simulation. The aim of the authors seems to be to start from basic mechanisms of industrial development without making any assumption about possible modelled properties of the system and to obtain the well-known features (*stylised facts*) from the co-working of these basic mechanisms of development. Similar assumption was made by Kwasnicki in his model of industrial dynamics (Kwasnicka, Kwasnicki, 1992, 1996, Kwasnicki, 1994/1996, 2000).

There are also numerous models that can be identified as having 'Schumpeterian flavour'. The model presented by Andersen (1997) is based on Pasinetti's scheme of the structural economic dynamics of a labour economy with inclusion of an evolutionary, micro-economic foundation. A proposition of Bruckner, Ebeling and Scharnhorst (1989), Bruckner, Ebeling, Jimenez Montano and Scharnhorst (1994) apply general n-dimensional birth-death transition model to describe technological development. Because of a natural limitation on the length of a paper, we will only point out a large number of other existing model, e.g., Metcalfe (1993, 1994), Windrum and Birchenhall, (1998) Englmann (1994), Iwai (1984, 1984a), Nelson and Wolff (1997), Saviotti and Mani (1993).

Agent-based computational economics

Artificial life (a-life) is the name of flourishing, multidisciplinary field of research that attempts to develop mathematical models and use computer simulations to demonstrate ways in which living organisms grow and evolve. It is hoped that through this way deeper insights into the nature of organic life will be gained together with better understanding of origin metabolic processes and in a wider sense of the origin of life. Christopher Langton who organized the first a-life workshop at Santa Fe in 1987 coined the term 'artificial life' in the 1980s. In fact two men have made very similar theoretical research under the name of self-replicating (or cellular) automata. John von Neumann, the Hungarian-born mathematician and a pioneer of computer science, and the Polish mathematician Stanislaw Ulam in the early 1950s had begun to explore the nature of very basic theoretical forms called self-replicating, cellular automata. Their intention was to apply this basic concept to the growth, development, and reproduction of living creatures. These theoretical, mathematical 'cells' can be used to simulate biological and physical processes by repetitively subjecting each cell to a simple set of rules, e.g., every cell has a colour that changes according to its update rules and the colours of its neighbouring cells. Von Neumann and Ulam proved that, using a rather complex set of rules, it is possible to draw an initial configuration of cells in such a way that the configuration would 'reproduce' itself. These cellular automata consist of a lattice of cells. Each cell is characterized by specific values which can change according to fixed rules. A cell's new value is calculated on the basis of its current value and the values of its immediate neighbours. It is shown that such cellular automata naturally form patterns, reproduce and 'die'.

Langton used the work of von Neumann as a starting point to design a simple a-life system that could be simulated on a computer. In 1979 he developed an 'organism' that displayed many lifelike properties. The loop-shaped ‘creature’ reproduced itself in such a way that as new generations spread outward from the initial organism they left “dead” generations inside the expanding area. In the opinion of Langton the behaviour of these forms mimicked the real-life processes of mutation and evolution.

There are numerous examples of agent based-modelling. Biologist Tom Ray created ‘agent’ programs in his laptop. The aim of each agent was to make a copy of itself in memory. Ray assumed a finite lifetime of each program. He left the programs running all night and in the morning he noticed that his agents were engaging in the digital equivalents of competition, fraud and sex. When the program-agents copied themselves random changes of their code occurred. So it can be said that they mutated and evolved. Naturally most mutations were destructive and ‘died’, but some changes let an agent do its job better in a sense that they consisted of fewer instructions and were able to copy themselves quicker, more reliably and run faster. The shorter versions replicated quicker and very soon outnumbered their larger ‘competitors’.

The a-life approach is sometime called ‘agent-based modelling’ to pinpoint its mathematical difference from the to differential equations approach. We can write down the differential equations for interacting population of individuals (e.g. Lotka Volterra equation of prey-predator system) but we can also follow individual histories of each animal (element, agent, firm) and summarise their histories into more aggregate characteristics. Contemporary a-life researchers try to identify the distinctive behaviours of living creatures and then use them to devise software simulations that ‘move, eat, mate, fight and cooperate’ without incorporating those features explicitly into the modes of behaviour of these elements. The recipe to prepare a-life software (or ‘silicon’ species, as it is sometime called) is rather simple: prepare an environment in which the synthetic organisms can act, create a few hundred individuals to populate it and define a set of rules for them to follow. Try to simplify the problem as much as possible while keeping what is essential. Write a program which simulates the simple rules with interactions and randomizing elements. Run the program many times with different random number seeds to attempt to understand how the simple rules give rise to the observed behaviour. Locate the sources of behaviour and the effects of different parameters. Simplify the simulation even further if possible, or add additional elements that were found to be necessary. We can summarize this approach in following ‘equation’: *Agents (microlevel entities) + Environment+ Dynamics = A-Life*.

In this approach, life is treated as a kind of game in which each agent struggles for existence with the mixture of chance and necessity by applying a set of basic behavioural rules. A small number of rules can generate amazingly complex patterns of behaviour, such as groups of independent agents organizing themselves into a semi-isolated groups of agents. This feature makes the a-life approach a potentially powerful research tool.

Current efforts of a-life researchers are focussed on searching for so-called emergent hierarchical organisation (EHO). The aim of this kind of modelling is to discover whether, and under what conditions, recorded computer-simulated histories exhibit interesting *emergent properties*. The term 'emergent properties' means that they arise spontaneously from the dynamics of the system, rather than being imposed by some external authority. Observed order, like specific evolution of an industry with its initial, mature and declining phases, emerges from the aggregate of large number of individuals acting alone and independently.

A similar approach has been applied in economic analysis, called either *artificial economics* or *agent-based economics*. The intention is very similar to that of a-life: allow for economic interactions between artificial agents initially having no knowledge of their environment but with abilities to learn, and next observe what sorts of markets, institutions and technologies develop, and how the agents co-ordinate their actions and organise themselves into an economy. Some models rooted in neo-schumpeterian tradition are very close to ACE approach.

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