Working Paper

Innovation Regimes, Entry and Market Structure

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IIASA
International Institute for Applied Systems Analysis □ A-2361 Laxenburg □ Austria
Telephone: +43 2236 807 □ Fax: +43 2236 71313 □ E-Mail: info@iiasa.ac.at

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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

Innovation regimes, entry and market structure

Witold Kwasnicki[1]

Abstract.

The paper contains a description of an evolutionary model of industrial dynamics and a report on simulation study of the model. The presentation of the model is partitioned into two sections, in the first section we focus on the economic features of industrial development with no technological change embedded, extended version of this model with the search for innovation process included is presented in the next section.

In the next two sections results of simulation study on technological regimes and firms entry are presented. Technological regimes relate to different types of innovation captured by the model, so we consider the cost regime, the technical performance regime and the capital productivity regime. In section III we investigate the influence of this different types of innovation on development of the industry, particularly on the industry concentration and on the products' price distribution. In the next section evolution of industry structure with possibility of firms entries is investigated.

Key words: Evolutionary dynamics, innovation, technological regimes, firms' entry.

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Institute of Engineering Cybernetics, Technical University of Wroclaw, Wyb. Wyspianskiego 27, 50 370 Wroclaw, Poland; e-mail: kwasnicki@ictadmin.ict.pwr.wroc.pl.

I. The basic 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. Technological and economic processes are coupled in the model, and it seems to be one of its important features. 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.

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.

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 innovation allows to modernize current production but also 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.

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 $c_i(t)$.

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. Because of our assumption that there is no search for innovation so all products' characteristics are constant and the same for all products. This assumption impose that technical competitiveness is uniform for all firms. In the next section this assumption will be weakened and the technical competitiveness will alter due to emergences of technical innovations. 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. We assume that competitiveness of products with the price $p_i(t)$ is equal to

$$c(p_i(t)) = \frac{q}{(p_i(t))^{\alpha}} \tag{1}$$

where q is the technical competitiveness (constant during the simulation of the basic model), α the elasticity of price in the competitiveness; α is characteristic of the market and describes the sensitivity of the market on price fluctuations.

Let's denote by $c_i(t)$ competitiveness of products of firm *i* at time t, i.e. $c_i(t) = c(p_i(t))$.

(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

$$p^e(t) = p^p(t)\ (1-f_i(t-1)) + p_i(t)\ f_i(t-1) \tag{2}$$

Similarly, the average competitiveness is expected to be equal to

$$c^e(t) = c^p(t)\ (1-f_i(t-1)) + c_i(t)\ f_i(t-1) \tag{3}$$

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.[1] 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·exp(B·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 (2) and (3) 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

$$Q^d(t) = \frac{M(t)}{p^e(t)} \tag{4}$$

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

$$M(t) = N \exp(\gamma t) \ (p^e(t))^\beta \tag{5}$$

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

$$f_i(t) = f_i(t-1) \ \frac{c_i(t)}{c^e(t)} \tag{6}$$

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.[2]

(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,

$$Q_i^s(t) = f_i(t)\ Q^d(t) \tag{7}$$

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

$$K_i(t) = Q_i^s(t)/A \tag{8}$$

'A' in the above equation is the productivity of capital. Because there is no R&D process then firms do not improve the productivity of capital and in the basic model the productivity A is constant and uniform for all firms during simulation runs.

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

$$Q_i^s(t) = K_i(t)\ A \tag{9}$$

(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

$$\Gamma_i = Q_i^s(t)\ (p_i(t) - V\ v(Q_i^s(t)) - \eta) \tag{10}$$

$$\Pi_i = \Gamma_i - K_i(t)\ (\rho + \delta) \tag{11}$$

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 $Q^s(t)$, 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:

$$O_1(t+1) = (1-F_i)\,\frac{\Gamma_i(t+1)}{\Gamma(t)} + F_i\,\frac{Q_i^s(t+1)}{QS(t)}$$
$$F_i = a_4\,\exp(-a_5\,\frac{Q_i^s(t+1)}{QS(t)}) \qquad (12)$$

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 (10)), QS is the global production of the industry in year *t*, Γ the global net income of all firms in year *t*. Γ(t) and QS(t) play the role of constants in the equation (12) 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 (12), 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:

$$IC_i(t) = \max \left\{ 0,\ \delta\ K_i(t-1) + \mu\ \Pi_i(t-1) \right\} \tag{13}$$

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

$$DR_i(t) = D_i(t-1)/\mu_1 \tag{14}$$

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 (13)):

$$IC_i(t) = \max \left\{ 0,\ \delta\ K_i(t-1) + \mu\ (SV_i(t-1)\ -\ DR_i(t)) \right\} \tag{15}$$

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

$$D_i(t) = (D_i(t-1) - DR_i(t))\ (1+\rho_1) + ICr_i(t) \tag{16}$$

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):

$$SP_i(t) = \max\{0,\ \Pi_i(t)\}\ \exp\left(-\frac{SV_i(t-1)}{ToSave\ K_i(t-1)}\right) \tag{17}$$

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

$$SV_i(t) = (SV_i(t-1) - DR_i(t))\ (1+\rho_1) - IS_i(t) + SP_i(t) \tag{18}$$

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.[3] 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 was presented in the decision making procedure; see equations (4), (4) and (5) 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:

$$p(t) = \sum_i p_i(t) \frac{Q_i^s(t)}{Q^s(t)} \tag{19}$$

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

$$Q^s(t) = \sum_i Q_i^s(t) \tag{20}$$

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

$$QS(t) = \min \{ Q^d(t), Q^s(t) \} \tag{21}$$

The general selection equations of firm competition in a market has the following form (for comment see also note 2),

$$f_i(t) = f_i(t-1) \frac{c_i(t)}{c(t)} \tag{22}$$

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

$$c(t) = \sum_i f_i(t-1)\, c_i(t) \tag{23}$$

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

$$Q_i^d(t) = QS(t)\, f_i(t) \tag{24}$$

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 (24) 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 (22) and (24)), 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

$$w = \min \left\{ 1, \frac{Q^d(t)}{Q^s(t)} \right\} \tag{25}$$

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 (22), 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 $QS_i'(t)$,

$$QS_i'(t) = \min\ \{Q_i^s(t), w\ Q_i^d(t)\ \} = \min\ \{Q_i^s(t), w\ QS(t).$$
$$QS_i'(t) = \min\ \{Q_i^s(t), w\ QS(t)\, f_i(t-1)\frac{c_i(t)}{c(t)}\ \} \tag{26}$$

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

$$QS'(t) = \sum_i QS_i'(t) = \sum_i \min\ \{Q_i^s(t), w\ Q_i^d(t)\} \tag{27}$$

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

$$QS''(t) = QS(t) - QS'(t) \tag{28}$$

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

$$QN_i(t) = \min\ \{0,\ Q_i^s(t) - w\ Q_i^d(t)\} \tag{29}$$

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

$$f_i'' = \frac{QN_i(t)}{\sum_j QN_j(t)} = \frac{\min\ \{0,\ Q_i^s(t) - w\ Q_i^d(t)\}}{\sum_j \min\ \{0,\ Q_j^s(t) - w\ Q_j^d(t)\}} \tag{30}$$

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

$$QS_i''(t) = QS''(t)\, f_i'' = (QS(t) - QS'(t))\, f_i'' \tag{31}$$

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

$$\begin{aligned} QS_i(t) &= QS_i'(t) + QS_i''(t) \\ QS_i(t) &= \min\ \{Q_i^s(t), w\ Q_i^d(t)\} + (QS(t) - QS'(t))\, f_i'' \end{aligned} \tag{32}$$

The general meaning of the supply-demand alignment process as described above parallels that of equations ((22), (23), (24)). 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 (25) to (32) are equivalent to equations (22) to (24).

