J Evol Econ (1996) 6: 375–409

Journal of
Evolutionary
Economics

Innovation regimes, entry and market structure

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Abstract. This paper contains a description of an evolutionary model of industrial dynamics and a report on the simulation study of the model. The presentation of the model is partitioned into two sections. In the first section I focus on the economic features of industrial development with no technological change imbedded, while an extended version of this model with the search for innovation process included is presented in the next section. In the next two sections, results of the simulation study on technological regimes and firm entry are presented. Technological regimes relate to different types of innovation captured by the model, so I consider the cost regime, the technical performance regime and the capital productivity regime. In Sect. III I investigate the influence of the different types of innovation on the development of the industry, particularly on industry concentration and on the products' price distribution, and in the fourth section an evolution of industry structure with the possibility of firm entry is investigated.

Key words: Evolutionary dynamics—Innovation—Technological regimes—Firms' entry

I The basic model

The model here employed describes the behaviour of a number of competing firms producing functionally equivalent products. The decisions of a firm relating to investment, price, profit, and so on, are based on the firm's evaluation of the 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, and there is no possibility of characterizing the limitation and uncertainty of knowledge in statistical terms, for example, in terms of probability distributions. Firms' decisions can thus only be suboptimal.

The general structure of the evolutionary model of industrial dynamics is presented in Fig. 1. The product's price depends on the current innovation status of

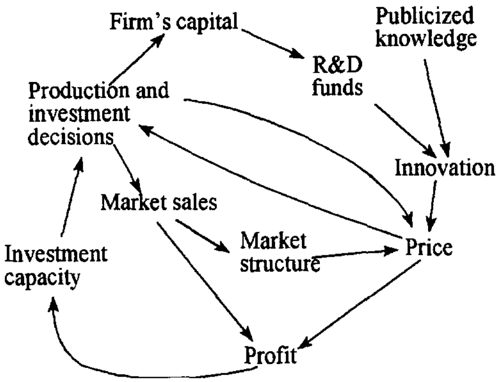

Fig. 1. General structure of the evolutionary industrial model

a firm, on the actual structure of the market, and on the level of assumed production to be sold. The two arrows between Price and Production indicate that price is established in an interactive way to meet of the firm's objectives (that is, to maintain a relatively high profit in the near future and to further the firm's development in the long term). Modernization of products through innovation and/or the initiation a new production through radical innovation depend on the investment capacity of the firm. Each firm takes into account all economic constraints, as they emerge during the firm's development. Therefore, it frequently occurs that, because of economic (financial) constraints, some promising invention is not incorporated into the firm's practice. One of the distinctive features of the model is the coupling of technological development and economic processes. Current investment capacity is also taken into account by each firm in the investment process and price-setting. The success of each firm in the search for innovation depends not only on the amount of R&D funds spent in the search for innovation, but also on the extent to which the competitor's private knowledge is made public. Making the private knowledge of a firm known to competitors can in some cases speed up industrial development, but also diminishes a firm's incentives to spend more on R&D projects. The advantages of making public the private knowledge of the firm should be weighted against the disadvantages.

The causal relationship between the main variables of the industrial model are shown in Fig. 2, essentially a more detailed description of the structure presented in Fig. 1. A firm's investment capacity depends on the firm's savings and the availability of credit, and also, indirectly, on the firm's debt. Production and investment decisions rely on the firm's expectations of the future behaviour of its competitors, the market structure, expected profit, and the actual trend of the firm's market share. The current technical and economic characteristics of output (in terms of their technical competitiveness, being the measure of the products' technical performance), and the characteristics of the technology used in manufacturing (in terms of unit production cost and productivity of capital) are taken into account in the setting of price, investment, and production. Because of the inevitable discrepancies between a firm's expectations and the real behaviour of the market, the quantity of the product offered for sale is different from that demanded. The firm's savings and its ability to pay current debts depend on the real profit and income of that firm.

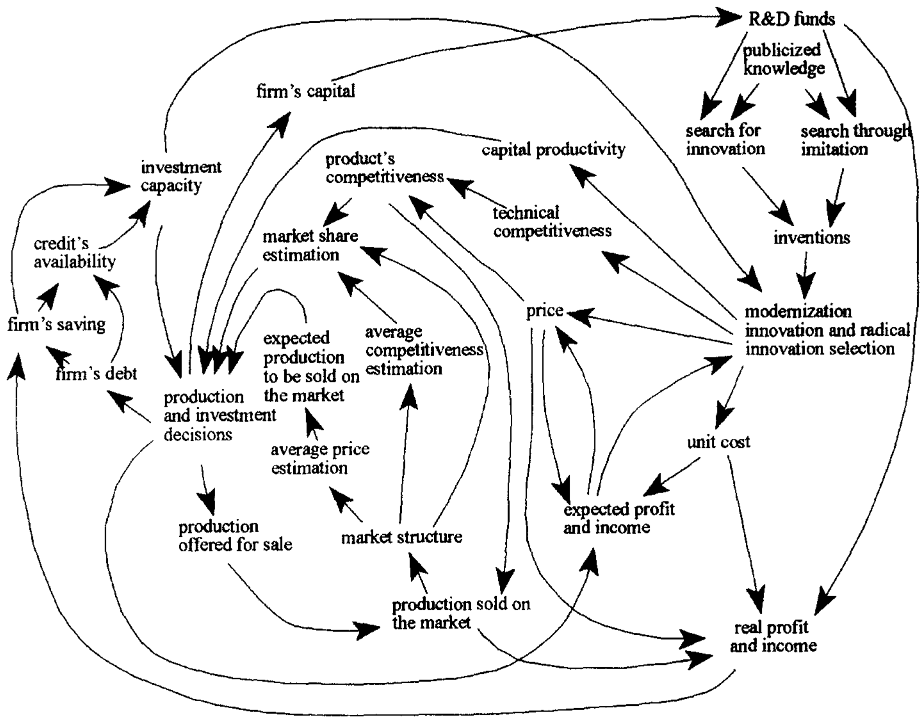

Fig. 2. Causal relationships in the evolutionary industrial model

We distinguish between innovation and invention (the latter being a novelty considered for introduction into practice and thus becoming an innovation). There are two general ways of searching for inventions: autonomous, in-house research by each firm, and the imitation of competitors. Publicized knowledge does not only permit imitation by competitors. From a number of inventions only a small fraction are selected to become innovations. Innovation allows the modernization of current production, but also can initiate new, radical ways of production by implanting essentially new technology. In general, each innovation can effect a reduction in the unit cost of production, increasing the productivity of capital and improvements in technical product performance, but frequently it happens that an improvement in one factor is accompanied by a deterioration in the others. Therefore, firms usually face the problem of balancing the positive and negative factors of each invention, and allow it to become an innovation if positive factors indicate that the firm's objectives will be attained.

Firms' decisions

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). Another problem is how to model this process in a formal way. A lot of attempts have been made to imitate real decision-making processes, some of which are very sophisticated and very close to reality. The purpose here, being a first approximation, is to capture the general and the most essential features of firms' decision-making processes; at this stage of the model's development there is no necessity to feature this process in detail. What is proposed is only an initial, very rough approximation of the decision-making process on the firm level.

Here a procedure is presented for evaluating the production, investment, expected income and profit in succeeding periods of time of firm i selling its product at price $p_i(t)$. The problem of choosing the appropriate price $p_i(t)$ will be discussed later.

a) Calculation of the product competitiveness $c_i(t)$

Two kinds of product competitiveness are distinguished: technical competitiveness and overall competitiveness (or, simply, competitiveness). Technical competitiveness reflects the quality of technical performance of the product on the market, and depends directly on the values of the product's technical characteristics, such as reliability, convenience, lifespan, safety of use, cost of use, quality and aestheticism. Overall competitiveness describes product attractiveness, and depends on technical competitiveness and product price. There is no search for innovation in the model presented in this section, and so all characteristics of products are constant and uniform for all products.[1] In the next section this assumption will be weakened and the technical competitiveness will alter because of the emergence of technical innovations. Competitiveness, as a measure of attractiveness of a product, grows with a reduction in its price and an improved technical performance. It is assumed that product competitiveness at a price $p_i(t)$ is equal to

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

where q is technical competitiveness (constant during the simulation of the basic model), and α the elasticity of price; α is thus a characteristic of the market and describes the sensitivity of the market to price fluctuations. Let us denote by $c_i(t)$ the competitiveness of products of firm i at time t, that is, $c_i(t) = c(p_i(t))$.

b) Estimation of the average price and average competitiveness

It may be said, without much exaggeration, that all man's decisions are made on the basis of his expectations. But as Herbert Simon asserts: 'economists do not disagree about many things, but they disagree about a few crucial things, in particular, how people form expectations' (Simon 1986, p. 504). It is rational to assume that, in general, a firm knows nothing about the current and future decisions of competitors. It is assumed that the decisions of any firm are made independently on the basis of its

[1] This assumption imposes the corollary of the uniformity of technical competitiveness of all firms.

