Monopoly and perfect competition – there are two sides to every coin

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It is well-documented fact that the profit gained by firms and market prices are related to the market structure. In common understanding, great concentration of the market causes higher prices and the higher firms' profit. A pure competition case relates to a situation of a large number of firms competing on the finite market, in the course of market development the possibilities of making positive profit disappear and at the equilibrium state the profit of competitive firms is equal to zero, the only profit made by firms is the 'normal' profit embedded into the supply function in the form of the opportunity costs. Monopoly is the other side of a market spectrum. A monopolist feels his safe situation on the market and tries to increase the price to relatively high level to gain great positive profit. Some theoretical considerations based on the evolutionary model of industrial dynamics suggest that it is true in most situations but there are some specific situations (industrial regimes) which impose a monopolist to behave similarly to the firms competing on the pure market and vice versa, there are situations allowing competitive firms to apply monopolists' strategy and to gain large positive profit.

In the first section of the paper a description of an evolutionary model of industrial dynamics is presented. The second and the third sections contain results of a simulation study of the model. The model's analysis presented in the second section is focussed on equilibrium analysis. Behaviour of the model for a wide spectrum of the model's parameters is investigated. Study dynamics of industrial development related to the main subject of the paper is presented in the next section. In both sections it is shown how different modes of industrial development emerge for different industry concentration and different values of the unit cost of production and the productivity of capital.

2. The evolutionary model of industrial dynamics

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

Each firm tries to improve its position in the industry and in the market by introducing innovations in order to minimize the unit costs of production, maximize the productivity of capital, and maximize the competitiveness of its products on the market. The general structure of the model is presented in Figure 1.

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

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

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

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

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

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

(1) Search for innovation (i.e., search for new sets of routines which potentially may replace the old set currently employed by a firm).

(2) Firms' decision making process (calculation and comparison of investment, production, net income, profit, and some other characteristics of development which may be attained by employing the old and the new sets of routines. Decisions of each firm on: (a) continuation of production by employing old routines or modernizing production, and (b) opening (or not) of new units).

(3) Entry of new firms.

(4) Selling process (market evaluation of the offered pool of products; calculation of firms' characteristics: production sold, shares in global production and global sales, total profits, profit rates, research funds, etc).

The search for innovation

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

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

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

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

The firm may also allocate some funds for gaining knowledge from other competing firms and try to imitate some routines employed by competitors (recombination). It is assumed that recombination may occur only between segments, not between individual routines, that is, a firm may gain knowledge about the whole domain of activity of another firm, for example, by licensing. A single routine may be transmitted (transition, see Figure 2) with some probability from firm to firm. It is assumed that after transition a routine belongs to the subset of latent routines. At any time a random transposition of a latent routine to the subset of active routines may occur (Figure 3). It is assumed that the probabilities of transition of a routine from one firm to another and the probabilities of transposition of a routine (from a latent to an active routine) are independent of R&D funds, and have the same constant value for all routines.

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

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

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

Firm's decisions

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

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

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

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

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

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

where F_i is the magnitude coefficient (with values between 0 and 1), Q_i^s the supply of firm i, Γ_i the expected income of firm i at t +1 (defined by equation (6), below), QS is the global production of the industry in year t and Γ the global net income of all firms in year t. $\Gamma(t)$ and $QS(t)$ play the role of constants in equation (5) and ensure that the values of both terms in this equation are of the same order.

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

$$\Gamma_i = Q_i^s(t)\left(p_i(t) - Vv(Q_i^s(t)) - \eta\right), \qquad (2)$$

$$\Pi_i = \Gamma_i - K_i(t)(\rho + \delta), \qquad (3)$$

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

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

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

Entry

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

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

Products competitiveness on the market

The productivity of capital, variable costs of production and product characteristics are the functions of routines employed by a firm (see Figure 4). Each routine has multiple, pleiotropic effects, that is, may affect many characteristics of products, as well as productivity, and the variable costs of production. Similarly, the productivity of capital, unit costs of production and each characteristic of the product can be function of a number of routines (polygeneity). We assume that the transformation of the set of routines into the set of product characteristics is described by *m* functions F_d,

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The above equations are valid if the production offered by the firms exactly fits the demand of the market. This is a very rare situation and therefore these equations have to be adjusted to states of discrepancy between global demand and global production, and discrepancy between the demand for products of a specific firm and the production offered by this firm. The details of this adjustment process is presented in Kwasnicki (1996). Equation (17) describes the market demand for products of firm i offered at a price $p_i(t)$ and with competitiveness $c_i(t)$. In general, however, the supply of firm i is different from the specific demand for its products. The realization of the demand for products of firm *i* does not depend only on these two values of demand and supply, but on the whole pool of products offered for sale on the market. The alignment of supply and demand of all firms present on the market is an adaptive process performed in a highly iterative and interactive mode between sellers and buyers. In our model, we simulate the iterative alignment of supply and demand in a two-stage process in which a part of the demand is fulfilled in the first stage, and the rest of the demand is, if possible, fulfilled in the second stage. If there is no global oversupply of production, then in the first stage of the supply–demand alignment process all demand for production of specific firms, wherever possible, is fulfilled, but there is still the shortfall in production of firms which underestimated demand for their products. This part of demand is fulfilled in the second stage of the supply–demand alignment process. At this stage, the products of the firms which produce more than the specific demand are sold to replace the shortfall in production by the firms which underestimated the demand for their products.

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

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

Simulation – equilibrium analysis

One of the general validity test of any model, used especially at the initial phases of a model's development, is to check if some characteristics (e.g. rates of changes of some important variables) of the model's behaviour do not depend on used units of measurement. During testing the validity of our model from this point of view we have observed that the development of the model is exactly the same for the same value of a factor equal to the multiplication of the productivity of capital and the unit cost of production, that is, the *AV* factor. The preliminary observations on this phenomenon are presented in Kwasnicki (1996, pp. 122-127). In this paper I would like to investigate this phenomena more closely to build a platform for further, envisaged, empirical research of selected industries.

From definition, productivity of capital *A* is equal to quantity of production *Q* divided by the capital used in production process *K*, and unit cost of production is equal to total cost of production *C* divided by the production volume *Q*. Therefore, the *AV* factor is equal to the total cost of production to capital, i.e. *C*/*K*. Let us call this factor the cost ratio.

One of the aims of introducing innovations is increasing the productivity of capital and reducing unit cost of production. Therefore, introduced innovations change also values of the cost ratio. It can either increase (if improvement of productivity of capital is greater then cost reduction), decrease (cost reduction is greater then productivity improvement), or became constant (if ratios of changes of productivity of capital and cost reduction are exactly the same). There are some empirical evidences that in the last one hundred years the productivity of capital stays almost at the same level but unit cost of production of majority of industries was significantly reduced. Simulation results focussed on a search for so-called innovation regimes (see Kwasnicki, 1996a) suggest also that innovation allowing for reduction of the unit cost of production is more eagerly accepted by firms then innovations leading to increasing the productivity of capital. A view that in the course of development of modern industries the cost ratio is significantly reduced seems to be justified. There arises question on the significance of the *AV* reduction on the modes of development of modern industries?