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

$$f_i(t) = \frac{QS_i(t)}{QS(t)} \tag{33}$$

The real income and profit of firm i is equal to

$$\Gamma_i = QS_i(t)\ (p_i(t) - V\ v(Q_i^s(t)) - \eta) \tag{34}$$

$$\Pi_i = \Gamma_i - K_i(t)\ (\rho + \delta) - D_i(t)/\mu_1 \tag{35}$$

$K_i(t)$ in eqs. (34) and (35) 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.[4]

Effective capital of the firm is equal to

$$K_i(t) = QS_i(t)/A \tag{36}$$

Global sales are equal to

$$GS(t) = \sum_i QS_i(t)\ p_i(t) \tag{37}$$

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

$$fs_i(t) = QS_i(t)\ p_i(t)/GS(t) \tag{38}$$

II. Innovation and Economic Development.

Essence of cultural development in general, and socio-economic evolution in particular, lays in the creative process of human being. Possibilities of observation of real tissue of creative processes is almost impossible. 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 generally, out of possibilities of any observations. The only way to deal with the creative processes and dare to describe them in 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 heuristic, analogies, and metaphors). This kind of approach is proposed in this section, where the extension of the basic model with innovative processes embedded is presented. We treat this proposition as the first approximation being the subject of further development ('stepwise concretization').

The creative process from its nature is the evolutionary process, and as such its description ought to be based on proper understanding of the hereditary information. Accordingly 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". Great 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.[5] Distinguishing these two spaces enables us to separate firms' decisions from the 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.

Beside the first step, the three other are almost exactly the same as in the basic model described in the former section. The only difference is that the productivity of capital A, the unit cost of production V, and technical competitiveness q are now functions of the routines applied by each firm, and may vary accordingly to discovered inventions and introduced innovations. 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).

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.

$$R_i = (h_2 \exp(-h_1 K_i) + h_0) K_i \tag{39}$$

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.

$$R_i^m = g_i R_i \qquad R_i^r = (1 - g_i) R_i \tag{40}$$

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.

$$g_i(t+1) = (1 + \frac{G}{K_i} \frac{f_i(t) - f_i(t-1)}{f_i(t-1)}) \; g_i(t) \tag{41}$$

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,

$$NoExp_i = round(e \; (R_i)^{\psi} \;) + E_0 \tag{42}$$

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,

$$PrMut_i = a^m \; (R_i^m)^{\zeta} + b^m \tag{43}$$

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,

$$MaxMut_i = a^u \ (R_i^m)^{\vartheta} + b^u \tag{44}$$

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:

$$PrRec_i = a^r \ (R_i^r)^{\xi} + b^r \tag{45}$$

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,

$$PrRence_i = u_1 \exp(-u_2 K_i) \qquad (46)$$

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 AND COMPETITION

Productivity of capital, variable cost of production and product characteristics 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,

$$z_d = F_d(r) \qquad d = 1,2,3,\ldots,m \qquad (47)$$

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

A product's attractiveness on the market depends on values of the product's characteristics and its price. In the former section, the products competitiveness (see equation (1)) is a function of constant technical competitiveness and varying products' price. 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.

Similar to the equation (1) the competitiveness of products with characteristics z and price p is equal to,

$$c(p, z) = \frac{q(z)}{p^{\alpha}}, \qquad z = (z_1, z_2, z_3, \ldots, z_m) \tag{48}$$

where q(z) is the technical competitiveness, z a vector of products' characteristics, and α the elasticity of price in the competitiveness.

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), the cost functions V(r) and v(Q) 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'.

$$IM_i(t) = K_i(t) \ \| r - r' \| \tag{49}$$

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

The research is financed from the current firms income so the relevant equations (34) and (35) for the firm's profit Π_i and income Γ_i ought to be modified.

$$\Gamma_i = QS_i(t) \ (p_i(t) - V(r) \ v(Q_i(t)) - \eta) \tag{50}$$

$$\Pi_i = \Gamma_i - K_i(t) \ (\rho + \delta) - D_i(t)/\mu_1 - R_i(t) \tag{51}$$

where Q_i^s is the current production of firm i, QS_i the production of firm i sold on the market, p_i the products' price, V(r) the unit cost of production when routines r are applied, K_i the capital, D_i the debt of firm i, R_i the research funds of firm i.

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) and v(Q). 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.

III. Innovation regimes.

Three basic kind of innovations are captured by our model, namely innovations leading to: (1) reduction of the unit cost of production, (2) advancement of the products' technical performance, and (3) increase of the productivity of capital. In general any real innovation causes changes of all three features of technological development. We are able to control the type of innovations and e.g. to allow for emergence of innovations which cause the changes of only one separated feature of progress and concurrently to keep the other two fixed. Therefore we may speak about three basic modes of technological development; we name these three modes of development as 'regimes', so we have the cost regime, the technical performance regime and the capital productivity regime. In this section we would like to investigate the influence of this different types of innovation on development of the industry, particularly on the industry concentration and on the products' price distribution. To make the results comparable in different simulation runs it is assumed that there are no entrants and the competition process is confined to the initial 12 firms. The initial condition of simulation are set in such a way that in all the experiments presented in this section the innovation process is gradual one, without any jumps - i.e. recrudescence is not present and no fulguration is observed.

The result of this series of experiment are summed up in Table 1. In Fig. 3 the development of the variable cost of production, the technical competitiveness and the productivity of capital in these three regimes for 'normal' rate of innovations emergence are presented.

In the simulation runs with the reduction of unit cost of production as the only target of innovation activity (technical competitiveness and productivity of capital being constant) two modes of development are distinguished - the normal and the fast, related to the rate of cost reduction: in the first run, labeled as 'normal', the average annual rate of the unit cost reduction is around 0.6% and in the second run, labeled as 'fast', the cost reduction is around 3.5% annually. Reduction of the cost of production leads also to the reduction of price, but the rate of price reduction is much smaller then the rate of cost reduction. In the case of normal rate of the cost reduction price decrease only 0.25% annually (see Fig. 4a); so in the end of simulation the price margin is significantly higher then at the beginning (the price/cost ratio is equal to 1.7 in the end of simulation, compare to 1.3 at the beginning); and in the case of fast rate of cost reduction (3.5% annually) the price is reduced only slightly more then 1.5% annually, and the price margin in the end of simulation is 3.2.

Reduction of the cost of production narrows the possibilities of the 'obsolete' firms to apply relevant strategies to keep the pace forced by the leaders. Possibility of making the obsolete products more competitive through price reduction is very limited, so the non-innovators and firms which are not able to imitate the innovation and reduce the costs of production within relatively short period are quickly eliminated from the market. The Herfindahl firms' number equivalent in this experiment is reduced from initial 12 firms to 4 firms in the end of simulation (average value of n_H is equal to 7.14 firms). Heavy cost reduction rate, as in the fast mode, leads to much quicker elimination of 'obsolete' competitors from the market. In the end of the simulation run the Herfindahl firm number equivalent is equal to 1.06 (there is one big firm and two very small competitors - the average n_H number equivalent is equal to 2.33 in this run).

Because of strong tendency to high industry concentration and very limited possibility of choosing relevant price strategy by the 'obsolete' firms, the price diversity in the cost regime is not very high - the average standard deviation is equal to 1.68% in the first experiment and 2.46% in the second one (Table 1 and Fig. 4a).

