# Evolutionary modeling and industrial structure emergence

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## Abstract

In the first part of the paper an outline of the evolutionary model of industrial dynamics is presented. The second part deals with a simulation study of the model focused on identification of necessary conditions for emergence of different industrial strictures. Textbooks of traditional economics distinguish four typical industry structures and study them under the names of pure competition, pure monopoly, oligopoly and monopolistic competition. Variations in behaviour modes of differently concentrated industries ought to be an outcome of the cooperation of well-understood evolutionary mechanisms, and not the result of juggling differently placed curves representing supply, demand, marginal revenue, marginal cost, average costs, etc. Textbook analysis of industrial structures usually omits influence of innovation on market behaviour. Evolutionary approach and simulation allow for such kind of analysis and through that allow enriching the industrial development study. One of the important conclusions from that paper is that evolutionary analysis may be considered as very useful and complementary tool to teach economics.

## Introduction

Almost all evolutionary economics (on EE foundations see Dopfer, 2005) models worked out in the last decades are dynamical ones and are focused on far-from-equilibrium analysis. There is no place to make review and to characterize evolutionary models in economics in details.[1] In a nutshell the other main features of evolutionary models may be summarised as follows:

- Development seen in historical perspective; macro-characteristics flow from aggregation of micro-behaviours of economic agents;

[1] good reviews of recent literature on evolutionary modelling can be found in: Silverberg, Gerald, 1997, 'Evolutionary Modeling in Economics: Recent History and Immediate Prospects', Research Memoranda 008, Maastricht : MERIT, Maastricht Economic Research Institute on Innovation and Technology, (downloadable from http://ideas.repec.org/p/dgr/umamer/1997008.html), Silverberg, Gerald and Verspagen, Bart, 1995 (2003), 'Evolutionary theorizing on economic growth', in: K. Dopfer (ed.), *The Evolutionary Principles of Economics*, revised 2003, forthcoming, Cambridge, Cambridge University Press (downloadable from: http://ideas.repec.org/p/wop/iasawp/wp95078.html), Frenken Koen (2005), 'History, State And Prospects Of Evolutionary Models Of Technical Change: A Review With Special Emphasis On Complexity Theory", Utrecht University, The Netherlands. http://www.complexityscience.org/NoE/Frenkencomplexityreview.pdf, see also our 'Schumpeterian modelling' (2003) at http://prawo.uni.wroc.pl/~kwasnicki/todownload/Schumpeterian modelling.pdf and 'Comparative analysis of selected neo-schumpeterian models of industrial dynamics', paper presented at the *Nelson and Winter Conference*, Aalborg, June 12-15, 2001 at http://prawo.uni.wroc.pl/~kwasnicki/todownload/NWconference.pdf

- Population perspective;
- Diversity and heterogeneity of behaviour;
- Search for novelties (innovation), hereditary information;
- Selection which leads to differential growth;
- Spontaneity of development.

Some of those features seem to be crucial to call a model an evolutionary one, in our opinion to those crucial features belong: diversity and heterogeneity of economic agents (firms) and their behaviour, search for innovation based on a concept of hereditary information (knowledge), and selection process which leads to diversified rate of growth and spontaneity of development. Heterogeneity and variety can therefore be considered as an important characteristic of evolutionary approaches to technological change (Nelson 1995; Saviotti 1996). Interesting question in relation to economic evolutionary models is presence of decision-making procedures. In many models that procedure is not present, in many others it has more or less complicated form.

In the remaining part of this chapter we outline an evolutionary model[2] and we present a selection of current simulation results of that model. The main aim of this chapter is to show that evolutionary modelling can be used not only as an efficient research tool in economic analysis but also as supporting tool in the economic education.

**The evolutionary model of industrial dynamics**

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. All firms take the decisions simultaneously and independently 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 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 evaluate the products. 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.

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).

[2] Further reading on that model can be found at http://prawo.uni.wroc.pl/~kwasnicki/e-model.htm

*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 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 behavioural 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).

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 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). A single routine may be transmitted (*transition*, Figure 1) 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 2). 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.

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.

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. Each firm also considers current investment capability and the possibility of borrowing.

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.

We assume that firms apply the following objective function:

$$O_i(t+1) = (1-F_i)\frac{\Gamma_i(t+1)}{\Gamma(t)} + F_i\frac{Q_i^s(t+1)}{QS(t)},$$
$$F_i = a_1 \exp(-a_2 \frac{Q_i^s(t+1)}{QS(t)}), \tag{1}$$

where $F_i$ is the magnitude coefficient (with values between 0 and 1), $Q_i$ the supply of firm $i$, $\Gamma_i$ the expected income of firm $i$ at $t$ +1 (defined by equation (2), below), $QS$ is the global production of the industry in year $t$ and $\Gamma$ the global net income of all firms in year $t$. $\Gamma(t)$ and $QS(t)$ play the role of constants in equation and ensure that the values of both terms in this equation are of the same order, $a_1$ and $a_2$ are parameters.

The expected income of firm $i$ ($\Gamma_i$) is defined as

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

where $V$ is unit production costs, $v(Q)$ is the factor of unit production cost as a function of the scale of production (economies of scale), $\eta$ is the constant production cost.

The function $O_i$ expresses short- and long-term thinking of firms during the decision-making process (the first and second terms in equation (1), respectively). Plausible values for the parameters are $a_1 = 1$ and $a_2 = 5$, 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).

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

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

where $z_d$ is the value of characteristic *d*, *m* the number of product characteristics, and *r* the set of routines. It is assumed 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.

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

$$c(p,z) = \frac{q(z)}{p^{\alpha}}\ , \qquad z = (z_1, z_2, \ldots., z_m), \tag{4}$$

where *q*(*z*) is the technical competitiveness, *z* a vector of product characteristics, and $\alpha$ 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.

All products manufactured by the entrants and incumbents 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.

Dynamics of industry development depends also on so called replicator (selection) equation imposing that the share 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 the average competitiveness.

**Simulation of industry development**

Textbooks of traditional economics distinguish four typical industry structures and study them under the name of pure (perfect) competition, monopoly, oligopoly and monopolistic competition.[3] To explain how prices and profits are formed in the typical industries,

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[3] What follows is only a short description of the essential features of these basic structures as understood by traditional (textbook) economics:

*Pure (or perfect) competition* is a feature of industry which consists of a large number of independent firms producing a standardized product; no single firm can influence market price; the firm's demand curve is perfectly elastic, therefore price equals marginal revenue.