Naturally economic process is extremely dynamic one, with a large number of emerging innovations and bounded rational decisions of managers (related to prices, investments and level of production) influencing development of any industry. Because of this dynamic nature of economic process we can expect that reaching the equilibrium is very difficult, and the vision of pursuit the equilibrium seems to be more close to real industrial development. Naturally using our simulation model we are able to investigate dynamics of industrial processes but it is also difficult to work out general conclusions concerning industrial development looking only at dynamic trajectories of development of different industries. An attempt to investigate dynamic properties of the model in the presence of innovation and economy of scale is presented in the next section. Comparison of simulation results presented in both sections allows to see differences between static and dynamic views of economic process.

To catch general view on industrial development let us start from investigation equilibrium properties of the model, keeping in mind that in fact it is dynamic process. Making a number of simulations for different values of the cost factor and also other parameters of the model (e.g., number of firm and their sizes, i.e. industry concentration) we are able to generate surface describing the equilibria of industry development for different values of the cost ratio and industry concentration. As it was said, industry development can be seen as pursuit of moving equilibrium. If we assume that in the course of development the cost ratio is reduced and also the concentration of industry changes then, as the first approximation, trajectories of industry development can be seen as lines on the previously generated surface of equilibrium values.

Large number of simulation experiments for different values of the cost ratio (*AV*), industry concentration (i.e. number of competing firm n), rate of industry growth (γ), normal rate of return (ρ), price elasticity in the demand function (β), and many others were made. Equilibrium values of one such simulation series of experiment are presented in Tables 1 and 2 (in some experiments, industry does not reach stable equilibrium but fluctuates around steady state – these cases are italicized in the Tables). It was assumed that there is no innovation. Some parameters are constant in these series experiments (e.g. β=-0.3, γ=0, ρ=0.05). Simulation approach allows to select relatively large spectrum of change of the cost ratios – from 0.01 to 100, and also wide spectrum of change of industry concentration – from pure monopoly (n=1) to pure competition (n=24). Looking at the results presented in Table 1 we can see that there are two zones – first where equilibrium profit is equal to zero, and the second with the positive profit. The surface of equilibrium profit to capital ratio is presented in Figure 5, it is graphical presentation of the results in Table 1. As we see values of profit to capital ratio are for some simulations very large – naturally it is hardly to expect that such high values can be observed in real industrial processes but it is an advantage of simulation approach that we are able to create some extreme conditions and observe the hypothetical development of enquired system for those extreme conditions. We present all simulation results just to give general (although in some cases purely theoretical) view of industrial development. The border separating the two mentioned zones is drawn also in Figure 5 (the solid, thick line). In Figure 6 the same surface is enlarged to observe more details around the border. To observe the rate of growth of the profit the surface presented in Figures 5 and 6 can be 'sliced' for constant values of the cost ratio or constant values of the industry concentration. The relevant functions are presented in Figures 7 and 8 (Figures 7b and 8b corresponds to the surface presented in Figure 6a). Looking at all those figures, it is seen that after crossing the border from the zero profit zone, profit grows relatively quickly with growing values of the *AV* ratio or with increasing the concentration of the market. Irregular behaviour observed for relatively large number of firms (small concentration) are because of mentioned earlier fluctuations of development.

An analogous surface can be drawn using the simulation date from Table 2. A shape of the surface of the price margin is slightly different then the profit surface (see Figure 9 and its enlargement in Figure 10). To see more details of the price margin surface we ought to look at it from different perspective, therefore the order of *AV* and *n* axes is different then that on Figures 5 and 6. In the zero profit zone the price margin hyperbolically decreases (see also Figures 11 and 12 where the price margin surface is sliced in similar way as it was done in Figures 7 and 8 with the profit ratio surface). After reaching the border separating the two mentioned zones the price margin is constant but this constant value depends on industry concentration (and the price margin is the smaller the smaller is the concentration and the smaller is the value of the cost ratio). It can be said that the shape of the price margin surface reverses the shape of the profit ratio surface – in the zero profit zone the price margin decreases hyperbolically and vice versa in the hyperbolical growth of the profit ratio the surface of the price margin is relatively flat.

From qualitatively point of view the shapes of the profit ratio surface and the price margin surface are almost the same for different values of other model's parameters. For example for different kinds of the market (defined by the values of the price elasticity β in the demand function) we observe the same two zones but the border between these two zones is slightly shifted. The β parameter is greater then zero for commodities fulfilling primary needs and is negative for commodities fulfilling higher-order needs. The shift is the greater the smaller is the cost ratio *AV* and the greater is the concentration of the industry. The borders for four kinds of markets are presented in Figure 13. Let us notice that even for the primary goods markets (β>0) and for high concentration there are industry states where profit is equal to zero.

For a growing market (i.e., the rate of the market growth γ is greater then zero) the shape of the surfaces is almost exactly the same (and also the border does not change), the only difference is that instead of zero profit zone we have the flat area with the positive profit, e.g. for γ=0.05 the equilibrium value of profit to capital ratio in this zone is equal to 4.88%. Discussion on the impacts of the price elasticity β and the rate of market size growth γ on industry development is presented in (Kwasnicki, 1996, p. 136-141).

Simulation – dynamic analysis

The results presented in the former section can wrongly suggest that modes of development of real industry processes are smooth and seemingly deterministic. Because of innovation and firms interaction and also 'natural' errors made by decision-makers (bounded rationality of industry actors) industry development is far from being smooth process. In this section we present results of three simulation runs just to illustrate the theoretical finding presented in the former section. It seems that, at least at the level of stylized facts, the simulation results are very close to real industrial processes. Naturally the best way to illustrate the theory would be to collect relevant data of real industrial processes and to compare the simulation results to industrial records. The author hopes that it would be possible to collect such records in future.

In the first simulation run it was assumed that innovation can be introduced by firms and that there is no economy of scale. Innovation can lead to a unit cost (*V*) reduction and productivity of capital (*A*) increasing. The changes of these two factors can cause either increasing and decreasing of the cost factor (*AV*). But concurrently to changes of costs and productivity there occur improvements of products' technical performance, i.e. increasing of technological competitiveness. Therefore, each innovation can be considered as complex one. Each firm trying to introduce innovation faces the problem of considering positive and negative factors of each innovation. It frequently happens that accepted innovation allows to increase technical competitiveness but also increase of unit cost of production or decreasing of productivity of capital, but also it happens that reduction of unit cost of production is accompanied by decreasing of technical competitiveness and decreasing of productivity of capital.

In the second experiment it was assumed that there are no innovation and the only way to reduce unit cost of production is exploitation of economy of scale. The third experiment is a combination of two former simulations – innovations and economy of scale are present and in a sense cooperate in the process of cost reduction.

