Working Paper

Chance and Necessity in Industrial Development

Witold Kwasnicki

WP-95-65
July 1995

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Preface

The research project on *Systems Analysis of Technological and Economic Dynamics* at IIASA is concerned with modeling technological and organisational change; the broader economic developments that are associated with technological change, both as cause and effect; the processes by which economic agents – first of all, business firms – acquire and develop the capabilities to generate, imitate and adopt technological and organisational innovations; and the aggregate dynamics – at the levels of single industries and whole economies – engendered by the interactions among agents which are heterogeneous in their innovative abilities, behavioural rules and expectations. The central purpose is to develop stronger theory and better modeling techniques. However, the basic philosophy is that such theoretical and modeling work is most fruitful when attention is paid to the known empirical details of the phenomena the work aims to address: therefore, a considerable effort is put into a better understanding of the 'stylized facts' concerning corporate organisation routines and strategy; industrial evolution and the 'demography' of firms; patterns of macroeconomic growth and trade.

From a modeling perspective, over the last decade considerable progress has been made on various techniques of dynamic modeling. Some of this work has employed ordinary differential and difference equations, and some of it stochastic equations. A number of efforts have taken advantage of the growing power of simulation techniques. Others have employed more traditional mathematics. As a result of this theoretical work, the toolkit for modeling technological and economic dynamics is significantly richer than it was a decade ago.

During the same period, there have been major advances in the empirical understanding. There are now many more detailed technological histories available. Much more is known about the similarities and differences of technical advance in different fields and industries and there is some understanding of the key variables that lie behind those differences. A number of studies have provided rich information about how industry structure co-evolves with technology. In addition to empirical work at the technology or sector level, the last decade has also seen a great deal of empirical research on productivity growth and measured technical advance at the level of whole economies. A considerable body of empirical research now exists on the facts that seem associated with different rates of productivity growth across the range of nations, with the dynamics of convergence and divergence in the levels and rates of growth of income, with the diverse national institutional arrangements in which technological change is embedded.

As a result of this recent empirical work, the questions that successful theory and useful modeling techniques ought to address now are much more clearly defined. The theoretical work has often been undertaken in appreciation of certain stylized facts that needed to be explained. The list of these 'facts' is indeed very long, ranging from the microeconomic evidence concerning for example dynamic increasing returns in learning activities or the persistence of particular sets of problem-solving routines within business firms; the industry-level evidence on entry, exit and size-distributions – approximately log-normal – all the way to the evidence regarding the time-series properties of major economic aggregates. However, the connection between the theoretical work and the empirical phenomena has so far not been very close. The philosophy of this project is that the chances of developing powerful new theory and useful new analytical techniques can be greatly enhanced by performing the work in an environment where scholars who understand the empirical phenomena provide questions and challenges for the theorists and their work.

In particular, the project is meant to pursue an 'evolutionary' interpretation of technological and economic dynamics modeling, first, the processes by which individual agents and organisations learn, search, adapt; second, the economic analogues of 'natural selection' by which interactive environments – often markets – winnow out a population whose members have different attributes and behavioural traits; and, third, the collective emergence of statistical patterns, regularities and higher-level structures as the aggregate outcomes of the two former processes.

Together with a group of researchers located permanently at IIASA, the project coordinates multiple research efforts undertaken in several institutions around the world, organises workshops and provides a venue of scientific discussion among scholars working on evolutionary modeling, computer simulation and non-linear dynamical systems.

The research focuses upon the following three major areas:

1. Learning Processes and Organisational Competence.
2. Technological and Industrial Dynamics
3. Innovation, Competition and Macrodynamics

Chance and Necessity in Industrial Development

Witold Kwasnicki[1]

The evolutionary model of industrial dynamics is presented in the first section of the paper. In the following two sections results of a simulation study of the model focused on different modes of search for innovation and role of random events in economic development are presented; namely in the second section we investigate the development of industry under different assumptions related to firms' search for innovations (autonomous research, imitation, search for radical innovation, etc.) and in the third section problems of cumulative causation, path-dependence and irreversibility are discussed.

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The essence of cultural development in general, and socio-economic evolution in particular, lies in the creative process of human being. The real tissue of creative processes is almost impossible to observe. Collection of relevant quantitative data on innovation processes is mostly confined to such data as number of researchers, R&D funds, number of patents, etc. Estimation of some essential parameters and characteristics (e.g. probability of emergence of innovation within assumed period of time) on the basis of such aggregate data is almost impossible. Most important, and the most interesting, phenomena of creative/cognitive processes occur in the mind of researchers, and these kind of processes are, in general, out of reach of any observations. The only way to deal with the creative processes and dare to describe them in a more or less formal way is to make some arbitrary assumptions, incorporate them into the economic model and observe if development of the model resembles the development of real processes. In some sense, it is a combination of quantitative modelling (based on hard economic data) and qualitative modelling (based on heuristics, analogies, and metaphors). This kind of approach is proposed in this paper. We treat this proposition as the first approximation being the subject of further development ('stepwise concretization').

The creative process is evolutionary by nature, and as such its description ought to be based on proper understanding of the hereditary information. According to the tradition established by J.A. Schumpeter, and S. Winter and R. Nelson 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 the firm. Each firm searches for new routines and new combinations of routines. Nelson and Winter (1982, p. 14) define routines as "regular and predictable behavioral patterns of firms" and include in this term such characteristics of firms 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". 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).

Each firm tends to improve its situation within the industry and in the market by introducing new combinations of routines in order to minimize the unit cost of production, maximize the productivity of capital, and maximize the competitiveness of its products in the market. Productivity of capital, unit cost of production, and characteristics of products manufactured by a firm depend on the routines employed by the firm (examples of the product's characteristics are: reliability, convenience, lifetime, safety of use, cost of use, quality, aesthetic values). The search activity 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 products' characteristics and prices. We may speak about the existence of two spaces: the space of routines and the space of product characteristics.[1] Distinguishing these two spaces enables us to separate firms' decisions from the

[1] A space of routines and a space of characteristics play in our model an analogous role to a space of genotypes and a space of phenotypes in biology. The existence of these two types of spaces is a general property of evolutionary processes (Kwasnicka, Kwasnicki, 1986). Probably the search spaces (i.e. spaces of routines and spaces of genotypes) are discrete spaces contrary to the evaluation spaces (i.e. space of characteristics and space of phenotypes) which are continuous spaces. The dimension of the space of routines (space of genotypes) is much greater then the dimension of the space of characteristics (space of phenotypes). As some simulation experiments reveal, big differences in the dimensions of the two spaces play important role in long term evolution and among others enables escape from so-called evolutionary traps.

market's decisions. As in the basic model discrete time, e.g. a year or a quarter, is assumed, and the firms' decisions relating to investment, production, research funds, etc. are taken simultaneously and independently by all firms at the beginning of each period. 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. Due to imbalances of global supply and demand as well as 'local' imbalances of demand and supply of products of a specific firm it may happen that 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 selling the better ones. But during long periods the preference for better products, i.e. those with a lower price and better characteristics, prevails.

In the model presented below each firm may simultaneously produce products with different prices and different values of the characteristics, that is, 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 the searching activity. New technical or organizational solutions (i.e. new set of routines) may be much better than the actual ones but full modernization of production is not possible because of investment constraints on the firm. In such situations the firm continues production employing the old routines and tries to open a new unit where production, on a lesser scale, employing the new set of routines is started. Subsequently the 'old' production may be reduced and after some time superseded by the 'new' production.

Simulation of industry development in the model is made in discrete time in four steps:

(1) Search for the new sets of routines which potentially may replace the 'old' set currently employed by a firm.

(2) Calculation and comparison of the investment, the production, the net income, the 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 making modernization of production, and (b) opening (or not) of new units.

(3) Entry of new firms.

(4) 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.

Due to innovation and new technologies introduced by firms the modernization investment is also taken into account in the decision making process (i.e. beside the expansionary investment related to the growth of production we have the modernization investment related to adjusting the 'old' capital to 'new' technology).

I. The model.

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. There is no possibility of characterizing the limitation and the uncertainty of knowledge in statistical terms, e.g. in terms of probability distributions. Firms' decisions can 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. 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.

The general structure of the evolutionary model of industrial dynamics is presented in Fig. 1. The product's price depends on current innovation being in hands of a firm, on actual structure of the market and on the level of assumed 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 provide fulfilling the firms objectives (i.e. to keep relatively high profit in a near future and a further firms development in the long term perspective). Modernization of products through innovation and/or initiating a new production through applying a radical innovation depend on an investment capacity of the firm. So each firm managing innovation takes into account all economic constraints, as they emerge during the firm's development. Therefore it frequently occurs that due to economic (financial) constraints some prosperous invention is not put into the firm's practice. Coupling technological development and economic processes is one of the distinguished feature of the model. Current investment capacity is taken also into account by each firm in the investment process and the price setting. Success of each firm in the search for innovation depends not only on R&D funds spend by each firm to search for innovation but also on the extend to make the firms' private knowledge to be public. Making the private knowledge of a firm known to their competitors can in some cases speeds up a whole industrial development but also diminishes a firm's incentives to spend more funds to R&D projects. We may expect a kind of balanced ratio of making the private firms knowledge to be public.

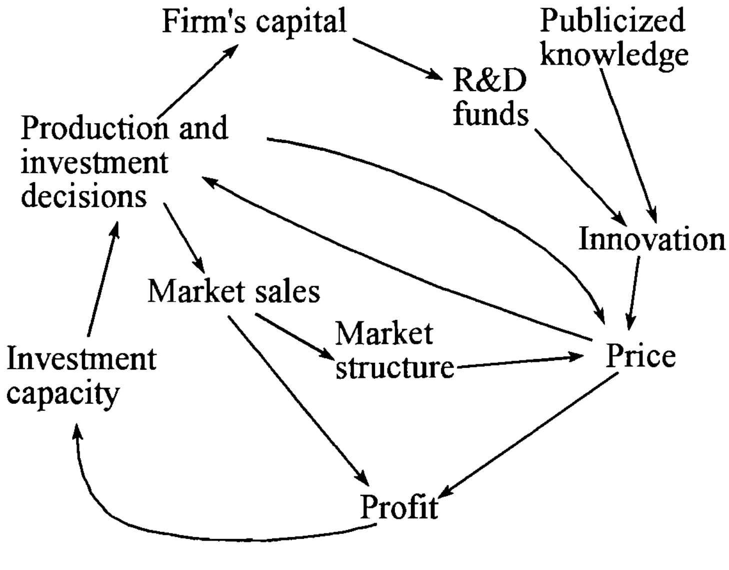

Fig. 1. General structure of the evolutionary industrial model

Causal relationship between main variables of industrial model presented in the following sections are shown in Fig. 2. In some way it is more detailed description of the structure presented in Fig. 1. Firm's investment capacity depends on firm's savings and the credit's availability, and also, through indirect way, on the firm's debt. Production and investment decisions rely on firm's expectations related to future behavior of its competitors, market structure, expected profit and the actual trend of firm's market share. Current technical and economic characteristics of products offered for sale (in terms of their technical competitiveness, being the measure of products' technical performance), and characteristic of technology used to manufacture the products (in terms of unit cost of production and productivity of capital) are taken into account in the setting process of price, 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 than those demanded by the market (it can be either smaller or greater then the demand). The firm's saving and its ability to pay current debts depend on real profit and income of that firm.