expectations of what other firms will decide. The simplest assumption is that next time the competitors will behave as in the past. Therefore, firm i estimates that in the succeeding period $(t, t+1)$ the average price will be equal to

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

Similarly, the average competitiveness is expected to be equal to

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

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

Equations (2) and (3) enable us to model diversified situations faced by different firms, for example, the ability of a small firm to "form" the average price is much less than that of a large firm. Small firms are, in general, 'price takers' in the sense that they assume that the future average price will be very close to the trend value, and large firms play the role of 'price leaders' or 'price makers'.

c) Estimation of the global production

After estimating the average price of all products on the market, global production that is, the global demand $Q^d(t)$, can be estimated. It is assumed that all firms know the demand function,

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

where $M(t)$ is an amount of money which the market is inclined to spend to buy products at an average price $p^e(t)$. It is assumed that

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

where N is a parameter characterizing the initial market size, γ the growth rate of the market, and β the elasticity of the average price. Consumption theory and the results of empirical research (for example, McConnell 1984, p. 415) show that almost all price elasticities in demand functions are negative: for primary needs (for example, food, clothing) the elasticities are between 0 and -1, those of secondary (or 'luxury') needs are below -1. So, it may be expected that for commodities fulfilling primary

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[2] The expressions (2) and (3) have the same mathematical form for each firm. It is a simplification, made intentionally to catch the most essential features of the industrial processes. From an evolutionary perspective the fomulae ought to be firm specific, and the knowledge (firm's routines) and firm's experience ought to be embedded in them. We hope to make the next 'stepwise concretization' in this direction after gathering the results of the first elementary experiments with the model.

needs, β is greater than zero and smaller than one, and for commodities fulfilling higher-order needs (for example, entertainment) β is smaller than zero.

d) Estimation of the market share of firm i

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

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

This means that the share of firm i increases if the competitiveness of its products is greater than the average competitiveness of all products offered for sale, and declines if the competitiveness is smaller than the average competitiveness.[3]

e) Estimation of the production of firm i

Having estimated the expected share and the expected size of the market, firm i is able to estimate the quantity of production to be accepted by the market on the basis of the simple equation,

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

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

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

where A is the productivity of capital. Because there is no R&D process, firms do not improve the productivity of capital, and in the basic model A is constant and uniform for all firms.

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

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

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

f) Estimation of the expected income and profit

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

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

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

where Γ_i is the expected income of firm i at time $t+1$, Π_i is the expected profit at time $t+1$, $Q_i^s(t)$ the output (supply), V the unit production cost (because there is no innovation, V is constant and uniform for all firms during the simulation), $v(Q_i^s)$ is the factor of unit production cost as a function of a 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).

For a given price $p_i(t)$, the expansionary investment, the production in the next year, and expected profit and income are calculated by applying the procedure presented above. The problem to be discussed is the way of setting the product price $p_i(t)$. It is assumed that a firm takes into account its investment capabilities and estimates the values of an objective function for different prices of its products. The price for which the objective function reaches the maximum value is chosen by a firm as the price of its products.[4]

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

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

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

where F_i is the magnitude coefficient (with values between 0 and 1), Q_i^s the production of firm i in year $t+1$, Γ_i is the expected income of firm i at $t+1$ (defined by equation (10)), QS 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 (12) and ensure that the values of both terms are of the same order. The function O_1 expresses the short- and long-term thinking of firms during the decision-making process (the first and second terms in equation (12), respectively). The plausible values of the parameters are $a_4 = 1$ and $a_5 = 5$; this means that long-term thinking is much more important for the survival of the firms, and that the firms apply flexible strategy (so that, the relative importance of short- and long-term components changes in the course of the firm's development, with the long-term being much more important for small firms than for big firms).

The decision-making procedure presented above provides a formal scheme for finding the proper value of the price. I treat this scheme as an approximation of what

[4] It is not a maximization in the strict sense, since the estimation of values of the objective function is not perfect and is made for the next year only; this is not a global optimization once and for all as firms apply this rule from year to year.

is done by real decision-makers. They, of course, do not make such calculations from year to year, but rather think in the routine mode: 'My decisions ought to provide for the future prospects of the firm and also should allow income (or profit) to be maintained at some relatively high level'. Decisions on the future level of production and the future product price depend on the actual investment capabilities of the firm. It is possible to embody in the model different ways of calculating the firms' investment capabilities. I propose to investigate two formulae, one as proposed by Nelson and Winter (1982), and Winter (1984), in which the investment capability of firm i in period $(t, t+1)$ is a function of profits (II) in period $(t-1, t)$; and the second in which the investment capability depends on the firm's current savings (SV). Let us call these two the Π-investment and the SV-investment strategies, respectively. The investment capability of firm i in the Π-investment strategy is equal to:

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

where δ is physical capital depreciation, μ a coefficient equal to one for $\Pi_i < 0$, and equal to μ_0 for $\Pi_i > 0$. The credit parameter μ_0 is greater than, or equal to, one. If μ_0 is greater than one, firm i takes credit if its overall investment $I_i(t)$ at time t exceeds the sum of the amortization and profit at $(t-1)$.[5]

I propose to incorporate more explicitly the process of credit-taking and its future repayment. In the SV-investment strategy, it is assumed that every year a firm spares a fraction of its current profit for investment in future development. If, at any time, required investment exceeds current savings, then the firm debt increases but is repaid within an assumed period. Saving and debt increase every year at the interest rate ρ_1. If it is assumed that credit ought to be repaid within μ_1 years on average, then the compensation (the debt repayment) in the next year is equal to

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

The investment capability of firm i at time t depends on current savings SV_i and current compensation DR_i, and is equal to (the meaning of parameters δ and μ remains as in equation (13))

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

It may happen that the required investment of firm i exceeds the firm's own funds (equal to the sum of amortization $\delta K_i(t-1)$ and current savings $(SV_i - DR_i)$). If this is the case, and μ is greater than one, the firm accepts credit to finance the investment. Let us denote by ICr_i the investment financed by credit and by IS_i the investment financed by the firm's own savings (that is, the capital depreciation funds $\delta K_i(t-1)$ excluded). To simplify the calculation, the structure of the debt is not considered so it is assumed, as a first approximation, that the debt at time t is characterized by its total value, and is equal to

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

The debt is diminished by current repayment and increases according to the interest rate (the first term), and is enlarged by current investment financed by credit, ICr_i. Each year the firm spares a fraction of its current profit for savings. It is

[5] Nelson and Winter (1982) say nothing about the method of taking credit and its future repayment. It would seem that a firm takes credit from banks if required investment exceeds its current profit, without an eye to future repayment.

assumed that the fraction of profit allocated to savings depends on the relation between current savings and the firm's capital; the greater the savings, the lower the proportion of actual profit (if positive) which is set aside for savings. A parameter *ToSave* controls the fraction of profit for savings. To determine the amount of money passed for saving SP_i we use the following formula (the expression $\exp(\cdot)$ is a fraction of positive profit spent for saving):

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

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

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

Firms' entry

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

In general, any firm may enter the market, but if a firm's characteristics are unsatisfactory, then it is quickly eliminated from the market. Because of the limited capacity of computer memory a threshold for potential entrants is assumed; to control the number of entering firms it is assumed that a firm enters the market if the estimated value of objective O_1 of that firm is greater than an estimated average value of the objective O_1 for the industry.[6] By making this assumption, a more competitive environment is provided for all firms – for operating firms and for entrants.

As a result of competition the market shares of firms with competitiveness smaller than average decrease, and the shares of firms with competitiveness greater than average increase. A firm is driven from the market if it does not keep pace with competitors. To limit the number of very small firms, it is also assumed that a firm is eliminated if its market share is smaller than some assumed minimum share, for example, 0.1%.[7]

Competition of products in the market

All products manufactured by the entrants and the firms existing in the previous period are put on the market and evaluated. After that, all decisions are left to buyers; these decisions primarily depend on the relative value of competitiveness of all products offered, but quantities of products of each firm offered for sale are also taken into account.

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[6] It may be expected that a similar threshold exists in real industrial processes.

[7] It is possible to add other criteria for withdrawing a firm, for example, bankruptcy, if the firm's current debt exceeds an assumed fraction of the firm's current capital.