On the contrary to the situation in the cost regime the possibilities to choose relevant price policy to keep position on the market are much wider in the case of innovations leading to improvement of product's technical performance. Reduction of price compensate the temporal technical backwardness of product and allow to keep overall competitiveness of obsolete products almost at the same level as the advanced ones. This prolongs the period for followers to imitate the technology leader. In technical regime two modes of development are tested also - normal with the average annual rate of the technical competitiveness around 0.7%, and the fast, with the annual growth of the technical competitiveness equal to 3.2%.

The price policy of technological leaders in the technical performance regime helps followers to keep the pace of technological progress. The leaders increase slightly the price to reach higher profit - they choose the strategy of balanced price rising, to gain higher profit, and concurrently to keep the overall competitiveness of their products at relatively high level. So in the technical regime we observe two opposite tendencies concerning the price policy - reduction of price by followers (to rise their products' competitiveness and to keep their place on the market) and rising the price by the leaders (to gain higher profit from their temporary "monopoly position"). This leads to much higher diversity of price in these two innovation regimes - compare two pictures on Fig. 4a and b. The average standard deviation of price in run with the normal rate of growth of the technical competitiveness is 3.44%, i.e. slightly more then twice of the relevant value in the first experiment in the cost regime, and is over 27% for the fast rate of technical competitiveness. Price fluctuations in the first phase of development (Fig. 4b) are due to the mentioned above interplay of the two different price policies. The steady growth of the average price in the second phase of development (after $t = 50$) is due to higher concentration of the industry.

If we provide the conditions for pure competition (e.g. through allowing free entry of new firms) the price fluctuate around the equilibrium value, as it is in the initial phase (up to $t=50$) of the simulation run presented in Fig. 4b. So it may be said that contrary to the steady trend of price diminishing as observed in the cost regime no such mode of price development is observed in the technical regime - many simulation runs confirm the finding that fluctuations of price around the equilibrium value are typical pattern of development in the technical regime.

Rapid technical progress leads to much greater concentration of the industry, for 'normal' technical improvement the average value of Herfindahl firms number equivalent is 8.9 firms, but for rapid technical progress this number is 2.39. The price diversity in this run is almost 8 times greater then for the normal rate of change of technical competitiveness (over 27%).

If we compare the modes of development in the cost regime and the technical regime we then see that the cost reduction leads to relatively high concentration of the industry, high price reduction and relatively small diversity of price and almost reverse tendencies are observed in the technical regime - smaller concentration, almost no price reduction (in the long-term perspective) and high diversity of price.

Contrary to the two discussed regimes, the capital productivity regime may be called neutral. Even high rate of productivity growth does not lead to large industry concentration. For 'normal' rate of the productivity growth (0.6% annually) the concentration of industry is all the time almost the same (the Herfindahl number equivalent in the whole period of simulation is very close to 12 - see Table 1), and even relatively high rate of the productivity change leads only to slightly greater concentration (for almost 4% annual growth of the productivity of capital the average Herfindahl number is 11.32, i.e. very close to the initial 12 firms). The strategy of productivity improvement seems to be rather ineffective weapon to eliminate the competitors from the market although it provides comparable good economic effects, e.g. the profit is almost the same as in the case od technical regime and even slightly larger then in the case of the cost regime (see Table 1). But as it was observed in numerous simulation runs cost reduction (especially very rapid) leads to much higher concentration of the market and enable to gain larger profit due to (temporary) monopoly position on the market.

The results of simulation runs of the productivity regime seem to be in full consistency with the statistical analysis of economic growth made in the 1950s. From this point of view our model and simulation results may hint explanations of the results of this statistical study, particularly of the results which are with evident friction to the neoclassical view of growth along the production function - that the ratio of capital engaged to the volume of production is constant during analyzed period. This view is also supported by the results of simulation runs with so called 'complex' innovation regime, i.e. in which simulation conditions are crated in such a way that routines modifications influence concurrently the unit cost of production, the products' technical performance and the productivity of capital.

A number of simulation runs for the 'complex' regime were done and a large spectrum of behaviour is observed, the results of four of them are presented in Table 1. Random factors play essential role in this regime, frequently an innovation generated at the beginning of the simulation decide on the future path of development of the whole industry (i.e. this innovation create a chreod, in terminology of Waddington). Rarely we observe harmonious development leading to moderate rates of improvement of the productivity of capital (A), the technical competitiveness (q) and reduction of the unit cost of production (V). The main reason is that probability of emergence of innovation which enable simultaneous reduction of the cost of production, increasing of the technical competitiveness and the productivity of capital is very small. The most typical situation is that firms find inventions enabling an advance of only one of these features (either q, V, or A), and the improvement of the two other features is done in succeeding stages of development of the basic innovation as the results of future research efforts leading to improvements of that basic innovation. The most frequent mode of development is that firms accept much more eagerly inventions leading to cost reduction and/or to rising technical competitiveness. The productivity of capital is frequently kept almost at the same level. The results of such typical situation are presented in Table 1 (the "complex" regime labeled as normal (A)) and in Fig. 5. An average productivity of capital (equal to 0.11) is only slightly greater then the initial value (0.10), but development of the productivity of capital is not static, as we see on Fig. 5c it fluctuates. The fluctuations of the productivity of capital, as well as cost of production and technical competitiveness, are due to intertwined (pleiotropic) character of impact of innovation on industry development in the complex regime. In the initial phase of development cost reduction and improvement of technical performance are observed (Fig. 5a and b). In the end of the fourth decade an inventions reducing significantly cost of production is found. But the reduction of the unit cost of production in that invention is coupled with decreasing of the technical competitiveness, nevertheless the invention is accepted purely on basis of economic reasons. As it turned out it was very difficult to improve the technical performance starting from that formerly accepted innovation. In the second half of the simulation period the firms' innovative efforts are concentrated on the cost reduction and the technical competitiveness is kept almost constant. If we compare the results of the former ('pure') innovation regimes with the results of the 'complex' regime we see much higher discrepancy of the frontier of technological development (as measured by the maximum of technical competitiveness, the maximum productivity of capital, and the minimum of the unit cost of production) and the average performance of the industry.

Analysis of the simulation results for the complex regime suggests that there is no stable pattern of behaviour, random factors play essential role and the behaviour of industry (e.g. such characteristics as profit/capital rate, industry concentration, price diversity) depends strongly on a prevailing innovation regime, e.g. if due to purely random factors R&D efforts result in emergence of innovation reducing the unit cost we observe higher industry concentration, but if due to random factors the technical regime prevails then we may observe higher diversity of price and smaller tendency to higher industry concentration.

The simulation results for different innovative regimes have revealed interesting property of the industry development related to the supply and demand balance. For the cost regime and for the productivity regime the supply to demand ratio fluctuates around the equilibrium value (see Fig. 6a, and b), and the mode of S/D ratio development does not depend on the rate of change. From the qualitative point of view the picture is almost the same for slow, medium and large rates of innovation. An average value of the S/D ratio for these two regimes is always slightly above 1 (e.g. for the cost regime (fast) it is equal to 1.0014). Very similar picture of development is for small and medium (labeled by as the normal) rates of growth of technical competitiveness (see Fig.