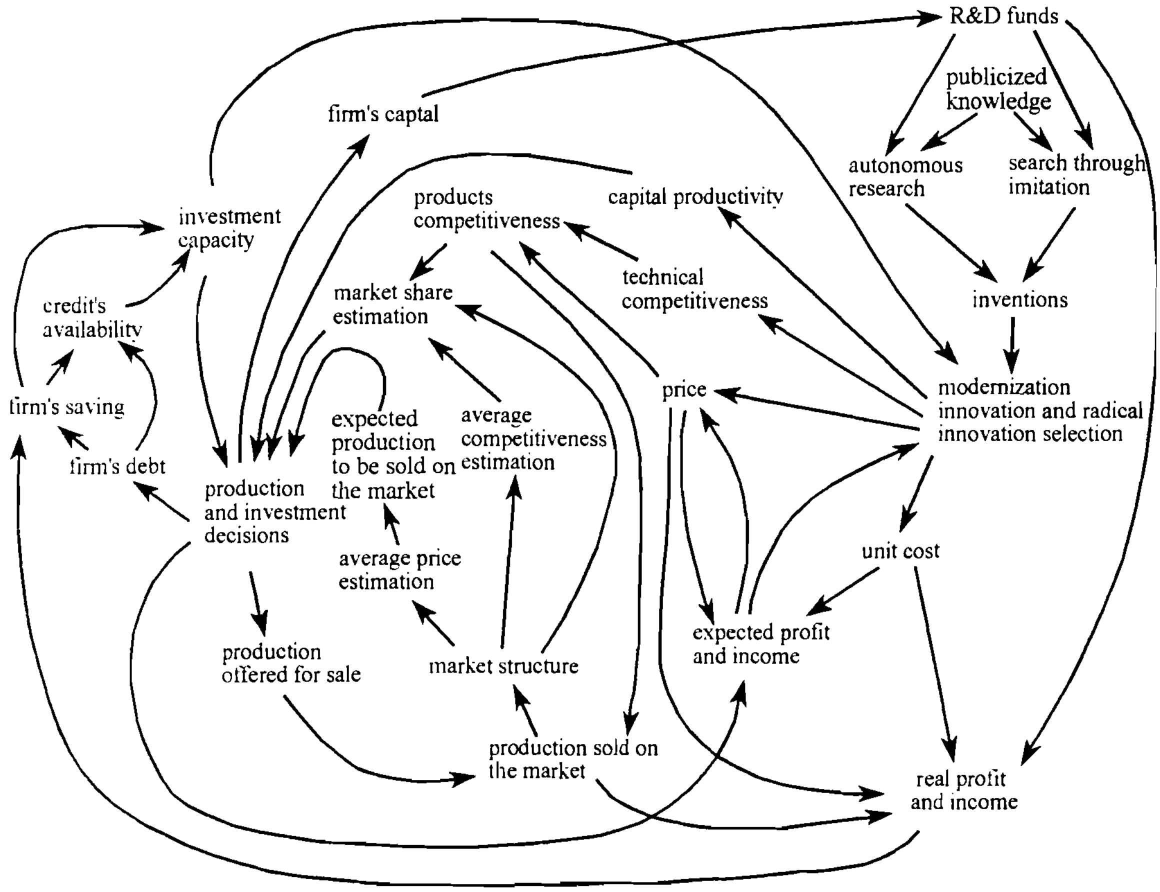

Fig. 2. Causal relationship in the evolutionary industrial model

We distinguish innovation and invention (i.e. a novelty being considered to be introduced into practice and become innovation). There are two general ways of searching for inventions, namely autonomous, in-house research of each firm and by imitation of competitors. Publicized knowledge allows not only for imitation of competitors. The public knowledge can relate also to the ways of making research, the arrow from the publicized knowledge to autonomous research indicate that influence. From a number of inventions only small fraction is selected to become innovations. An nnovation allows to modernize current production but also it can initiate new, radical way of production, i.e. by implanting essentially new technology. In general each innovation can induce reduction of the unit cost of production, increasing of the productivity of capital and improvements of technical product performance, but frequently it happens that improvement of one factor is accompanied by deterioration of the two other. Therefore usually firms face the problem of balancing positive and negative factors of each invention and accept it to become innovation if positive factors allows to fulfill firms' objectives.

SEARCH PROCESS

We assume that at time t a firm unit is characterized by a set of routines actually employed by the firm. There are two types of routines - **active**, i.e. routines employed by this firm in its every-day practice, and **latent**, i.e. 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, etc. 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 of generation of new sets of routines, namely: *mutation, recombination, transition and transposition.*

The probability of discovery of a new routine (*mutation*) depends on the research funds allocated by the firm for autonomous research, in-house development. The firm may also allocate some funds for gaining knowledge of other competing firms and try to imitate (*recombination*) some routines employed by competitors. It is assumed that recombination may occur only between segments, not between individual routines, i.e. a firm may gain knowledge about whole domain of activity of another firm e.g. by licensing. A single routine may be transmitted (*transition*) with some probability from firm to firm. It is assumed that after transition a routine belongs to a subset of latent routines. At any time a random *transposition* of a latent routine to a subset of active routines may occur. A more detailed description of the four basic mechanisms of evolution of routines is presented in the following sections.

Research Funds

It is assumed that R&D funds (R_i) allocated by a firm into research (*innovation* and *imitation*) are a function of actual firm capital (K_i) of the firm.

$$R_i = (h_2 \exp(-h_1 K_i) + h_0)\, K_i \qquad (1)$$

Research funds are proportional to a firm's capital if h_1 and h_2 are equal to zero. If h_1 and h_2 are greater than zero small firms allocate a greater percentage of their capital into research and a local maximum of R&D funds will appear near $K_i = 1/h_1$. Total R&D funds are partitioned into funds (R_i^m) for innovation (*mutation*) and funds (R_i^r) for imitation (*recombination*). The strategy of research of firm i at year t is described by the coefficient (g_i) of partition of total R&D expenditure into innovation and imitation.

$$R_i^m = g_i R_i \qquad R_i^r = (1-g_i) R_i \qquad (2)$$

The strategy of research changes from year to year and depends on the actual state of affairs of a firm. It is assumed that the share of research on innovation increases if the firm's share in global production is increasing (i.e. if assumed position of the firm on a background of other competing firm is good). If a firm's share decreases, more funds are allocated to imitation, i.e. a firm supposes that there are other firms applying better technology and it is better and safer to search for these technologies. The rate of change of coefficient g_i depends on the size of a firm and it is smaller the larger the firm is.

$$g_i(t+1) = (1 + \frac{G}{K_i} \frac{f_i(t) - f_i(t-1)}{f_i(t-1)})\, g_i(t) \tag{3}$$

where $g_i(t)$ is the coefficient of R&D funds partition at time t, G is the constant parameter controlling rate of change of g_i, and $f_i(t)$ is the share of firm i in global production at time t.

During any year of searching activity more than one set of new routines r' may be found. The number of such alternative sets of routines, the so-called number of experiments, is a function of research funds,

$$NoExp_i = round(e\ (R_i)^{\psi}\ ) + E_0 \tag{4}$$

where NoExp is the number of experiments of firm i, e, ψ, and E_0 are coefficients with the same values for all firms, R_i is the R&D expenditure of firm i, and round (x) is a function producing the closest integer number to x.

Mutation

We assume that routines mutate independently of each other. Since the range of the routines is bounded, we numerate all possible routines and assume that the range is from *MinRut* to *MaxRut*. Let r_{lk} denotes the l-th routine in the k-th segment employed by a firm in period (t-1,t). After mutation routine r_{lk} :

1. is not changed, i.e. $r'_{lk} = r_{lk}$, with probability (1-PrMut), or
2. is changed and is equal to

$$r'_{lk} = r_{lk} + x; \qquad x \in (-MaxMut, MaxMut)$$

with probability PrMut/(2·MaxMut) for every x.

The probability of mutation of a routine depends on R&D funds allocated by firm i to search for innovations,

$$PrMut_i = a^m\ (R_i^m)^{\zeta}\ + b^m \tag{5}$$

where a^m, ζ are coefficients controlling probability of mutation, and b^m is the probability of mutation related to the public knowledge.

Maximum scope of search depends also on the funds allocated to autonomous research, and we assume that,

$$MaxMut_i = a^u\ (R_i^m)^{\vartheta}\ + b^u \tag{6}$$

where a^u, ϑ are coefficients controlling the scope of mutation, and b^u is the scope of mutation related to the public knowledge.

Recombination

A firm i may get knowledge about the routines of a single segment of a firm j with probability *PrRec*. At the same time the firm i may get knowledge employed by different firms, so new sets of routines may consist of routines of different firms. In the model the firm i may apply one of three strategies of recombination:

(1) conditional probability of recombination of segment k of firm-unit i with segment k of firm-unit j is proportional to the share of firm-unit j in global production;
(2) conditional probability of recombination of segment k of firm-unit i with segment k of firm-unit j is proportional to the rate of expansion of firm-unit j, i.e. is proportional to the derivative of the share of firm-unit j;
(3) conditional probability of recombination of segment k of firm-unit i with segment k of firm-unit j is reciprocal to the number of firms existing in the market, i.e. is equal for each firm-unit j.

The probability of recombination of a segment is a function of R&D funds allocated to imitation:

$$PrRec_i = a^r \, (R_i^r)^\xi + b^r \tag{7}$$

where a^r, ξ are coefficients controlling probability of recombination, b^r is the probability of recombination related to the public knowledge.

Transition, Transposition and Recrudescence

We assume 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) are independent of R&D funds, and have the same constant value for all routines. 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 we observe very active processes of search for new combination of routines. We call this phenomena recrudescence. We view recrudescence as an intrinsic ability of a firm's research staff to search for original, radical innovations by employing some daring, sometime looking as insane ideas. This ability is connected mainly with the personalities of the researchers and random factors play an essential role in search for innovations by recrudescence, so the probability of recrudescence is not related to R&D funds allocated by a firm to 'normal' research.

We assume that recrudescence is more probable in small firms than in large ones which spend huge quantities on R&D, although by assuming that u_2 is equal to zero in the below equation we get that the probability of recrudescence does not depend on the firm's size and is constant (equal to u_1). The probability of recrudescence in firm i is equal to,

$$PrRence_i = u_1 \exp(-u_2 \, K_i) \tag{8}$$

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

PRODUCTS' DIFFERENTIATION

Productivity of capital (A), variable cost of production (V) and product characteristics (z) are functions of the routines employed by a firm. Each routine has multiple, pleiotropic effects, i.e. may affect many products characteristics, as well as productivity, and the variable cost of production.

We assume that the transformation of the set of routines into the set of products' characteristics is described by m functions F_d,

$$z_d = F_d(r) \qquad d = 1,2,3,...,m \tag{9}$$

where z_d is the value of d characteristic, m the number of products' characteristics, and r the set of routines.