It is assumed that the global demand $Q^d(t)$ for products on the market is equal to an amount of money – $M(t)$ – which the market is inclined to spend on products offered for sale by the firms divided by the average price, $p(t)$, of the products offered; see equations (4) and (5) defining the demand function, where instead of $p^e(t)$ it is necessary to put $p(t)$. The only difference is that, in the decision-making process, firms use their estimated values of the average price, as a result of their expectations of the future market and behaviour of competitors, and here the average price in the demand function is counted using the whole pool of products offered for sale. Therefore, the average price of products is

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

The supply is equal to

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

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

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

The general selection equations of a firm's competition in a market have the following form (for comment see also footnote 3 on page 380),

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

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

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

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

The quantity of products potentially sold by firm i (the demand) is equal to

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

The above equations are valid if the production offered by the firms exactly fits the demand of the market. This is a very rare situation, and therefore these equations have to be adjusted for 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. Equation (24) describes the market demand for products of firm i offered at a price $p_i(t)$ and with competitiveness $c_i(t)$. In general, a real production (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, $Q_i^d(t)$, and supply, $Q_i(t)$, but on the whole pool of products offered for sale. The alignment of the supply and demand of production of all firms present 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 is, if possible, fulfilled in the second, succeeding, stage of the alignment. If there is no global oversupply, then in the first stage all demand for production of specific firms, wherever possible, is fulfilled, but there is still the shortfall in production of firms which underestimated the demands for their products. This part of the demand is fulfilled in the second stage. At this stage, the products of the firms which produce more than the specific demand are sold to replace the shortfall in production by firms which underestimated the demand for their products.

The supply-demand alignment process is slightly different if the global oversupply of production occurs. It seems 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 (22) and (24)), and (2) the production bought as the outcome of the non-competitive process (let us call it the cooperative process). In principle, this part of production does not depend on product competitiveness, but depends primarily on the volume of production offered for sale; random factors play a much more important role in the choice of relevant products to be purchased. In general, the division of the production of each firm into these two parts depends on the value of the global oversupply. The higher the oversupply, the larger is the part of the production of each firm which is sold on the basis of the non-competitive preferences.

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

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

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

Usually the global oversupply, if such occurs, is small, so the major part of production is distributed under the influence of the competitive mechanisms and only a small part is distributed as a result of cooperative distribution. But to understand 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 atypical firm produces much more than is demanded. The question is: what is the result of the market selling-buying process? It may 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 atypical firm does not influence the behavior of the market. In an extreme case, we may imagine that the volume of production of the atypical firm is infinite and the rest of the firms continue to produce exactly what is demanded. Does it 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 that 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 atypical firm. It seems that, in the case of the overproduction of one firm, its share in global production sold will increase at the expense of all firms producing exactly what is demanded. In the extreme case, when overproduction of the atypical firm tends to infinity (i.e. the coefficient w is approaching zero), the only products sold on the market belong to that firm, and the shares of all other firms are going to 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 the overproduction is not sold on the market and is lost by the firm. In effect, the atypical firm's profit is much smaller than expected, or even may be negative; after some time the firm's development will be stopped and in the end it will be eliminated from the market.

The incorporation of coefficient w also permits the entry of new competitors into the market. Without the assumption of the two-stage distribution in the supply-demand alignment process, the entry of a new firm might be very difficult, and it would be necessary to add a special procedure to allow entry in the case of global oversupply. In such a case, when all firms' production meets the demands for their products, there would be no place for new entrants. The competition process, as described by the selection equation (22), cannot be initiated because of the zero value of the share of the entrant at the previous instant, $f_i(t-1)$. The assumption that the $(1-w)$ fraction of the global demand is fulfilled in the cooperative stage of the alignment process enables the entry of new firms. Similarly, entry is possible if there is no global oversupply (that is, $w = 1$). In such a case, there is a place on the market for the new entrant and, in general, all its production is sold.

It is assumed that, at the competitive stage of the supply-demand alignment process, the demand is partially fulfilled by production OS_i^{comp},

$$QS_i^{comp}(t) = \min\{Q_i^s(t), wQ_i^d(t)\} = \min\{Q_i^s(t), wQS(t)f_i(t)\},$$

$$QS_i^{comp}(t) = \min\left\{Q_i^s(t), wQS(t)f_i(t-1)\frac{c_i(t)}{c(t)}\right\}. \tag{26}$$

The remaining $(1-w)$ fraction of the demand may be fulfilled in the cooperative stage if there is such production available, that is, if $Q_i^s(t) > wQ_i^d(t)$. It is assumed that this fraction of the demand is fulfilled in the cooperative stage according to the distribution of unsold products in the competitive stage. After completion of the competitive stage of the supply-demand alignment process, the global production sold is equal to

$$QS^{comp}(t) = \sum_i QS_i^{comp}(t) = \sum_i \min\{Q_i^s(t), wQ_i^d(t)\}. \tag{27}$$

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

$$QS^{coop}(t) = QS(t) - QS^{comp}(t). \tag{28}$$

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

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

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

$$f_i^{coop} = \frac{QN_i(t)}{\sum_j QN_j(t)} = \frac{\min\{0, Q_i^s(t) - wQ_i^d(t)\}}{\sum_j \min\{0, Q_j^s(t) - wQ_j^d(t)\}}. \tag{30}$$

It is assumed that the fulfilment of the demand for products of firm i in the cooperative stage is proportional to the fraction f_i^{coop}, so

$$QS_i^{coop}(t) = QS^{coop}(t) f_i^{coop} = (QS(t) - QS^{comp}(t)) f_i^{coop}. \tag{31}$$

Finally, the production sold is the sum of production accepted in the competitive and the cooperative stages,

$$QS_i(t) = QS_i^{comp}(t) + QS_i^{coop}(t),$$
$$QS_i(t) = \min\{Q_i^s(t), wQ_i^d(t)\} + (QS(t) - QS^{comp}(t)) f_i^{coop}. \tag{32}$$

The general meaning of the supply-demand alignment process as described above parallels that of equations (22), (23), (24). If supply exactly meets market demand (that is, if $Q^s(t) = Q^d(t)$ and $Q_i^s(t) = Q_i^d(t)$ for all i), equations from (25) to (32) are equivalent to equations (22) to (24).

The market share of the production sold of firm i is

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

The real income and profit of firm i are as follows:

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

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

$K_i(t)$ in equations (34) and (35) is the value of capital allocated by firm i to produce $Q_i^s(t)$, so profits are smaller than expected if the firm inappropriately evaluates the required level of production and manufactures more than it can sell in the market.[8]

Effective capital of the firm is expressed as

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

and global sales are equal to

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

The market share of firm i in global sales is

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

[8] There arises the question of what is to be done with the excess production. It is assumed that this part of the production is lost. It is possible to incorporate the backlogs into a model, but this leads to much greater complexity. The production may be modernized due to innovations applied, so it would be necessary to remember the quantities of orders and unsold production at different moments, together with the technical characteristics. It seems that our assumption on excess production does not lead to large errors, bearing in mind that (1) the model is focused on long-term industry development, (2) yearly overproduction is normally not very high, and (3) to consider backlogs and delivery delays it would be necessary to take into account also all related costs, for example, the storing of the unsold production.

II Innovation and economic development

The essence of cultural development in general, and socio-economic evolution in particular, lies in the creative process of human beings. The real tissue of creative processes is almost impossible to observe, with collection of relevant quantitative data on innovation processes mostly confined to such data as number of researchers, R&D funds, number of patents, and so on. Estimation of some essential parameters and characteristics (for example, the probability of the emergence of innovation within an assumed period of time) on the basis of such aggregate data is almost impossible. The most important, and most interesting, phenomena of creative/cognitive processes occur in the minds of researchers, and these kinds of processes are, in general, out of reach of any observation. The only way to deal with the creative process and dare to describe it in a more or less formal way is to make some arbitrary assumptions, incorporate them into the economic model and observe whether the development of the model resembles the development of the real process. In some sense, it is a combination of quantitative modelling (based on hard economic data) and qualitative modelling (based on heuristics, analogies and metaphors). This kind of approach is proposed in this section, where the extension of the basic model with innovative processes embedded is presented. This proposition is treated as the first approximation, being the subject of further development ('stepwise concretization').

The creative process is evolutionary by nature, and as such its description ought to be based on a proper understanding of hereditary information. According to the tradition established by J.A. Schumpeter, and S. Winter and R. Nelson, we use the term 'routine' for the basic unit of hereditary information of a firm. The set of routines applied by the firm is one of the basic characteristics describing the firm, and each firm searches for new routines and new combinations of routines.[9]

Each firm tends to improve its situation within the industry and the market by introducing new combinations of routines in order to minimize the unit cost of production, maximize the productivity of capital, and maximize the competitiveness of its products in the market. 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 market decisions depend on product characteristics and prices. We may speak of the existence of two spaces: the space of routines and the space of product characteristics.[10]

[9] Nelson and Winter (1982, p. 14) define routines as 'regular and predictable behavioral patterns of firms' and include in this term such characteristics of firms as 'technical routines for producing things... procedures of hiring and firing, ordering new inventory, stepping up production of items in high demand, policies regarding investment, research and development, advertising, business strategies about product diversification and overseas investment'. 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).

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

Distinguishing these two spaces enables us to separate firm decisions from market decisions. As in the basic model, discrete time, for example, a year or a quarter is assumed, and decisions relating to investment, production, research funds, and so on, are taken simultaneously and independently by all firms at the beginning of each period. After the decisions are made, firms undertake production and put products on the market. The products are evaluated by the market, and the quantities of different firms' products sold depend on relative prices, the relative value of product characteristics, and the level of saturation of the market. Because of imbalances of global supply and demand, as well as 'local' imbalances of demand and supply of products of a specific firm, it may happen that the products evaluated as the best are not sold in the full quantity offered, and, conversely, the inferior products are frequently sold in spite of the possibility of selling the better ones. But during long periods the preference for better products, that is, those with a lower price and better characteristics, prevails.