6c), the average value of S/D in the whole period of simulation is equal to 1.0003. But, for some reason, for fast technical development instability od the supply and demand occurs. The value of S/D ratio drops below 1 and is the smaller the faster is the development, e.g. for the average annual rate of development equal to 1.5% the average value of S/D is 0.984, and for rather fast development (3.2%) the average value of S/D ratio is 0.927 - development of the ratio in this case is presented in Fig. 6d. To make supply and demand more balanced we have tried to change the firm's decision strategies in many ways (e.g. by making much stronger the relationship of the expected development of price with the current imbalance of supply and demand) and the results were always very similar - the average value of S/D ratio is always significantly smaller then 1. It seems that the firms act as to leave the 'free place' for newcomers, to make the entry of new firms easier. And it turns out to be true, the situation is significantly better if we allow the entry of new firms. The development of the S/D ratio in this case is presented in Fig. 6e. The average value of S/D in this run is significantly smaller (0.983). The free entry of new competitors causes also much quicker recovery from the deep imbalance and quicker development of the industry toward the equilibrium.

IV. Entry and the Industry Structure

As we have seen in the previous experiments, the acquiescence for firms' entry greatly influences the values of important characteristics of industry development, such as profit, price structure, and of the supply and the demand balance (Table 1 and Fig. 6). It occurs that opportunity of free entry of new competitors greatly influences also the industry structure, especially in the periods of radical innovation emergence. To investigate how industry structure is formed under conditions of the free entry the following two simulation runs with specific initial conditions were prepared.

In both runs, in the first phase of simulation (i.e. up to $t = 30$) only incremental innovations are introduced (i.e. they cause only moderate: reduction of the cost of production, increase of technical competitiveness, and rise of the productivity of capital). In the 30th year the recrudescence mechanism of innovation generation is activated. In effect, radical innovation emerges followed by quick and significant reduction of the cost of production, rise of the technical competitiveness and rise of the productivity of capital within the whole industry. Conditions of simulation in the two runs were prepared in such a way that in both experiments the changes of the three characteristics of industry development are very similar, as presented in Fig. 7. It is true that emergence of such radical innovation in real industrial processes is very improbable phenomenon, but to see more clearly the impact of innovation on the development of the industry such extremely radical innovation emergence was intentionally forced. The only difference in the initial conditions created in these two runs is that in the first simulation run no entry of new firms is allowed, contrary to the second run where the free entry of new competitors is enabled.

Naturally, the first difference in the industrial development of these two runs lies in the number of firms and firms' units, what is presented in Fig. 8. If no entry is allowed (the upper chart) all 12 initial firms are present in the market up to $t = 65$, but since that year more and more firms are eliminated from the market, so at the end of simulation only two of them are present. Diversification of the industry structure due to emergence of innovations is observed from the beginning of simulation, but in the first phase of development, i.e. when only incremental innovations emerge, the diversification is relatively small and the concentration grows only gradually (see n_H – the Herfindahl firms' number equivalent in the upper chart). With the four years' delays, after the emergence of the radical innovation, a significant diversification of firms' size is observed, no firm is eliminated but some of them reach significant shares on the market so the concentration grows very quickly. The radical innovation causes also emergence of multi-unit firms – as can be seen in the upper chart from $t = 30$ more and more firms become multi-unit operations (there were up to 16 units present). Even at the end of the simulation, when only two firms compete on the market, each firm has two units. The bulk of the production is made in the modern units but still small fraction of production is based on the obsolete technologies.[6] The growth of the number of firms in the free entry simulation run is presented in the bottom chart of Fig. 8.

In the first phase of development of the industry new firms enter the market only incidentally. But since the emergence of radical innovation, firms grow very quickly in number, up to the maximum of 32 firms. Concurrently to the growth of the number of firms a similar increase of the number of units is observed (there are maximum 41 units). At the end of simulation 28 firms are present on the market. Some of the initial firms adopt the new technology, open new units, and are present on the market up to the end of simulation but majority of the initial firms are eliminated from the market, so at the end of simulation the number of units is very close to the number of firms. Diversification of the industry in the first phase of development is very similar to that in the run with no entry, since the emergence of the radical innovation similar tendency towards higher concentration is also observed, but due to the increasing number of successful entrants the concentration is never so high as in the former run – the minimum Herfindahl index in this run is equal to 6 firms. Around $t = 40$ the process of concentration growth is stopped and since that moment a steady tendency towards pure competition is observed. At the end of simulation the Herfindahl index of concentration is equal to 10 firms, i.e. five times greater than in the run with no entry.

The shares of the eight largest firms in both simulation runs, which are presented in Fig. 9, give also some view on the development of structure of industry. As it was mentioned before (Fig. 8, Table 2, and note 6) at the end of simulation the Herfindahl firms' number equivalent in the run with no entry is equal to 2, these two firms which survived are labelled as 1 and 10 (see the left chart in Fig. 9). What needs to be notified is that these two firms were not the biggest ones just at the moment of emergence of radical innovation, in fact both firms were steadily eliminated from the market (see the first phase of industry development in the left chart of Fig. 9). The innovation was found by firm 1 and applied at $t = 30$; the fact that the radical innovation was invented by small firms is partly due to our assumption that the probability of emergence of radical innovation is greater for small firms. The award of being the first innovator is greater profit and the largest share on the market. The only firm which successfully adopted new technology and followed the first innovator is firm 10, all other firms, in spite of their relative advantages at the moment of emergence of radical innovation, are eliminated from the market. So at the end of simulation the industry represents the case of classical duopoly.

The picture is radically different in the case of free entry. The first firm which applied the radical innovation in this run is firm 5 (the right chart in Fig. 9), some other firms quickly followed this innovation, but as it turned out all the 'old' firms are eliminated from the market and their places are captured by newcomers.[7]

As a result of stronger competition the old firms are quickly eliminated from the market, so within the eight largest firms operating on the market at the end of simulation there is only one old firm (i.e. the founder of the advanced technology, firm 5). The distribution of firms' shares at the end of simulation is almost balanced, the Herfindahl number equivalent is equal to 10.12 at the end of simulation – see Table 2, the share of the largest firm in the last year is around 15%, five other firms have only slightly smaller shares (from 9% to 14%), and late followers have shares around 7%, but, due to small improvements introduced by them, their shares grow significantly quicker than those of all other firms. Up to the moment of emergence of radical innovation the supply and the demand are almost balanced in both simulation runs (see Fig. 10). Emergence of the radical innovation also causes an extreme increase of the technical competitiveness. As we have shown in the previous section with the simulation of technical performance regime the quick growth of technical competitiveness causes large imbalance of the supply and the demand (see Fig. 6 d and e). This imbalance is also observed in the two discussed simulation runs after emergence of the radical innovation. If no new competitors enter the market we observe a kind of stabilization of the supply-demand imbalance at the level of 3% (the S/D ratio is around 0.97 – see upper chart of Fig. 10) but if the entry of new firms is allowed we observe the tendency to balance the supply and demand (bottom chart of Fig. 10 after $t = 40$).

The average value of the S/D ratio after the emergence of radical innovation is 95.9% in the no-entry run and 99.1% in the free entry run. The possibility of free entry causes also much smaller maximal imbalance just after the emergence of radical innovation. The minimum value of S/D ratio is equal to 90% if no competitors enter the market and is equal to 96% if free entry is allowed.