We distinguish two kinds of a product's competitiveness: technical competitiveness and overall competitiveness (or simply competitiveness). The technical competitiveness reflects the quality of technical performance of the product on the market. The technical competitiveness depends directly on values of the product's technical characteristics, such as e.g. reliability, convenience, lifetime, safety of use, cost of use, quality, aesthetic values. The overall competitiveness describes the product's attractiveness on the market and depends on technical competitiveness and the product's price. Competitiveness, as the measure of products attractiveness, is the greater the smaller is the product's price and the better technical performance of this product. In the presence of innovation the technical competitiveness varies accordingly to modification of routines made by each firm, or due to introducing essentially new routines. Technical competitiveness is an explicit function of products' characteristics. As it was said each routine does not influence directly product's performance but indirectly through influences of the products' characteristics. We assume the existence of a function q enabling calculation of technical competitiveness of products manufactured by different firms. We say that function q describes the adaptive landscape in the space of products' characteristics. In general this function depends also on some external factors, vary in time, and is the result of co-evolution of many related industries. We say that the shape of adaptive landscape is dynamic, with many adaptive peaks of varying altitudes. In the course of time some adaptive peaks lost their relevant importance, some become higher.

The competitiveness of products with characteristics z and price p is equal to,

$$c(p_i(t), z) = \frac{q(z)}{(p_i(t))^{\alpha}}, \qquad z = (z_1, z_2, z_3, \dots, z_m) \tag{10}$$

where q(z) is the technical competitiveness, z a vector of products' characteristics, and α the elasticity of price in the competitiveness; α is characteristic of the market and describes the sensitivity of the market on price fluctuations.

Due to the ongoing search process, at any moment each firm may find a number of alternative sets of routines. Lets 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 the old routines r by applying the decision making procedure presented in the former section. The only difference is that values of productivity of capital A, the unit cost of production V, and technical competitiveness q are not constant but are modified accordingly to actually considered set of routines, either r or r'. 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 making modernization (i.e. replacing the r routines by r' routines) depends on the expected value of the firm's objective and investment firm's capabilities. Modernization is made if the maximum value of the objective distinguished from the all considered alternative sets of routines r' is greater than the value of objective possible to get 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 to make the 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 the capital, *InitCapital.*

We assume that the productivity function A(r) and the cost functions V(r) are not firm specific and have the same function's form for all firms.

To modernize production it is necessary to incur an extra investment. The modernization investment depends on the discrepancy between the 'old' routines r and the 'new' routines r'. For simplicity of calculation, we assume that the modernization investment IM is non-decreasing function of distance between the old routines r actually applied by a firm and the new set of routines r'.

$$IM_i(t) = K_i(t) \parallel r - r' \parallel \quad (11)$$

where $\parallel .. \parallel$ is the distance function.

Our model does not include explicitly the notion of labor, considered in economic analysis as the classical factor of production. Such important economic characteristics as labor and wages ought to be present in any model, and are present in our model, although indirectly, namely they are present in the cost functions V(r). At current stage of the model's development it is not necessary to disaggregate the cost's functions, although there is still open possibility to isolate labor and wages and built them explicitly into the model. It will be done in future development of the model as the natural process the model's stepwise concretization.

It is a kind of tradition that if economists speak on technological progress and innovation they distinguish two kinds of innovation - namely product and process innovation. The discrimination of such type of innovation is not relevant to our approach. We focus our interest on innovation which influence some operationally defined economic variables such e.g. cost of production, productivity of capital or technical product's performance. But, although in hidden form, process and product innovation are present in our model - we may say that innovation focused on reduction of cost of production, and partly on productivity of capital is related to the process innovation, and innovation aiming for better technical performance of products is mainly related to the product innovation.

FIRMS' DECISIONS

It seems that one of the crucial problem 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 avoid direct inquiry and observations of the process." (Simon, 1986, p.38). The other problem is how to model this process using some formal apparatus. There are a lot of attempts to imitate real decision making processes, some of them very sophisticated and very close to reality. Our purpose, being a first approximation, is to catch the general and the most essential features of firms' decision making process and at this stage of the model's development we see no necessity to feature this process in details. What we propose is only first, very rough approximation of the decision making process on the firm's level. This proposition does not close the road for further development of the procedure modeling decision making process in subsequent versions of the model.

Here we present the procedure of evaluation of production, investment, expected income and profit in the succeeding instant of time of firm *i* selling its product at product price $p_i(t)$. The problem of choosing the appropriate price $p_i(t)$ will be discussed later on.

(a) Calculation of the product's competitiveness $c_i(t)$.

For a given value of the technical competitiveness q and the price p_i the value of the product competitiveness (see eq. 10) ic calcualted. Let's denote by $c_i(t)$ competitiveness of products of firm *i* at time t, i.e. $c_i(t) = c(p_i(t), z)$.

(b) Estimation of the average price and average competitiveness.

It may be said, making no rudimentary exaggeration, that all man's decisions are made on the basis of his expectations, but as Herbert Simon asserts: "economists do not disagree about many things, but they disagree about a few crucial things, in particular, how people form expectations." (Simon, 1986, p. 504) It is rationale to assume that, in general, each firm does not know anything about current and future decisions of competitors. We assume that the decisions of each firm are made independently on the basis of the firm's expectations what other firms (competitors) will decide. The simplest assumption is that in the next period the competitors will behave in a similar way as in the past. Therefore the firm *i* estimates that in the succeeding period (t,t+1) the average price will be equal to

$$p^e(t) = p^p(t)\ (1-f_i(t-1)) + p_i(t)\ f_i(t-1) \qquad (12)$$

Similarly, the average competitiveness is expected to be equal to

$$c^e(t) = c^p(t)\ (1-f_i(t-1)) + c_i(t)\ f_i(t-1) \qquad (13)$$

where $f_i(t-1)$ is the market share of firm *i* in the previous instant of time, $p^p(t)$ and $c^p(t)$ are trend values of average price and average competitiveness, respectively.[2] It is assumed that the prediction of the trend values $p^p(t)$ and $c^p(t)$ are made outside of the industry and are known to all firms. Different formulas to calculate these values are built-in the model (e.g. moving averages, linear and exponential trends) but in all simulations presented below the exponential trend $[A\cdot\exp(B\cdot t)]$ is assumed; values of the average price and the average competitiveness in the last 5 years of industry development suit to calculate the optimal values of the parameters A and B.

The equations (12) and (13) enable us to model diversified situations faced by different firms, e.g. weight of small firm to form the average price is much smaller then the large firms, 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, and vice versa, large firms play, in general, the role of 'price leaders' or 'price makers' so their weight in formation of the future average price is much more significant.

(c) Estimation of the global production.

After apprehending the average price of all product on the market an estimation of the global production sold on the market, i.e the global demand $Q^d(t)$, may be done.

We assume that all firms know the demand function and the demand function is equal to

$$Q^d(t) = \frac{M(t)}{p^e(t)} \qquad (14)$$

M(t) is an amount of money which the market is inclined to spend to buy products with an average price $p^e(t)$. We assume that

$$M(t) = N \exp(\gamma t)\ (p^e(t))^\beta \qquad (15)$$

[2] The expressions in eqs. (12) and (13) have the same mathematical form for each firm. It is simplification, made by us intentionally to catch the most essential features of the industrial processes. From evolutionary perspective the formulas ought to be firm's specific in which the knowledge (firm's routines) and firm's experience ought to be embedded. We hope to make the next 'stepwise concretization' in this direction after gathering the results of first elementary experiments of the model.

where N is a parameter characterizing the initial market size, γ the growth rate of the market size, and β the elasticity of the average price.

The consumption theory and results of empirical research (e.g. McConnell, 1984, p. 415) show that almost all price elasticities in demand functions are negative: for primary needs (like e.g. food, clothing) elasticities are between 0 and -1, that of secondary (or "luxury") needs are below -1. So, it may be expected that for commodities fulfilling primary needs β is greater than zero and smaller then one and for commodities fulfilling higher order needs (e.g. entertainment) β is smaller than zero.

(d) Estimation of the market share of firm i.

After estimation of the average competitiveness of all product offered for sale on the market and perceiving the competitiveness of its own products firm *i* may try to estimate its future market share. We propose deterministic selective equations similar to those used in our former models of evolutionary processes (Kwasnicki, 1979; Kwasnicka, et al., 1983). The share of firm i in period (t,t+1) is equal to

$$f_i(t) = f_i(t-1)\,\frac{c_i(t)}{c^e(t)} \tag{16}$$

It means that the share of firm *i* increase if its products' competitiveness is greater then the average competitiveness of all products offered for sale on the market and decline if the competitiveness is smaller then the average competitiveness.[3]

(e) Estimation of the production of firm *i*.

Having the expected share and the expected size of the market, firm *i* is able to estimate quantity of production to be accepted by the market (i.e. the supply of production of firm i) on the basis of the simple equation,

$$Q_i^s(t) = f_i(t)\,Q^d(t) \tag{17}$$

Capital needed to produce output $Q_i^s(t)$ is equal to

$$K_i(t) = Q_i^s(t)/A \tag{18}$$

'A' in the above equation is the productivity of capital.

If required growth of the capital of firm *i* is greater than the investment capability of firm *i* then it is assumed that the capital of firm *i* at time *t* is equal to the sum of the investment capability and the capital at *t*-1, minus the capital physical depreciation (the amortization). For such calculated capital the production $Q_i^s(t)$ is recalculated as

[3] There is possibility to apply stochastic selective equations. Probably the stochastic equations would be closer to reality due to essentially random process of 'meeting' specific product with specific buyer, but at actual level of development of the model the deterministic selective equations catch the problem and give satisfactory results. The proposed selective equations may be treated as first approximation and there is still open possibility to make them stochastic after thorough investigation of the deterministic model. Our intention is that at the initial stage of the model's enquiry the random factors ought to be related only to the innovation process, to enable full evaluation of the influence of innovation on the behaviour of the model. From its nature the search for innovation is a stochastic process and assumption of deterministic process of innovations' emergence leads to significant departure of the model's behaviour from patterns of development observed in real processes.

$$Q_i^s(t) = K_i(t)\,A \tag{19}$$

(f) Estimation of the expected income and profit.

The last step in the decision making procedure is calculation of the expected income and profit of firm i, which are equal to

$$\Gamma_i = Q_i^s(t)\,(p_i(t) - V\,v(Q_i^s(t)) - \eta) \tag{20}$$

$$\Pi_i = \Gamma_i - K_i(t)\,(\rho + \delta) \tag{21}$$

where Γ_i is the expected income of firm i at time t+1, Π_i is the expected profit of firm i at time t+1, $Q_i^s(t)$ the output (supply) of firm i, V the unit production cost (because there is no innovation, V is constant and uniform for all firms during the simulation), $v(Q_i^s)$ is the factor of unit production cost as the function of a scale of production (economies of scale), η is the constant production cost, $K_i(t)$ the capital needed to manufacture the output $Q_i^s(t)$, ρ the normal rate of return, δ the physical capital depreciation rate (the amortization).

For a given price $p_i(t)$ the expansionary investment, the production in the next year, and expected profit and income are calculated by applying the procedure presented above. The problem needed to be discussed is the way of choosing the products' price $p_i(t)$. We assume that a firm takes into account its investment capabilities and evaluates (estimates) values of an objective function for different values of price of its products. The price for which the objective function reaches the maximum value is chosen by a firm as the price of its products. It is not maximization in strict sense. The estimation of values of the objective function is not perfect and made only for the next year, so this is not global, once and for all, optimization, the firms apply this rule from year to year.