Let us call this three experiments 'innovation', 'economy of scale' and 'innovation & economy of scale', respectively. These labels are used in all following figures. The results of basic characteristics of development in all these experiments (namely unit cost of production, productivity of capital and technical competitiveness) are presented in Figures 14 and 15. In the first experiment innovations allows to reduce the average value of unit cost of production five times (from initial 5 to 0.986). Economy of scale in the second experiment allows to reduce average cost almost nine times (from initial value of 4.86 to 0.53 in the last year of simulation). Let us notice rather smooth curves of characteristics in the second experiment and fluctuated development in the presence of innovation (what is mainly caused by random process of innovation emergencies). Because of no innovation in the 'economy of scale' experiment, values of productivity of capital and technical competitiveness are constant and equal to their initial values during the whole simulation period (0.1 and 0.14, respectively). Cost reduction in the third experiment is accelerated by cooperation of innovation and economy of scale – the average unit cost of production is more than 300 times reduced (from initial value of 4.86 to 0.014). In the year 49 one small firm introduced innovation allowing for significant improvement of products' technical performance (technical competitiveness of that innovation was almost 40% better than the average technical competitiveness in the industry) and to improve also productivity of capital (by around 10%). As it is frequently observed in real processes, the technical performance and productivity of capital improvements are accompanied by increasing of the unit cost of production (in our simulation experiment that increase is around seven times above the average cost –the average cost increased because of economy of scale exploitation by large firms in the period just before introducing the innovation). In spite of this disadvantage the innovation was accepted by the market. Therefore in the next decade almost tenfold increasing of unit cost of production was observed, but due of further innovations and once again economy of scale exploitation the cost was reduced to the final value of 0.014. Concurrently improvement of technical competitiveness was observed, and the final value of average competitiveness is 2.36. Let us notice the second radical innovation, which emerged in the beginning of the ninth decade. The innovation allowed for further improvement of technical competitiveness by almost 30% but it was accompanied by a small increasing of unit cost of production and slight deterioration of productivity of capital (compare Figures 14 and 15). Improvement of technical performance was considered as more advantageous than the deterioration of cost of production and productivity of capital.

Changes of the cost ratio *(AV)* are presented in Figure 16a (note the logarithmic scale of the *AV* axis). In the presence of innovation the cost ratio was reduced 2.6 times (from initial value of 0.5 to the final value in the last year of 0.19). Economy of scale allowed to reduce the cost ratio more than 9 times in the second experiment(to the final value equal to 0.053). In the third experiment the cooperation of innovation and economy of scale allowed to reduce the cost ratio more than 200 times (to the final value 0.0023). We can see that synergic effect of innovation and economy of scale is much greater than simply multiplication of separated influences of both factors.

The differences of development in all three experiments are also visible in changes of industry concentration. In Figure 16b the Herfindahl firm's number equivalent (n_H) is presented. In all three experiments there are 12 firms of different size at the initial moment (the largest firm has 16.7% share of the market the smallest 0.5% share, what makes that the initial industry was equivalent to almost 9 equal sized firms – n_H= 8.93). Each year a number of new firms try to enter the industry. In all experiments, because of either innovation and economy of scale, the industry becomes more and more concentrated (although in the second experiment in the first decade after the first radical innovation emergence the industry concentration decreased). In 'innovation' experiment in the final year of simulation there are 18 firms but most of them are rather small and the market is equivalent to duopoly (n_H=1.82). Economy of scale causes much greater concentration. When there is no innovation and only economy of scale influences concentration the smaller firms are very quickly eliminated and since the year 90 only one firm operates on the market (out of the initial 12 firms). Allowing firms to innovate causes fluctuation of industry concentration. In the third experiment in the end of simulation five firms operated in the market, although four of them were rather small (n_H = 1.013).

Comparing the fluctuation of industry concentration with parallel changes of other characteristics of industry development we can observe that the fluctuations are mainly correlated to emergence of innovation, and the more radical innovation introduced the higher increase of number of the entering firms on the market. As it was mentioned earlier, in the third experiment two radical innovation emerged in the third experiment around the years 50 and 90, but only the first innovation caused reduction of industry concentration (there are more than 50 firms operating on the market in the next decades after the first radical innovation emergence and the maximum value of n_H is equal to 18.9). It happened that the first radical innovation was found by small firms and the large firms were not able to copy it in relatively short period of time. It gave the possibility to enter the market by other small firms and therefore in the end of sixth decade the Herifindahl equivalent number of firms was equal to almost 20 firms. The second radical innovation was found by the largest firm and therefore we do not observe similar reduction of industry concentration in the ninth decade.

Discussed results presented in the Figures14 to 16 allow to draw trajectories of development of profit to capital ratio and the margin of price over the plane $n_H \times \log (AV)$. The best way it would be to draw these trajectories together with the equilibrium surfaces (as presented in Figures 6 and 10) but the readability of such figures is very poor. We present only the trajectory of Profit/Capital ratio (Figure 17). In Figure 17a all three trajectories are drawn but the picture is dominated but the trajectory of the third experiments (profit to capital ratio in the third experiment is much greater then in the two other experiment). Therefore, in Figure 17b we present the trajectories for two first experiments. We can see that the trajectories fluctuate and are placed above and also below the 'equilibrium' surface. Fluctuations are much significant in the presence of innovation. In all three trajectories we can distinguish two phases: the first phase is characterized by domination of increasing concentration of industry and the second one by the reduction of the cost factor AV. The trajectory marked 'innovation' in Figure 17b is rather typical trajectory in the presence of innovation – with rather large fluctuations, turns and reverses of the course of development. Similar view is produced by the trajectory of a price margin, but instead of presenting the trajectories, to observe more details, let we look at the changes of these two characteristics as a function of time. In Figure 18 average values of profit to capital ratio is presented. When there is no economy of scale and only innovation processes influence industry development the fluctuations of profit to capital ratio and price margins are significant. Introducing (incremental) innovation allows to get profit around 8% but also, in some periods, causes an average profit to drop to the value of -2% (but even at this stage of development still some advantageous firms are able to produce rather high positive profit). Small fluctuations in the simulation run with presence of economy of scale (and no innovation) are caused by discrepancies of firms expectations on future development of the industry and real industry development (this wrong decisions can be ascribed to firms' bounded rationality). The same kind of fluctuation is observed in the third experiment (see Figure 18b, and also a more detailed chart in the top right corner of that figure). Radical innovation which emerged in year 49 caused relatively deep reduction of average profit in the 5th decade (to -27%) but within next few years industry witnessed high growth and the average profit increased to 55% (but very quickly dropped to relatively small values of 4%). The second radical innovation (in the 9th decade) was found by the largest firm. At the moment of that innovation introduction there were 32 operating firms but most of them very small (n_H = 1.97). The largest firm was not able to exploit the advantages of this radical innovation because at this stage the capital ratio *AV* was relatively small (around 0.03). The maximum average profit after emergence of this innovation was less then 2%.

Development of a price margin is presented in the Figure 19. In the presence of innovation (and no economy of scale) the price margin was no greater then 2.3. Slightly grater price margin was observed in the presence economy of scale (Figure 19a). Maximum value of this ratio was around 5. Full exploitation of innovation process and economy of scale caused very high price margin values (up to 160) and high concentration of industry. But it does not mean that the largest firm in the third experiment (being in fact very close to monopolist position) reached enormous profits. As it was mentioned, the cost ratio *AV* at this stage of development was around 0.03 and, accordingly to the findings presented in the former section, this caused that in the last decades of simulation the profit of this 'monopolist' was no larger then 0.7%.

Conclusions

The presented results are purely theoretical and ought to be the subject of further study and verification. In particular a comparative study of real industrial processes focussed on the modes of development related to different values of the cost ratio ought to be made. But even at the current stage of research, after the preliminary simulation studies and a 'stylized' comparison of the models' behaviour with real industrial development, it transpires that for plausible values of the cost ratio the behaviour of our model strongly resembles the behaviour of real industries.