The free entry causes also different development of price and its structure within the industry (Table 2). In both runs the price is only slightly reduced in the first phase of development, due to incremental reduction of the unit cost of production (see both charts in Fig. 11). The emergence of radical innovation causes significant reduction of the unit cost of production and as it might be expected this ought to result in the parallel significant reduction of the price. The process of price reduction occurs in the first years after the emergence of radical innovation, but due to higher concentration of the industry it is stopped in the run with no entry allowed. The tendency towards price reduction caused by the cost reduction is neutralized by the reverse tendency towards greater industry concentration. It is not the case in the simulation with free entry allowed, the price is quickly reduced just in the first period after the emergence of radical innovation and is still reduced (although not so quickly) in the following decades due to incremental reduction of the unit cost of production and more competitive conditions on the market (smaller concentration of the industry). Emergence of the radical innovation causes also significant increase of the diversity of price. In the simulation with no entry the high diversity occurs just after the emergence of the innovation and is kept almost on the same level during the following whole period up to the end of simulation (see left chart of Fig. 11). Contrary to the conservation of the structure of prices within industry in the case of no entry the continuous tendency to reduce the diversity of price is observed if free entry is allowed (the right chart in Fig. 12, compare also relevant values of the standard deviation of price in Table 2).

Notes.

1. The expressions in eqs. (2) and (3) 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.
2. 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.
3. It may be expected that similar threshold exist in real industrial processes.
4. 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.
5. 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.
6. The exact values at the end of simulation are as follows: for the largest firm (no. 10), the market share in the global production of the modern unit is 45.2% and the price of product 5.67 (the overall competitiveness of the modern production is 0.1222), in the 'obsolete' unit 6.3% of the global production is made, and the price of product is much lower – 3.25 (but due to the lower price the overall competitiveness is only slightly smaller than the modern production, 0.115), for the second largest firm (no. 1) the relevant values are very similar, the market share of the modern unit is 42.4% and the product price 5.7 (the overall competitiveness is 0.1218), in the 'obsolete'

unit 6.1% of the global production is made, and the product price is 3.15 (the overall competitiveness is 0.114).

7. The firm labelled by 10 at the end of the simulation, in the right chart, is in fact the new firm, the old firm with the same label 10 was eliminated from the market at $t = 59$, and its place is occupied by new firm which entered the market at $t = 68$ – in fact this new firm becomes the second largest firm with the share only slightly smaller than that of the leader.

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Table 1. Price and industry structure in different innovation regimes.

	n_H	П/C %	Price	Price st.dev. %	A max	q max	V min
Variable cost							
normal	7.14	0.617	5.37	1.68	0.100	0.32	2.59
fast	2.33	-0.795	2.73	2.46	0.100	0.32	0.44
Technical performance							
normal	8.90	1.847	6.62	3.44	0.100	0.58	5.00
fast	2.39	10.610	7.42	27.45	0.100	8.49	5.00
fast with entrants	9.90	-0.544	6.38	12.91	0.100	14.34	5.00
Productivity of capital							
normal	12.00	1.672	6.10	2.10	0.177	0.32	5.00
fast	11.16	6.932	5.49	4.50	1.160	0.32	5. 0 0
"Complex"							
normal(A)	2.04	3.232	4.12	7.28	0.112	0.64	1.46
normal(B)	9.04	5.883	6.17	4.05	0.175	0.44	4.25
fast(A)	3.10	11.756	4.04	9.15	0.384	0.82	2.60
fast(B)	4.35	0.833	3.30	4.95	0.153	0.92	0.58

Note: values of firms number equivalent n_H, the ratio of Profit/Capital П/C, and Price are average values in the whole period of simulation from 0 to 100.

Table 2. No entry - free entry experiment

	n_H	П/C %	Price	Price st.dev. %	A max	q max	V min
no entry							
0-100	3.08	14.30	5.67	11.64	0.18	3.60	2.99
95-100	2.00	26.48	5.37	15.21	0.18	3.60	2.90
free entry							
0-100	9.04	0.23	4.88	8.92	0.17	3.69	3.12
95-100	10.12	0.31	4.01	6.37	0.17	3.70	3.12