Different price setting procedures (based on different objective functions and the markup rules) have been scrutinized, the results are presented in (Kwasnicki, Kwasnicka, 1992). The results suggest that firms apply the following objective function:

$$O_1(t+1) = (1-F_i)\,\frac{\Gamma_i(t+1)}{\Gamma(t)} + F_i\,\frac{Q_i^s(t+1)}{QS(t)}$$
$$F_i = a_4 \exp\left(-a_5\,\frac{Q_i^s(t+1)}{QS(t)}\right) \tag{22}$$

where F_i is the magnitude coefficient (with values between 0 and 1), Q_i^s the supply production of firm i in year t+1, Γ_i the expected income of firm i at t+1 (defined by equation (20)), QS is the global production of the industry in year t, Γ the global net income of all firms in year t. $\Gamma(t)$ and QS(t) play the role of constants in the equation (22) and provide the values of both terms in this equation to be of the same order.

The O_1 function expresses short- and long-term thinking of firms during the decision making process (the first and second terms in equation (22), respectively). The plausible values of the parameters are $a_4 = 1$ and $a_5 = 5$ (Kwasnicki, Kwasnicka, 1992); it means that the long term-thinking is much more important for the firms survival and that the firms apply flexible strategy i.e. the relative importance of short- and long-term changes in the course of firms development (the long-term is much more important for the small firms than for the big ones).

The decision making procedure presented above with the search for the 'optimal' price procedure based on the objective concept construct the formal scheme to find the proper value of the price. We treat this scheme as an approximation (abstraction) of what is made by real decision makers. They of course do not make such calculations from year to year, they think rather in the routine mode: "My decisions ought to 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 future level of production and the future products' price depend on the actual investment capabilities of the firm. There is possible to embody in the model different ways of calculation of firms' investment capabilities. We propose to investigate two formulas. One as proposed by Nelson and Winter (1982), and Winter (1984) in which the investment capability of the firm *i* in period $(t,t+1)$ is a function of profits (Π) of the firm *i* in period $(t-1,t)$ and the second in which the investment capability depends on the firm's current saving (SV). Let's call these two strategies as the Π-investment and the SV-investment strategies, respectively.

Investment capability of firm i in the Π-investment is equal to:

$$IC_i(t) = \max\{0,\ \delta\ K_i(t-1) + \mu\ \Pi_i(t-1)\} \tag{23}$$

where δ is the physical capital depreciation, μ the coefficient equal to 1 for $\Pi_i < 0$, and equal to μ_0 for $\Pi_i > 0$.

The credit parameter μ_0 is greater or equal to one. If μ_0 is greater then one, firm i takes credit if its overall investment $I_i(t)$ at time t exceeds the sum of the amortization and the profit of the firm at $(t-1)$. Nelson and Winter (1982) do not mention anything about the way of taking credit and future its repaying. As we understand a firm in this model takes credits from banks if required investment exceeds its current profit, without taking care on future repaying it..

We propose to incorporate more explicitly the process of credits taking and its future repaying. In the SV-investment strategy we assume that at every year a firm spare a fraction of its current profit for saving to be invested in future firm's development. If at any time required investment exceeds current savings then the firm takes credit and its debt increases. The debt is repaid within assumed period. The savings and debts increase every year accordingly to assumed interest rate ρ_1.

If we assume that credit ought to be repaid on average within μ_1 years then the compensations (the debt repay) in the next year is equal to

$$DR_i(t) = D_i(t-1)/\mu_1 \tag{24}$$

The investment capability of firm *i* at time *t* depends on current savings SV_i and current compensations DR_i, and is equal to (meaning of parameters δ and μ as in equation (23)):

$$IC_i(t) = \max\{0,\ \delta\ K_i(t-1) + \mu\ (SV_i(t-1) - DR_i(t))\} \tag{25}$$

It may happen that required investment of firm *i* exceeds the firms own funds (equal to the sum of amortization $\delta \cdot K_i(t-1)$ and current savings $(SV_i - DR_i)$). If this is a case and μ is greater then 1 the firm takes credit to finance the exceeding investment. Let's denote by ICr_i the investment financed by credit and by IS_i investment financed by the firm's own savings (i.e. the capital depreciation funds $\delta \cdot K_i(t-1)$ excluded). To simplify the calculations, we do not consider the structure of debt (i.e. we do not recognize moments of credits' taking), so we assume, as a first approximation, that the debt at time t is characterized by its total value, i.e. is equal to

$$D_i(t) = (D_i(t-1) - DR_i(t))\ (1+\rho_1) + ICr_i(t) \tag{26}$$

The debt is diminished by the current repayment and increase accordingly to the interest rate (the first term) and is enlarged by current investment financed by credit, ICr_i. At each year the firm i spare a fraction of its current profit for savings. We assume that fraction of profit spent for savings depends on relation of current savings and firm's capital, the greater savings the less fraction of actual profit (if positive) is passed for savings. A parameter *ToSave* controls the fraction of profit for savings. To delimit the amount of money passed for saving SP_i we use the following formula (the expression exp(∘) is a fraction of positive profit spent for saving):

$$SP_i(t) = \max\{0, \Pi_i(t)\} \exp\left(-\frac{SV_i(t-1)}{ToSave\, K_i(t-1)}\right) \tag{27}$$

The savings at time t are reduced by current obligations related to repay the debt DR_i, multiplied accordingly to the interest rate ρ_1, reduced by the investment financed from firm's own resources IS_i ,and raised by current savings from profit, so the saving is equal to

$$SV_i(t) = (SV_i(t-1) - DR_i(t))\,(1+\rho_1) - IS_i(t) + SP_i(t) \tag{28}$$

FIRMS' ENTRY

In each period $(t,t+1)$ a number of firms try to enter the market. Each firm enters the market with assumed capital equal to *InitCapital* and with the initial price of its products equal to the predicted average price. The number of potential entrants (i.e. firms trying to enter the market) is the greater the larger is the concentration of the industry.

In general any firm may enter the market and if firm's characteristics are unsatisfactory then the firm is quickly eliminated (superseded) from the market. But due to limited capacity of computer's memory we assume a threshold for entrants, namely to control a number of entering firm we assume that a firm enter the market if estimated value of objective O_1 of that firm is greater then an estimated average value of the objective O_1 within the industry.[4] Making this assumption we provide higher competitive environment for all firms - for operating firms and for entrants.

As the result of competition the market shares of firms with competitiveness smaller than average competitiveness decrease, and the shares of firms with competitiveness greater than average competitiveness increase. A firm is driven from the market if it does not keep pace with competitors (i.e. in the long run its products' competitiveness is smaller than the average competitiveness). To limit the number of very small firms we assume also that a firm is eliminated from the register of firms if its market share is smaller than some assumed minimum share (e.g. 0.1%), or if its current debt exceeds an assumed fraction of the firm's current capital (e.g. 90%).

COMPETITION OF PRODUCTS IN THE MARKET

All products manufactured by the entrants and the firms existing in the previous period are put on the market and evaluated. Since that time all decisions are left to buyers, whose decisions primary depend on the relative values of competitiveness of all offered products, but quantities of products of each firm offered for sale are also taken into account.
We assume that the global demand of products, $Q^d(t)$, 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, as it

[4] It may be expected that similar threshold exist in real industrial processes.

was presented in the decision making procedure; see equations (14) and (15) defining the demand function, where instead of $p^e(t)$ it is necessary to place p(t). The only difference is that in the decision making process firms use their estimated values of the average price, as the result of their expectations of future market and the competitors behaviours, and here the average price in the demand function is counted using the whole pool of products offered for sale on the market (i.e. the supply). Therefore the average price of products is equal to:

$$p(t) = \sum_i p_i(t) \frac{Q_i^s(t)}{Q^s(t)} \tag{29}$$

The global output offered for sale (the supply) is equal to

$$Q^s(t) = \sum_i Q_i^s(t) \tag{30}$$

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

$$QS(t) = \min \{ Q^d(t), Q^s(t) \} \tag{31}$$

The general selection equations of firm competition in a market has the following form (for comment see also footnote 3 on page 12),

$$f_i(t) = f_i(t-1) \frac{c_i(t)}{c(t)} \tag{32}$$

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

$$c(t) = \sum_i f_i(t-1)\, c_i(t) \tag{33}$$

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

The quantity of products potentially sold by the firm *i* on the market (i.e. the demand for products of firm i) is equal to

$$Q_i^d(t) = QS(t)\, f_i(t) \tag{34}$$

The above equations are valid if the production offered by the firms fits exactly the demand of the market. This is a very rare state and therefore these equations have to be adjusted to states of discrepancy between global demand and global production, and of discrepancy between the demand for products of specific firm and the production offered by this firm. Equation (34) describes the market demand for products of firm i offered by the price $p_i(t)$ and with the competitiveness $c_i(t)$. In general the real production (the supply) of firm i is different then 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 the demand, $Q_i^d(t)$, and the supply, $Q_i^s(t)$, but on the whole pool of products offered for sale on the market. The alignment of the supply and demand of production of all firms present on the market is an adaptive process performed in highly iterative and interactive mode between sellers and buyers. In our model we simulate the iterative alignment of the supply and the demand in 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 succeeding stage of the alignment. If there is no global oversupply of production then in the first stage of the supply-demand alignment process all demands for production of specific firms, wherever possible, are fulfilled, but there is still the unsatisfied production of firms which underestimated the demands for their products. This part of the demand is fulfilled in the second stage of the supply-demand alignment process. At this stage the products of the firms which produce more then the specific demand are sold instead of the production unsatisfied by the firms which underestimated the demand for their products.

The supply-demand alignment process is slightly different if the global oversupply of production occurs. It seems to us reasonable to assume that in such a case the production of each firm sold on the market is partitioned into (1) the production bought as the outcome of the competitive process (as described by the equations (32) and (34)), and (2) the production bought as the outcome of the non-competitive process (lets call it the cooperative process) - in principle this part of production does not depend on the products competitiveness but primarily depends on the mass of production offered for sale, i.e. random factors play much important role in preference of relevant products to be bought within this part of the production. In general the partition of the production of each firm into these two parts depends on the value of the global oversupply. The higher the oversupply the larger part of production of each firm is sold on the basis of the non-competitive preferences.

To evaluate the shares of these two parts of production we construct the coefficient w which depends on the global demand and the global supply, namely

$$w = \min\left\{1, \frac{Q^d(t)}{Q^s(t)}\right\} \tag{35}$$

The coefficient **w** divides the behaviour of the model into two regimes: **w** is equal to one if the demand exceeds the supply, and is smaller than one for the oversupplied market. If there is no global oversupply (i.e. w = 1) then, as it was said, the products of the firms which produce more than the demand are sold instead of the potential production of the firms which produce less than the demand (it is done in the second stage of the supply-demand alignment process, see below). If there is global oversupply then maximum w·100% of the demand is supplied by the production of each firm in the first, competitive stage of the alignment process, and the rest (1-w)·100% of the demand is supplied in the second, cooperative stage (if such production is available).