*Monopoly* is where there is a sole producer of a commodity, and there are no straight substitutes for that commodity.

traditional economics uses such notions as: demand and supply functions, marginal cost, average total cost, average variable cost, average fixed cost, marginal revenue, total revenue, and so on. Usually, each typical situation is considered separately in different chapters. Reading these chapters and looking at diagrams supporting the reasoning one may get the impression that different mechanisms are responsible for the development of industries with different concentrations. It seems that the study of industry behaviour at different concentrations ought to be based on an understanding of the development mechanisms which are essentially invariable and do not depend on current industry conditions, particularly on the actual number of competitors. Variations in behaviour modes of differently concentrated industries ought to be an outcome of the cooperation of well-understood mechanisms of development, and not the result of juggling differently placed curves representing supply, demand, marginal revenue, marginal cost, average total cost, average variable cost, average fixed cost and many other variables. We do not claim that the findings of traditional economics flowing from the analysis of 'curves placement' are wrong, quite the contrary, they are in accord with real phenomena, but does such analysis explain anything?

To prove that the long-run profit is equal to zero for perfect competition market the traditional economic theories assume an infinite number of competitors on the market. In reality, as in our simulation, the number of competitors may be only finite, but we may expect that for a reasonably large number of competitors the results will be very close to the theoretical predictions. How many firms may be treated, from a practical point of view, as 'the infinite number of competitors'? Some characteristics of the industry at the equilibrium state obtained in a series of experiments with a different number of competitors, under additional assumptions that the initial size of all firms is the same (that is, equi-partition of the market is assumed) and that the size of the market is constant (that is, $\gamma = 0$), are presented in Table 1.

The controlling variable in the series of experiments is the number of competitors. The results presented in Table 1 are the outcome of the co-working of the same mechanisms of development embedded in the model described in the previous section. The results are grouped into two parts: for the normal rate of return, $\rho$, equal to zero, and for the rate $\rho$ equal to 5%. Our normal rate of return corresponds, in some way, to the normal profit embedded in the neoclassical supply function. The value of the normal rate of return may be considered as an effect of the development of the whole economy, and for any single industry may be treated as exogenous. In any real processes the normal rate of return is greater than zero, but the results of a simulation for equal to zero are presented as an example of some extreme, theoretical case, just to compare the role played by the normal rate of return for industry development. The values of profit under $\rho = 0$ may be considered as a 'natural' normal rate of return. In both series of experiments close similarity of the model's behaviour to real industrial processes is observed and in this sense the results correspond to the findings of traditional economics. As in real processes of industry development, the greater the concentration of the industry, the larger the profit of the existing firms, but with the difference that, in contrast to the assumption of profit maximization of traditional economics, the objective of the firms in our model (the $O_i$ - eq. 1)) is a combination of the short term (firm's income) and long term (firm's production, or expected firm's share).[4] The one extreme is

*Oligopoly* is characterized by the presence within the industry of a few firms, each of which has a significant fraction of the market. Firms are interdependent; the behaviour of any one firm directly affects, and is affected by, the actions of competitors.

*Monopolistic competition* – there is a large enough number of firms; each firm has little control over price, interdependence is very weak or practically absent, so collusion is basically impossible; products are characterized by real and imaginary differences; a firm's entry is relatively easy.

[4] more detailed discussion on efficiency of different firms objectives are presented in (Kwasnicki, 1992, 1996).

monopoly (with profit in excess of 150% in our simulations), the other is perfect competition between an infinite number of firms with profit equal to zero. The profit drops very quickly with an increasing number of competitors. In our simulations, industries with the Herfindahl firms' number equivalent[5] $n_H$ greater then 12 competitors may be considered as very close to the ideal situation of perfect competition (profit to capital ratio for these industries is smaller than $10^{-7}$). Dynamics of change strongly depends on industry concentration. Starting from the same initial conditions, the more concentrated industries reach an equilibrium state much quicker. For fewer than eight competitors the equilibrium state is reached within 20–40 years but for a greater number of competitors the dynamics is significantly slower and for industry very close to perfect competition (over 15 competitors), equilibrium is reached within 80–120 years. Many other simulation experiments suggest that for plausible values of parameters the competition process may be considered as perfect for the industries with the Herfindahl firms' number equivalent greater than 12. We observe a trade-off between the profit rate and the normal rate of return, for example, for highly concentrated industry if the normal rate of return increases from 0 to 5%, as in Table 1, the profit rate decreases also by 5%, and the price is kept on the same level. But the trade-off acts up to the moment when a positive profit for the same price of products is maintained. If the profit for the same price becomes a loss, then firms decide to increase the price to keep a zero profit and are satisfied with the normal rate of return. In our simulation, for $\rho = 5\%$, the trade-off is observed for industry with fewer than nine competitors; for a greater number of firms the 'natural' normal rate of return is lower than 5%, and the firms increase the price to keep profit equal to zero (compare relevant values in Table 1). The positive normal rate of return also causes the profit to sales ratio to diminish but there is no full trade-off as between the normal rate of return and the profit/capital ratio. Reduction of the profit/sales ratio is always smaller than the increase in the normal rate of return.

Changes of the values of the capital physical depreciation have a similar effect on the characteristics of industry development as changes in the normal rate of return, for example, we observe a similar trade-off between the capital physical depreciation and the profit as we observe in experiments with a positive normal rate of return; reduction of the capital physical depreciation (amortization) in highly concentrated industry by 5% leads to an increase of the profit/capital ratio, also by 5%. So it may be expected that for highly concentrated industries the rising of amortization or rising of the normal rate of return will not significantly affect the products' price, but for less concentrated industries we may expect higher prices to cover the higher opportunity costs.

The dynamics of change also depends on the initial structure of industry. To investigate to what extent the initial firms' size distribution influences the dynamics of the process, the following series of experiments were made. Starting from highly diversified firms' size we measure the values of basic characteristics of industry over the course of time and observe the tendency towards uniform distribution for different concentrations of the industry. The initial Herfindahl firms' number equivalent and some general characteristics of development of the model for a different number of competitors for $t$ = 100 and 200 are presented in Table 2. For relatively high concentration of the market (that is, for the number of firms smaller than eight) there are no significant differences in the dynamics of change between industries with uniform and non-uniform firms' size distribution. This is due to a very strong tendency towards uniform distribution (caused by intensive price competition) for the highly

[5] The Herfindahl–Hirschman index of concentration of the industry is equal to: $H = \Sigma_i (f_i)^2$, where $f_i$ is the market share of fim *i*.
The Herfindahl firms' number equivalent is defined as $n_H = 1/H$, and is the number of equal-sized firms that would have the same H index as the actual size distribution of firms.

concentrated industries. The more concentrated the industry is, the quicker the uniform firms' size distribution is reached – compare values of $T_e$ in Table 2, for highly concentrated industries. For a small concentration of the industry the dynamics of reaching the equilibrium state is significantly lower and also there is no such strong tendency towards the uniform firm's size distribution; quite the contrary, some conservative tendency to stabilize the size distribution is observed. For industries very near to perfect competition the distribution of the firms' size is almost the same as at the beginning of simulation (see in relevant values of $n_H$ for years 0, 50 and 100, when the number of firms is greater than 12). As we will see in the next section the only way for small firms to pursue the big firms and to gain higher market shares is to introduce innovation.