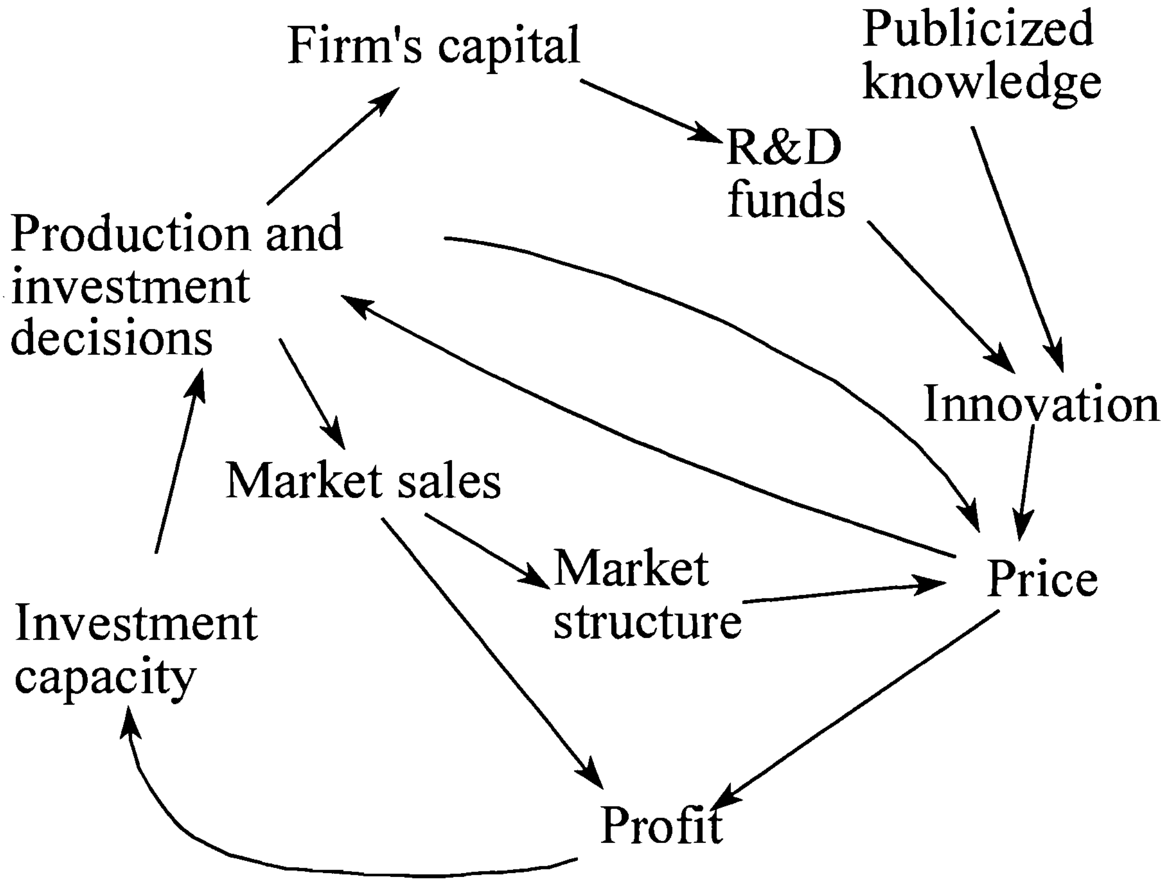

Fig. 1. General structure of the evolutionary industrial model

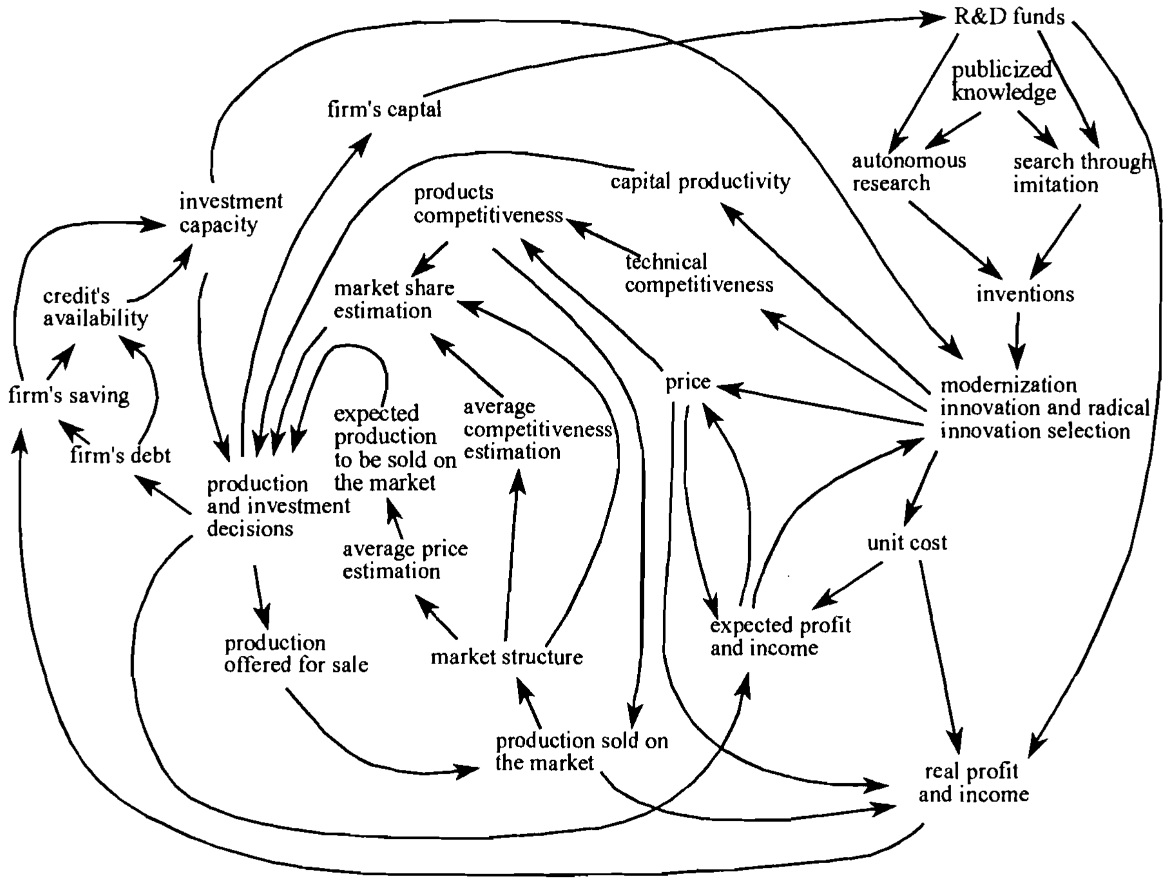

Fig. 2. Causal relationship in the evolutionary industrial model

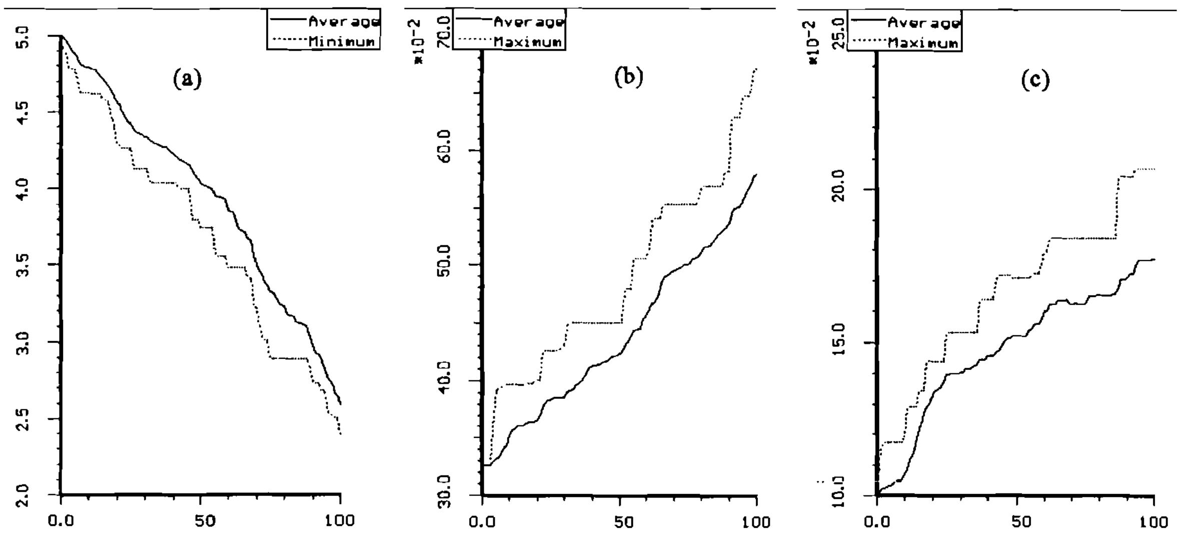

Fig. 3. Innovation regimes: variable cost of production (a), technical competitiveness (c), and productivity of capital (c)

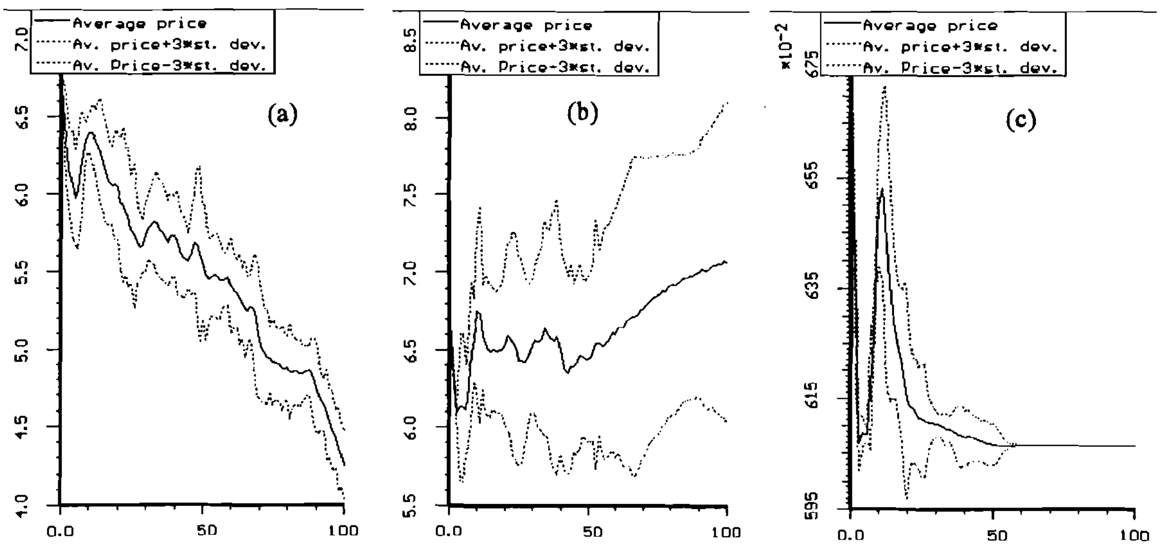

Fig. 4. Price for different innovation regimes: cost (a), technical performance (b), and productivity (c)