Usually the global oversupply, if occurs, is small so the majority of production is distributed under the influence of the competitive mechanisms and only small part is distributed as the result of the cooperative distribution. But to understood the necessity of distinguishing the two proposed stages of selling-buying process let's consider the following, albeit artificial, situation: with one firm exception, the production of all other firms meet exactly the demand for their products. The peculiar firm produces much greater then the demand for its products. The question is, what is the result of the market selling-buying process? We may assume that the production sold by all firms is exactly equal to the specific demands for their products, what is equivalent to assumption that the mass of the overproduction made by the odd firm does not influence the behaviour of the market. In extreme case we may image that the volume of the production of the odd firm is infinite and the rest firms still produce exactly what is demanded. Does it still mean that the abundant products will be unnoticed by the buyers and still they will be clung to the infinitesimal production of all firms producing exactly what is demanded? It seems to us that more adequate description require 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 odd firm. And it seems that in the case of the overproduction of one firm its share in the global production sold will increase in the expense of all firms producing exactly what is demanded. In the extreme case, when overproduction of the odd firm goes to be infinite (i.e. the coefficient w is approaching zero) the only products sold on the market belongs to that firm, and the shares of all other firm are going to be zero. But it does not mean that producing more then it is demanded is advantageous strategy for the firm and that it is effective weapon to eliminate the competitors; in fact the bulk of the overproduction is not sold on the market and lost by the firm. In effect the odd firm's profit is much smaller then expected, or even may be negative, and after some period the firm's development will be stopped and in the end the firm will be eliminated from the market.

Incorporation of coefficient w enables also the entry of new competitors on the market. Without the assumption of the two stage distribution in the supply-demand alignment process the entry of new firm might be very difficult, and it would be necessary to add special procedure to allow the entry in the case of the global oversupply. In a case of the global oversupply, when all firms' production meet the demands for their products, there would be place for the entrants. The competition process, as described by the selection equation (32), can not be initiated due to the zero value of the share of the entrant in the previous instant of time, $f_i(t-1)$. The assumption that the (1-w) fraction of the global demand is fulfilled in the cooperative stage of the alignment process enable the entry of new firms. Similarly the entry is possible if there is no global oversupply (i.e. w = 1). In such a case there is the place on the market for the entrant and, in general, all its production is sold on the market.

We assume that at the competitive stage of the supply-demand alignment process the demand is partially fulfilled by production $QS_i'(t)$,

$$\begin{aligned} QS_i'(t) &= \min\{Q_i^s(t), w\, Q_i^d(t)\} = \min\{Q_i^s(t), w\, QS(t)\, f_i(t)\} \\ QS_i'(t) &= \min\{Q_i^s(t), w\, QS(t)\, f_i(t-1)\frac{c_i(t)}{c(t)}\} \end{aligned} \tag{36}$$

The rest (1-w) fraction of the demand may be fulfilled in the cooperative stage if there is such production available i.e. if $Q_i^s(t) > w \cdot Q_i^d(t)$. We assume that this fraction of the demand is fulfilled in the cooperative stage accordingly to the distribution of unsold products in the competitive stage.

After completion of the competitive stage of the supply-demand alignment process the global production sold is equal to

$$QS'(t) = \sum_i QS_i'(t) = \sum_i \min\{Q_i^s(t), w\, Q_i^d(t)\} \tag{37}$$

So the unfulfilled global production after the first stage, to be supplied in the second stage of the alignment, is equal to

$$QS''(t) = QS(t) - QS'(t) \tag{38}$$

The unsold production $QN_i(t)$ of firm i is equal to

$$QN_i(t) = \min\{0,\ Q_i^s(t) - w\, Q_i^d(t)\} \tag{39}$$

The fraction of unsold products of firm *i* in the global production unsold in the first stage of the alignment process is equal to

$$f_i^{\prime\prime} = \frac{QN_i(t)}{\sum_j QN_j(t)} = \frac{\min\{0,\ Q_i^s(t)-w\ Q_i^d(t)\}}{\sum_j \min\{0,\ Q_j^s(t)-w\ Q_j^d(t)\}} \tag{40}$$

We assume that the fulfillment of the demand for products of firm *i* in the cooperative stage of the alignment process is proportional to the fraction f_i'', so

$$QS_i''(t) = QS''(t)\, f_i'' = (QS(t)-QS'(t))\, f_i'' \tag{41}$$

Finally the production sold is the sum of production accepted in the competitive and the cooperative stages of the supply-demand alignment process,

$$\begin{aligned} QS_i(t) &= QS_i'(t) + QS_i''(t) \\ QS_i(t) &= \min\{Q_i^s(t), w\ Q_i^d(t)\} + (QS(t)-QS'(t))\, f_i'' \end{aligned} \tag{42}$$

The general meaning of the supply-demand alignment process as described above parallels that of equations ((32), (33), (34)). If supply exactly meets market demand (i.e. if $Q^s(t) = Q^d(t)$ and $Q_i^s(t) = Q_i^d(t)$ for all i), equations from (35) to (42) are equivalent to equations (32) to (34).

The market share of the production sold of firm i is equal to

$$f_i(t) = \frac{QS_i(t)}{QS(t)} \tag{43}$$

The research is financed from the current firms income so the real income and profit of firm *i* is equal to

$$\Gamma_i = QS_i(t)\ (p_i(t)-V(r)\ v(Q_i(t))-\eta) \tag{44}$$

$$\Pi_i = \Gamma_i - K_i(t)\ (\rho+\delta) - D_i(t)/\mu_1 - R_i(t) \tag{45}$$

where Q_i^s is the current production of firm i, QS the production of firm i sold on the market, p the products' price, V(r) the unit cost of production when routines r are applied; $K_i(t)$ in the above equations is the value of capital allocated by firm *i* to produce the output $Q_i^s(t)$, so profits are smaller than expected if the firm inappropriately evaluates the required level of production and manufactures more than it can sell in the market.[5]

Effective capital of the firm is equal to

[5] There arise the question what is done with the outstripped production. We assume that this part of production is lost. It is possible to incorporate the backlogs into the model, but this leads to much greater model's complexity in the presence of innovations. The production may be modernized due to applied innovations, so it would be necessary to remember the quantities of orders and unsold production at different instants of time together with its technical characteristics. It seems that our assumption on the outstripped production does not lead to large errors, bearing in mind that (1) the model is focused on long term industry development, (2) yearly overproduction is normally not very high, and (3) to consider backlogs and delivery delays it would be necessary to take into account also all related costs e.g. of storing of the not sold production.

$$K_i(t) = QS_i(t)/A \tag{46}$$

Global sales are equal to

$$GS(t) = \sum_i QS_i(t)\ p_i(t) \tag{47}$$

The market share of firm i in global sales is equal to

$$fs_i(t) = QS_i(t)\ p_i(t)/GS(t) \tag{48}$$

II. Innovation – Groping in the Dark

In all simulation experiments presented below the number of firms is constant, equal to 12. No entry of new firms is assumed in this section, mainly to provide the comparability of results in different runs under the same simulation conditions. There is no possibility to abstain from the randomness of the development in the presence of innovation, the search process is by its nature a stochastic one. Also the entry of new firms is a stochastic process. Involving two stochastic processes causes problems in the proper interpretation of results, so without losing the generality of consideration it is reasonable to assume that no new firm may enter the market. But in some specific experiments the free entry will be allowed.

The search for innovation is a result of interplay of different mechanisms of novelty generation, i.e. different strategies of search. Dichotomously the firms' strategies may be partitioned into: innovation search (i.e. an attempt to search for real novelty through autonomous, in-house research of a firm) and imitation (i.e. search for innovation through recombination of some existing solutions). But within the innovation strategy two mechanisms ought to be distinguished: search for novelty through relatively small modification of current solutions and search for radical novelty through essential rebuilding (reshaping) of existing solutions. Let us call the innovation strategy through moderate modifications as 'mutation' and the search strategy for a radical novelty as '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 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 towards 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.[6] It seems that the practice of re-

[6] The evolutionary development (with the presence of innovation) resembles the trip of Alice with the Red Queen from "the Second Square" to "the Eight 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 Alice that "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*

crudescence is different. As we have said before, recrudescence reflects phenomena frequently observed in creative processes and described as revelation, vision, bisociation (Arthur Koestler), or gestalt–switch (Karl Popper).

Contrary to imitation and mutation, recrudescence is hardly detectable during the 'normal' research, and may be called the dormant mechanism, but is fervent 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 these inventions are useless but some of them initiate the way for emergence of radical innovation which focuses attention of the majority of researchers; in effect the ratio of 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 with the economic state of affairs – during the 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. The results of such series of experiments are presented in Fig. 3 and in Table 1 (for each mechanism, results of two simulation runs with relatively small and large probabilities of innovation emergence – labelled by us as 'normal' and 'high' – are presented). Adaptive landscapes describing the performance index (technical competitiveness) are defined in the space of technical characteristics – $q(z)$ in equation 10. As we may expect 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 complicated landscape by relevant definition of function $q(z)$, but to control the results of experiments it is better to start simulation with simple, stable adaptive landscapes. In the following experiment we assume that there are

Table 1. The innovation strategies

	n_H	Π/K %	Price	Price st.dev. %	A (100)	q (100)	V (100)
Innovation (mutation)							
normal	7.55	5.09	6.82	5.56	0.106	0.83	4.91
high	5.85	7.13	7.05	6.05	0.100	0.96	4.74
Innovation and Imitation (private knowledge only)							
normal	9.82	0.53	6.41	2.00	0.106	0.97	4.87
high	10.00	0.48	6.40	1.69	0.114	0.99	4.84
Innovation and Imitation (public knowledge only)							
normal	10.31	0.77	6.40	1.57	0.109	0.95	4.83
high	10.72	0.12	6.36	1.42	0.100	0.97	4.85
Innovation, Imitation and Recrudescence							
	6.04	0.33	6.18	5.41	0.155	1.14	4.91

Looking-Glass, Lettrex, Warszawa, 1991, Chapter II.

only two technical characteristics,[7] the adaptive landscape does not change its shape during the simulation and there are two local peaks with altitudes equal to 1.0 and 1.5.