In the following series of experiments an investigation of the ability of free entrants to penetrate the industries of different concentrations has been made (no economies of scale present). It was assumed that for a given number of equal-sized firms, at some moment, a small firm with an assumed small capital enters the market. From the moment of entrance we observe the evolution of the structure of industry, and particularly we observe the market share of the entrant. What interest us is 'does the entrant's market share grows to reach the same size as that of the initial firms?' or in another way 'is the firms' size distribution at equilibrium uniform?'. As a measure of convergence we use time $T_e$ which spans from the moment of entrance to the moment of the uniform firms' size distribution (let us call this time the penetration time). As it turns out, the invasion is quite easy for a highly concentrated industry, for example, for the monopoly industry the newcomer is able to increase its initial market share of 0.5% to the equilibrium 50% market fraction in nine years: for two, three, and four firms the relevant values of the penetration time $T_e$ are 16, 22 and 35 years, respectively. The penetration time grows hyperbolically with diminishing concentration of industry, for example, if the industry is dominated by six competitors, the newcomer needs 98 years to get the same fraction of the market as the initial firms, and for seven firms the relevant time becomes very long, namely 195 years. There is no possibility of penetrating the market if the number of firms is greater than seven. Because of much higher competitive conditions the average profit within the industry is very small, and the newcomer is not able to collect enough capital to invest and to raise its market share.[6] The penetration time for $n_{\mathrm{H}}$ greater than seven is infinite; at the equilibrium state the newcomer's market share stabilizes at a very low level, which is lower the smaller the industry concentration is, for example, for eight, nine, ten and fifteen competitors the newcomer's share at equilibrium is equal to 0.35%, 0.11%, 0.1%, and 0.09%, respectively.

In the basic model only the price competition is considered, and as we see it is very difficult to enter the market under perfect competition. The prerequisite for successful invasion of the highly competitive market is concurrent introduction of the product's innovation, but this problem will be discussed in the next section, where the model which incorporates a search for innovation process will be presented. The orthodox economics states that in oligopolist industries market shares are usually determined on the basis of non-price competition, such as advertising and product variations, so the real firms' size distribution deviates from the uniform one, and that oligopolists frequently have adequate financial resources to finance non-price competition. Basically it is true, and we observe such type of industry behaviour in the presence of incremental innovations (to some extent responsible for the 'product variations').

*From monopoly to perfect competition*

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[6] The raising of the price above that imposed by the 'old' firms, to get higher profit, is not possible because of diminishing competitiveness of the newcomer's products.

Typical history of any industry starts from a single founder firm. For some time that firm is a monopolist on a small market. In a course of time the market is growing and new competitors enter the market. Orthodox (textbook) economics assumes that with no entry barriers and no innovation the industry will evolve toward perfect competition with large number of equal, small firms. Let us create that situation in our simulation. We start from a single, small firm, the industry growth rate is equal to 3%, firms do not innovate, and there is possibility of firms' entering into a market. Even in such simple economy the process of industry development is far from that proposed in economics textbook. The results are presented in Figures 4 to 7. Steady growth of a number of firms operating on the market are summarised in Figure 4. Due to relevant incumbents price policy we do not observe exits from the market. After 150 years of development there are 21 firms but contrary to the orthodox postulate firms are not equal sized. In fact only the early entrants (in our experiment first 5 entrants) are able to compete efficiently with the founder firm and relatively quickly all six firms have the same market shares equal to 16% (see Figure 5). This efficient competition was able due to 'natural' price policy of the monopolist. The founder firm increased the price in the first years of industry development up to 19 units (Figure 7) and next was forced do reduce the price in a course of new competitors emergence. Entering firms impose lower price therefore their products are more competitive and their market shares increase. Let us notice that this process of price competition leads to diversity of prices on the market (in Figure 7, this high diversity of price is seen by comparison of two dotted lines related to the range 'average price ± three standard deviations'). Later entrants are not able to compete efficiently because the average price is significantly reduced and the price margin is very low. The good example of such late entrant is 'firm 7' which entered the market at the 27th year. Although the price and its diversity at this time were relatively high but during the expansion of that firm the price was significantly reduced to its equilibrium value therefore after over 100 years, in the end of simulation its market share was equal to 9%, i.e. much lower then the share of the first six firms with their market shares equal to 14%. To the end of simulation another 14 firms entered the market and their equilibrium shares was the lower the later was the entering year. We can say that contrary to the orthodox postulate that under perfect competition we have a large number of equal sized firms, our simulation results suggests that natural mechanisms of competition force emergence of different sized firms. The equilibrium firms' size distribution is far form the orthodox uniform one, in fact it consists of two segments – the first segment relates to the relatively few early entrants and has uniform distribution and the second one relates to later entrants and its distribution is highly skewed. Typical equilibrium distribution is presented in Figure 6 – the first six firms reach equal shares and all other 15 entrants have much lower shares (the shares of last 9 entrants is smaller then 0.5%).[7]

The path from monopoly to perfect competition structure is also seen in time changes of profit to capital ratio (Figure 8). In the first years of industry evolution the concentration was very high (Herfindahl firms' number equivalent was smaller then 2 firms – see Figure 4, $n_H$, 'H number equivalent') and the profit ratio skyrocket to almost 130%, but it was quickly reduced in the next decades to less then 20%. In the equilibrium the profit ratio is very close to the growth rate of the market i.e. to 3%. This is another flaw of the orthodox economics, which teaches that under perfect competition the profit ratio is equal to zero. It is true only for the stable market. Just for comparison in Figure 8 changes of the profit ratio in the case of stable market (i.e. for growth rate equal to zero) is presented in Figure 8 (dotted line). It is seen that there is no significant differences between stable and growing markets in the early

[7] In the end of simulation, when the industry was very close to the equilibrium state, there was 21 firms of different size but the Herfindahl firms' number equivalent was equal to 8.2 (i.e. the market situation was similar to the perfect competition of roughly 8 equal sized firms of 12.5% market share each) – see Figure 4.

decades of evolution but the differences are significant at the near equilibrium states. The profit is equal to zero for stable market but is close to the market growth ratio for expanding market.

*Innovation and industry evolution*

The most important weakness of the orthodox economics seems to be lack of innovation in their models and concentration on equilibrium analysis. Innovation can be considered as the heart of modern economic evolution. Here we present only a small sample of the simulation results just to show how similarities of the proposed model's behaviour to real industrial innovative processes.

