“Leaping across the mountains, bounding over the hills” punctualism and gradualism in economic development

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Discussion on the gradual vs. punctuated modes of development are present for decades not only in biology but also in economics. It seems that there are evidences that both kind of development can be identified in the sphere of socio-economic processes. We will use simulation approach to support our suggestions. Economic evolution is not gradual but ought to be seen as combination of gradual development (in the phase of climbing the local peak in the adaptive landscape) and punctuated (in short periods after emergences of radical innovation, i.e. ‘jumps’ from a lower local peak to a higher peak in the adaptive landscape).

In the first section of the paper short comments on possibilities of validation of simulation models in economics are presented. In the second part a description of evolutionary model of industry development is presented. This part is followed by simulation study focussed on investigation of diversity of modes of industrial development.

What is a mode of development of evolutionary processes? In a 1972 Stephen Jay Gould and Niles Eldredge published a paper on *Punctuated equilibria: an alternative to phyletic gradualism* and since that time biologists are engaged in vigorous discussion on two conflicting views of modes of natural evolution, namely gradualism and punctualism. Similar discussion can be notified in economics on modes of economic development in the presence of innovation. It seems that there are evidences that both kind of development can be identified in the sphere of socio-economic processes. We will use simulation approach to support our suggestions that:
(1) average characteristics of development can be considered as continuously changing (so it can support gradualism) but frontier of development is far from being continuous, and from that point of view evolution ought to be considered as punctuated;
(2) using metaphor of adaptive landscape we can show that biological population is able to evolve (drift) from the local adaptive landscape down the valley and from there gradually evolve up a higher hill (i.e., the evolution can be considered as gradual). But drift is very improbable in the socio-economic evolution mainly because of specificity of socio-economic processes (especially the possibility of pre-evaluation of inventions and using in practice only those which allow for potential progress). Therefore economic evolution is not gradual but ought to be seen as combination of gradual development (in the phase of climbing the local peak in the adaptive landscape) and punctuated (in short periods of ‘jumps’ from a lower local peak to a higher peak in the adaptive landscape).

The main subject of the conference is ‘applied evolutionary economics’. Therefore, in the first section of the paper some short comments on possibilities of validation of simulation models in economics are presented. In the second part of the paper a description of evolutionary model of industry development is presented. This part is followed by simulation study focussed on investigation of diversity of modes of industrial development. The paper ends by short summary of obtained results and conclusions.

Biological analogies have played an essential role in the process of creation of the model of industrial development which simulation results are presented in this paper. The model describes the behaviour of a number of competing firms producing functionally equivalent products. The decisions of a firm relating to investment, price, profit, etc. are based on the firm's evaluation of behaviour of other competing firms and the expected response of the market. The firm's knowledge of the market and knowledge of the future behaviour of competitors is limited and uncertain. The decisions are taken simultaneously and independently by all firms at the beginning of each period (e.g. once a year or a quarter). After the decisions are made the firms undertake production and put the products on the market. The products are evaluated by the market, and the quantities of different firms' products sold in the market depend on the relative prices, the relative value of products' characteristics and the level of saturation of the market. Frequently the products evaluated as the best are not sold in the full quantity offered, and conversely, the inferior products are frequently sold in spite of the possibility of buying the better ones. But during long periods the preference for better products, i.e., those with a lower price and better characteristics, prevails.

1. The specificity of the simulation approach

A simulation study requires well-designed methods of model development, validation and verification. A model of a real phenomenon is always a simplified, idealized and approximate representation of the process. Any theoretical system is a kind of abstraction describing in very specific way relations between some selected abstract entities. This kind of system can be treated as a model representing selected aspects of reality only when there exists homeomorphisms between real objects and abstract objects.

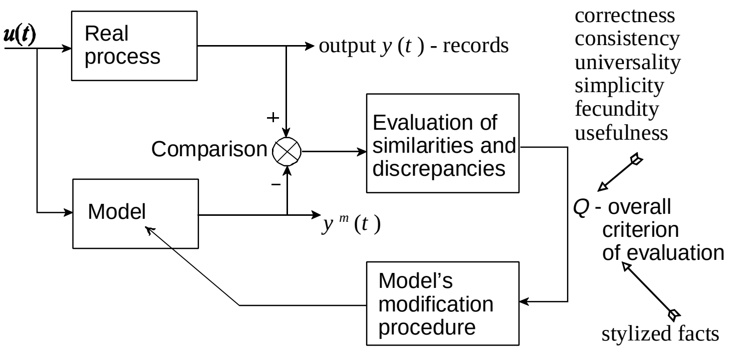


Figure 1. Model and reality

The model representation depends on the aims of our inquiry and on all constraints related to the process. Exactness and validity of a model of a technical (engineering) system is reached mainly through so-called identification. Having collected records of real process behaviour for given input $u(t)$ and output $y^m(t)$ the modeller tries to adjust the models behaviour to reality either by selecting the proper (optimal) values of the model's parameters or by changing the model's structure. In a schematic form the process of model adjustment is represented in Figure 1. This kind of adjustment is sometimes called 'behaviour replication test', whose main aim is to compare the model behaviour with the behaviour of the system being modelled. Where historical time series (or the results of a real system's development in the factory or laboratory) are available, the model must be capable of producing similar data. That is, for the same initial conditions and inputs, the model's behaviour should parallel the historical data. An important question is how closely the model's behaviour should match the historical data, since historical data are less than perfect and, sometimes, far from perfect. If historical data are very poor or nonexistent, the test may be one of reasonableness and we ought to use another validation tests. In most cases a specific criterion of the model's exactness is employed, such as mean- square error. For an assumed criterion the model adjusting process can be done analytically or through simulation, applying one of the well-known optimization algorithms. This ‘technical’ approach through model parameter identification is not fully applicable to socio-economic models. First of all, in most socio-economic phenomena we are not able to select a class of suitable models (linear models are frequently not applicable). Evaluation of socio-economic models thus must proceed in a different way than engineering ones. In contrast, this ‘engineering’ vision of socio-economic processes prevails in orthodox economics. For orthodox economists make assumptions, similar to those made in classical physics and engineering, on the possibility of: (1) isolating a specific sphere of socio-economic reality, (2) specifying all relations of phenomena within the sphere with the external environment, and (3) building a model which describes all important phenomena observed within the chosen sphere, with all essential influences of the external environment included. On the basis of such a model some optimal control, or optimal path of development, is calculated. Such a mechanistic approach to socio-economic processes turned out to be wrong and misleading. A lot of decisions made by policymakers on the basis of such models caused strong social and economic tensions, especially visible in the 1970s, that is, during the period of radical structural changes of the economies of industrialized countries.

In socio-economic processes, the clear isolation of well-defined spheres of reality, the specification of important relations with the external environment, the building of relevant mathematical models and optimizing the choice of suitable policies are almost impossible. Questions concerning optimal decisions in a long-term perspective and in periods of structural change lose their significance. Far more important become the questions about the mechanisms of long-term development and on the possibilities of controlling the economic process to reach a satisfaction (not optimal) course of development.

Contrary to engineering systems, there is no possibility of making repeated experiments with socio-economic systems. It is much easier to disaggregate whole engineering systems into a number of smaller subsystems which can be analysed separately. Socio-economic systems are highly interrelated, and disaggregation into semi-isolated subsystems is frequently impossible. In engineering systems optimization (related to searching for better – or the best – performance of given system, optimal control of engineering processes or limited resources) is the primary aim of modelling (and simulation) efforts. It seems that in the social sciences and in economics the main aims of models’ building are: better understanding of mechanisms of development of observed phenomena (processes), building different, alternative scenarios of development of given socio-economic systems, and education of the decision-maker through ‘imprinting’ proper intuitions. This last aim is achieved through interactive applications of simulation models to test decisions made by managers and analysing the reaction of the model.