Values of the cost ratio are simple real numbers and do not depend on the units of measure of capital and production. It seems that the cost ratio may be used as the practical characteristic for the classification of industries. Small values of the cost ratio indicate that in this type of industry a large capital is required to manufacture products at relatively low cost, and vice versa, a large cost ratio means that in this type of industry a relatively small capital is engaged to manufacture products at high cost. Industries with large productivity of capital and low unit cost of production may have the same cost ratio as industries with small productivity of capital and high unit cost of production; and the result is that in all such cases the characteristics of the industry development, in the absence of innovations, are exactly the same.

It may be expected that labour cost is a major part of the unit cost of production, so the invariability of development of different types of industries for the same value of the cost ratio resembles the classical finding of substituting labour with capital.

On the basis of the presented results one may draw the conclusion that it is possible to imagine situations (industry regimes) in which highly concentrated industries behave as industry with large number of firms being in a state of pure competition (namely, for very small values of the cost ratio *AV*) and also industry regimes in which numerous competitors behave as oligopolist (or even as a monopolist), namely, for high values of the cost ratio *AV*. These findings are purely theoretical and ought to be verified using real data of industrial development. The open question is if in real industrial processes we observe such small and large values of the cost ratio?

As a hypothesis, it may be stated that in real industrial processes, because of introducing innovations reducing unit cost of production, the cost factor is reduced in successive stages of an industry development. Therefore, for matured innovative industries we can expect higher competitive conditions of development.

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Table 1. Profit to Capital for different values of the cost ratio and the industry concentration

	number of firms (*n*)							
AV	1	2	4	8	12	16	20	24
0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.075	4.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	12.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	44.76	5.08	0.00	0.00	0.00	0.00	0.00	0.00
0.5	141.10	42.69	12.10	0.00	0.00	0.00	0.00	0.00
0.75	228.86	74.04	28.14	4.75	0.00	0.00	0.00	0.00
1	303.80	105.38	44.19	12.10	1.28	0.00	0.00	0.00
2	627.60	230.77	108.38	44.19	22.57	11.08	5.27	1.73
5	1599.00	606.90	300.96	140.50	86.43	59.50	*39.29*	*78.57*
7.5	2409.00	920.40	461.44	220.75	139.64	99.26	*26.25*	
10	3218.00	1233.80	621.92	301.00	192.85	139.01	*43.43*	
20	6456.00	2488.00	1263.80	622.00	405.70	298.02	*112.00*	
50	16170.00	6249.20	3189.60	1585.00	1044.30	775.04		
75	24266.00	9383.80	4794.40	2385.50	1576.40	1172.60		
100	32361.00	12151.80	6399.20	3190.00	2108.60	1570.10		

Table 2. Price to unit cost for different values of the cost ratio and the industry concentration

	number of firms (*n*)							
AV	1	2	4	8	12	16	20	24
0.01	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
0.02	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00
0.05	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
0.075	4.24	3.67	3.67	3.67	3.67	3.67	3.67	3.67
0.1	4.24	3.00	3.00	3.00	3.00	3.00	3.00	3.00
0.2	4.24	2.25	2.00	2.00	2.00	2.00	2.00	2.00
0.5	4.24	2.25	1.64	1.40	1.40	1.40	1.40	1.40
0.75	4.24	2.25	1.64	1.32	1.27	1.27	1.27	1.27
1	4.24	2.25	1.64	1.32	1.21	1.20	1.20	1.20
2	4.24	2.25	1.64	1.32	1.21	1.16	1.13	1.11
5	4.24	2.25	1.64	1.32	1.21	1.16	*1.13*	*1.11*
7.5	4.24	2.25	1.64	1.32	1.21	1.16	*1.09*	
10	4.24	2.25	1.64	1.32	1.21	1.16	*1.09*	
20	4.24	2.25	1.64	1.32	1.21	1.16	*1.09*	
50	4.24	2.25	1.64	1.32	1.21	1.16		
75	4.24	2.25	1.64	1.32	1.21	1.16		
100	4.24	2.25	1.64	1.32	1.21	1.16		