The only difference with the conditions of simulation presented in the former section is possibility of searching for innovation, i.e. firms are able to modify their routines just to find innovations leading to improving technical competitiveness of their products, diminishing unit cost of production and to increasing the productivity of capital. Just to show how diversified is behaviour of the firms the changes of technical competitiveness, variable cost of production and productivity of capital is presented in Figures 9, 10 and 11. Beside the average values of relevant characteristics the so called frontiers of development is presented (namely maximum values of technical competitiveness, minimum values of unit cost of production and maximum productivity of capital). The discrepancies between the average values and the frontiers give a hint about the existing diversity of firms' characteristics. It is important to underline that the mode of development perceived through the average values is rather gradual one but the mode of frontiers development is far from being gradual. It is clearly seen that the frontiers evolution is punctuated one (i.e. the stasis periods are separated by jumps of the frontier values). The jumps in the frontiers are related to radical innovations' emergence. In the stasis phases innovations are also introduced but they are incremental ones. The most visible effect of introducing radical innovation relates to increase of market shares of successful firms; firm 8 introduced the first radical innovation (around the year 40) and firm 9 the second radical innovation around the year 70 and their shares increased significantly during next two-three decades after introducing the radical innovation (see Figure 12). Success in the term of gaining significant market share can be reached also by introducing a series of relatively important incremental innovations – this is a case of firm 6 (Figure 12) which introduced such series in the third decade of industry development. Let's notice that beside relatively small number of firms having significant shares of the market, all the time there exist a large number of small and very small firms (Figure 12).

This process of radical innovation emergence strongly influences the mode of changes of other characteristics of industry development. As an example we present changes of firms' number, price and profit ratio (Figures 13, 14, and 15, respectively). We see that the emergence and dissemination of radical innovation causes increased number of exits and significant reduction number of firms as well as increase of market concentration (Figure 13 – number of firms, exits and 'H number equivalent'). Emergence of radical innovation causes also increase of price diversity (Figure 14). This occurs because innovative firms tends to increase the price (to gain temporal monopoly rent and to cover the costs of R&D process) and the unsuccessful firms, having no possibility to imitate the innovation of successful firm decrease the price just to made their technologically obsolete products more competitive.

The last decades of industry development in our simulation run seems to be interesting. The orthodox economics suggests that high industry concentration is usually related to high prices and large profits. Figures 13, 14, and 15 show that in that period we have relatively large number of firms operating on the market (around 40 firms) but concentration of the market was rather high (H number of equivalent was equal to 3.2 firms). This high concentration is accompanied by low, although diversified, price (Figure 14) and very small profit ratio (1.5%). We can identify the development of the industry in the last decades of simulation to well known, orthodox market structure of monopolistic competition.

**Summary**

Results of simulation experiments show that evolutionary modelling allows to support textbook conclusions related to industry development but also to reveal the weakness of the orthodox, textbook analysis. Repertoire of behaviour of evolutionary models is much richer that those presented in the economics textbook. We can say that all phenomena related to textbook industrial analysis can be explained within the evolutionary paradigm but the evolutionary analysis allows to explain much wider spectrum of phenomena. Among them are (discussed in that chapters) questions related to the necessary number of firms operating in a market to call the market the perfect competitive one, problems of trade-off between profit rate and the normal rate of return, non-uniform firms size distribution for the perfect competition market, the importance of innovation for industry behaviour. It is shown that the closeness of evolutionary modelling to real processes is far reaching. One of the important conclusions from that paper and from the experience of teaching microeconomics is that evolutionary analysis may be considered as very useful and complementary tool to teach economics.

## References


Dopfer Kurt (ed.) (2005), *The Evolutionary Foundations of Economics*, Cambridge University Press.

Frenken Koen (2005), 'History, State And Prospects Of Evolutionary Models Of Technical Change: A Review With Special Emphasis On Complexity Theory', Utrecht University, The Netherlands. http://www.complexityscience.org/NoE/Frenkencomplexityreview.pdf ,

Kwasnicki W., Kwasnicka H. (1992), Market, Innovation, Competition. An Evolutionary Model of Industrial Dynamics, *Journal of Economic Behavior and Organization*, vol. 19, 343-68.

Kwasnicki Witold (1996), *Knowledge, Innovation, and Economy. An Evolutionary Exploration*., Edward Elgar Publishing Limited; Cheltenham, UK, Brookfield (the first edition in 1994 by Oficyna Wydawnicza Politechniki Wroclawskiej).

Nelson, R.R. (1995) 'Recent evolutionary theorizing about economic change', *Journal of Economic Literature* 33, pp. 48-90.

Nelson Richard R., Winter Sidney G. (1982), *An Evolutionary Theory of Economic Change*, Harvard University Press, Cambridge, MA.

Saviotti, P.P. (1996) *Technological Evolution, Variety and the Economy* (Cheltenham & Brookfield: Edward Elgar).

Silverberg, Gerald (1997), 'Evolutionary Modeling in Economics: Recent History and Immediate Prospects', Research Memoranda 008, Maastricht : MERIT, Maastricht Economic Research Institute on Innovation and Technology, (downloadable from http://ideas.repec.org/p/dgr/umamer/1997008.html),

Silverberg, Gerald and Verspagen, Bart (1995 (2003)), 'Evolutionary theorizing on economic growth', in: K. Dopfer (ed.), *The Evolutionary Principles of Economics*, revised 2003, forthcoming, Cambridge, Cambridge University Press (downloadable from: http://ideas.repec.org/p/wop/iasawp/wp95078.html),

Simon H.A. (1986), On behavioral and rational foundations of economic dynamics, [in:] Day R.H., Eliasson G. (eds.), *The Dynamics of Market Economies*, Amsterdam: North-Holland.

Wallace A.R. (1898), *The Wonderful Century. Its Successes and Failures*, New York.

Winter Sidney (1984), Schumpeterian competition in alternative technological regimes, *Journal of Economic Behavior and Organization* 5, 287-320.


## Key terms

*Evolutionary economics* – in the broadest sense it is a study of economic phenomena using analogies and metaphors of biological evolution. It represents an alternative approach to so-called "mainstream economics", where analyses is based on mechanical analogies and metaphors borrowed form classical physics.

*Routine* –'regular and predictable behavioural patterns of firms', in evolutionary economics, the concept of routine plays similar role as concept of gene in evolutionary biology.

*Competitiveness* – ability of economic agents (firms) to compete on the market by offering technologically advanced or cheaper products.

*Replicator equation* –a differential or difference equation that defines the selection dynamics of a population of competing agents (firms), considered within a frame evolutionary economics (also of evolutionary games).