The different nature of engineering and socio-economic systems also causes differences in the possibility of testing and validating of developed models. As was mentioned, in engineering systems it is possible to compare numerical data (records of development of real systems) with numerical output of a model. In socio-economic system collection of reliable set of proper data (records) is frequently impossible. Therefore, validation of socio-economic models is frequently done on the bases of so-called stylized facts. As Nicholas Kaldor (1961) wrote:

> Any theory must necessary be based on abstraction; but the type of abstraction chosen cannot be decided in a vacuum: it must be appropriate to characteristic features of economic process as recorded by experience. Hence the theorist, in choosing a particular theoretical approach, ought to start off with a summary of facts which he regards as relevant to his problem. Since facts, as recorded by statisticians, are always subject to numerous snags and qualifications, and for that reason are incapable of being accurately summarized, the theorist, in my view, should be free to start off with a ‘stylized’ view of facts - i.e. concentrate on broad tendencies, ignoring individual details, and proceed on the ‘as if’ method, i.e. construct a hypothesis that could account for these ‘stylized facts’ without necessarily committing himself to the historical accuracy, or sufficiency, of the facts or tendencies thus summarized.

Facing the problem of choosing between alternative models we do not evaluate any single assumption, law, or conclusion which are parts of each model. In fact we try to build sub-criteria (such as *correctness, consistency, universality, simplicity, fecundity, usefulness)* and try to evaluate each alternative model applying these sub-criteria. In the next step of our evaluation process, subjective weights are attached to each sub-criterion and on the basis of the general index thus constructed the whole model is evaluated. This general index helps us to find a final answer to the general question: which model do we prefer?

It is good to have one, general indicator (hopefully as a scalar) allowing for evaluation of exactness of the model and its validity. In engineering system a mean-square criterion is used, and sometimes it is possible to construct such a criterion for socio-economic systems. But in most cases only a highly subjective overall criterion is used based on selected stylized facts and at least some the six sub-criterions mentioned above. This specificity of socio-economic system is indicated in Figure 1 by mentioning stylized facts and subjective sub-criteria.

Even when we are able to collect relevant data it is often very difficult to identify trends simply because stochastic factors dominate. The question arises how to evaluate similarities if both variables are realizations of essentially the same stochastic process. A fundamental question is how to evaluate and how to decide when a model leads to satisfactory results and is acceptable for further research? It is much easier to evaluate a model if the stochastic process is stationary and ergodic. There are well-know stochastic tests to evaluate the level of similarities between different realizations of the same process, as, e.g. variance analysis and confidence intervals. Unfortunately most real processes (especially those of a socio-economic sphere) are nonstationary ones and it is very difficult to work out effective tests of their evaluation.

There are no general rules for proper selection of appropriate level of detail, demarcation of boundaries between a model and its environment, and similar considerations. It is still the “art” aspect of simulation model development. The usefulness of any analytical model or simulation model ultimately lies in the subjective view of the model builder and its user.

The basic test of a model’s validity is that all important factors in the real system exerting an influence on the behaviour of the system must appear in the model. Further, all factors in the model must have a counterpart in the real system (homeomorphism). The development of the simulation approach in the last decades indicates an important shift from traditional statistical tests toward more qualitative and subjective tests belonging to two main classes: model structure tests and model behaviour tests. Among the first class the most popular and important are the model parameter tests and the extreme conditions test. To the second class belong behavioural replication, anomalous behaviour, sensitivity, prediction, family member and boundary tests. Behavioural replication, anomalous behaviour and boundary tests have been mentioned earlier in this chapter.

Model parameter tests can be considered as a basic test. All the time we ought to be sure that the assumed values of all model’s parameters are plausible one, reasonable and consistent with whatever supporting data might exist. It is possible that some elements that are not usually quantified ought to be estimated because of critical importance to the system being modelled (as, e.g. related to creative processes with respect to such important feature of economic models as innovations or technological change).

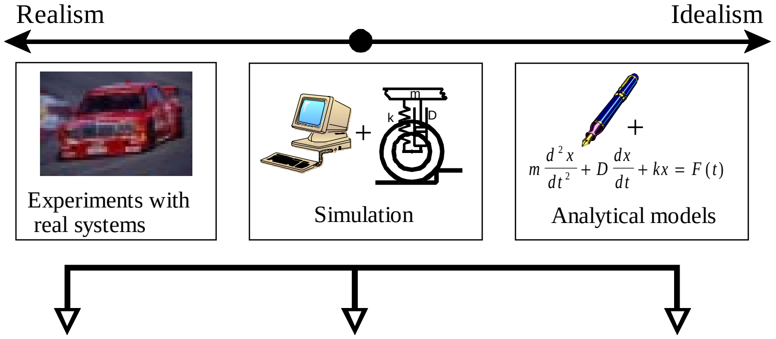
Extreme condition tests show the ability of a model to function properly under extreme conditions. Positive results of these tests support significantly increase confidence in model. It was Francis Bacon who emphasized the importance of active experiment with the main objective of compelling Nature to manifest its properties in conditions never, or rarely, observed in natural processes. It is worth mentioning this kind of test because testing extreme conditions may easily be overlooked, especially in the early stages of model development. Neglecting this testing may degrade model performance under both normal conditions and when the model is used to answer questions falling outside the operating regions emphasized in early development.

While making simulations and testing the model (e.g., extreme condition or behavioural replication tests) we ought to look for anomalous behaviour of the model. Tests of anomalous behaviour may contribute convincingly to establishing model validity.

Small, reasonable changes in a model's parameter values should not normally produce radical behavioural changes. Most social systems, but certainly not all, are stable. Positive results of behaviour sensitivity test increase confidence in the model but, on the other hand, simulation models are often used to search for parameters values that can effect behavioural changes. Therefore, we ought to be very cautious in using that test for models' validation purposes.

Confidence in the model is also reinforced if the model not only replicates long-term historical behaviour but also allows for prediction of system development. A special instance of prediction is retroprognosis – real data from periods of the far past are used to identify the model's parameters and then simulation results for the years following the identification period are compared to the subsequent development.

Three techniques of models building and development are presented in Figure 2. Left side of this spectrum is represented by research made on real (physical) objects (e.g. testing new design of a car driving on different kinds of surfaces). The other side of the whole spectrum are mathematical (analytical) models, e.g., working out a set of differential equations to describe a car suspension system and solving it analytically. The third alternative, namely simulation, is placed somewhere between these two extremes. In deriving simulation model, the system (e.g., a suspension system) is partitioned into elementary subsystems (springs, shock absorbers, torsion bars, stabilizers, etc., in economics it can be firms, consumers, banks, markets, etc.). The next step is to build sub-models for those subsystems and to connect them to form a model for the whole system. To be closer to reality the sub-models are usually nonlinear ones and therefore the simulation models are normally unsolvable analytically. It is very difficult to made experiments on real objects in socio-economic sciences, although some preliminary steps toward that direction are made through so-called experimental economics, where in laboratory conditions situations very close to reality are created. Most investigations in economics are covered by the two other techniques. For socio-economic systems it is very difficult (if ever possible) to make repeated experiments as it is in the case of 'technical' systems. It is also very difficult to build analytical



Advantages

- realism - final verification	- imitative realism - study of nonexisting systems - time passing control - criterion elasticity - controllability and repeatability of experiments - limited mathematical skills - relative low costs - use of expert knowledge	- generality of results - optimal solutions

Disadvantages

- system has to exit - improper time scale - constrained values of control parameters - limited number of possible experiments	- lack of generality of results - large number of experiments required - optimization problems - long duration of simulation studies - simulation misusing	- far reaching simplifications - sophisticated mathematics

Figure 2. Three techniques of real processes study

models (e.g. in a form of differential equations), but even if it is possible, in most cases it is impossible to solve that equations and to get analytical solutions describing behaviour of the model. Very frequently, to obtain results and to get knowledge about dynamics of system behaviour it is necessary to build computer simulation model which reflect as far as possible a structure of real system and its mechanisms of development. There is no space to discuss details of advantages and disadvantages of experimental, analytical and simulation techniques. The sketch of pros and cons of those approaches is presented in Figure 2.