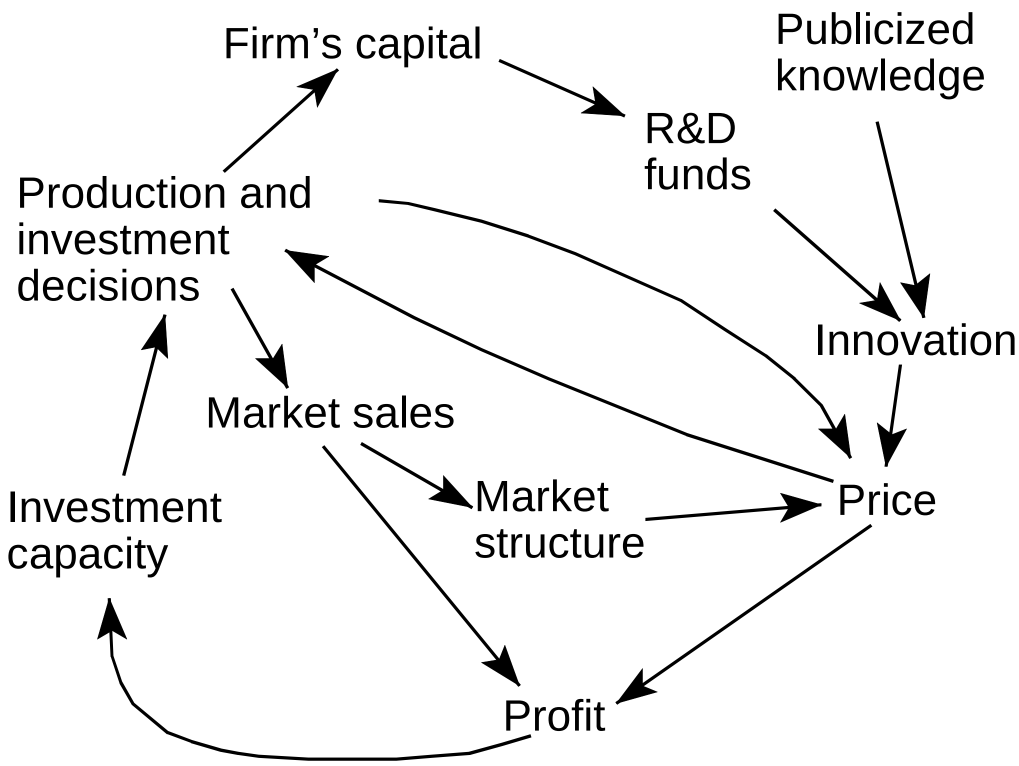

Figure 1. General structure of the evolutionary industrial model

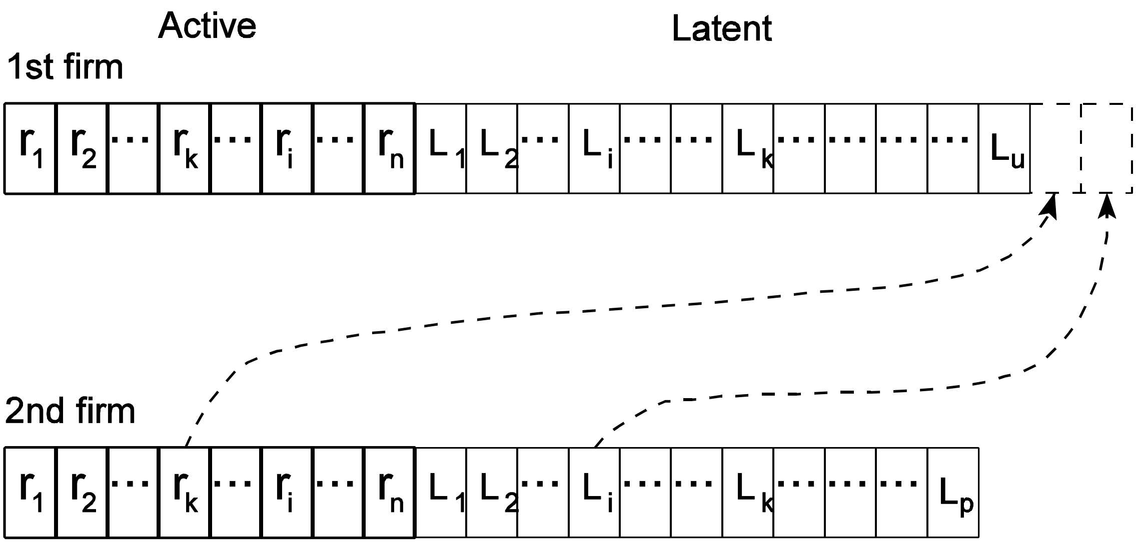

Figure 2. Routines transition

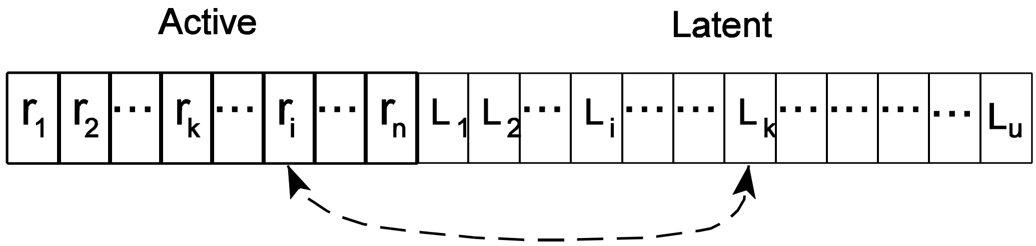

Figure 3. Routines transposition

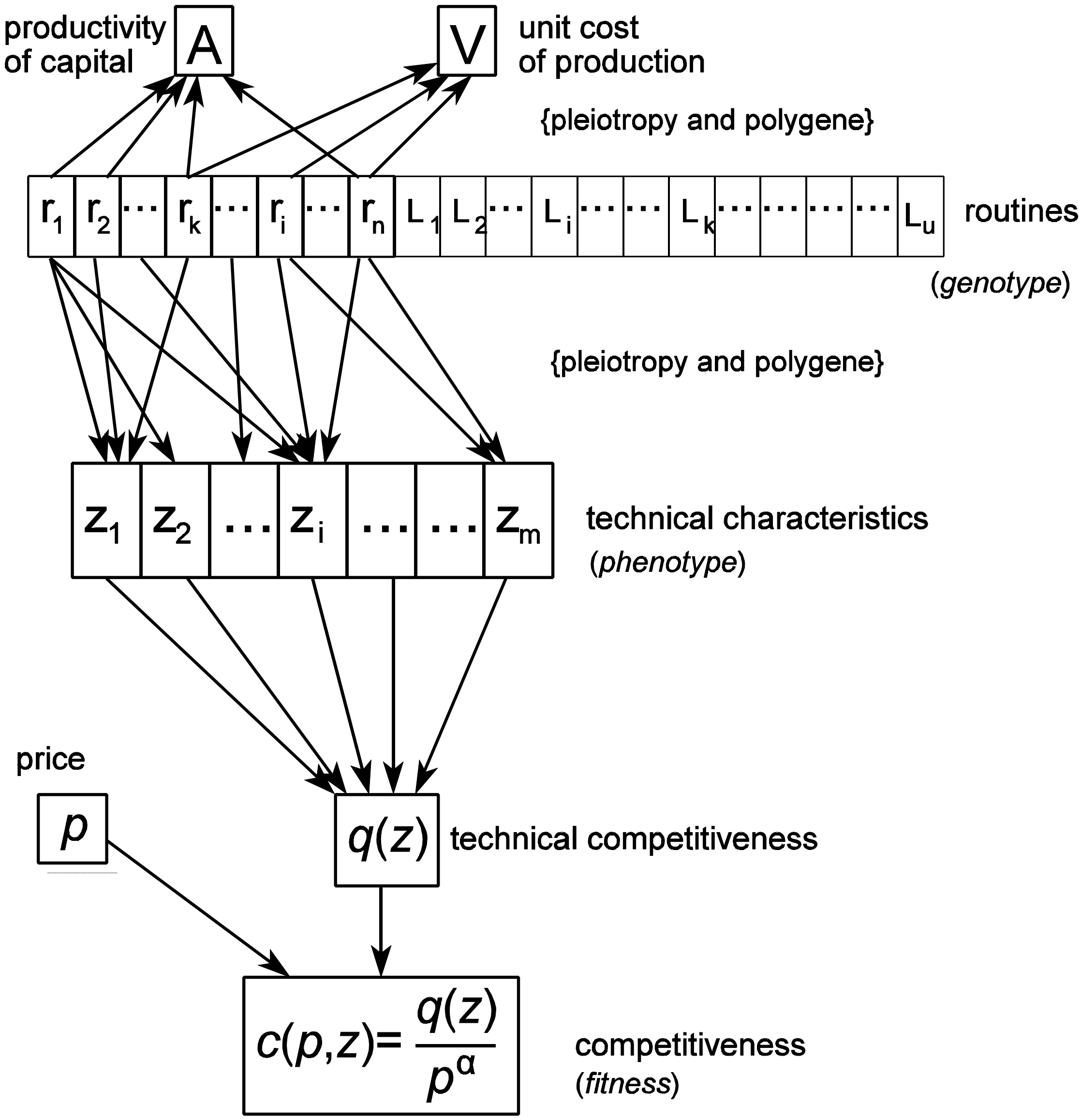

Figure 4. From routines to competitiveness, productivity of capital and unit cost of production