*Table 1. Industry concentration; global characteristics at the equilibrium state*

| $n$<br>$n_H(0)$ | $\Pi/K$<br>[%] | $\Pi/S$<br>[%] | $p/V$ |
|---|---|---|---|
| *normal rate of return* $\rho = 0$ | | | |
| 1 | 151.907 | 71.685 | 4.2382 |
| 2 | 52.692 | 46.757 | 2.2539 |
| 4 | 22.096 | 26.915 | 1.6419 |
| 6 | 11.450 | 16.026 | 1.4290 |
| 8 | 6.050 | 9.160 | 1.3210 |
| 10 | 2.804 | 4.464 | 1.2561 |
| 12 | 0.643 | 1.060 | 1.2128 |
| 13 | 0.000 | 0.000 | 1.2000 |
| 16 | 0.000 | 0.000 | 1.2000 |
| 32 | 0.000 | 0.000 | 1.2000 |
| *normal rate of return* $\rho = 0,05$ | | | |
| 1 | 146.908 | 69.326 | 4.2382 |
| 2 | 47.692 | 42.321 | 2.2539 |
| 4 | 17.096 | 20.824 | 1.6419 |
| 6 | 6.450 | 9.028 | 1.4290 |
| 8 | 1.050 | 1.590 | 1.3210 |
| 10 | 0.000 | 0.000 | 1.3000 |
| 12 | 0.000 | 0.000 | 1.3000 |
| 16 | 0.000 | 0.000 | 1.3000 |
| 32 | 0.000 | 0.000 | 1.3000 |

Where: Π - profit; *K* – capital; *S* – sales; *p* – price; *V* – unit cost of production

*Table 2. Concentration of the market. Non-uniform firms' size distribution*

| $n$ | $n_H(0)$ | $n_H(100)$ | $n_H(200)$ | $T_e$<br>[year] | $\Pi/K(100)$<br>[%] | $\Pi/K(100)$<br>[%] | $p/V(200)$ |
|---|---|---|---|---|---|---|---|
| 2 | 1.02 | 2.00 | 2.00 | 14 | 47.692 | 47.692 | 2.2539 |
| 4 | 2.61 | 4.00 | 4.00 | 22 | 17.096 | 17.096 | 1.6419 |
| 6 | 4.18 | 6.00 | 6.00 | 47 | 6.450 | 6.450 | 1.4290 |
| 8 | 5.75 | 7.30 | 7.68 | – | 2.932 | 2.282 | 1.3456 |
| 12 | 8.93 | 9.76 | 9.81 | – | 0.216 | 0.033 | 1.3007 |
| 16 | 12.12 | 12.15 | 12.16 | – | 0.026 | 0.001 | 1.3000 |
| 32 | 25.52 | 25.59 | 25.59 | – | 0. 022 | 0.001 | 1.3000 |

Note: $T_e$ is a year in which the H index is equal to the number of firms, i.e. $n_H = n$. The years of measurement of relevant characteristics are given in parentheses.

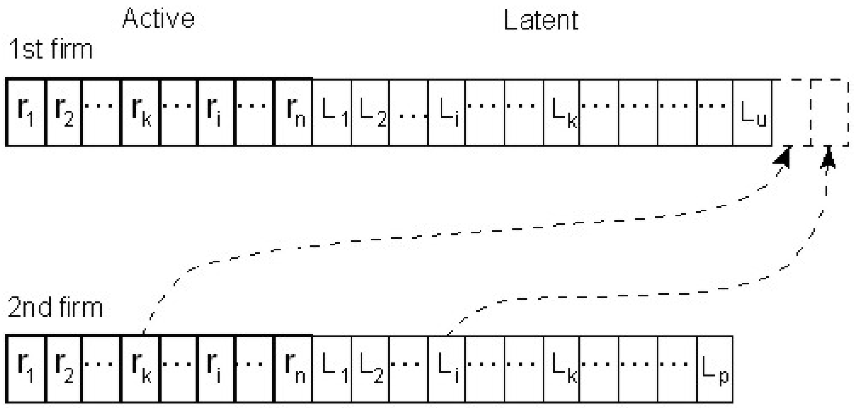


*Figure 1. Routines transition*

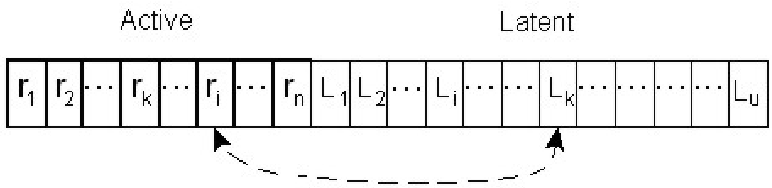


*Figure 2. Routines transposition*

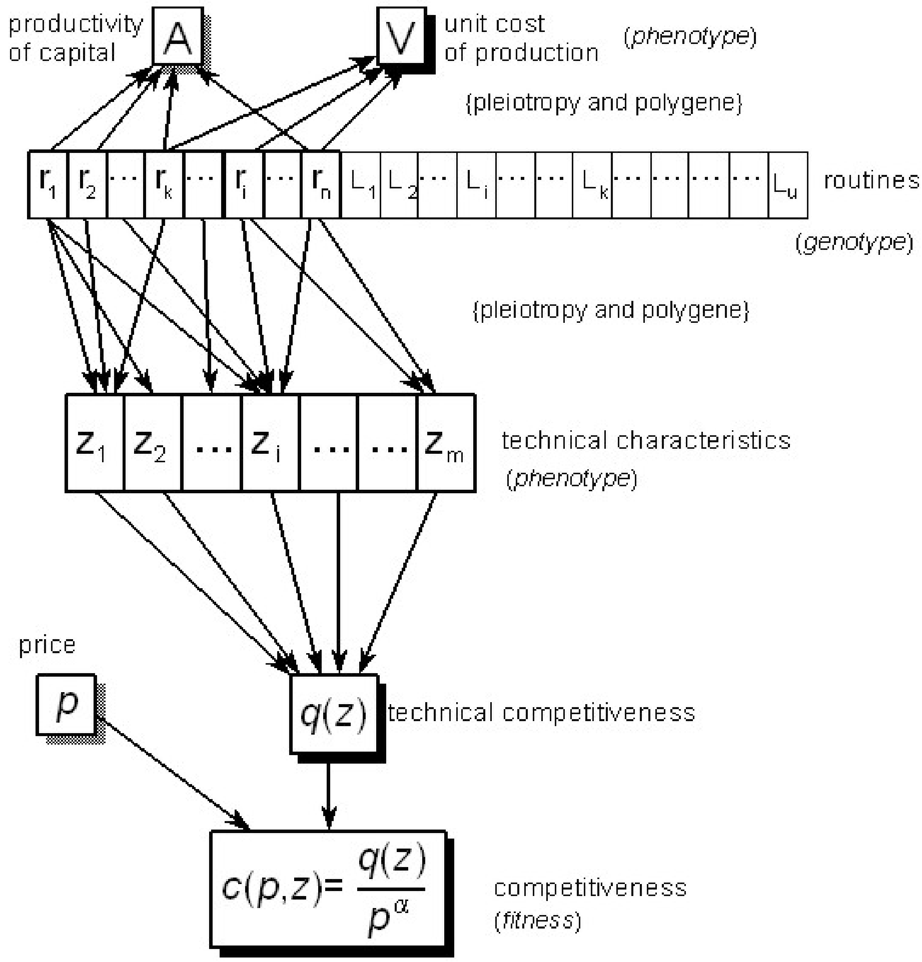


*Figure 3. From routines to competitiveness, productivity of capital and unit cost of production – from 'genotype to phenotype'*