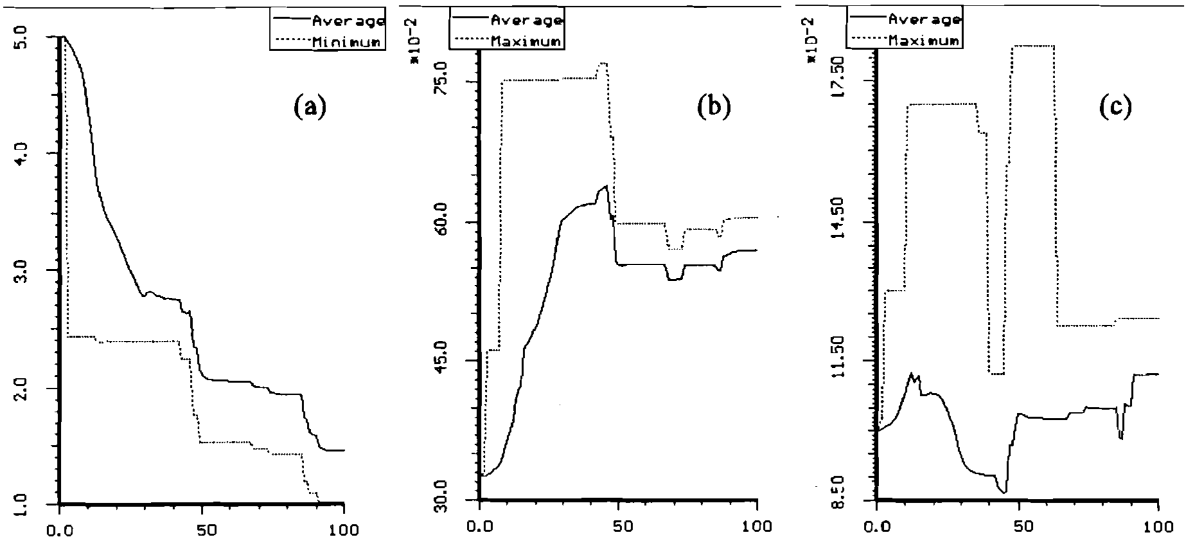

Fig. 5. Variable cost of production (a), technical competitiveness (b), and productivity of capital (c) in the "complex" regime

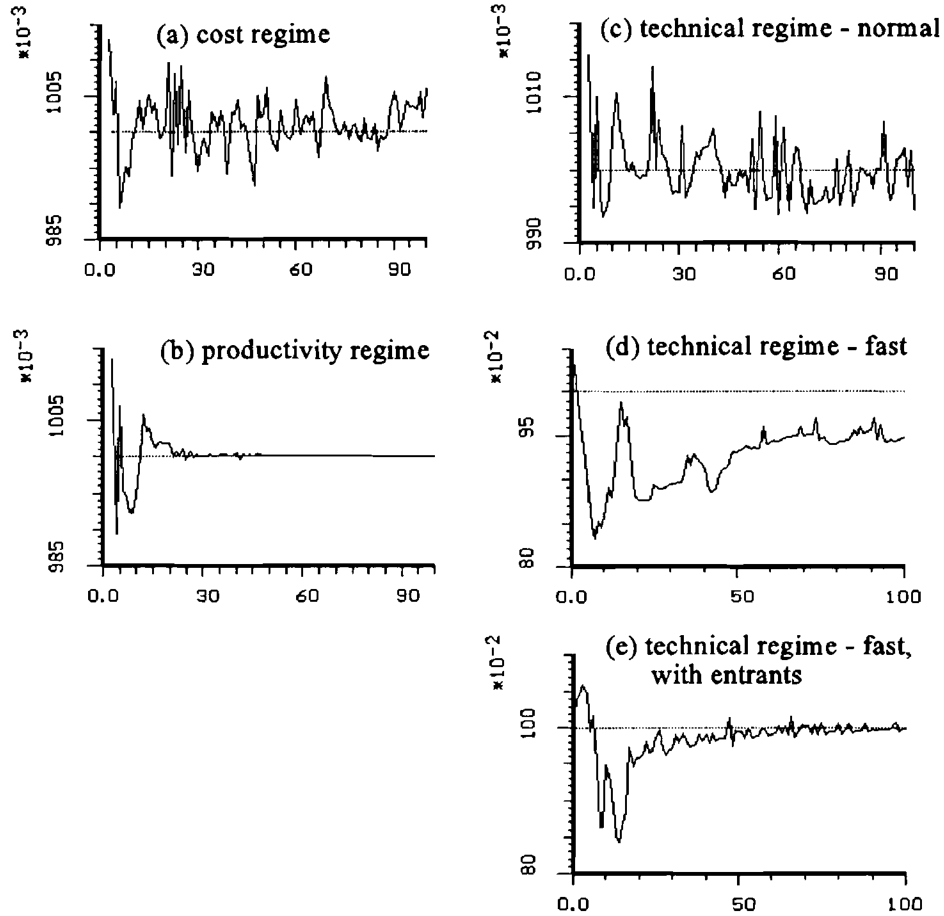

Fig. 6. The Supply/Demand ratio for different innovation regimes

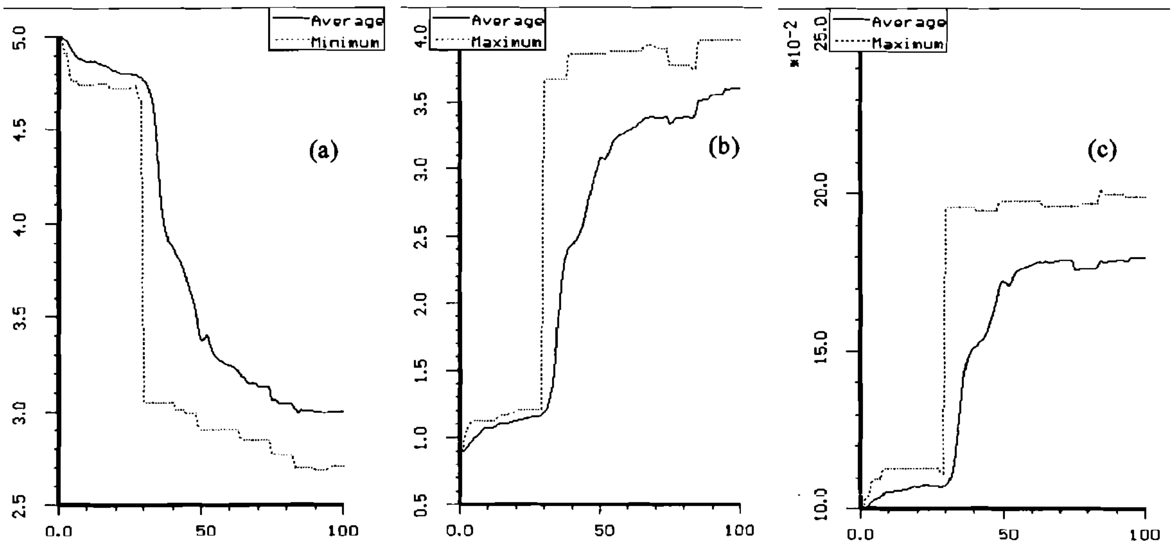

Fig 7. Cost of production (a), technical competitiveness (b), and productivity of capital (c) in 'no entry – free entry' experiment

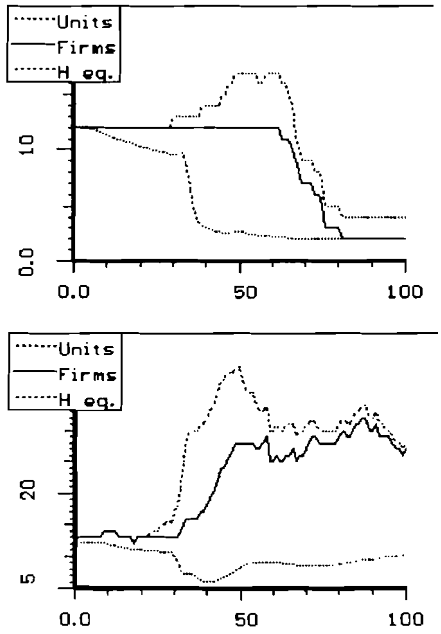

Fig 8. Number of firms in the no entry (upper chart) – free entry (lower chart) experiment