In the model presented below, each firm may simultaneously produce products with different prices and different values of the characteristics; that is, the firm may be a multi-unit operation. Different units of the same firm manufacture products by employing different sets of routines. Multi-unit firms exist because of the searching activity. New technical or organizational solutions (that is, a new set of routines) may be much better than the current ones, but full modernization of production is not possible because of investment constraints. In such situations, the firm continues production employing the old routines, and tries to open a new unit, producing, on a lesser scale, employing the new set of routines. Subsequently, the 'old' production may be reduced and after some time superseded by the 'new' production.

In the model, a simulation of industry development is made in discrete time in four steps:

1. Search for the new sets of routines which potentially may replace the 'old' set currently employed.
2. Calculate and compare the investment, production, net income, profit and other characteristics of development, which may be obtained by employing the 'old' and the 'new' sets of routines. Decisions of each firm on: (a) continuation of production by employing old routines or making modernization of production, and (b) opening (or not) of new units.
3. Entry of new firms.
4. Market evaluation of the offered pool of products. Calculation of firms' characteristics: production sold, shares in global production and global sales, total profits, profit rates, research funds, and so on.

Apart from the first step, the three others are almost exactly the same as in the basic model described in the previous section. The only difference is that the productivity of capital A, the unit cost of production V, and technical competitiveness q are now the functions of routines applied by each firm, and may vary according to discovered inventions and introduced innovations. Because of innovation and new technologies introduced by firms, the modernization investment is also taken into account in the decision-making process (that is, besides the expansionary investment related to the growth of production, we have the modernization of investment related to adjusting the 'old' capital to 'new' technology).

Search process

We assume that at time t a firm is characterized by a set of routines. There are two types of routines: *active*, that is, routines employed by the firm in its everyday practice, and *latent*, that is, routines which are available to the 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 also 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 or in-house development. The firm may also allocate some funds for gaining knowledge of other competing firms and try to imitate (recombination) some routines employed by competitors. It is assumed that recombination may occur only between segments, not between individual routines, so that, 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) with some probability from firm to firm. It is assumed that after transition a routine belongs to a subset of latent routines. At any time a random transposition of a latent routine to a subset of active routines may occur. A more detailed description of the four basic mechanisms of evolution of routines is presented in the following sections.

Research funds

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

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

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

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

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

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

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

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

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

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

Mutation

It is assumed that routines mutate independently of one another. Since the range of the routines is bounded, all possible routines are enumerated and it is assumed that the range is from $MinRut$ to $MaxRut$. Let r_{lk} denote the l-th routine in the k-th segment employed by a firm in period $(t-1, t)$. After mutation routine r_{lk}:

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

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

with probability $PrMut/(2MaxMut)$ for every x. The probability of mutation of a routine depends on R&D funds allocated by firm i to search for innovations,

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

where a^m, ζ are coefficients controlling probability of mutation, and b^m is the probability of mutation related to the public knowledge. The maximum scope of the search depends also on the funds allocated to autonomous research, and it is assumed that,

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

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

Recombination

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

1. conditional probability of recombination of segment k of firm-unit i with segment k of firm-unit j is proportional to the share of firm-unit j in global production;

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

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

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

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

Transition, transposition and recrudescence

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 some 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 by assuming that u_2 is equal to zero in the equation below, the probability of recrudescence does not depend on the firm's size and is constant (equal to u_1). The probability of recrudescence in firm i is equal to,

$$PrRence_i = u_1 \exp(-u_2 K_i). \tag{46}$$

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 in short periods of recrudescence for the emergence of radical innovations.

Differentiation and competition of products

Productivity of capital, variable cost of production and product characteristics are the functions of routines employed by a firm. Each routine has multiple, pleiotropic effects, that may affect many characteristics of products, as well as productivity, and the variable cost of production. We assume that the transformation of the set of routines into the set of product characteristics is described by m functions F_d,

$$z_d = F_d(r), \quad d = 1, 2, 3, \ldots, m, \tag{47}$$

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

Attractiveness of the product on the market depends on the values of the product characteristics and its price. In the former section, product competitiveness (see equation (1)) is a function of constant technical competitiveness and varying product price. 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 characteristic. As we have said, each routine does not influence directly the product's performance, but does so indirectly through the influences of its characteristics. We assume the existence of a function q enabling calculation of technical competitiveness of products manufactured by different firms. We say that function q describes the adaptive landscape in the space of 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. We say that 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 relevant importance, while some become higher.

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

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

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

Due to the ongoing search process, at any moment each firm may find a number of alternative sets of routines. 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 presented in the previous section. The only difference is that values of productivity of capital A, the unit cost of production V, and technical competitiveness q, are not constant but are modified according to an actually considered set of routines, either r or r^*. For each alternative set of routines the price, production, investment (including the modernization investment), and value of objective function are calculated. The decision of firm i on making modernization (replacing the r routines by r^* routines) depends on the expected value of the firm's objective and its investment capabilities. Modernization is made if the maximum value of the objective distinguished from all considered alternative sets of routines r^* is greater than the value of the objective 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 us to make modernization, then the firm:

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

It is assumed that the productivity function $A(r)$, and the cost functions $V(r)$ and $v(Q)$ are not firm specific and have the same function form for all firms.

To modernize production it is necessary to incur an extra investment. The modernization investment depends on the discrepancy between the 'old' routines

r and the 'new' routines r^*. For simplicity of calculation, it is assumed that the 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^*.

$$IM_i(t) = K_i(t) \| r - r^* \|, \tag{49}$$

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

Research is financed from the current firm's income, so the relevant equations (34) and (35) for the firm's profit Π_i and income Γ_i ought to be modified. Thus:

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

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

where Q_i^s is the current production of firm i, QS_i the production of firm i sold on the market, p_i the product price, $V(r)$ the unit cost of production when routines r are applied, K_i the capital, D_i the debt of firm i, and R_i the research funds of firm i.[11]

It is a kind of tradition that, if economists speak of technological progress and innovation, they distinguish two kinds of innovation, namely product and process innovation. The discrimination of such types of innovation is not relevant to our approach. Our interest is focused on innovation which influences some operationally-defined economic variables, such as cost of production, productivity of capital or technical product performance. But, although in hidden form, process and product innovation are present in our model – we may say that innovation focused on the reduction of the cost of production, and to a degree on productivity of capital, is related to process innovation, and innovation aiming at better technical performance of products is related mainly to the product innovation.

III Innovation regimes

Three basic kinds of innovation are captured by our model, namely innovations leading to: (1) reduction of the unit cost of production, (2) advancement of the product's technical performance, and (3) increase in the productivity of capital. In general, any real innovation causes changes in all three features of technological development. We are able to control the type of innovations; for example, we can allow the emergence of innovations which cause changes in only one area, and to keep the other two fixed. Therefore, we may speak about three basic modes of technological development called 'regimes': the cost regime, the technical performance regime, and the capital productivity regime. In this section, the influence of these different types of innovation on the development of the industry will be investigated, particularly on industry concentration and on product price distribution. To make the results comparable it is assumed that there are no new entrants and the competition process is confined to the initial 12 firms. The initial conditions

[11] Our model does not include explicitly the notion of labour, considered in economic analysis as the classical factor of production. Such important economic characteristics as labour and wages ought to be present in any model, and are present in our model, although indirectly, in the cost functions $V(r)$ and $v(Q)$. At the current stage of the model's development it is not necessary to disaggregate the cost functions, although the possibility still exists to isolate labour and wages and build them explicitly into the model. This will be done in the future development of the model as a natural process of the model's stepwise concretization.

Table 1. Price and industry structure in different innovation regimes

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

Note: values of firms number equivalent n_H, the ratio of Profit/Capital Π/K, and Price are average values during the whole period of simulation from 0 to 100

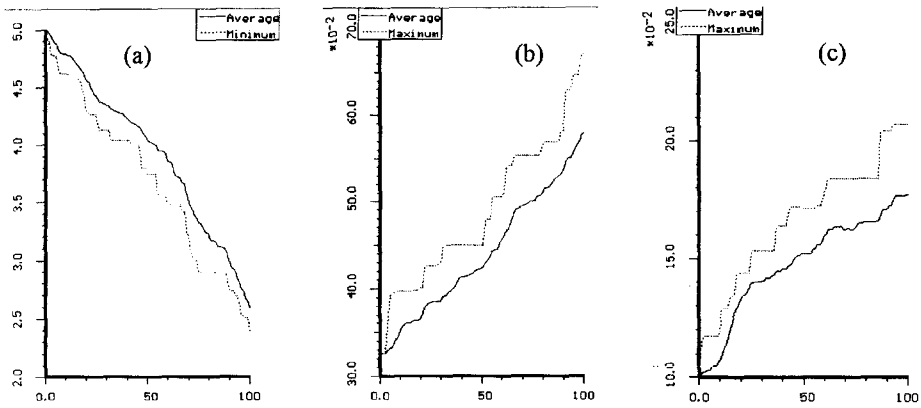

Fig. 3a–c. Innovation regimes: variable cost of production (a), technical competitiveness (b) and productivity of capital (c)

of the simulation are set in such a way that in all the experiments presented, the innovation process is a gradual one, that is, recrudescence is not present and no fulguration is observed.