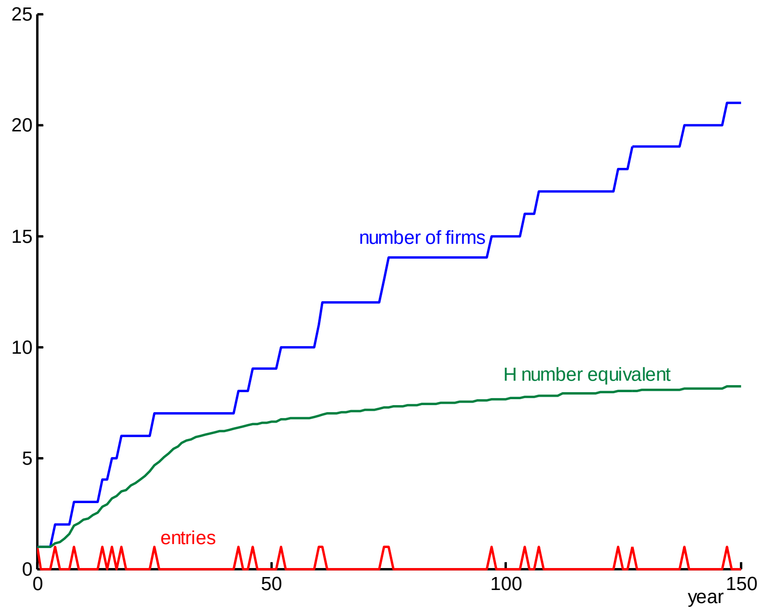


*Figure 4. Number of firms, entries and Hefindahl-Hirshman firms' number equivalent*