2. The evolutionary model of industrial dynamics

The model is described in detail in (Kwasnicki, Kwasnicka, 1992, 1994; Kwasnicki, 1994/1996). Due to space limitations, the presentation of the model here will be confined to a general description without going into the mathematical details. The model describes the behaviour of a number of competing firms producing functionally equivalent products. The decisions of a firm relating to investment, price, profit, etc. are based on the firm's evaluation of behaviour of other, competing firms, and the expected response of the market. The firm's knowledge of the market and knowledge of the future behaviour of competitors is limited and uncertain. Firms' decisions can thus only be suboptimal. The decisions are taken simultaneously and independently by all firms at the beginning of each period (e.g. once a year or a quarter). After the decisions are made the firms undertake production and put the products on the market. The products are evaluated by the market, and the quantities of different firms' products sold in the market depend on the relative prices, the relative value of products' characteristics and the level of saturation of the market. In the long run, a preference for better products, i.e. those with a lower price and better characteristics, prevails.

Each firm tries to improve its position in the industry and in the market by introducing innovations in order to minimize the unit costs of production, maximize the productivity of capital, and maximize the competitiveness of its products on the market. The general structure of the model is presented in Figure 3.

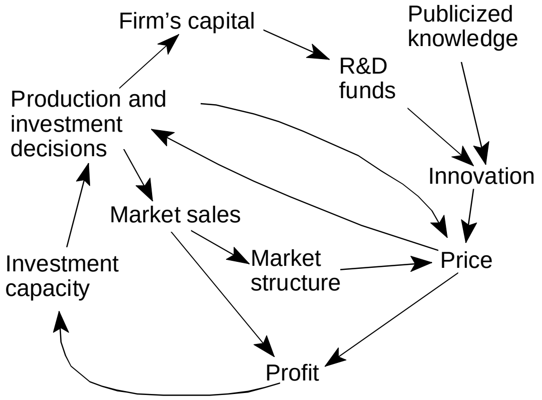


Figure 3. General structure of the evolutionary industrial model

The product's price depends on the current technology of the firm, on market structure and on the assumed level of production to be sold on the market. The two arrows between Price and Production indicate that the price is established in an interactive way to fulfil the firms objectives (i.e., to keep relatively high profits in the near future and to assure further development in the long run). Modernization of products through innovation and/or initiating new products by applying radical innovation depends on the investment capacity of the firm. Thus, in managing innovation, each firm takes into account all economic constraints, as they emerge during the firm's development. It thus frequently occurs that to economic constraints prevent a prosperous invention from being put into practice.

One of the distinguished features of the model is the coupling of technological development and economic processes. Current investment capacity is taken into account by each firm in the decision making process. Success of each firm in the search for innovation depends not only on R&D funds spent by each firm to search for innovation, but also on the extent to which firms make private knowledge public. Making the private knowledge of a firm public can in some cases speed up industrial development, but also diminishes a firm's incentives to spend more funds on

R&D projects. We may therefore expect only a certain part of private knowledge to be made public.

Firms' investment capacity depends on firms' savings and available credits, and also, indirectly, on the firm's debt. Production and investment decisions are based on the firm's expectations on future behavior of its competitors, market structure, expected profit and the past trend of the firm's market share. Current technical and economic characteristics of products offered for sale and the technology used to manufacture the products are taken into account in the price setting decisions, investment and production. Due to inevitable discrepancies between a firm's expectation and real behaviour of the market, the firm's production offered for sale on the market is different from market demand (it can be either smaller or larger than demand).

We distinguish invention (i.e. a novelty being considered to be introduced into practice) and innovation (an invention introduced into the production process). There are two ways in which firms search for inventions: autonomous, in-house research, and imitation of competitors. Public knowledge allows not only for imitation of competitors, but may also concern the research process (the arrow from public knowledge to autonomous research indicates this influence). From all inventions only a small fraction is selected to actually be used. Innovation may modernize current production but can also initiate new, radical way of production, i.e. by introducing essentially new technology. In general, each innovation may reduce unit costs, increase the productivity of capital, and improve product performance. However, it frequently happens that improvement of one factor is accompanied by deterioration of the two other. Firms therefore face the problem of balancing positive and negative factors of each invention. An invention will only become an innovation if the positive factors prevail.

In the model each firm may simultaneously produce products with different prices and different values of the characteristics, i.e., the firm may be a multi-unit operation. Different units of the same firm manufacture products by employing different sets of routines. Multi-unit firms exist because of searching activity. New technical or organizational solutions (i.e. a new set of routines) may be much better than the actual ones but immediate full modernization of production is not possible because of investment constraints on the firm. In such situations the firm continues production using the old routines and tries to open a new unit where production applying the new set of routines is started on a smaller scale. Subsequently, old production techniques may be slowly phased out.

Simulation of industry development is done in discrete time in four steps:

(1) Search for innovation (i.e., search for new sets of routines which potentially may replace the old set currently employed by a firm).
(2) Firms' decision making process (calculation and comparison of investment, production, net income, profit, and some other characteristics of development which may be attained by employing the old and the new sets of routines. Decisions of each firm on: (a) continuation of production by employing old routines or modernizing production, and (b) opening (or not) of new units).
(3) Entry of new firms.
(4) Selling process (market evaluation of the offered pool of products; calculation of firms' characteristics: production sold, shares in global production and global sales, total profits, profit rates, research funds, etc).

The search for innovation

The creative process is evolutionary by nature, and as such its description should be based on a proper understanding of the hereditary information (see Kwasnicki, 1996, Chapter 2). According to the tradition established by Schumpeter, and Nelson and Winter (1982), we use the term ‘routine’ to name the basic unit of the hereditary information of a firm. The set of routines applied by the firm is one of the basic characteristics describing it. In order to improve its position in the industry and in the market, each firm searches for new routines and new combinations of routines to reduce the unit costs of production, increase the productivity of capital, and improve the competitiveness of its products in the market. Nelson and Winter (1982, p. 14) define routines as ‘regular and predictable behavioral patterns of firms’ and include in this term such characteristics as ‘technical routines for producing things ... procedures of hiring and firing, ordering new inventory, stepping up production of items in high demand, policies regarding investment, research and development, advertising, business strategies about product diversification and overseas investment’. A large part of research activity is also governed by routines. ‘Routines govern choices as well as describe methods, and reflect the facts of management practice and organizational sociology as well as those of technology’ (Winter, 1984).

Productivity of capital, unit costs of production, and characteristics of products manufactured by a firm depend on the routines employed by the firm (examples of the product characteristics are reliability, convenience, lifetime, safety of use, cost of use, quality and aesthetic value). The search activities of firms ‘involve the manipulation and recombination of the actual technological and organizational ideas and skills associated with a particular economic context’ (Winter, 1984), while the market decisions depend on the product characteristics and prices. We may speak about the existence of two spaces: the space of routines and the space of product characteristics.[1]

We assume that at time *t* a firm is characterized by a set of routines actually employed by the firm. There are two types of routines: *active*, that is, routines employed by this firm in its everyday practice, and *latent*, that is, routines which are stored by a firm but not actually applied. Latent routines may be included in the active set of routines at a future time. The set of routines is divided into separate subsets, called segments, consisting of similar routines employed by the firm in different domains of the firm’s activity. Examples are segments relating to productive activity, managerial and organizational activity, marketing, and so on. In each segment, either active or latent routines may exist. The set of routines employed by a firm may evolve. There are four basic mechanisms for generating new sets of routines, namely: *mutation*, *recombination*, *transition* and *transposition*.