The results of this series of experiments are summed up in Table 1. In Fig. 3 the development of the variable cost of production, the technical competitiveness and

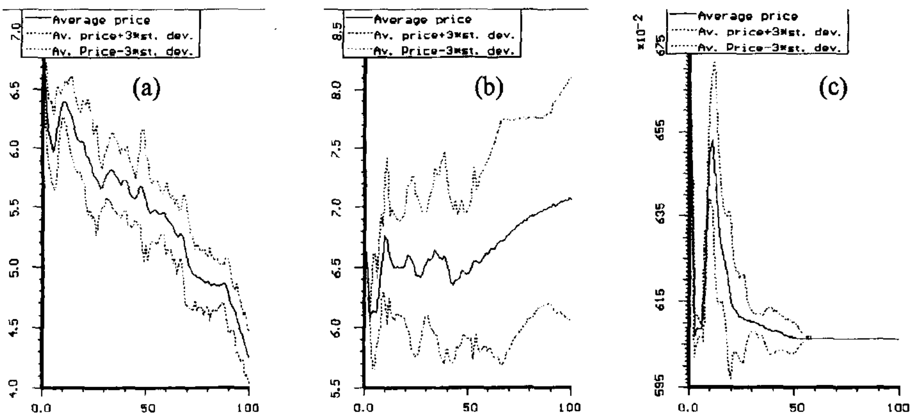

Fig. 4a–c. Price for different innovation regimes: cost (a), technical performance (b) and productivity (c)

the productivity of capital in these three regimes for a 'normal' rate of innovation emergence are presented.

In the simulation runs, with the reduction of unit cost of production as the only target of innovation activity (technical competitiveness and productivity of capital being constant), two modes of development are distinguished, related to the rate of cost reduction: in the first run, labelled 'normal', the average annual rate of unit cost reduction is about 0.6%, and in the second run, labelled 'fast', the cost reduction is about 3.5% annually.

Reduction of the cost of production also leads to a reduction in price, but the rate of price reduction is much smaller than the rate of cost reduction. In the case of the normal rate of cost reduction, price decreases only 0.25% annually (see Fig. 4a). At the end of the simulation the price margin is significantly higher than at the beginning (the price/cost ratio is equal to 1.7 at the end of the simulation, compared to 1.3 at the beginning); and in the case of the fast rate of cost reduction (3.5% annually), the price is reduced only slightly more than 1.5% annually, and the price margin at the end of the simulation is 3.2.

A reduction of the cost of production narrows the possibilities for 'obsolete' firms to apply relevant strategies to keep the pace forced by the leaders. The possibility of making obsolete products more competitive through price reduction is very limited, so the non-innovators and firms unable to imitate the innovation and reduce the costs of production within a relatively short period, are quickly eliminated from the market. The number of Herfindahl firms' in this experiment is reduced from the initial 12 to four at the end of the simulation (average value of n_H is equal to 7.14 firms). Heavy cost reduction rate, as in the fast mode, leads to much quicker elimination of 'obsolete' competitors from the market. At the end of the simulation run, the Herfindahl firms' number equivalent is equal to 1.06 (there is one big firm and two very small competitors – the average n_H number equivalent is equal to 2.33 in this run).

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

In contrast to the situation in the cost regime, the possibilities of choosing a relevant price policy to keep the position on the market are much wider in the case of innovations leading to an improvement of the product's technical performance. Reduction of the price compensates for the temporal technical backwardness of the product and allows the overall competitiveness of obsolete products to be kept almost at the same level as the advanced ones. This prolongs the period for followers to imitate the technology leader. In the technical regime, two modes of development are also tested: normal (with the average annual rate of technical competitiveness about 0.7%), and fast (with the annual growth of technical competitiveness equal to 3.2%). The price policy of technological leaders in the technical performance regime helps their followers to maintain the pace of technological progress. The leaders increase price slightly to attain a higher profit – they choose the strategy of balanced price rising, to gain higher profit, and concurrently to keep the overall competitiveness of their products at a relatively high level. So in the technical regime two opposite tendencies concerning price policy are observed – a reduction of the price by followers (to raise their product competitiveness and to keep their place in the market), and an increase in price by the leaders (to gain higher profit from their temporary 'monopoly position'). This leads to a much higher diversity of price in these two innovation regimes – compare the two diagrams in Fig. 4a, b. The average standard deviation of price in the run with the normal rate of growth of technical competitiveness is 3.44%, slightly more than twice the relevant value in the first experiment in the cost regime, and over 27% for the fast rate of technical competitiveness. Price fluctuations in the first phase of development (Fig. 4b) are due to the above-mentioned interplay of the two different price policies. The steady growth of the average price in the second phase of development (after $t = 50$) is due to higher concentration of the industry.

If the conditions for pure competition are provided (for example, through allowing free entry of new firms), price fluctuates around the equilibrium value, as it does in the initial phase (up to $t = 50$) of the simulation run presented in Fig. 4b. So it may be said that, in contrast to the steady trend of diminishing price as observed in the cost regime, no such mode of price development is observed in the technical regime – many simulation runs confirm the finding that fluctuations of price around the equilibrium value are a typical pattern of development in the technical regime. Rapid technical progress leads to much greater concentration of the industry – for 'normal' technical improvement the average value of the Herfindahl firm number equivalent is 8.9 firms, but for rapid technical progress this number is 2.39. The price diversity in this run is almost eight times greater than is the normal rate of change of technical competitiveness (over 27%).

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

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

The results of simulation runs of the productivity regime seem to be fully consistent with the statistical analysis of economic growth made in the 1950s. From this point of view, our model and simulation results may hint at explanations for the results, particularly for the results which are in conflict with the neoclassical view of growth – that the ratio of capital engaged to the volume of production is constant during the analysed period. This view is also supported by the results of simulation runs with a so-called 'complex' innovation regime, in which simulation conditions are created in such a way that routine modifications influence concurrently the unit cost of production, the product's technical performance, and the productivity of capital.

A number of simulation runs for the 'complex' regime were done and a large spectrum of behaviour was observed; the results of four of them are presented in Table 1. Random factors play an essential role in this regime; frequently an innovation generated at the beginning of the simulation decides the future path of development for the whole industry (this innovation creates a chreod, in the terminology of Waddington). We rarely observe harmonious development leading to moderate rates of improvement of the productivity of capital (A), technical competitiveness (q), and reduction of the unit cost of production (V), the main reason being that the probability of the emergence of innovation (which enables simultaneous reduction of the cost of production), and increases in the technical competitiveness and productivity of capital, is very small. The most typical situation is that of firms using inventions enabling an advance of only one of these features (either q, V or A), while the two other features are improved in succeeding stages of development as a result of future research efforts leading to improvements of that basic innovation. The most frequent mode of development is that of firms accepting much more eagerly inventions leading to cost reduction, and/or to rising technical competitiveness. The productivity of capital is frequently kept almost at the same level. The results of such typical situations are presented in Table 1 (the 'complex' regime labelled normal (A)) and in Fig. 5.

An average productivity of capital (equal to 0.11) is only slightly greater than the initial value (0.10), but development of the productivity of capital is not static, and as we see in Fig. 5c it fluctuates. The fluctuations of the productivity of capital, as well as the cost of production and technical competitiveness, are due to the interwined (pleiotropic) character of the impact of innovation on industry development in the complex regime. In the initial phase of development, cost reduction and the improvement of technical performance are observed (Fig. 5a, b). At the end of the fourth decade, an invention reducing significantly the cost of production is found. But while reduction of the unit cost of production in that invention is coupled with a decrease in technical competitiveness nevertheless the invention is accepted purely

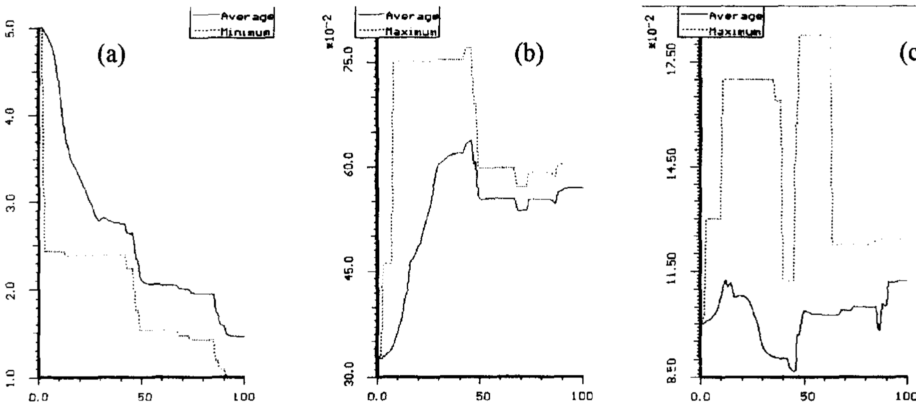

Fig. 5a–c. Variable cost of production (a), technical competitiveness (b) and productivity of capital (c) in the 'complex' regime

for economic reasons. As it turned out, it was very difficult to improve the technical performance starting from that formerly accepted innovation. In the second half of the simulation period, the firms' innovative efforts are concentrated on cost reduction and technical competitiveness is kept almost constant. If we compare the results of the former ('pure') innovation regimes with the results of the 'complex' regime, we see a much higher discrepancy between the frontier of technological development (as measured by the maximum of technical competitiveness, the maximum productivity of capital, and the minimum of the unit cost of production) and the average performance of the industry.