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 higher peak provide 50% better performance than the solutions around the lower peak. The map of this adaptive landscape is presented in Fig. 3. The initial values of the product characteristics are much closer to the first lower peak so we may expect that trajectory of evolution at the first stage of the industry development will evolve towards the lower peak and next the firms will try to find better products with characteristics closer to the second, higher peak. 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, that is, during the R&D precess firms evaluate the performance index, i.e. the technical competitiveness, of specific product with assumed values of characteristics[8]. 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 Fig. 3. The performance index (i.e. technical competitiveness) of products defined by known values of their characteristics marked by dots is known for firms (and only this part of adaptive landscape is known for individual firms, i.e. these firms which make 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 Fig. 3 suggest also differences in the vigorousness of the search process. Some of the inventions are adopted by firms and become innovations, i.e. products offered for sale on the market. Average values of characteristics of products sold on the market at any time t are markėd

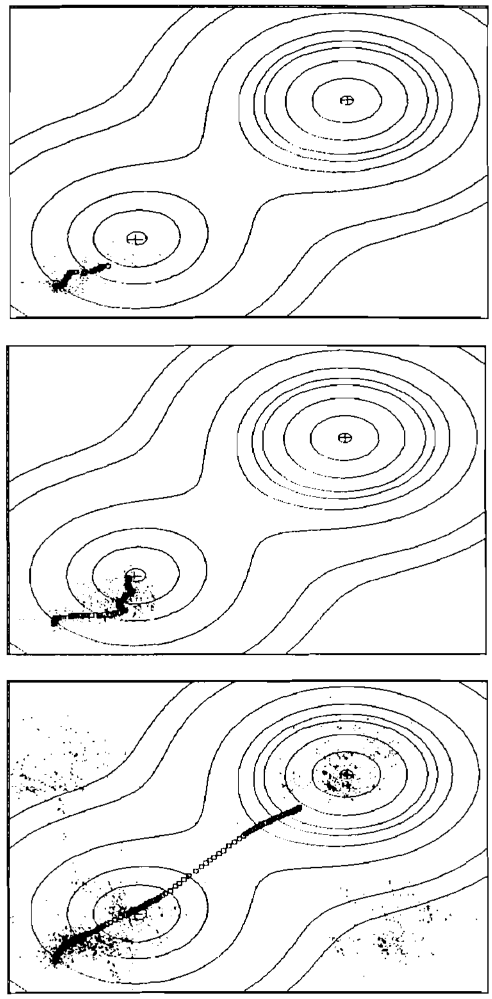

Fig. 3. Trajectories of development for different modes of the search process

[7] The only reason to assume two characteristics is the convenience of graphical presentation of simulation results, there is no constraint to assume greater number of characteristics. Findings for the two-dimensional landscape are valid for higher dimensional ones.

[8] To enable proper evaluation of the simulation results, it is assumed that all firms are able to calculate exact values of the performance index (technical competitiveness). In real processes the accuracy of the performance index evaluation is firm specific and depends on firm's routines and firm's experience.

by squares.[9] We say that the average values of product characteristics sold on the market mark the trajectory of industry development in the adaptive landscape.

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 towards the lower peak. The scope of search for invention is not very large (the top chart in Fig. 3), the research is focused around local firms' positions in the adaptive landscape. Progress is not very impressive, within assumed period of simulation firms have not reached even the local peak, the maximum average value of technical competitiveness is 0.82. If we add the possibility of interchanging the knowledge (i.e. imitation of innovation) the evolution is slightly quicker, and within the assumed period of simulation the firms reach the lower peak (Fig. 3, the middle chart). 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. We will investigate more closely the role of random factors in the development of industry in the next section, but here we only say that even for the same simulation conditions and for such simple adaptive landscape, the trajectories of development are frequently significantly different for different simulation runs.

Imitation may be based on the knowledge gained through private efforts (i.e. by spending some private (individual firm) funds on imitation, and in this way increasing the probability of gaining the relevant knowledge or through public dissemination of knowledge. It turns out that the type of dissemination of knowledge does not influence significantly the speed of evolution (rates of change of technological competitiveness, productivity of capital or cost of production are very similar in experiments with public and private knowledge, as we call these two runs – see Table 1.). But the type of dissemination of knowledge greatly influences the structure of industry. Many simulation runs of industrial development suggest that privacy of knowledge leads to much greater concentration of industry (see relevant average values of Herfindahl firms' number equivalent n_H for imitation with private and public knowledge).[10] Similar tendency towards greater industry concentration is observed if there are some restrictions on imitation, which is clearly seen if we compare values of n_H in experiments with only mutation involved (i.e. full privacy of knowledge) and both experiments with mutation and imitation as presented in Table 1.

Privacy of knowledge leads also to higher profit. In the absence of imitation leaders of technological advancement 'feel' relatively safe, exploit their temporary monopoly position, and force the higher price of their products, what naturally leads to higher profit. Let us compare two simulation runs, the first with high innovation (mutation) ratio and the second with normal innovation and imitation ratio (see the results of these two runs in Table 1). In both cases the tempo of technological advancement is very similar, but the price and profit significantly differ. In the first case the average profit is around 7% and in the second one is slightly over the zero. The high profit in the absence of imitation is due to higher concentration of industry (applying only the results of autonomous research, some firms are not able to keep the pace of technological advancement and are superseded from the market) and is due to the higher products price imposed by technological leaders to utilize their temporary monopoly positions.

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

[10] In all experiments there are 12 equal firms so the initial Herfindahl firms' number equivalent is 12. As we have already mentioned, to make the results comparable the entry of new firms in all simulations in this section is prohibited.

In the second case the concentration of industry is not so high, the small firms are able to imitate the leaders, but to follow the leaders they are imposed to take credits (and repay it in future). The leaders feel not so safe in this situation and to keep the competitiveness of their products offer their products at a lower price. Therefore all firms, the leaders and followers, are satisfied with smaller profit to keep their position on the market. In the next section we will see how different kinds of innovations, also with different pace of change, focused on improvement of technical performance, raising productivity of capital, or reduction of the unit costs influence the structure of industry; here we only note that rapid technological development leads to much greater industry concentration – compare values of n_H in experiments with normal and high mutation, and in experiment with recrudescence in Table 1.

Greater values of probabilities of mutation and recombination accelerate the evolution and lead to relatively high ratio of technological development, i.e. the higher productivity of capital A, the greater technical competitiveness q, and the smaller the values of variable cost of production V (Table 1), but still do not allow to depart from the lower local peak (local optimum, as it is called sometimes) through finding the products with characteristics very close to the higher peak (i.e. of global optimum). We use the term 'evolutionary trap' to name the situation of catching the industry in local, lower peak of the adaptive landscape. Many other simulation runs with different adaptive landscapes let us state 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 we add the mechanism of recrudescence. In the first period (up to 50 years) mutation and imitation act on the normal levels, as in the former experiment, and the recrudescence acts rarely ($u_1 = 0.02$). The industry development is similar to that in the previous runs. At $t = 50$ industry is very close to the first lower peak and at this moment we allow recrudescence to act on a much higher level ($u_1 = 0.3$), within 15 years products with characteristics very close to the higher peak are found. At $t = 70$ the probability of recrudescence is reduced to the lower value (0.02). The trajectory of development in this run is shown in the bottom chart of Fig. 3. The scope of search in this run is much wider than in all previous runs. 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 recombination of solutions placed at these two peaks,[11] but what is crucial, 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.

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 cause also reduction of productivity of capital or rising the unit costs, and therefore they are not accepted simply on the basis of the economic judgments. The necessity of correlation of technical performance with economic factors (as productivity of capital and costs of production, but also other factors, e.g. current firm's investment capabilities) causes that many good looking inventions are not accepted by firms, and in effect probability of emergence of radical innovation is significantly smaller than the probability of finding radical invention.

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[11] In multi-peak adaptive landscapes, with many diversified industries included, when co-evolution of multi-industry economy is studied, recombination plays much more important role. Concurrently to recrudescence, inter-industry recombination of routines applied by firms of different industries may cause emergence of radical innovation within the existing industries, or lead to emergence of new industries not yet present in the economy.

Emergence of radical innovation is a kind of jump, punctuated process, but the shift from the lower to higher peak is not a sharp (punctuated) process, it is much more gradual process of shifting the position of the industry in the adaptive landscape. The main reason of this gradualism is that the overall competitiveness of products is the function of the technical competitiveness and the price.

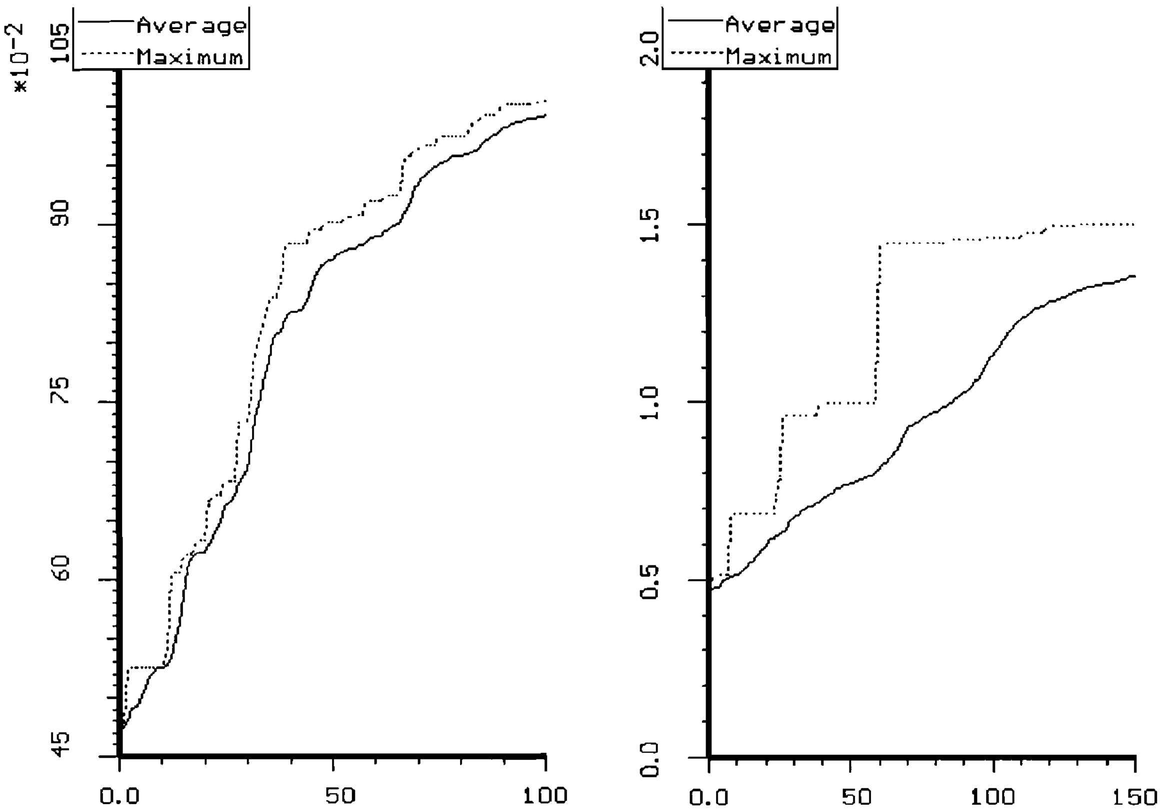

Fig. 4. Technical competitiveness in the two runs: mutation and imitation (left), and mutation, imitation and recrudescence (right)

To keep the overall competitiveness on relatively high level firms lower the price of products characterized by smaller technical competitiveness (i.e. placed at the lower peak) and vice versa products with higher competitiveness (i.e. 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 being on the frontier of technological development are only slightly greater than the competitiveness of the old-fashioned products. Therefore the elimination of the worse products from the market is not so sharp as it may be expected on the basis of the values of technical competitiveness only. In some circumstances the substitution phase may last quite long, 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.