The probability of discovering a new routine (mutation) depends on the research funds allocated by the firm for autonomous research, that is, in-house development. It is assumed that routines mutate independently of each other. The scope of mutation also depends on funds allocated for in-house development.

The firm may also allocate some funds for gaining knowledge from other competing firms and try to imitate some routines employed by competitors (recombination). It is assumed that recombination may occur only between segments, not between individual routines, that is, a firm may gain knowledge about the whole domain of activity of another firm, for example, by licensing. A single routine may be transmitted (transition, see Figure 4) with some probability from firm to firm. It is assumed that after transition a routine belongs to the subset of latent routines. At any time a random transposition of a latent routine to the subset of active routines may occur (Figure 5). It is assumed that the probabilities of transition of a routine from one firm to another and the probabilities of transposition of a routine (from a latent to an active routine)

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[1] In the model, the space of routines and the space of characteristics play model a role analogous to the space of genotypes and the space of phenotypes in biology. The existence of these two types of spaces is a general property of evolutionary processes. Probably the search spaces (that is, spaces of routines and spaces of genotypes) are discrete spaces in contrast to the evaluation spaces (that is, the space of characteristics and the space of phenotypes) which are continuous spaces. The dimension of the space of routines (space of genotypes) is much larger than the dimension of the space of characteristics (space of phenotypes).

are independent of R&D funds, and have the same constant value for all routines.

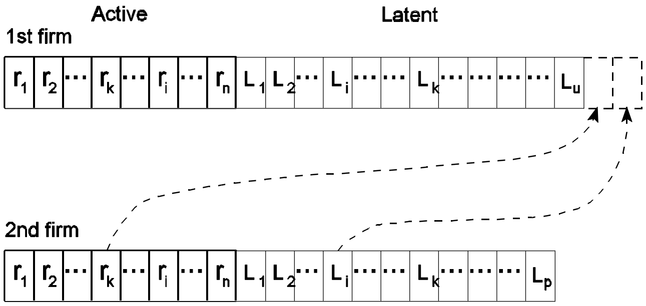

Figure 4. Routines transition

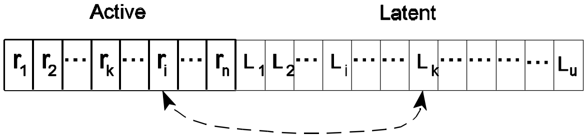

Figure 5. Routines transposition

In general, the probability of transposition of a routine for any firm is rather small. But randomly, from time to time, the value of this probability may abruptly increase and very active processes of search for a new combination of routines are observed. This phenomenon is called recrudescence. Recrudescence is viewed as an intrinsic ability of a firm's research staff to search for original, radical innovations by employing daring, sometimes apparently insane, ideas. This ability is connected mainly with the personalities of the researchers and random factors play an essential role in the search for innovations by recrudescence, so the probability of recrudescence is not related to R&D funds allocated by a firm to 'normal' research. It is assumed that recrudescence is more probable in small firms than in large ones which spend huge quantities on R&D, although it is possible to assume that the probability of recrudescence does not depend on firm size.

As a rule, mutation, recombination and transposition on a normal level (that is, with low probabilities in long periods) are responsible for small improvements and, during the short periods of recrudescence, for the emergence of radical innovations.

Firm's decisions

It seems that one of the crucial problems of contemporary economics is to understand the process of decision-making. Herbert Simon states that 'the dynamics of the economic system depends critically on just how economic agents go about making their decisions, and no way has been found for discovering how they do this that avoids direct inquiry and observations of the process' (Simon, 1986, p. 38).

The background of the decision making procedure adopted in the model is presented in detail in Kwasnicki (1996). It is assumed that each firm predicts future development of the market (in terms of future average price and future average product competitiveness), and on the basis of its expectations on future market development and expected decisions of its competitors, each firm decides on price of its products, investment and quantity of production which it expects to sell on the market. Current investment capability and the possibility of borrowing are also considered by each firm.

The decision making procedure allows to model diversified situations faced by different firms, for example, the power of a small firm to influence the average price is much smaller than that of a large firm. So, small firms are, in general, 'price takers' in the sense that they assume that the future average price will be very close to the trend value, while large firms generally play the role of 'price leaders' or 'price makers'.

Price, production and investment are set by a firm in such a way that some objective function is maximized. Contrary to the neoclassical assumption it is not a maximization in the strict sense. The estimation of values of the objective function is not perfect and is made for the next year only. In other words, it is not a global, once and for all, optimization, but rather an iterative process with different adjustments taking place from year to year.

Different price-setting procedures (based on different objective functions and the markup rules) have been scrutinized, the results of which are presented in Kwasnicki and Kwasnicka (1992), and Kwasnicki (1996). In many simulation experiments, firms were allowed to select different price setting procedures. The results of these experiments suggest that firms applying the objective O_1 function (presented below) dominate on the market and in the long run supersede all others. This objective function has the following form:

$$O_1(t+1) = (1 - F_i)\frac{\Gamma_i(t+1)}{\Gamma(t)} + F_i\frac{Q_i^s(t+1)}{QS(t)},$$
$$F_i = a_4 \exp\left(-a_5\frac{Q_i^s(t+1)}{QS(t)}\right), \tag{1}$$

where F_i is the magnitude coefficient (with values between 0 and 1), Q_i^s the supply of firm i, Γ_i the expected income of firm i at $t+1$ (defined by equation (2), below), QS is the global production of the industry in year t and Γ the global net income of all firms in year t. $\Gamma(t)$ and $QS(t)$ play the role of constants in equation (1) and ensure that the values of both terms in this equation are of the same order.

The expected income of firm i (Γ_i) and the expected profit of this firm (Π_i) are defined as

$$\Gamma_i = Q_i^s(t)(p_i(t) - Vv(Q_i^s(t)) - \eta), \tag{2}$$

$$\Pi_i = \Gamma_i - K_i(t)(\rho + \delta), \tag{3}$$

where V is unit production costs, $v(Q_i^s)$ is the factor of unit production cost as a function of the scale of production (economies of scale), η is the constant production cost, $K_i(t)$ the capital needed to obtain the output $Q_i^s(t)$, ρ the normal rate of return and δ the physical capital depreciation rate (amortization).

The function O_1 expresses short- and long-term thinking of firms during the decision-making process (the first and second terms in equation (1), respectively). Plausible values for the parameters are $a_4 = 1$ and $a_5 = 5$, implying that the long run is much more important for survival and that firms apply a flexible strategy, i.e., the relative importance of short- and long-term components changes in the course of firm's development (the long-term one is much more important for small firms than for the big ones).

The decision-making procedure presented above, with the search for the 'optimal' price-setting procedure based on the objective function concept constructs a formal scheme for finding the proper value of the price and expected production to be sold on the market. Naturally this scheme is only an approximation of what is done by real decision-makers. They, of course, do not make such calculations and formal optimization from year to year, they rather think in the routine mode: 'My decisions should provide for the future prospects of the firm and also should allow income (or profit) to be maintained at some relatively high level'. Decisions on the future level of production and the future product price depend on the actual investment capabilities of the firm.

Entry

In each period (t, $t + 1$) a number of firms try to enter the market. Each entrant enters the market with assumed capital equal to *InitCapital* and with the initial price of its products equal to the predicted average price. The larger the concentration of the industry, the greater the number of potential entrants (that is, firms trying to enter the market). The value of *InitCapital* is selected in such a way that the initial share of an entrant is not larger than 0.5%.

In general, any firm may enter the market and if a firm's characteristics are unsatisfactory, then it is quickly eliminated (superseded) from the market. But because of the limited capacity of computer memory for simulations, a threshold for potential entrants is assumed. It is assumed that a firm enters the market only if the estimated value of objective O_1 of that firm is greater than an estimated average value of the objective O_1 in the industry. It may be expected that a similar (rational) threshold exists in real industrial processes.