Analysis of the simulation results suggests that there is no stable pattern of behaviour: random factors play an essential role and the behaviour of industry (such characteristics as profit/capital rate, industry concentration and price diversity), depends strongly on a prevailing innovation regime. (If, due to purely random factors, R&D efforts result in the emergence of innovation reducing the unit cost, then we observe higher industry concentration. But if, due to random factors, the technical regime prevails, then we may observe greater diversity of price and a smaller tendency towards higher industry concentration.) Random factors influence not only the modes of development of some industry characteristics, but also play an essential role in the structural development of the whole industry.

The simulation results for different innovative regimes have revealed an interesting property of industry development related to the supply and demand balance. For the cost regime and for the productivity regime, the supply-to-demand ratio fluctuates around the equilibrium value (see Fig. 6a, b), and the mode of the S/D ratio development does not depend on the rate of change. From the qualitative point of view, the picture is almost the same for low, moderate and high rates of innovation. An average value of the S/D ratio for these two regimes is always slightly above one (for example, for the cost regime (fast) it is equal to 1.0014). A very similar picture of development is seen for low and moderate (labelled normal) rates of growth of technical competitiveness (see Fig. 6c); the average value of S/D in the whole period of simulation is equal to 1.0003. But, for some reason, for fast technical development, instability of supply and demand occurs. The value of the S/D ratio

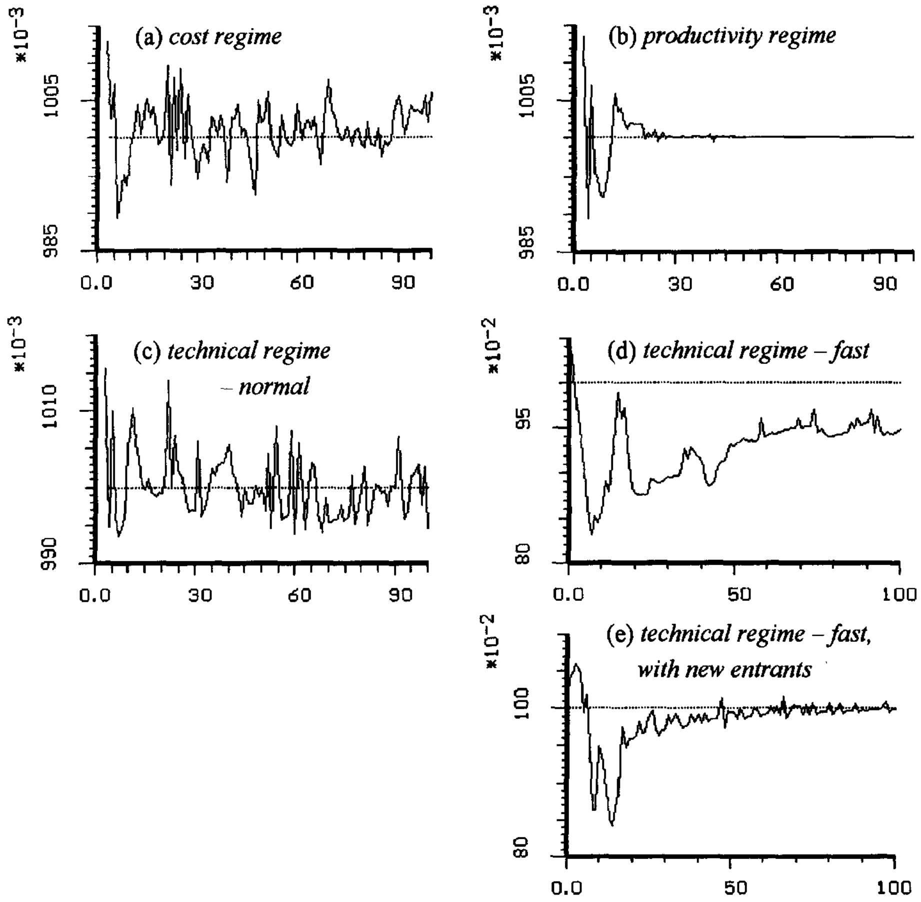

Fig. 6. The supply/demand ratio for different innovation regimes

drops below one and is the smaller the faster the development; for the average annual rate of development equal to 1.5% the average value of the S/D is 0.984, and for rather fast development (3.2%) the average value of S/D ratio is 0.927 – development of the ratio in this case is presented in Fig. 6d. To make supply and demand more balanced, an attempt has been made to change the firm's decision strategies in many ways (for example, by making much stronger the relationship of the expected development of price with the current imbalance of supply and demand), and the results were always very similar – the average value of the S/D ratio is always significantly smaller than one. It seems that the firms act so as to leave a 'free place' for newcomers, to make the entry of new firms easier. It turns out to be true – the situation is significantly better if we allow the entry of new firms. The development of the S/D ratio in this case is presented in Fig. 6e. The average value of S/D in this run is significantly smaller (0.983). The free entry of new competitors also causes much quicker recovery from the deep imbalance and quicker development of the industry towards the equilibrium.

IV Entry and industry structure

As we have seen in the previous experiments, the acquiescence for firm entry greatly influences the values of important characteristics of industry development, such as profit, price structure, and supply and the demand balance (Table 1 and Fig. 6). It follows that opportunity of entry also greatly influences the industry structure, especially in the periods of radical innovation emergence. To investigate how industry structure is formed under the conditions of free entry, the following two simulation runs with specific initial conditions were prepared. In both runs, in the first phase of simulation (up to $t = 30$) only incremental innovations are introduced (they cause only moderate reduction in the cost of production, increase in technical competitiveness, and rise in the productivity of capital). In the 30th year the recrudescence mechanism of innovation generation is activated. In effect, radical innovation emerges, followed by a quick and significant reduction in the cost of production, a rise in technical competitiveness and a rise in the productivity of capital within the whole industry. Conditions of simulation in the two runs were prepared in such a way that in both experiments, the changes of the three characteristics of industry development are very similar, as presented in Fig. 7.

It is true that the emergence of such radical innovation in real industrial processes is a very improbable phenomenon, but to see more clearly the impact of innovation on the development of the industry, such extremely radical innovation emergence was intentionally forced. The only difference in the initial conditions created in these two runs is that, in the first run, no entry of new firms is allowed, while in the second run, free entry is allowed.

Naturally, the first difference in the industrial development of these two runs lies in the number of firms and firms' units, which is presented in Fig. 8. If no entry is allowed (the upper chart), all 12 initial firms are presented in the market up to $t = 65$, but from that year more and more firms are eliminated from the market, so that by the end of the simulation, only two are present. Diversification of the industry structure due to the emergence of innovations is observed from the beginning of the

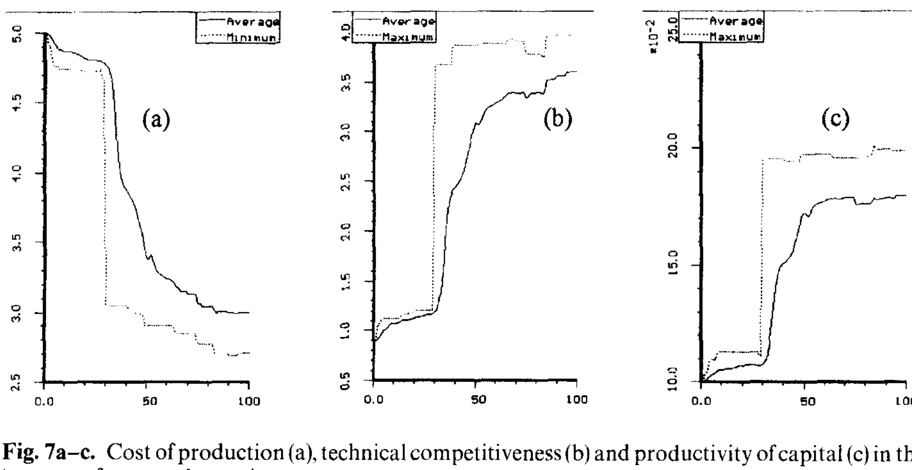

Fig. 7a–c. Cost of production (a), technical competitiveness (b) and productivity of capital (c) in the 'no entry-free entry' experiment