The substitution phase (i.e. in our simulation passing from the lower to the higher peak) is much shorter and the process of transformation is much quicker if we allow the entry of new firms – numerous runs with free entry confirm this finding, the results of some of them are presented in following sections. The substitution process is observed also within a single firm – in many cases, when the radical innovation is found the costs of modernization are normally so huge that even the big firm is not able to afford it. Stopping the production in the 'old' unit is not economically viable so the only rational decision is to continue the 'old' production and to open a new unit with the modern technology applied. In the course of time the old production is successively reduced and the new one grows. Usually, in the first phase of substitution within a firm the 'old-fashioned' production is still profitable and due to the larger mass of the 'old' production the firm is able to finance the quicker development of the new, small 'modern' unit from the sources worked out by 'the old fashioned unit'.

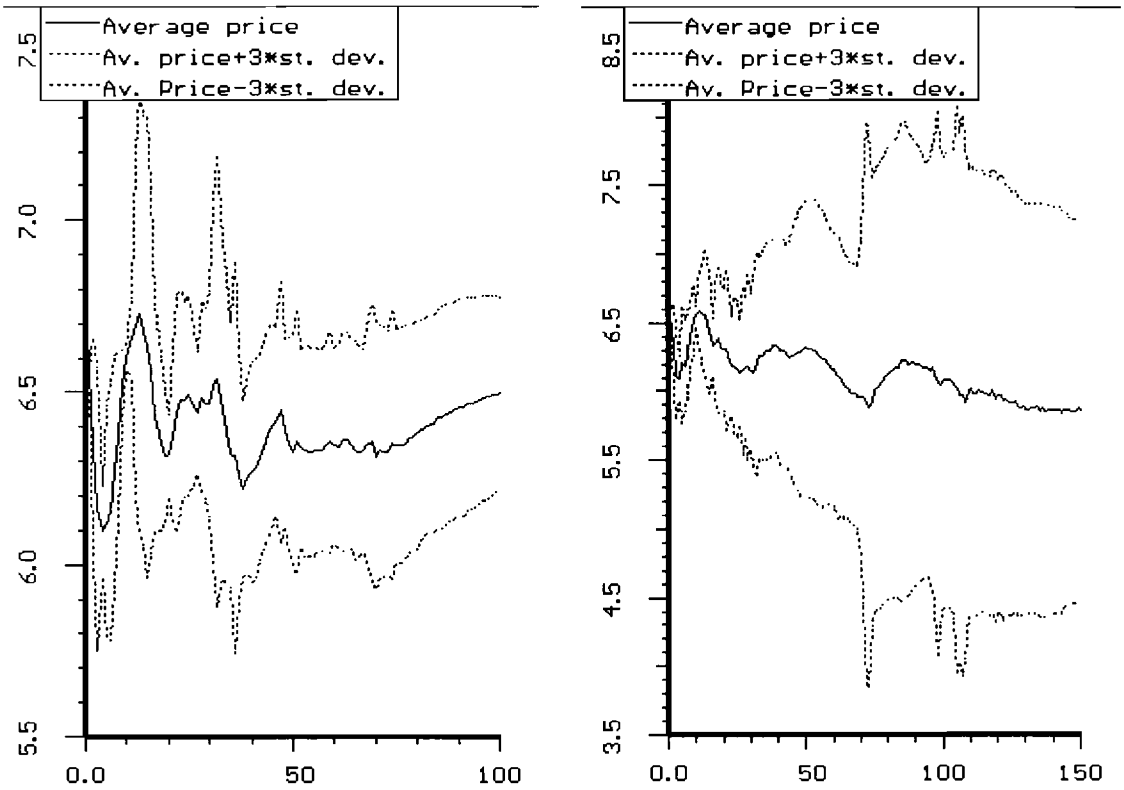

Fig. 5. Price and its diversity in two runs: mutation and imitation (left), and mutation, imitation, and recrudescence (right)

Different modes of innovation search lead to different evolution of characteristics of development. In Fig. 4 the development of technical competitiveness in two runs is presented, i.e. (1) only mutation and imitations of routines act (the left chart) and (2) with recrudescence involved (the right chart). If we compare the development in the initial phases of these two runs, when industry goes towards the first lower peak, it is difficult to detect significant differences in the mean characteristics of development, e.g. in the changes of average technical competitiveness. But due to different modes of search for innovation the development of the frontiers of technological development differs significantly. In the case of search for innovation by applying only mutation and imitation the development of the technological frontier is more or less gradual (see, e.g. the maximum technical competitiveness in the left chart of Fig. 4). The discrepancy between the frontier and the mean industry development is not very high (the two curves are placed very close). It is not the case if recrudescence mechanism is involved, jumps in the development of the technological frontier are clearly visible – see maximum technical competitiveness in the right chart of Fig. 4. The jumps are observed on the route towards the local peak (i.e. for $t < 50$, what suggests that even if recrudescence acts on the low level it also generates innovations) and also in the transition phase, of passing from the lower to the higher peaks. The discrepancy between the frontier of development and the mean industry development is much more significant in the presence of the recrudescence mechanism.

In Fig. 5 the changes of the average price and the price diversity for the same two runs as in Fig. 4 are presented. Structure of the price of product offered for sale on the market is affected also by technological development. When the rate of improvement is small the diversity of price within the industry is not very high. The standard deviation of price in the case of the modest ('normal') rate of development is around 2%, but the price diversity significantly increases in the case of emergence of radical innovation: see the right chart of Fig. 5 for t greater than 50, and also the left chart of the same figure in the periods of significant fluctuations of price and its standard deviation which are correlated with emergence of significant improvements. Standard deviation of price in the case of emergence of radical innovation (with recrudescence) is few times greater than in the case of relatively smooth progress (compare the relevant values of standard deviation presented in Table 1). Such structure of price is naturally related to earlier mentioned strategy of firms producing 'obsolete' products which attempt to keep the overall product competitiveness on relatively high level, through lowering the price of obsolete products. But high diversity of price is not only the result of high rate of technological development, it is also the result of privacy of knowledge and barriers to imitation. The standard deviation of price in the experiment with relatively low rate of technological progress with mutation as the only source of innovation (i.e. high privacy of knowledge) is even greater than in the case of quick progress but with relatively high rate of dissemination ('publicity') of knowledge (compare the results for 'innovation' and 'innovation, imitation, and recrudescence' in Table 1).

III. Cumulative Causation, Path-Dependence and Irreversibility

Cumulative causation,[12] path-dependence and irreversibility are immanent properties of all evolutionary processes. These phenomena are frequently observed in behaviour of models rooted in evolutionary episteme, contrary to 'mechanistic', general equilibrium models of neoclassical theory, which excludes these phenomena from the domain of its research. The ideas of cumulative causation and irreversibility have long been contrasted with the equilibrium analysis of orthodoxy.

The problem of path-dependence in economics was first recognized by the physicist Joseph Bertrand (in 1883), who discovered that, if out-of-equilibrium trading is incorporated into Walrasian model, then it leads to indeterminate and path-dependent results that are inconsistent with Walras's general approach. In his essay (1934), Nicholas Kaldor also saw the possibility of path-dependence in economic models. The idea that future development of an economic system is affected by the path it has followed out in the past is now accepted by many economic theorists. This contrasts with the mechanical view that, within well defined limits, from any starting point, a given system will develop to the same equilibrium – thus from the mechanistic-neoclassical viewpoint real time and history could be excluded from consideration. Development of modern mathematics, especially the study of non-linear dynamic models, has attracted

[12] Cumulative causation was frequently mentioned by Thorstein Veblen (1899) and was developed later on by Gunnar Myrdal (1934, 1957), William Kapp (1976) and Nicholas Kaldor (1966, 1972, 1978, 1985).

attention of many economists and put path-dependence back on the agenda of economic analysis, even for orthodox theorists.

One interesting case of path-dependence of current interest is the idea of 'lock-in' (e.g. Arthur, 1988, 1989) which states that with increasing returns, for instance, the more a technology is adopted the more it will be improved and productive. Arthur (1988) points out five particularly important sources of 'increasing return to adoption', namely learning by using, network externalities, scale economies in production, informational increasing returns, and technological interrelatedness. As Arthur (1988, p. 597) states, to observe the lock-in phenomena two properties ought to be preserved: "(i) that choices between alternative technologies are affected by the number of each alternative present in the adoption market at the time of choice; equivalently, that choices are affected by current market shares; (ii) that small events outside the model may influence the process [...]".

Irreversibility was recognized as an important feature of physical systems by Ludwig Boltzmann (1872), further on this idea was developed by the founders of quantum mechanics, and adopted by chemists (dissipative structures). Georgescu-Roegen (1971) points out that it is useless to model social or economic processes by means of mathematical models which entail reversible time. In his opinion, the social sciences could gain much profit in understanding socio-economic phenomena by making closer analogies between such phenomena and the irreversible processes of thermodynamics or biological evolution.

The phenomena of cumulative causation, path-dependence and irreversibility are observed in behaviour of our model in the presence of innovation. They appear to be natural phenomena, being the result of the evolutionary and self-organizational mechanisms embedded in the model. An emergence (fulguration) of significant innovation causes the specific course of future development and closes many other possible alternatives existing until then (see page ?). Frequently, in the behaviour of our model we observe that the technology adopted, which by pure chance focuses, e.g. on improving the technological performance, blocks up further emergence of innovations aimed to reduce the unit costs and/or to improve the productivity; and vice versa, sometimes a specific set of routines allows for the technological performance index to be radically improved once at a time and then blocks any further improvements of that technology, but paves the way to a change (chreod) in which the reduction of cost or increase of productivity of capital is the definitive effect of research (compare the results of simulation presented in the previous chapter related to the modes of search and the innovation regimes). Basically, the course of events in our model depends primarily on the past evolution of the pool of routines within the whole industry, and the past evolution of the set of routines of an individual firm. A specific role in determining the course of evolution is played by the latent routines which are beyond the action of the selective forces. Therefore, the contents of the set of latent routines of each firm strongly depend on random factors and past interaction of a firm with all other economic agents (competitors, cooperators, public institutions, university research units, etc.). The phenomena of path-dependence and irreversibility as observed in our model are an outcome of cooperation between the search mechanisms built-in the model (mutation-innovation, recombination-imitation, and recrudescence) and selection mechanisms (presented in section II).

As we have mentioned in discussing the search mechanisms (innovation strategies – page 20), the path along which an industry develops strongly depends on the modes of search for innovation. All results of model simulation support the general finding related to path-dependence that the path of development is always historical and unique. Even if we provide exactly the same simulation conditions and make numerous simulation runs for those conditions, the probability of developing along the same path is almost zero. In this sense uniqueness of development in our model represents a natural property observed in real processes of socio-economic development.

We may consider the development of socio-economic processes on at least two levels: the level of routines (i.e. hereditary information) and the level of aggregated characteristics of development (in our model – the productivity of capital, the unit cost of production, and the technical characteristics of products). We have to deal with the problem of path-dependence and irreversibility on these two levels.