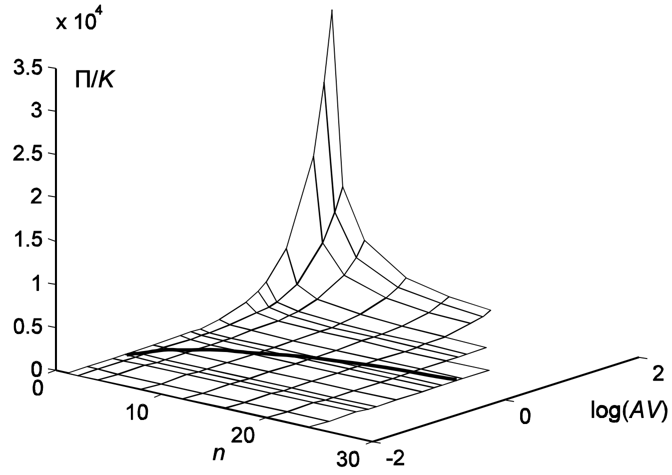

Figure 5. Profit as a function of the cost ratio and the industry concentration

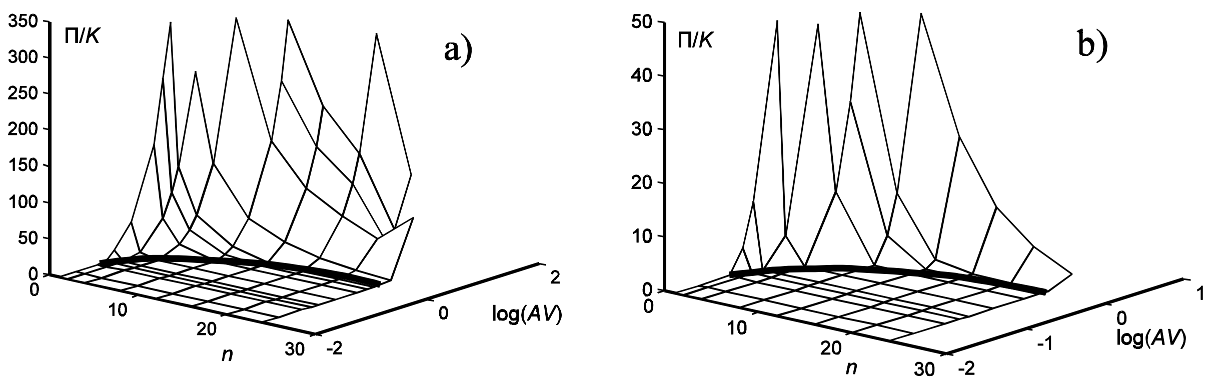

Figure 6. Profit as a function of the cost ratio and the industry concentration (enlargements)

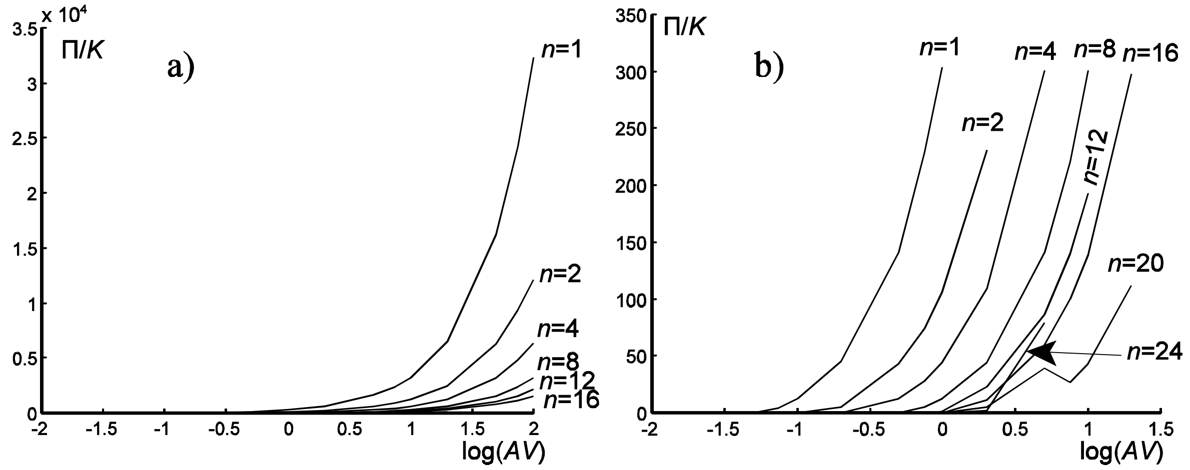

Figure 7. Profit as a function of the cost ratio (the industry concentration is a parameter)

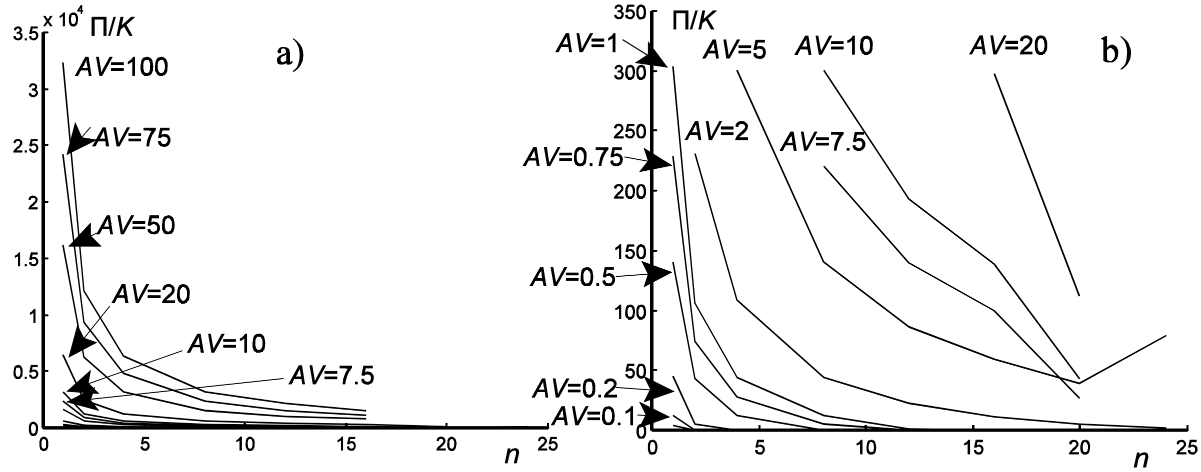

Figure 8. Profit as a function of the industry concentration (the cost ratio is a parameter)

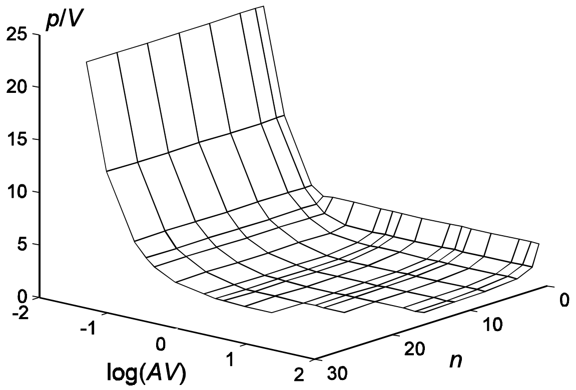

Figure 9. Price margin as a function of the cost ratio and the industry concentration

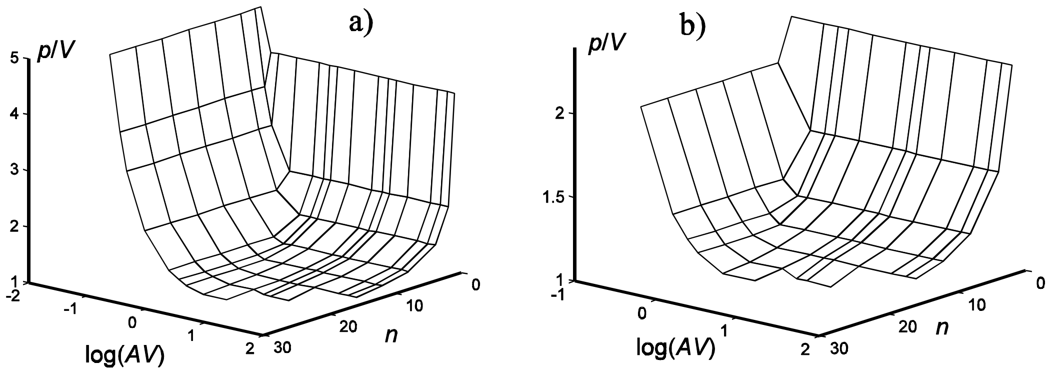

Figure 10. Price margin as a function of the cost ratio and the industry concentration (enlargements)