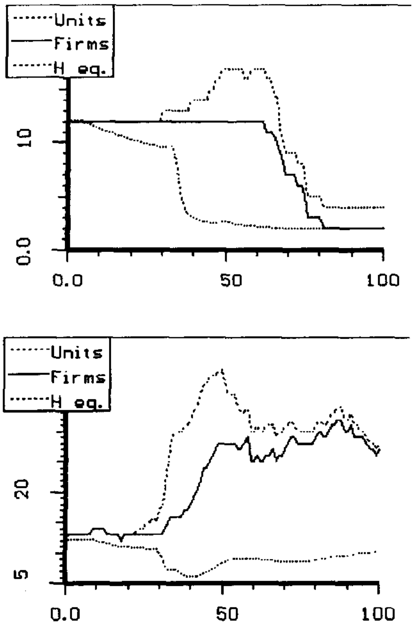

Fig. 8. Number of firms in the 'no entry-free entry' experiment (*upper* and *lower charts* respectively)

simulation, but in the first phase of development, when only incremental innovations emerge, the diversification is relatively small and the concentration grows only gradually (see n_H – the Herfindahl firms' number equivalent in the upper chart). With the four-year delay, after the emergence of the radical innovation, a significant diversification of firms' size is observed; no firm is eliminated, but some of them have significant shares of the market so concentration grows very quickly. The radical innovation also causes the emergence of multi-unit firms – as can be seen in the upper chart from $t = 30$, more and more firms become multi-unit operations (there were up to 16 units present). Even at the end of the simulation, when only two firms compete on the market, each firm has two units. The bulk of the production is made in the modern units, but still a small fraction of production is based on obsolete technologies.[12] The growth of the number of firms in the free entry simulation run is presented in the bottom chart of Fig. 8. In the first phase of development of the industry, new firms enter the market only incidentally. But following the emergence

[12] The exact values at the end of the simulation are as follows. For the largest firm (no. 10), the market share in the global production of the modern unit is 45,2% and the price of the product 5.67 (the overall competitiveness of the modern production is 0.1222); in the 'obsolete' unit 6.3% of the global production is made, and the price of the product is much lower – 3.25 (but because of the lower price the overall competitiveness is only slightly smaller than the modern production, 0.115). For the second largest firm (no. 1) the relevant values are very similar, the market share of the modern unit is 42.4% and the product price 5.7 (the overall competitiveness is 0.1218); in the 'obsolete' unit 6.1% of the global production is made, and the product price is 3.15 (the overall competitiveness is 0.114).

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

The shares of the eight largest firms in both simulation runs, are presented in Fig. 9, and give some view on the development of the structure of industry. As was mentioned before (Fig. 8, Table 2, and footnote 12), at the end of simulation, the Herfindahl firm number equivalent in the run with no entry is equal to two, and the two firms which survived are labelled 1 and 10 (see the left-hand chart in Fig. 9). What needs to be noted is that these two firms were not the biggest ones at the moment of emergence of radical innovation; in fact both firms were steadily

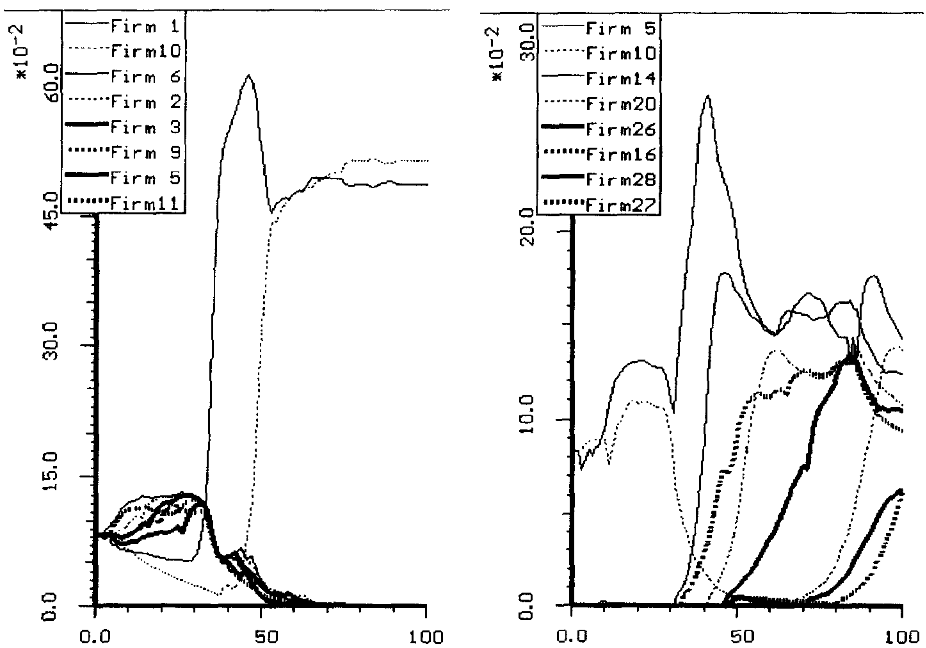

Fig. 9. Market shares of the eight largest firms in the 'no entry-free entry' experiment

Table 2. The 'no entry-free entry' experiment

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

eliminated from the market (see the first phase of industry development in the left-hand chart of Fig. 9).

The innovation was discovered by firm 1 and applied at $t = 30$; the fact that the radical innovation was invented by small firms is due partly to our assumption that the probability of the emergence of radical innovation is greater for small firms. The reward for being the first innovator is greater profit and the largest share of the market. The only firm which successfully adopted new technology and followed the first innovator is firm 10; all other firms, in spite of their relative advantages at the moment of emergence of the radical innovation, are eliminated. So at the end of the simulation, the industry represents the case of classical duopoly.

The picture is radically different in the case of free entry. The first firm which applied the radical innovation in this run is firm 5 (the right-hand chart in Fig. 9). Other firms quickly adopted this innovation, but as it turned out all the 'old' firms are eliminated from the market and their places are captured by newcomers.[13]

As a result of stronger competition, the old firms are quickly eliminated from the market, so within the eight largest firms operating at the end of simulation there is only one old firm (the founder of the advanced technology, firm 5). The distribution of firms' shares at the end of the simulation is almost balanced, and the Herfindahl number equivalent is equal to 10.12 at the end of simulation – see Table 2; the share of the largest firm in the last year is about 15%, five other firms have only slightly smaller shares (from 9% to 14%), and late followers have shares of about 7%. But, because of small improvements introduced by them, their shares grow significantly quicker than those of all other firms. Up to the moment of the emergence of radical innovation, the supply and demand are almost balanced in both simulation runs (see Fig. 10). Emergence of the radical innovation also causes a rapid increase in technical competitiveness. As has been shown in the previous section, with the simulation of the technical performance regime, the quick growth of technical competitiveness causes a large imbalance of supply and demand (see Fig. 6d, e). This imbalance is also observed in the two discussed simulation runs after the emergence of the radical innovation. If no new competitors enter the market, we observe a kind of stabilization of the supply-demand imbalance at the level of 3% (the S/D ratio is

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

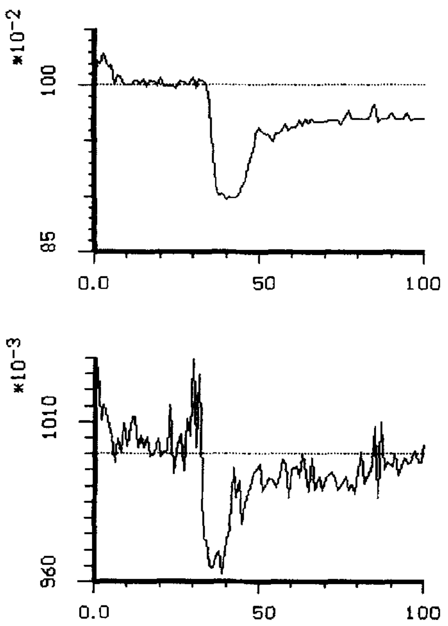

Fig. 10. Supply to demand ratio in the 'no entry-free entry' experiment (*upper* and *lower charts* respectively)

about 0.97 – see the upper chart of Fig. 10), but if the entry of new firms is allowed we observe a tendency toward balancing supply and demand (bottom chart of Fig. 10 after $t = 40$). The average value of the S/D ratio after the emergence of radical innovation is 95.9% in the no-entry run and 99.1% in the free-entry run. The possibility of free entry also causes much smaller maximal imbalance just after the emergence of the radical innovation. The minimum value of the S/D ratio is equal to 90% if no competitors enter the market, and is equal to 96% if free entry is allowed.