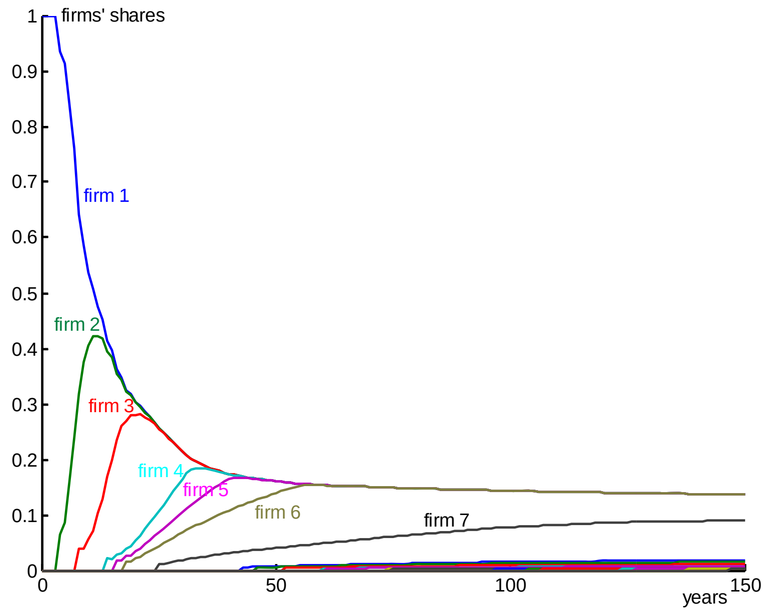


*Figure 5. Evolution of industry structure with entry and no innovation*

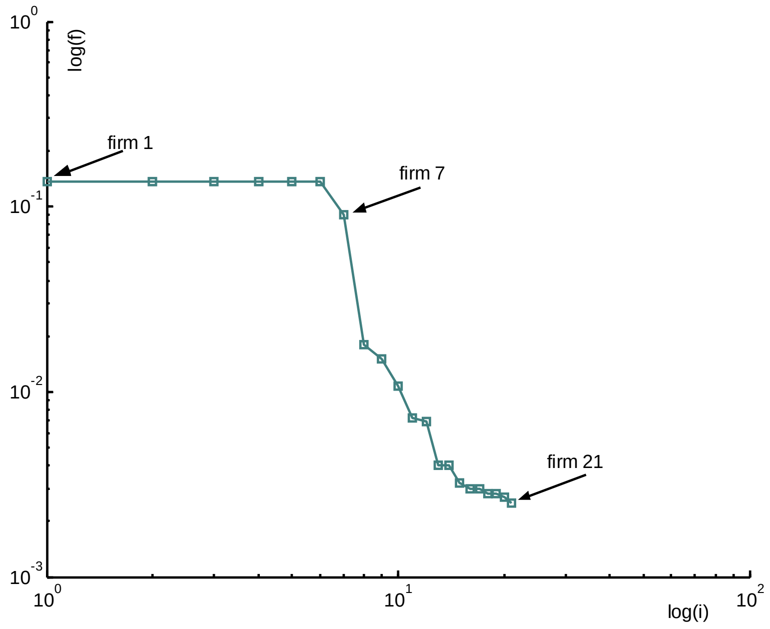


*Figure 6. Firms' size distribution (log-log skale)*

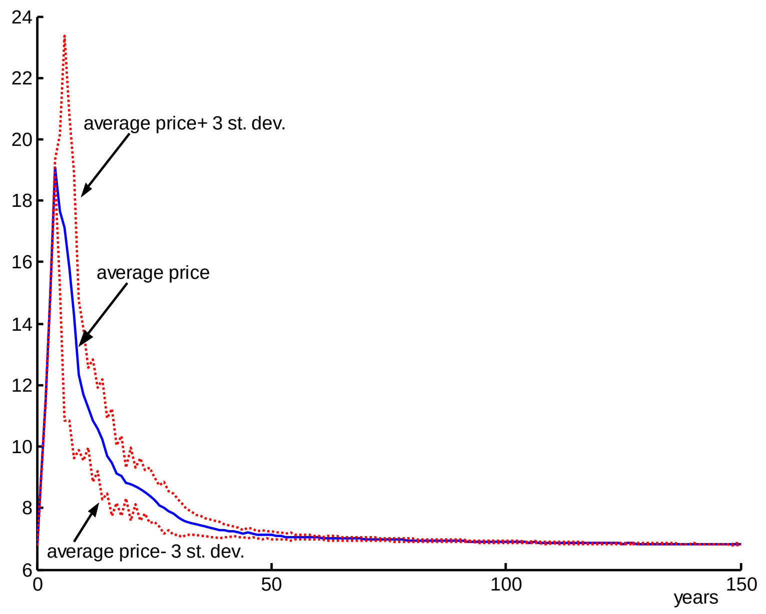


*Figure 7. From monopoly to competitive price*

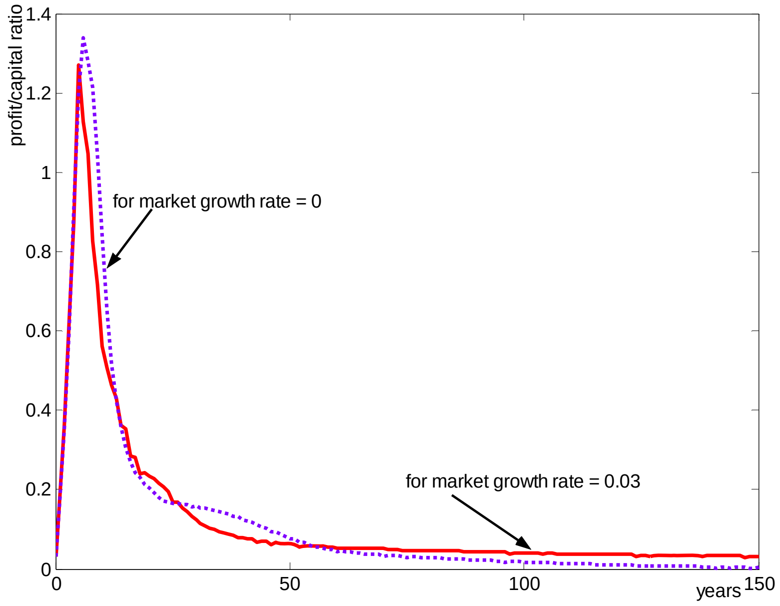


*Figure 8. Profit to capital ratio for stable and expanding market*

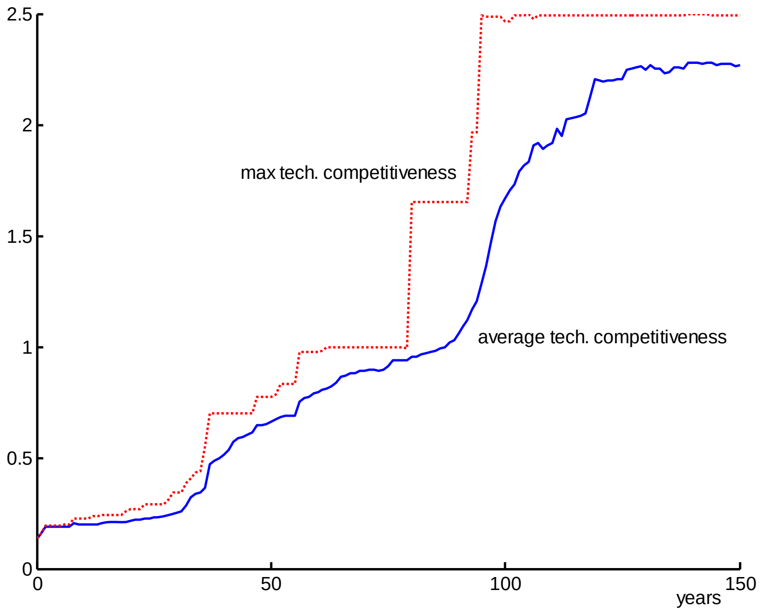


*Figure 9. Average technical competitiveness and maximum technical competitiveness*