Products competitiveness on the market

The productivity of capital, variable costs of production and product characteristics are the functions of routines employed by a firm (see Figure 6). Each routine has multiple, pleiotropic effects, that is, may affect many characteristics of products, as well as productivity, and the variable costs of production. Similarly, the productivity of capital, unit costs of production and each characteristic of the product can be function of a number of routines (polygeneity). We assume that the transformation of the set of routines into the set of product characteristics is described by m functions F_d,

$$z_d = F_d(r), \qquad d = 1, 2, 3, \ldots, m, \tag{4}$$

where z_d is the value of characteristic d, m the number of product characteristics, and r the set of routines. It is assumed also that the productivity of capital $A(r)$ and the unit cost of production $V(r)$ are also functions of firm's routines, where these functions are not firm specific and have the same form for all firms.

Attractiveness of the product on the market depends on the values of the product characteristics and its price. The competitiveness of products with characteristics z and price p is equal to

$$c(p, z) = \frac{q(z)}{p^{\alpha}}, \qquad z = (z_1, z_2, z_3, \ldots, z_m), \tag{5}$$

where $q(z)$ is the technical competitiveness, z a vector of product characteristics, and α price elasticity.

In the presence of innovation, technical competitiveness varies according to the modification of routines made by each firm, or because of introducing essentially new routines. Technical competitiveness is an explicit function of product characteristics. As explained above, each routine does not influence the product's performance directly, but only indirectly through the influence on its characteristics. We assume the existence of a function q enabling calculation of technical competitiveness of products manufactured by different firms. We say that q describes the adaptive landscape in the space of product characteristics. In general, this function depends also on some external factors, varies in time, and is the result of co-evolution of many related industries. The shape of the adaptive landscape is dynamic, with many adaptive peaks of varying altitudes. In the course of time some adaptive peaks lose their relative importance, others become higher.

Due to the ongoing search process, at any moment each firm may find a number of alternative sets of routines. Let us denote by r the set of routines actually applied by a firm and by r^* an alternative set of routines. Each firm evaluates all potential sets of routines r^* as well as the old routines r by applying the decision-making procedure outlined in the former section. For each alternative set of routines the price, production, investment (including the modernization investment), and value of objective function are calculated. The decision of firm i on modernization (i.e., replacing the r routines by r^* routines) depends on the expected value of the firm's objective function and its investment capability. Modernization is undertaken if the maximum value of the objective function from all considered alternative sets of routines r^* is greater than the value of the objective function possible by continuing the actually applied routines *r*, and if the investment capability of the firm permits such modernization. If the investment capability does not allow modernization, then the firm:

1. continues production employing the 'old' routines *r*, and
2. tries to open a new small unit where routines r^* are employed; production is started with an assumed value of capital equal to *InitCapital*.

To modernize production, extra investment is necessary. This 'modernization investment' depends on the discrepancy between the 'old' routines *r* and the 'new' routines r^*. For simplicity, it is assumed that modernization investment *IM* is a non-decreasing function of distance between the old routines *r* actually applied by a firm and the new set of routines r^*.

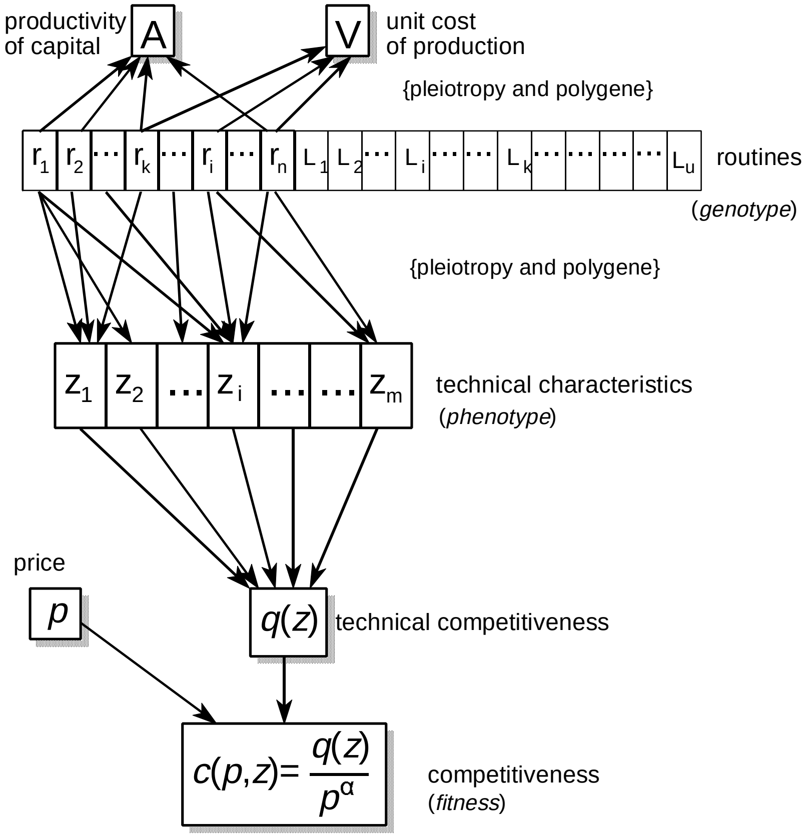

Figure 6. From routines to competitiveness, productivity of capital and unit cost of production

All products manufactured by the entrants and the firms existing in the previous period are put on the market and all other decisions are left to buyers; these decisions primarily depend on the relative values of competitiveness of all products offered, but quantities of products of each firm offered for sale are also taken into account. It is assumed that global demand $Q^d(t)$ for products potentially sold on a market is equal to an amount of money – $M(t)$ – which the market is inclined to spend on buying products offered for sale by the firms divided by the average price, $p(t)$, of the products offered by these firms,

$$Q^d(t) = \frac{M(t)}{p(t)}. \tag{6}$$

$M(t)$ is assumed to be equal to

$$M(t) = N\exp(\gamma t)(p(t))^{\beta} \tag{7}$$

where N is a parameter characterizing the initial market size, γ the growth rate of the market, and β the (average) price elasticity. The average price of all products offered for sale on the market is equal to

$$p(t) = \sum_i p_i(t) \frac{Q_i^s(t)}{Q^s(t)}. \tag{8}$$

where $Q^s(t)$ is global supply and is equal to

$$Q^s(t) = \sum_i Q_i^s(t). \tag{9}$$

Global production sold on the market is equal to the smaller value of demand $Q^d(t)$ and supply $Q^s(t)$,

$$QS(t) = \min\{Q^d(t),\ Q^s(t)\}. \tag{10}$$

The selection equation describing competition among firms (products) in the market has the following form (f_i is the market share of products manufactured by firm i):

$$f_i(t) = f_i(t-1)\frac{c_i(t)}{c(t)}, \tag{11}$$

where $c(t)$ is the average competitiveness of products offered for sale,

$$c(t) = \sum_i f_i(t-1)c_i(t). \tag{12}$$

This means that the share (f_i) of firm i in global output increases if the competitiveness of its products is higher than the average of all products present on the market, and decreases if the competitiveness is lower than the average. The rate of change is proportional to the difference between the competitiveness of products of firm i and average competitiveness.