Free entry also causes a different development of price and its structure within the industry (Table 2). In both runs the price is only slightly reduced in the first phase of development, because of an incremental reduction of the unit cost of production (see both charts in Fig. 11). The emergence of radical innovation causes significant reduction in the unit cost of production and, as might be expected, this ought to result in the parallel significant reduction of the price. The process of price reduction occurs in the first years after the emergence of radical innovation, but because of a higher concentration of the industry, it is stopped in the run with no entry.

The tendency towards price reduction caused by cost reduction is neutralized by the reverse tendency towards greater industry concentration. It is not the case in the simulation with free entry allowed, where the price is quickly reduced in the first period after the emergence of the radical innovation and continues to be reduced (although not so quickly) in the following decades because of incremental reduction in the unit cost of production and more competitive conditions on the market (smaller concentration of the industry). Emergence of the radical innovation also causes a significant increase in the diversity of price. In the simulation with no entry, high diversity occurs just after the emergence of the innovation and is kept almost on

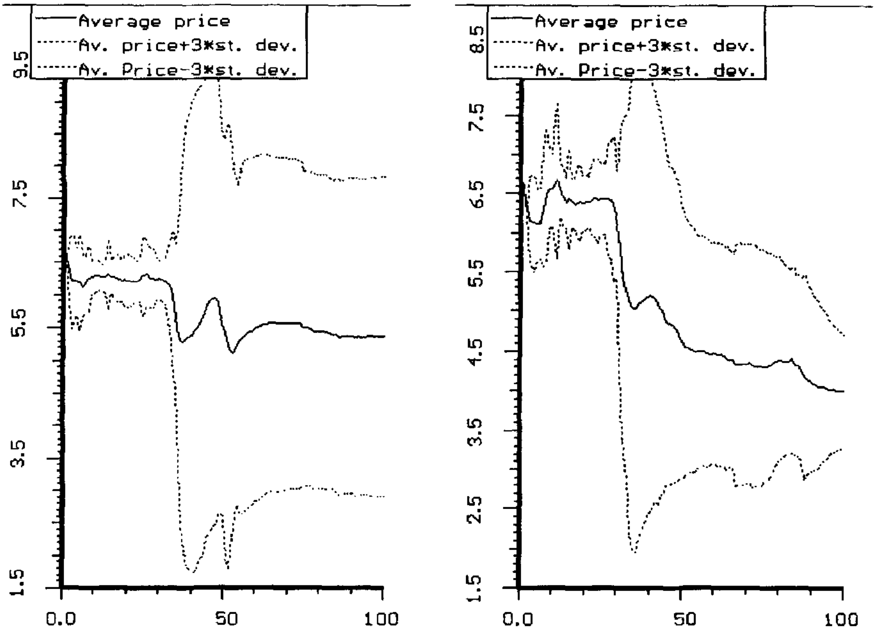

Fig. 11. Price in the 'no entry-free entry' experiment (*left* and *right charts* respectively)

the same level during the following whole period up to the end of the simulation (see left-hand chart of Fig. 11). In contrast to the conservation of the structure of prices within industry, in the case of no entry the continuous tendency to reduce the diversity of price is observed if free entry is allowed (the right-hand chart in Fig. 11; compare also the relevant values of the standard deviation of price in Table 2.

Conclusions

The basic model, presented in section 1 of this paper, embraces only an 'economic' part of industrial process, that is, without a research process causing the emergence of innovation. A simulation study of the basic model (Kwasnicki 1994, Chapter 6) show similarities and dissimilarities between the basic model's behaviour and the classical, well-known modes of development of real processes. As Nicholas Kaldor (1961) writes:

> Any theory must necessary be based on abstraction; but the type of abstraction chosen cannot be decided in a vacuum: it must be appropriate to characteristic features of economic process as recorded by experience. Hence the theorist, in choosing a particular theoretical approach, ought to start off with a summary of facts which he regards as relevant to his problem. Since facts, as recorded by statisticians, are always subject to numerous snags and qualifications, and for that reason are incapable of being accurately summarized, the theorist, in my

> view, should be free to start off with a 'stylised' view of facts – i.e. concentrate on broad tendencies, ignoring individual details, and proceed on the 'as if' method, i.e. construct a hypothesis that could account for these 'stylised facts' without necessary committing himself to the historical accuracy, or sufficiency, of the facts or tendencies this summarized.

Following his proposition, it is shown that the model reflects at least seven important 'stylised facts', namely:

- for a given market, the margin of price and firm profit increase with the concentration of industry (for example, from perfect competition, through oligopoly, duopoly, and ending with monopoly);
- there is a specific relationship between economies of scale and industry concentration: the larger the economies of scale the greater the industry concentration;
- 'the capital/labour ratio is rising more or less in proportion to productivity, and it is highest amongst the richest nations and lowest among the poorest, the capital/output ratio is much the same as between poor and rich countries – it is no higher in America ... than it is in India' (Kaldor 1985, p. 67). Kaldor calls it 'one of the best established "stylised facts" of capitalist development';
- in the presence of innovation, there is no uniform price for all products sold on the market but a great diversity of price is observed;
- emergence of innovation leads to temporal monopoly of the pioneer firm; at the first phase after innovation the monopoly firm gains extra profit that disappears in time, when competitors imitate the innovation;
- skewed distributions of business firm size and their long-term stability is the well established 'stylised fact' of industrial demography; size distributions of firms of real industries are very similar ('look like') to Pareto, Yule, or log normal distributions;
- industrial development is a unique historical process in which path-dependence and cumulative causation play important roles.

An evolutionary part of the model related to the search process for innovation is included in the basic model and presented in section II of this paper. Mechanisms of search for innovation seem to be the common property of all evolutionary processes, and in fact this part of the industrial models is 'borrowed' from my former model of biological evolution. It is reflected also in the nomenclature used (mutation, recombination, and so on) so well-known in biological models. Presented in this paper, the results of the simulation with an embedded search process expose the impact of the innovations on the modes of industry development.

Three basic innovation regimes corresponds to three kinds of innovations leading to: (1) reduction of the unit cost of production, (2) advancement of the product's technical performance, and (3) increase in the productivity of capital. The results of many simulation runs reveal that these different regimes significantly influence industry structure and price diversity.

Reduction of the cost of production leads to a reduction in price, but the rate of price reduction is much smaller than the rate of cost reduction. The possibility of making obsolete products more competitive through price reduction is very limited, so the non-innovators and firms not able to imitate the innovation and reduce the costs of production within a relatively short period are quickly eliminated from the market. If there are no entrants, the cost reduction leads to high industry concentration and relatively small diversity of price.

In contrast to the situation in the cost regime, the possibilities of choosing a relevant price policy to keep the position on the market are much wider in the case of innovations leading to an improvement of the product's technical performance. Reduction of the price compensates for the temporal technical backwardness of the product and allows the overall competitiveness of obsolete products to be kept at almost the same level as the advanced ones. In the technical regime, two opposite tendencies concerning the price policy are observed – a reduction of the price by followers (to raise their product competitiveness and to keep their place on the market) and an increase in the price by the leaders (to gain higher profit from their temporary 'monopoly position'). If we compare the modes of development in the cost regime and the technical regime, we then see that the cost reduction leads to relatively high concentration of the industry, high price reduction, and a relatively small diversity of price, almost opposite tendencies are observed in the technical regime – smaller concentration, almost no price reduction (in the long-term perspective), and high diversity of price.

The capital productivity regime may be called neutral. Even a high rate of productivity growth does not lead to large industry concentration and significant price reduction. The strategy of productivity improvement seems to be a rather ineffective weapon to eliminate competitors from the market, although it provides comparably good economic effects; the profit is almost the same as in the case of the technical regime and even slightly larger than in the case of the cost regime.

An interesting property of the industry development related to the supply and demand balance is observed for technical regime. In almost all simulation runs for all three innovation regimes the supply to demand ratio is very close to one; it fluctuates around the equilibrium value and the mode of the S/D ratio development does not depend on the rate of change. But for fast technical development instability of the supply and demand occurs (it can be named 'new products shortages'). The value of the S/D ratio drops heavily below one and is the smaller the faster the development. It is necessary to allow firm entry to make supply and demand more balanced. The entry also provide much quicker recovery from the deep imbalance and quicker development of the industry towards the equilibrium. Entry of new competitors allows not only to keep concentration of an industry on relatively low level and, through stronger competition, allows to reduce products price, but also allows to keep the market balanced.

Emergence of the radical innovation causes a significant increase of the diversity of price. In the simulation with no entry the high diversity occurs just after the emergence of the innovation and is kept almost on the same level during the following period. In contrast to the conservation of the structure of prices within industry in the case of no entry the continuous tendency to reduce the diversity of price is observed if free entry is allowed.

Acknowledgements. I gratefully appreciate discussions and comments of the members of the IIASA *Technological and Economic Dynamics Project* Yuri Kaniovski, Gerald Silverberg, and Bart Verspagen, during my visit at IIASA in January/February, 1995.

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