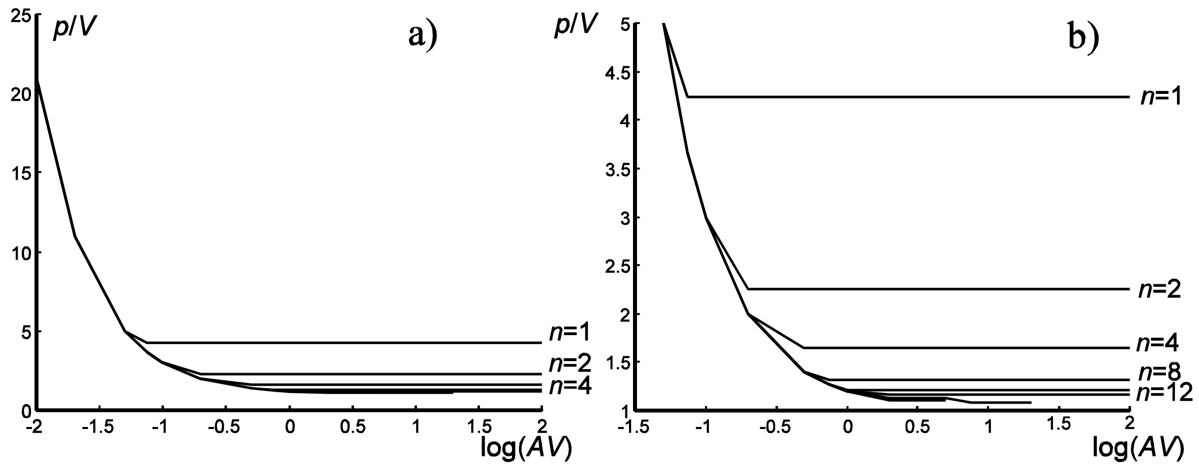

Figure 11. Price margin as a function of the cost ratio (industry concentration is a parameter)

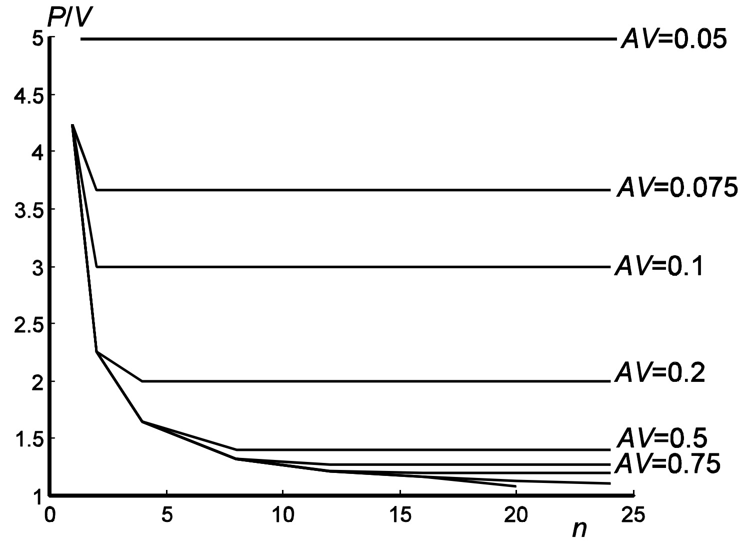

Figure 12. Price margin as a function of the industry concentration (the cost ratio is a parameter)

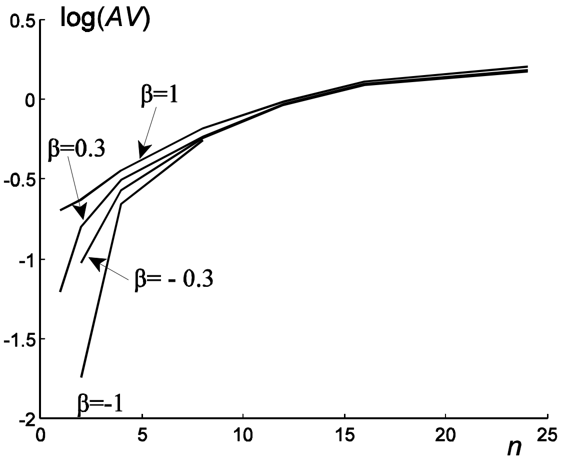

Figure 13. Border between zero profit and positive profit regions for four different kinds of industries

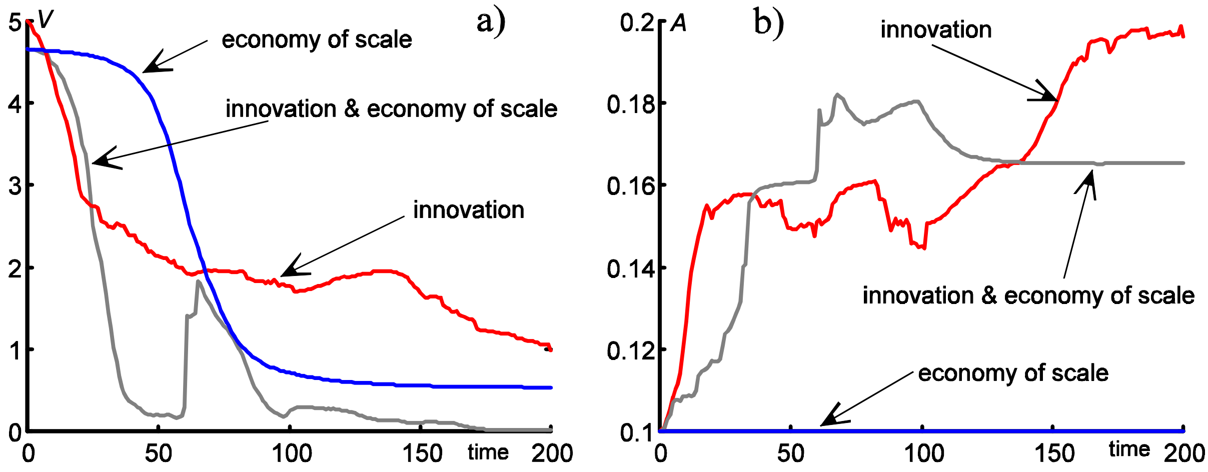

Figure 14. Variable cost of production and productivity of capital (average values)