Finally, the quantity of products potentially sold by firm i (i.e., the demand for products of firm i) is equal to

$$Q_i^d(t) = QS(t)f_i(t). \tag{13}$$

The above equations are valid if the production offered by the firms exactly fits the demand of the market. This is a very rare situation and therefore these equations have to be adjusted to states of discrepancy between global demand and global production, and discrepancy between the demand for products of a specific firm and the production offered by this firm. The details of this adjustment process is presented in Kwasnicki (1996). Equation (13) describes the market demand for products of firm i offered at a price $p_i(t)$ and with competitiveness $c_i(t)$. In general, however, the supply of firm i is different from the specific demand for its products. The realization of the demand for products of firm i does not depend only on these two values of demand and supply, but on the whole pool of products offered for sale on the market. The alignment of supply and demand of all firms present on the market is an adaptive process performed in a highly iterative and interactive mode between sellers and buyers. In our model, we simulate the iterative alignment of supply and demand in a two-stage process in which a part of the demand is fulfilled in the first stage, and the rest of the demand is, if possible, fulfilled in the second stage. If there is no global oversupply of production, then in the first stage of the supply–demand alignment process all demand for production of specific firms, wherever possible, is fulfilled, but there is still the shortfall in production of firms which underestimated demand for their products. This part of demand is fulfilled in the second stage of the supply–demand alignment process. At this stage, the products of the firms which produce more than the specific demand are sold to replace the shortfall in production by the firms which underestimated the demand for their products.

The supply–demand alignment process is slightly different if a global oversupply of production occurs. It seems reasonable to assume that in such a case the production of each firm sold on the market is divided into (1) the production bought as the outcome of the competitive process (as described by equations 15 and 17), and (2) the production bought as the outcome of a non-competitive process. The latter part of production does not depend directly on product competitiveness but primarily depends on the volume of production offered for sale, i.e., random factors play a much more important role in the choice of relevant products to be bought within this part of the production. In general, the division of production of each firm into these two parts depends on the value of global oversupply. The higher oversupply, the larger is the part of production of each firm which is sold on the basis of non-competitive preferences.

Usually global oversupply, if it occurs, is small, so the major part of production is distributed under the influence of competitive mechanisms and only a small part is distributed as a result of non-competitive distribution. But to clarify the necessity of distinguishing the two proposed stages of the selling–buying process let us consider the following, albeit artificial, situation. Except for one firm, the production of all other firms exactly meets the demand for their products. The a-typical firm produces much more than the demand for its products. It could be assumed that the production sold by all firms is exactly equal to the specific demands for their products, which is equivalent to the assumption that the volume of overproduction of the a-typical firm does not influence the behaviour of the market. In an extreme case, we may imagine that the volume of production of the a-typical firm is infinite and the rest of the firms continue to produce exactly what is demanded. Does this mean that the excessive production would go unnoticed by the buyers and that they would remain loyal to firms producing exactly what is demanded? It seems a more adequate description requires the incorporation of the assumption that the future distribution of products sold on the market depends on the level of overproduction of all firms, and particularly the level of overproduction of the a-typical firm. And it seems that in the case of the overproduction of one firm its share in the global production sold will increase at the expense of all firms producing exactly what is demanded. In the extreme case, when overproduction of the a-typical firm tends to infinity, the only products sold on the market belong to that firm, and the shares of all other firms will be zero. But it does not mean that producing more than is demanded is an advantageous strategy for the firm and that it is an effective weapon to eliminate the competitors. In fact, the bulk of overproduction is not sold on the market and is lost by the firm. In effect the a-typical firm’s profit is much smaller than expected, or even may be negative. After some time the firm’s development stop and in the end it will be eliminated from the market.

3. Punctuated versus gradual development

The search for innovation is a result of the interplay of different mechanisms of novelty generation, that is, different strategies of a search. Dichotomously the firms’ strategies may be partitioned into: an innovation search (that is, an attempt to search for real novelty through the autonomous, in-house research of a firm) and imitation (that is, a search for innovation through the recombination of some existing solutions). But within the innovation strategy two mechanisms ought to be distinguished: search for novelty through the relatively small modification of current solutions and search for radical novelty through the essential rebuilding (reshaping) of existing solutions. Let us call the innovation strategy through moderate modifications ‘mutation’ and the search strategy for a radical novelty ‘recrudescence’. All these three mechanisms of novelty generation are crucial for long-range economic development, and for all evolutionary processes in general. Mutations enable us to adjust current solutions (technologies) to local environments, to ongoing changes of exogenous conditions, and also to temporal changes of markets’ preferences on which the firms operate.

Recombination (imitation) enables relatively quick dissemination (diffusion) of innovations and also enables new solutions to be found through the search for new combinations of existing routines. Collaboration of mutation and imitation enables much quicker development, and provides competitive conditions within the industry, being important forces prohibiting a tendency toward market monopolization. Mutation and imitation act all the time on the same relatively high level, they are vigorous forces allowing each individual firm to keep its position on the market or, with a bit of luck, to reach a temporary superior position.[2] It seems that the practice of the recrudescence is different. As has been said before, the recrudescence reflects phenomena frequently observed in creative processes and described as revelation, vision, bisociation (Arthur Koestler), or gestalt–switch (Karl Popper).

In contrast to imitation and mutation, the recrudescence is hardly detectable during 'normal' research, and may be called a dormant mechanism, but it is highly active during the periods of stagnation, when prospects of current technologies seem to be exhausted. During these relatively short periods, large numbers of inventions are generated, most of which are useless but some of them open the way for the emergence of radical innovation which focuses the attention of the majority of researchers; in effect the ratio of the recrudescence diminishes. In the succeeding phase of the Kuhnian 'normal research', efforts are focused on such promising innovations which are further improved by mutation and recombination. As a hypothesis it may be stated that the ratio of recrudescence is strongly correlated to the economic state of affairs – during periods of prosperity the recrudescence is almost invisible but emerges and gains vital status during relatively short periods of depression and stagnation. In reality all mechanisms of novelty generation act concurrently. It seems interesting to isolate each mechanism and study the impact of each separated mechanism on the modes of industrial development. Adaptive landscapes describing the performance index (technical competitiveness) are defined in the space of technical characteristics – $q(z)$ in equation (5). As may be expected real adaptive landscapes are dynamic entities with many local peaks. The adaptive landscape's surface depends on the evolution of the industry under consideration as well as on the co-evolution of other related industries, but also, in general, on the whole socio-economic evolution. In principle it is possible to model such a complicated landscape by relevant definition of function $q(z)$, but to control the results of experiments it is better to start the simulation with simple, stable adaptive landscapes. In the following experiment it is assumed that there are only two technical characteristics, the adaptive landscape does not change its shape during the simulation and there are four local peaks with altitudes equal to 1.0, 1.5, 2.0 and 2.5, respectively. Values of $q(z)$ reflect relative preferences of different solutions. Multiplication of $q(z)$ by any positive number does not change the shape of the landscape and the behaviour of the model. It means that solutions around the second higher peak provide 50% better performance than the solutions around the lowest peak. The map of this adaptive landscape is

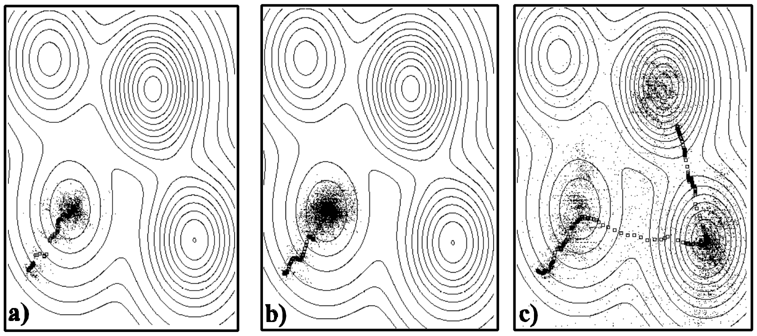

Figure 7. Trajectories of development: mutation (a), recombination (b), and recrudescence (c)