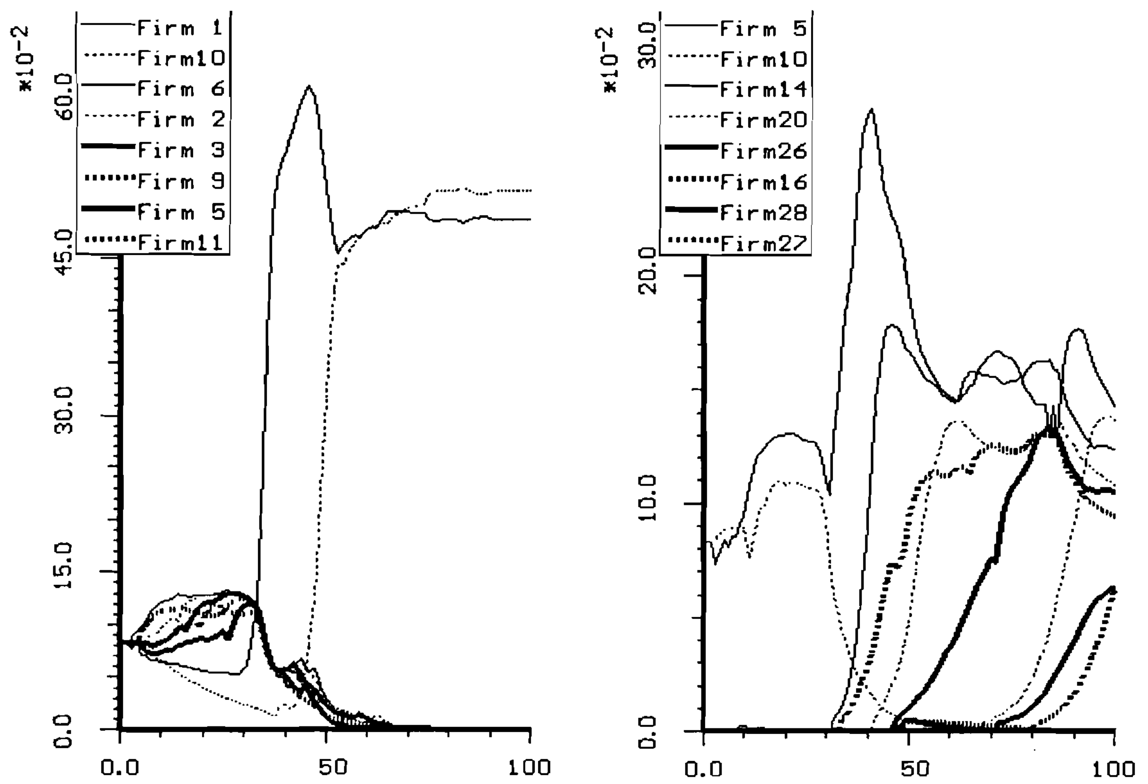

Fig. 9. Market shares of the eight largest firms in the no entry – free entry experiment

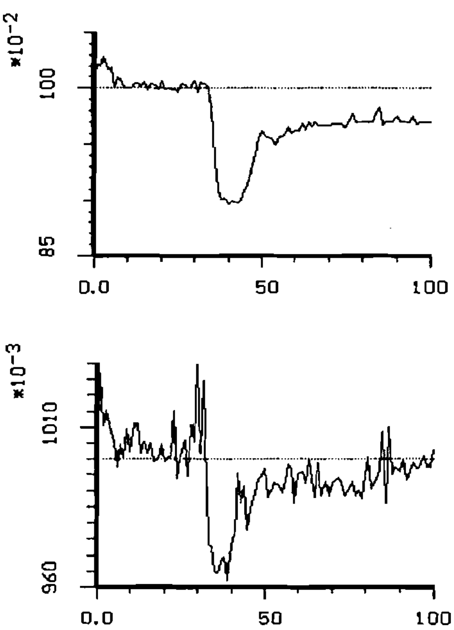

Fig. 10. Supply to demand ratio in the no entry (upper chart) – free entry (lower chart) experiment

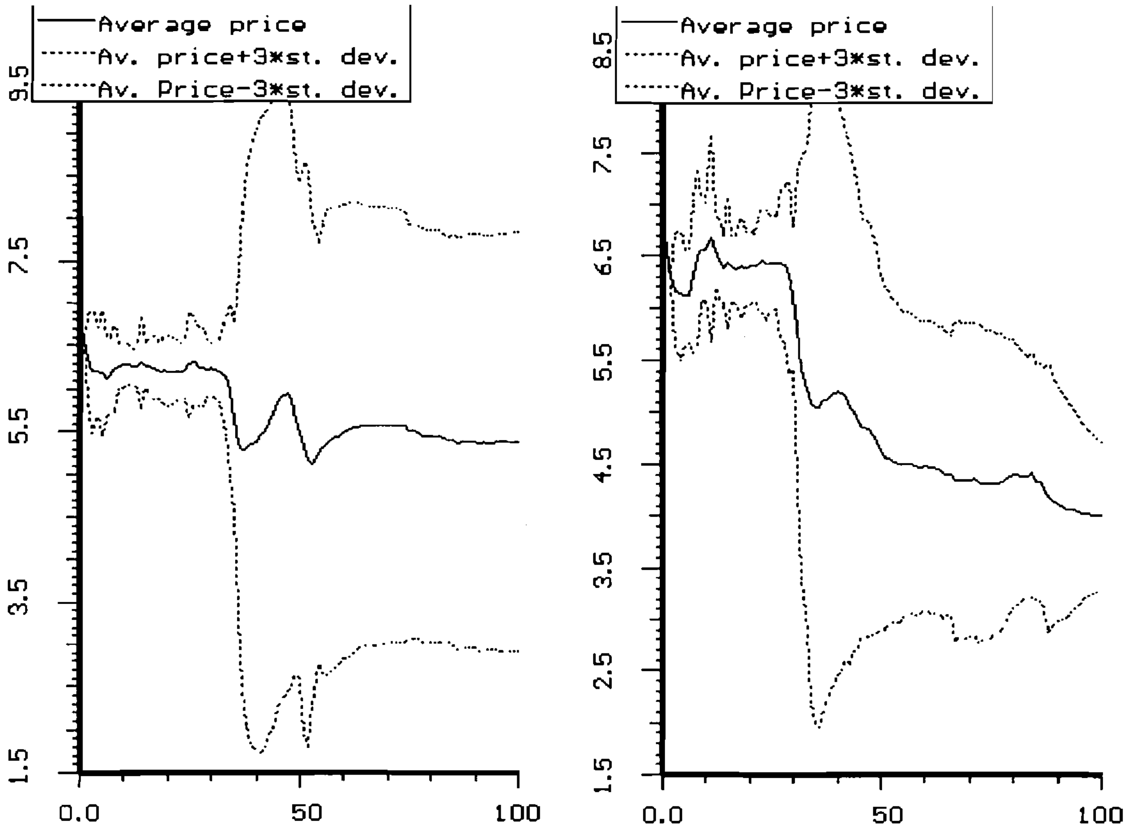

Fig. 11. Price in the no entry (left) – free entry (right) experiment