Our simulation runs reveal that the indeterminacy of the trajectory of development strongly depends on the dimensions of the adaptive landscape. Even for a very simple, stable adaptive landscape with only one peak, when the final target is predetermined, the path of reaching the peak is highly indeterminate for a relatively large number of technical characteristics. For two or three characteristics the path is almost always along the shortest way from the current position of an industry to the peak, only slightly deviating from it. But for more than five characteristics the scope of search for innovation is much larger, the set of inventions with the same adaptive value is so expanded that the probability of the same innovation emerging in different runs is very small. For high dimensional adaptive landscape, the development of industry along the path traced by the shortest way to the adaptive peak is very rare. In all our simulations the path looks rather like a zigzag or a winding road. Frequently the future path is predetermined just at the beginning of simulation run. It is difficult to represent, in our three dimensional world, the industry trajectory traced in high dimensional adaptive landscapes in a graphical form. To show how big the deviations of trajectories are in different simulation runs let us take, for example, the values of the characteristics in the middle of the route obtained in four runs (two for the two dimensional adaptive landscape and two for the seven dimensional landscape). Besides the dimensionality of adaptive landscape, the conditions of simulation in all four runs are the same, particularly there is only one peak, the initial values of all technical characteristics are equal to zero and the target characteristics (i.e. the coordinates of the peak) are all equal to one. For two dimensional adaptive landscape the deviations of the average values of characteristics in the middle of the route are not significant, they are equal to : (0.48, 0.45) in the first run, and (0.47, 0.52) in the second one. In the seven dimensional adaptive landscape the deviations are much more significant, and the relevant values are equal to: (0.21, 0.57, 0.59, 0.32, 0.75, 0.64, 0.47) in the first run, and (0.49, 0.69, 0.53, 0.42, 0.52, 0.37, 0.43) in the second one.

At any time the whole population of products sold on the market may also be characterized by their distribution within the space of product characteristics. Besides the above-mentioned significant deviations of average values of relevant product characteristics for high dimensional adaptive landscape we also observe much greater dispersion of each characteristic within the population of products in each simulation run. The population of products may be represented at any time as a multidimensional cloud (or clouds) of different density; it may be said that the more dimensional the adaptive landscape is, the greater the relative size of the cloud[13] is.

But even for small dimensional adaptive landscapes we observe immense indeterminacy of development on the routine level. In all evolutionary processes a dimension of the hereditary (in our case routines) space is much greater than the dimension of the phenotype space. This property implies that the same set of phenotypes (characteristics) may be fulfilled by different sets of routines.

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[13] Measured e.g. as an average value of the dispersions of all technical characteristics.

This causes that even for two or three dimensional adaptive landscape, when the paths (trajectories) of development are more or less similar, the development on the routine level is highly heterogeneous. There is no place (and necessity) to write out all 50 values of routines (as we have done in our simulations) for different simulation runs, but we should say that for the same simulation conditions a large spectrum of the modes of development is observed on the routine level. In some experiments most of the routines are subject to evolution but in majority of experiments the whole set of routines is partitioned into the sub-set of highly conservative routines, i.e. the values of which are not changed during the whole period of simulation, and the subset of highly evolving routines. What is important is that the contents of the conservative and evolving subsets of routines significantly vary in different runs. One may get an impression that at some moment (or in a very short period) at the initial phase of industry development random factors control the process of choosing the sets of evolving and conservative routines, and since that moment the mode of development at the routine level seems to be highly predetermined. The predetermination of development and the heterogeneity of development depend also on the modes of search for innovation. The heterogeneity of development is much smaller if only mutation and low recombination are involved in the innovative process, and is much greater if the transposition, transition and recrudescence act. If recrudescence is in action, then the predetermination of development occurs frequently in the phases of emergence of radical innovations. The random factors play essential role during these crucial periods and in fact it is almost impossible to predict what kind of innovation will emerge, what values of technical characteristics or what combination of unit cost of production, productivity of capital and technical competitiveness will be after emergence of the radical innovation. It seems possible to predict, albeit in some cases with considerable inaccuracy, the development of aggregate values of some characteristics of development (e.g. average values of the technical characteristics, the average values of the price, the unit cost of production, or the profit) but only if the industry develops along the hill towards the nearest, local adaptive peak. Prediction of development in the long perspective, in the multidimensional adaptive landscape with numerous peaks is a futile task. Let us give as an example the results of development in multi-peak, stable adaptive landscape. For convenience of presentation the landscape is only two dimensional.

We ought to keep in mind that in real processes the conditions are much more complex – the landscape is multidimensional, with a very large number of peaks, and dynamic, i.e. the surface of the landscape is changing all the time, some of the peaks disappear, some lose their importance, some new ones emerge. But we will see that even for this simple adaptive landscape the development of our artificial reality (as simulated by the computer) is much diversified and unpredictable, and path-dependent. Over 50 simulation runs for the adaptive landscape, presented in Fig. 6, were made. There are no two exactly the same trajectories within all 50 simulation runs, but it is possible to distinguish a few types of trajectories (the eight representative trajectories are presented in Fig. 6). As we see there are six peaks in the landscape: the three lowest are on the left and at the bottom of the map, the highest peak is on the right, and two middle peaks are placed in the centre of the map. In all eight runs the simulation conditions are exactly the same, particularly the starting point in the adaptive landscape (the initial location of the industry is on the left of the map, between the two low peaks). From the initial industry location three distinguishable varieties of trajectory development are recognized. The first two are towards the two nearest peaks (as in Fig. 6a and b) and the third one is the route between the two lowest peaks towards the middle ones (as in Fig. 6c). The route of future development is predetermined in the early stages of industry development. After 'choosing' the route towards the lowest peak (that upper left), initiating the evolution in that direction, it is almost impossible to reverse the course of development, e.g. towards the second lowest peak (i.e. that in the lower left corner on the map). But even for very similar trajectories the differences and the deviations are clearly visible, e.g. the trajectories in Fig. 6a, f, g, and h with the same tendency towards the lowest peak in the initial phase of development.

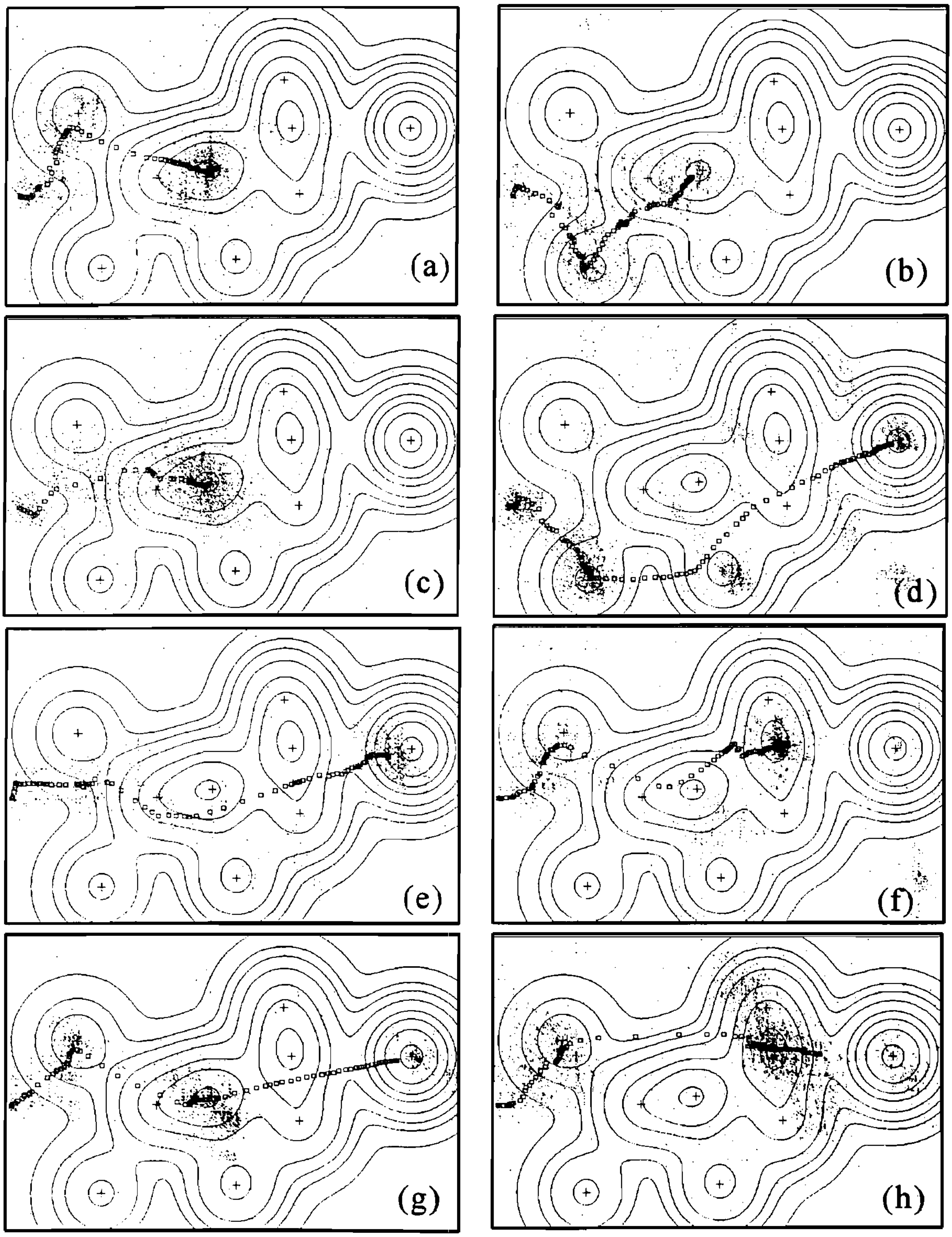

Fig. 6. Trajectories of development and path-dependence

For the routes quite similar in the first phase of development the further development is still not predetermined – in four runs the firms reached the lowest peak, but from this position the future course of development is still open – it may reach one of the middle peaks and stay there for a long time (as in Fig. 6a and f) or pass through one of the middle peaks and next reach the highest adaptive peak (as in Fig. 6g and h).

But once the way of development from the lowest peak is chosen, the future route is said to be almost predetermined, with only relatively small deviations of trajectories between different runs being detected (similar to those in the initial phase of development towards the lowest peak, as in Fig. 6a, f, g, and h).

The same indeterminacy of future development, in spite of similarities in the first phase of development, is observed for two other initial modes of development – compare Fig. 6b and d, and Fig. 6c and e.

The results presented above are obtained for very simple and almost artificial conditions. In real socio-economic processes the conditions are much more complicated due e.g. to mutual dependencies between development of different industries, co-evolution and influences of socio-political processes on the shape of adaptive landscape, so the path of development of a single industry is much more complex and untraceable. It is possible to distinguish some trends of development even during relatively long periods but at some crucial periods of development (e.g. in our simulations when industry is placed at any local peak) the future development is highly indeterminate, purely random event may change the current trend, causing the development along new chreod. To the spatial diversity of the development trajectories we should also add diversities observed in the course of time. The temporal differences are clearly visible in the phase of search for innovations which allow us to escape from evolutionary traps (local adaptive peaks) and triggering the development towards a higher adaptive peak. The time span from the moment of reaching the first local peak and the moment of emergence of radical innovation which paves the way for development towards the higher adaptive peak is highly random – in some runs the radical innovation is found very quickly, in others it is necessary to wait a few decades.

To sum up, indeterminacy of development, and the path-dependence related to it, can be observed at different levels: (1) economic characteristics (e.g. the productivity of capital or the unit cost of production), (2) technical (e.g. the characteristics of products), and (3) on the level of routines (hereditary information). The primary cause of any indeterminacy is naturally a change of our knowledge, our behaviour (i.e. routines).

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