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[2] The evolutionary development (with the presence of innovation) resembles Alice's trip with the Red Queen from 'the Second Square' to 'the Eighth Square' in 'The Garden of Live Flowers'. The Queen and Alice 'went so fast that at last they seemed to skim through the air, hardly touching the ground with their feet. ... The most curious part of the thing was, that the trees and the other things round them never changed their places at all: however fast they went, they never seemed to pass anything.' In the end the Queen explained to Alice: 'Now, *here*, you see, it takes all the running *you* can do, to keep the same place. If you want to get somewhere else, you must run at least twice as fast as that!' Lewis Carrol, *Through the Looking-Glass*, Warszawa: Lettrex, 1991, Chapter II.

presented in Figure 7. The initial values of the product characteristics are much closer to the lowest peak so we may expect that the trajectory of evolution at the first stage of the industry development will evolve toward that peak and then that the firms will try to find better products with characteristics closer to higher peaks. It is important, and ought to be emphasized, that the firms do not know the shape of the adaptive landscape and the only way to gain knowledge about the local shape of the landscape is to make an experiment – during the R&D process firms evaluate the performance index, that is, the technical competitiveness, of a specific product with assumed values of characteristics. All such experiments made by all firms during the whole period of simulation are marked by dots (pixels) on the background of the adaptive landscape in Figure 7. The performance index (that is, technical competitiveness) of products defined by known values of their characteristics marked by dots is known for firms (and only this part of the adaptive landscape is known for individual firms, that is, those firms which make a specific ‘experiment’). It may be said that dots mark all inventions found by the firms as the result of R&D process. The number and density of the dots in all three charts in Figure 7 also suggest differences in the vigorousness of the search process. Some of the inventions are adopted by firms and become innovations, that is, products offered for sale on the market. Average values of characteristics of products sold on the market at any time *t* are marked by squares.[3] We say that the average values of product characteristics sold on the market mark the trajectory of industry development in the adaptive landscape.

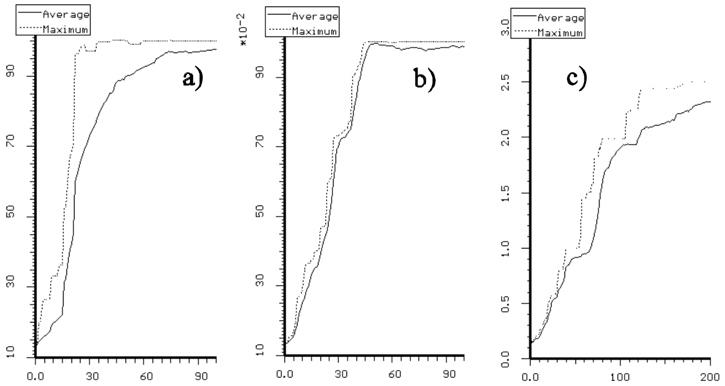

Figure 8. Quality of performance (technical competitiveness) for mutation (a), recombination (b), and recrudescence (c)

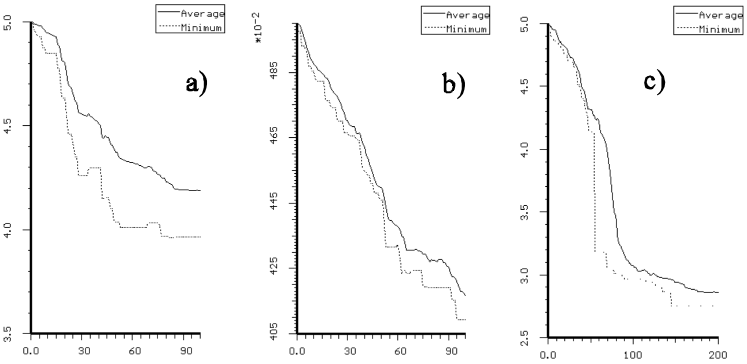

Figure 9. Cost of production for mutation (a), recombination (b), and recrudescence (c)

In the first experiment it was assumed that only mutation acts. The development of each firm is based only on its own knowledge and on autonomous research. The firms evolve almost directly through the shortest way toward the lowest peak. The scope of search for invention is not very large (Figure 7a), and the research is focused around local firms’ positions in the adaptive landscape. If we add the possibility of interchanging knowledge (that is, imitation of innovation) the evolution is slightly quicker (but the routines diversity is much smaller). The scope of search is also slightly wider than in the former experiment. Let us note that the trajectories of development in these two experiments significantly differ; the simulation conditions, besides the modes of research, in these experiments are exactly the same. Maximum and average technical

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[3] The density of the squares also gives a hint on the dynamics of changes: the more distanced the successive squares are, the quicker the changes within the industry.

competitiveness in these two experiments are presented in Figure 8 a and 8b, respectively; in Figure 9 the average unit cost of production and minimum unit cost of production are also presented. It is seen that imitation (recombination) allows for more smooth development; the discrepancy between the frontier of development (represented by the maximum technical competitiveness and minimum cost) and average values are much smaller when imitation is allowed.

In both cases the evolution stops at the lowest peak. Greater values of probabilities of mutation and recombination accelerate evolution and lead to a relatively high ratio of technological development but still do not allow a departure from the lower local peak (local optimum, as it is sometimes called) through finding products with characteristics very close to the higher peaks. We use the term ‘evolutionary trap’ to name the situation of confining the industry in the local, lower peak of the adaptive landscape. Many other simulation runs with different adaptive landscapes let us conclude that neither mutation nor recombination (imitation) allow us to escape from the majority of evolutionary traps. As our simulation experiments reveal, the mechanism of recrudescence makes this escape much easier. In the next simulation experiment this mechanism is added. In the first period (up to 50 years) mutation and imitation act on the normal levels, as in the former experiment, and recrudescence acts rarely. The industry development is similar to that in the previous runs. At $t = 50$ industry is very close to the first lowest peak and at this moment we allow the recrudescence to act on a much higher level; within 5 years products with characteristics very close to the higher peak (with altitude equal to 2.0) are found. At $t = 55$ the probability of recrudescence is reduced to the lower value. The scope of search in this run is much wider than in all previous runs, Figure 7c. Far-distanced areas are sampled but most of these attempts are fruitless. Not all far-placed inventions are generated by recrudescence; most of them are the result of a recombination of solutions placed at different peaks, but what is crucial is that the first inventions placed at the higher peak are always generated by recrudescence and open the way for the recombination of products ‘placed’ at these two peaks. After reaching the third peak, recrudescence with higher probabilities is allowed again and the solutions on the highest peak are found (see the trajectory of development in Figure 7c, technical competitiveness in Figure 8c, and unit cost of production in Figure 9c.

It may be said that recrudescence acts as a trigger, initiating the phase of radical transformations. Not all inventions providing better products performance are accepted; frequently modifications of routines which generate technical inventions placed at the higher peak also cause reduction of productivity of capital or a rise in the unit costs, and therefore they are not accepted simply on the basis of economic judgements. The necessity of correlation of technical performance with economic factors (as productivity of capital and costs of production, but also other factors, for example, a firm’s current investment capabilities) causes many promising inventions to be rejected by firms, and in practice the probability of the emergence of radical innovation is significantly smaller than the probability of finding radical technical invention.

The emergence of radical innovation is a kind of leap, a punctuated process, but the shift from the lower to the higher peak is not a sharp (punctuated) process; rather, it is a much more gradual process of shifting the position of the industry in the adaptive landscape. The main reason for this gradualism is that the overall competitiveness of products is the function of the technical competitiveness and the price – see equation (5). To keep the overall competitiveness on a relatively high level, firms lower the price of products characterized by smaller technical competitiveness (that is, placed at the lower peak) and vice versa products with higher competitiveness (that is, placed at the higher peak) are slightly more expensive (to gain greater profit), so the values of the overall competitiveness for the products of firms in the vanguard of technological development are only slightly greater than the competitiveness of the old-fashioned products. Therefore the elimination of the worst products from the market is not so sharp as may be expected on the basis of the values of technical competitiveness only. In some circumstances the substitution phase may last quite a long time, but in all cases we observe the steady tendency to reduce production of the old-fashioned products and to increase the production of the modern ones.