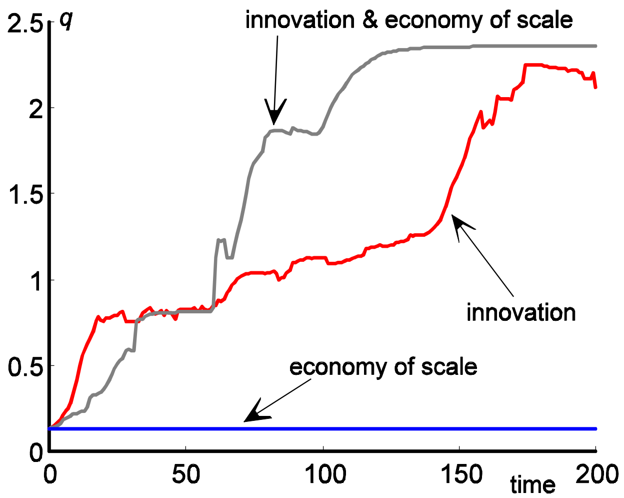

Figure 15. Average values of technical competitiveness

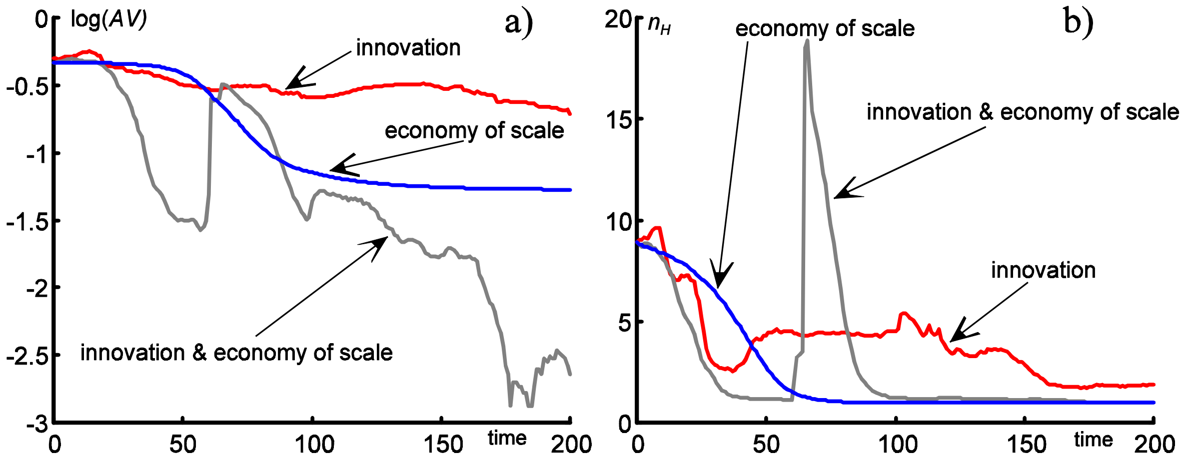

Figure 16. The cost ratio (AV) and Herfindahl firm number equivalent

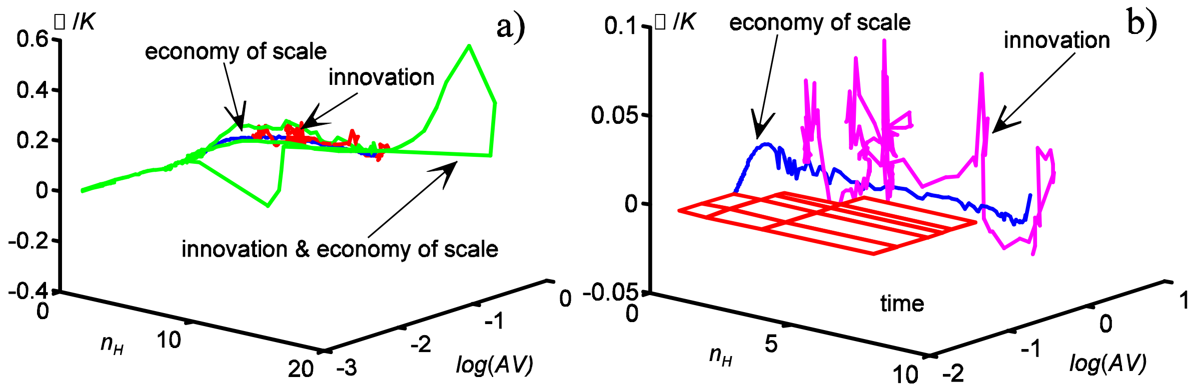

Figure 17. Profit to Capital ratio in the space of *AV* and *n*

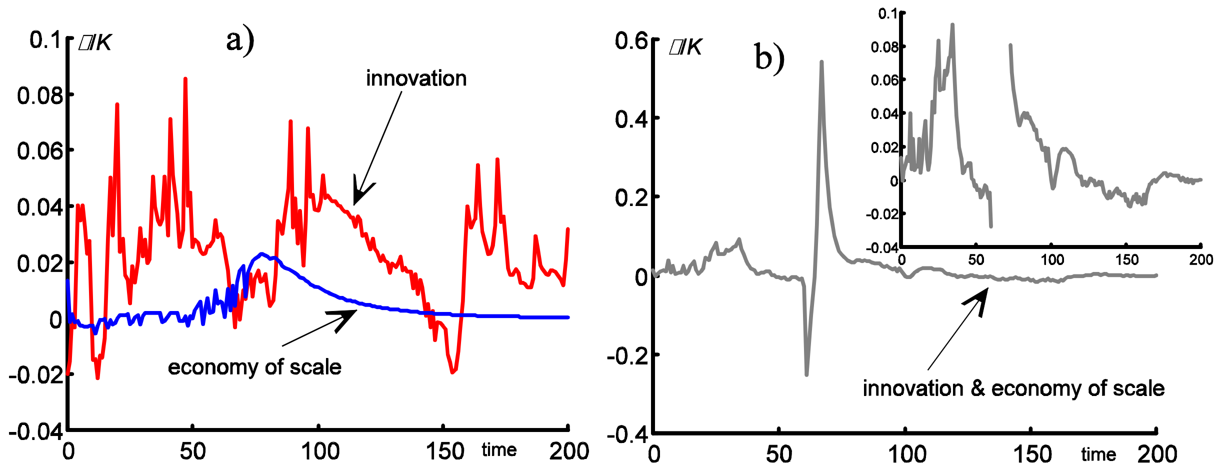

Figure 18. Profit to Capital ratio (average values)

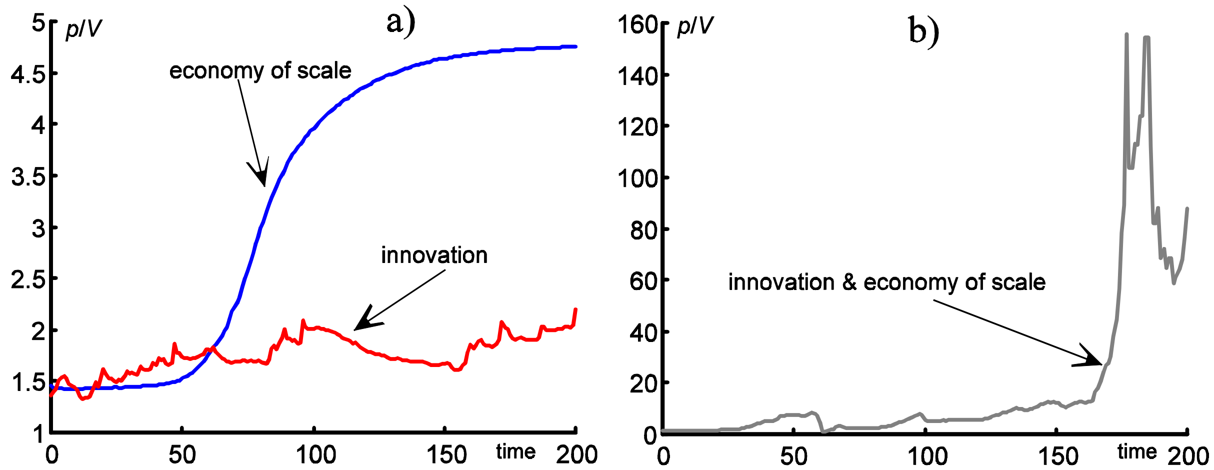

Figure 19. Price margin (average values)