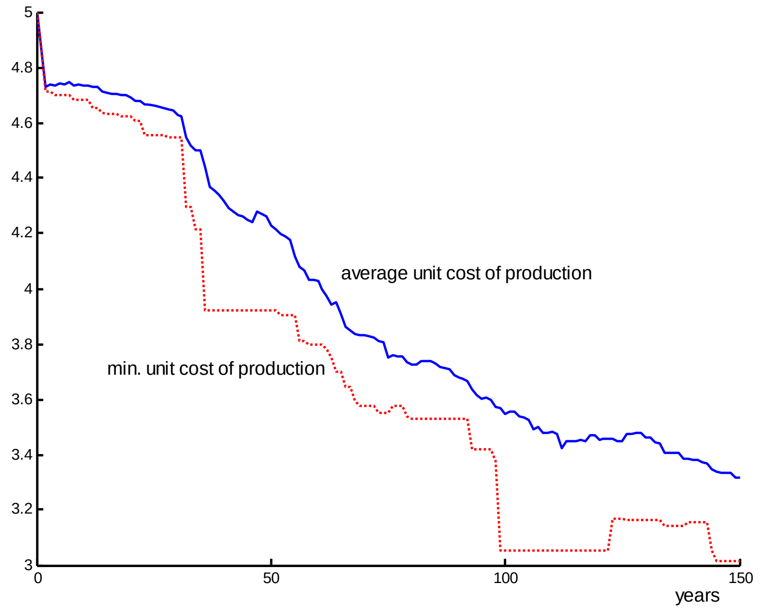


*Figure 10. Average unit cost of production and minimum unit cost of production*

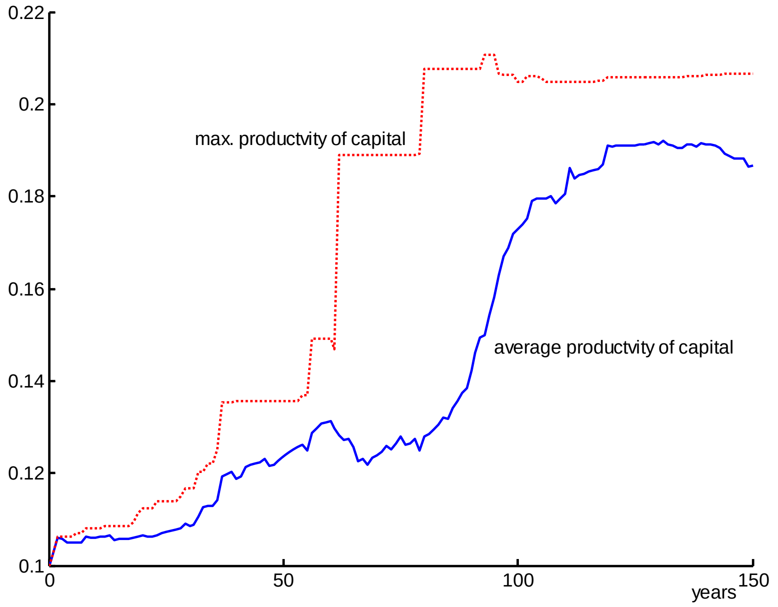


*Figure 11. Average productivity of capital and maximum productivity of capital*

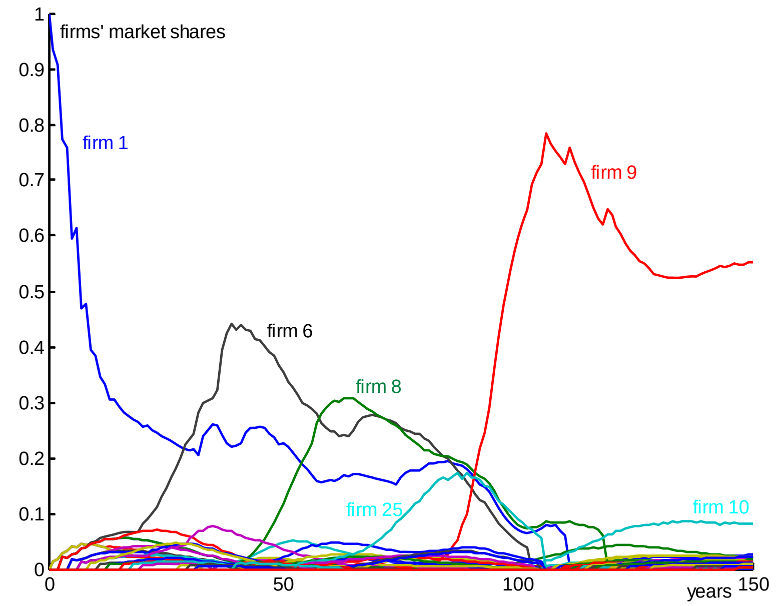


*Figure 12. Evolution of industry structure with entry, exit and innovation*

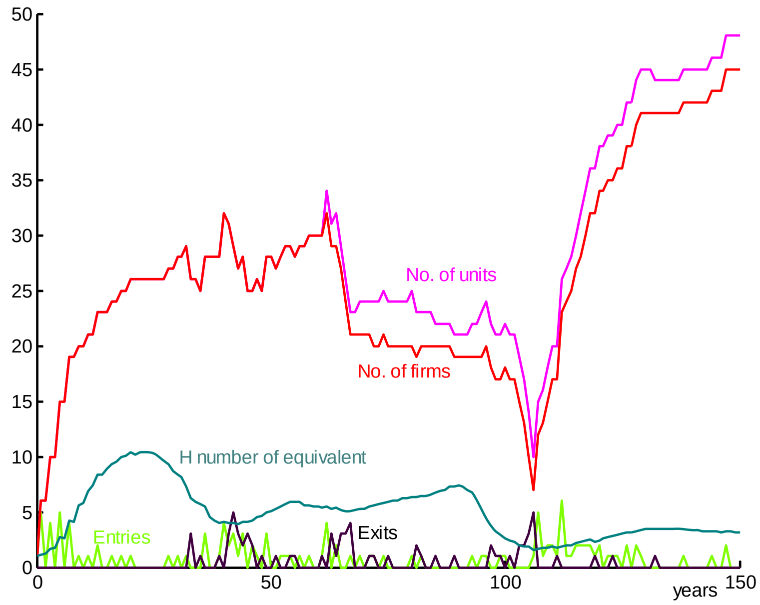


*Figure 13. Number of firms, units, entries anf exits*

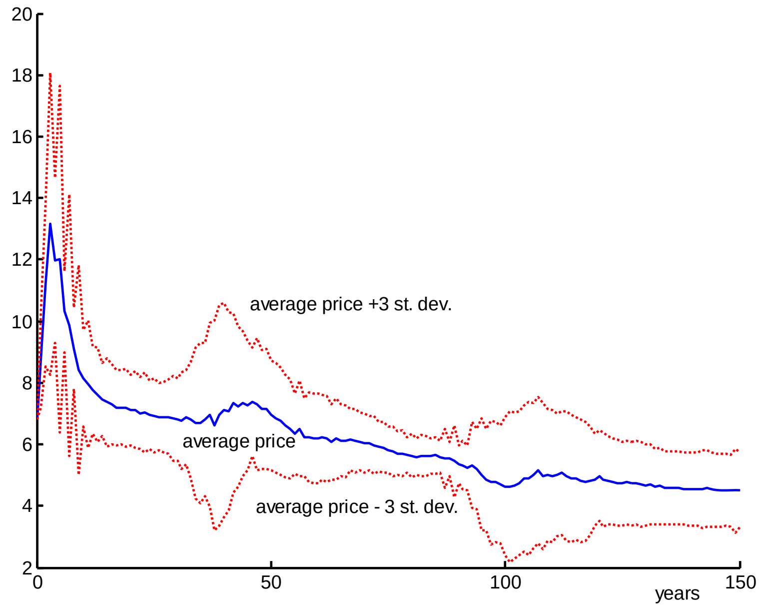


*Figure 14. Average price and its diversity*

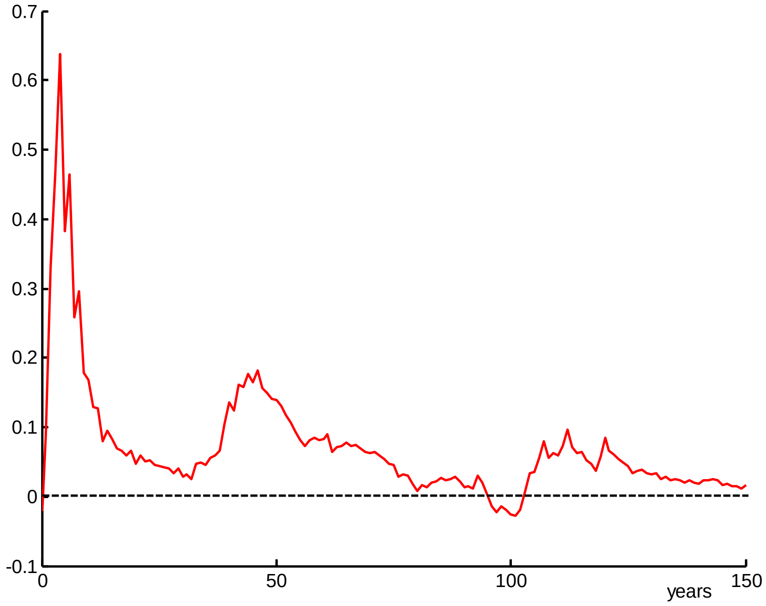


*Figure 15. Profit to capital ratio*