If a recrudescence mechanism is involved, jumps in the development of the technological frontier are clearly visible – see the maximum technical competitiveness in the Figure 8c, and minimum unit cost of production in Figure 9c. The jumps are observed on the route toward the local peak and also in the transition phase, of passing from the lower to the higher peaks.

Random factors play a crucial role in the evolution of the industry. We may say that the route toward local optimum is more or less predetermined; but after reaching the local optimum further development in multi peak landscape is hardly predicable. The highest peak can be reached by different routes. In our example it may happen that the best solutions are found just after reaching the lowest peak (see Figure 10b, and Figure 11b) or indirectly through the second lower peak as in Figure 10a, and Figure 11a.

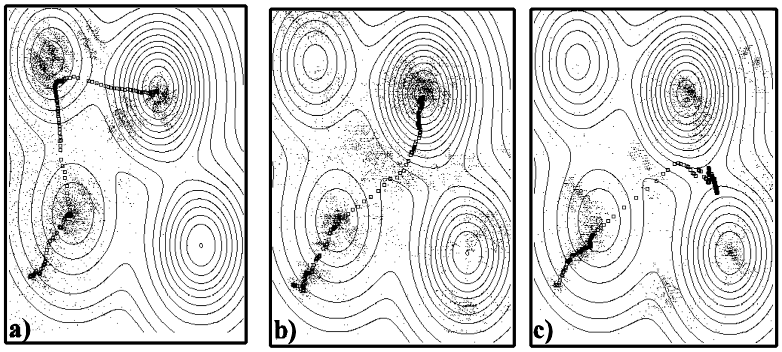

Figure 10. Trajectories of development (recrudescence, different runs)

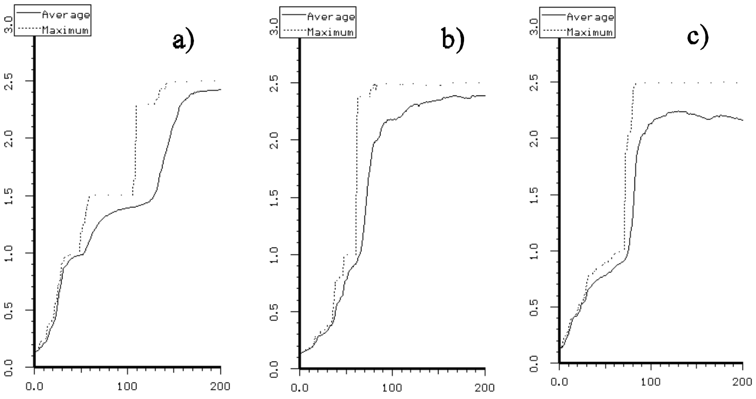

Figure 11. Quality of performance for three simulation runs

Specific simulation run is presented in Figure 10c, and Figure 11c. As we see, the trajectory goes somewhere between the highest and the second highest peaks. It is because some firms are placed on the highest peak and some other on the third peak. What is interesting, this partition exists in spite of essential differences in the technical competitiveness. This specific situation is not rare one in economic processes. We mention it because this case reflects some specificities of economic evolution. As it was mentioned, the overall competitiveness depends on technical competitiveness and price (see equation (5)). It happens that higher technical competitiveness of products of firms placed on the highest peak is accompanied by greater unit cost of production and vice versa, smaller technical competitiveness of products of firms placed on the lower peak is accompanied by lower cost of production. Therefore firms on the highest peak are forced to charge higher price for their production and firms on the lower peak charge lower price (because smaller unit cost). In consequence the overall competitiveness of both kind of firma is almost equal. Some consumers decide to buy better products for higher price some other consumers buy worse products for smaller price. The market share of firms placed on the highest peak and the share of firms placed on the lower peak are almost the same (in some simulations even the share of firms producing less technologically advanced products increase).

Figure 12 summarizes all results presented in Figures 7, 10 and 11. It is visible that trajectories of industry development are more or less gradual when firms evolve toward a local peak along the hill and is punctuated when after a relatively short period of being ‘trapped’ on a local peak a radical innovation, placed on the higher peak, is found. We have used the same landscape with four peaks in simulations of biological populations. Price mechanisms and pre-evaluation of new solutions (inventions) before ‘launching’ them into the environment (market) are one of distinguished features of industrial development from biological evolution. The differences make that for some conditions, modes of development can be different in both systems. The trajectories in biological evolution look very similar to that presented in Figure 12, with phased of gradual and punctuated modes of development, for large biological populations. Large populations are also not able to escape from the evolutionary trap in gradual way. Gradual process of development dominates in small biological populations (in our simulations with less then 15 individuals). In small biological populations it is possible to detect presence of genetical drift. Random changes of heritage information of the small population (genetic pool) cause that the population is able to evolve dawn the local peak toward a valley between lower and higher peaks and in the next phase the population is able to evolve gradually along the hill of the higher peak to reach the top of that hill.

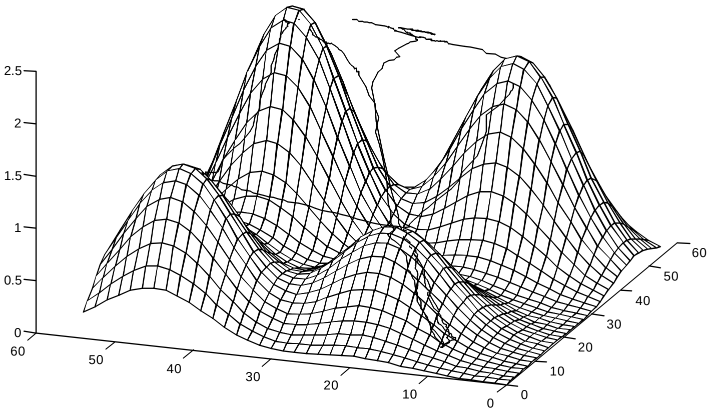

Figure 12.“Look! Here he comes, leaping across the mountains, bounding over the hills.”

Song of Solomon 2:8

(NIV – Bible Gateway , http://www.gospelcom.net/bible

Conclusions

All evolutionary processes, starting from biological evolution, through cultural, social and technological evolutions, and ending in the development of our personal knowledge, have common, general properties. Evolutionary processes are dynamical, historical ones which macro-characteristics flow from activities of individual agents. Fundamental features of evolutionary processes are diversity and heterogeneity of behaviours. Selection and search for innovation are two basic mechanisms of development. But we ought to be conscious that each particular evolutionary process has its own peculiarities, such that one related to investment, capital formation and price setting in economic evolution. Mechanisms of search for innovation seem to be the common property of all evolutionary processes, and in fact this part of the industrial model is ‘borrowed’ from our former model of biological evolution. It is reflected also in the nomenclature used, such as mutation, recombination, and so on, so well known in biological models.

Current experiences of using simulation models in evolutionary economics suggest that at current state of development of these models there is no possibility to validate them in similar way to that made in econometrics and in engineering. I doubt if it si possible to collect relevant records on industrial development and try to calibrate the evolutionary model to adjust its behaviour to real processes. The only reasonable way seems to compare the model with reality at the level of stylized facts. But it does not mean that strongly simplified versions of evolutionary models cannot be useful to model real industrial processes (e.g., to make prognoses of industrial development). We have done such simplification of the model presented in this paper to describe technological substitution (diffusion) processes. Such simplification allows to reduce the number of the model's parameters significantly to such a level that is possible to identify them on the basis of collected records of real substitution processes. In (Kwasnicka, Kwasnicki, 1996) we used this approach to analyze and to predict development of two processes, namely primary energy sources in the world energy consumption and the raw steel production in the United States.

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