Technological Competition: a Qualitative Product Life Cycle

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Abstract

In this work, it is proposed to consider the evolution of markets for technological innovative products as a co-evolutionary process, where the product characteristics are the results of the interaction between producers technological advances and buyers' preferences evolution. A methodological discussion identifies some necessary properties for a model to study this issue. A model of technological competition is developed, and its results discussed, to test a possible implementation of the supply side of the co-evolutionary process.

Keywords

Technological Competition, Co-Evolution, Modelling.

JEL Classification

C63, D43, D83, O32, O33

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Contents

Economics and Technological Innovation

The importance of technological innovation has always been acknowledged since the beginning of Economics. But the economists have always had difficulties to provide a general formal model for this phenomenon. In fact, markets for new products show characteristics that make it very difficult for abstraction and generalisation, but are at the very core of their functioning: variety and dynamics. That is, a new industry cannot make use of the assumption of homogeneous products and it is typically subjected to fast modifications. These industries seem to be the most difficult to abstract from the unique context of their historical development, being strongly dependent on other aspects of the economies where it takes place. In other words, the development of markets for new products seems to lack the necessary aspect to “make science” on them: each seems to be unique.

The literature referred to as Product Life Cycle (PLC) has identified a number of properties of these markets that are found in several industries[1] (Klepper, 1996). These properties concern the number of producers, rate of innovations and market shares at different stages of industries for new products development. As Klepper acknowledges (Klepper, 1997), the original input for PLC was provided by marketing literature, and this is reflected in its preponderant descriptive nature. While the properties there reported seem actually pretty general, their “explanations” and their applicability for forecasting or normative purposes seems still too vague, relying (when possible) on the unique characteristics of each market. In particular, the PLC literature seems uninterested in more qualitative problems, which are anyway at the base of technological advanced markets, that is, the direction of technological change.

This problem is determined, on the one side, by the technological capacities of producers, and, on the other side, by the preferences of buyers. Both aspects are, at least partly, influenced by economic reasons. In particular, buyers need to use their prefrences to choose among different products. It is normal, by standard neo-classical approach to Economics, to solve any problem of choice by applying the criterion of optimality: given the structure of buyers’ preferences, it is possible to define on

[1] Given the level of the discussion, the terms “markets” and “industries” will be used as synonyms, as it is often done in the literature of PLC.

optimal choice. The problem with the case of
technological advanced products is that, by definition of “new” product, buyers don’t have preferences at all. Rather, buyers are forced to “create” their preferences on the basis of their experience on related products and on the set of products offered. This latter set is typically only a sub-set of the whole technological possibilities, specially in the early stages of market development. Hence, it is likely that the choices of buyers cannot actually determine the most appropriate elements, both for inadequate experience of the new technology and for the immaturity of the products embodying it. The literature on the path-dependency (Arthur, 1989) showed that in many relevant cases, the technology developed along trajectories that cannot be qualified as optimal by any means. The literature on network externalities (Katz and Shapiro, 1985) replied that these cases can still be considered as optimal, if individual decision makers consider also the effects of the whole set of decision makers, and not only the technological aspects. That is, a buyer can decide it is optimal to choose a technologically inferior product, if this ensures that, being part of the “network”, he will enjoys enough utility to compensate for the technological gap between the two choices. This argument, while providing an explanation for choices between given products, leaves completely exogenous the characteristics of the products offered.

Of course, much of the technological development of innovative products is related to the general level and development of scientific and technical knowledge, and its economic effects have been extensively studied (e.g. Nelson and Winter, 1982). But most of these studies assume technological improvements as increments in “efficiency”, as if there were a unique and determined direction for technological advances. In many relevant cases, we can imagine that the producers have, at any moment, the possibility to choose different directions towards which dedicate their technological efforts. Only few of these are actually explored, and the demand can judge only among the ones which eventually reached the market. Hence, the very choice set available to the demand is only one portion of the technological possibilities, and the demand shapes its preferences only on the products that it can actually find on sale. Since the relative success of the different products is interpreted by producers as an indication of the most appreciated direction of technological improvement, they will try to concentrate their efforts on that direction. This two dynamics will provoke a spiral of choices and messages where the objective qualities of product are only present on the background, if they matter at all.

It is likely that the effects of the relation between the supply and demand sides of markets for innovative products result in similar patterns among different industries[2]. And, therefore, this can be configured as an economic problem where technological choices motivated by economic reasons and preferences modifications caused by these choices contribute in shaping the actual pattern of the market evolution.

The problem can be stated as a system with two co-evolving populations of producers and buyers. The following section discusses briefly some methodological issues, identifying the core aspects of a co-evolving system. This discussion provides evidence that the complexity of a co-evolving model prevents an analytical treatment, and calls for the use of simulation modelling. This technique, while extremely powerful, suffers from large difficulties both to build up and to let understand the contents of a simulation program. For this reason, is necessary to construct gradually the model adding further components only when the system has been sufficiently tested with the former components. For this reason, this paper focuses only on the study of the supply side of the system above sketched. The model presented is an implementation of a proposal by Richardson (1996) for a dynamic equilibrium model in cases of perfect competition, technological change and increasing returns. Such proposal, though not considering the aspects of demand preferences evolution, is extremely interesting in that it describes the supply side of the market according the lines here described. In particular, it focuses on the role of time and on the "viscosity" of demand in markets for technologically innovative products. Hence, it can be used as a bench-mark for testing a system to represent the supply side of a model containing the characteristics sketched above. The last section contains the description of the model and the results obtained.

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[2] See Windrum and Birchenhall (1996).

Co-evolution, Dynamics and Time

Co-evolution

The definition of co-evolution is clearly drawn from the biological metaphor, as its "component" concept of evolution. Evolution refers to the dynamics of a system composed by many differentiated individuals, making up a population. There is one necessary characteristic for a population in order to say that it evolves, and this is strictly linked with the time dynamics. A system is said to evolve if there are two different time dynamics: a faster "demographic" dynamic and a slower "genetic" dynamic. The demographic dynamics modifies the composition of the population (i.e. the fittest elements will gain a bigger share of the population). The genetic dynamics creates individuals with new features, on the basis of population composition resulting from many repeated "demographic" steps. That is, it is more likely that the new genetically mutated individuals in the future will be obtained by the elements that previously proved to be successful. We can say that the demographic dynamics modifies the composition of a population on the basis of (given) genetic traits. On the other hand, the genetic evolution of a population takes place as a modification of genetic traits, given an average composition of the population. In order to solve this apparent circular reasoning, we need to consider explicitly the time length of the two dynamics.

The co-evolution takes place when two populations depend on each other for their "demographic" performance. That is, their fitness function is reciprocally determined by the other population. Of course, this is different from systems where evolving populations, though influencing each other, do not co-evolve, even when sharing the same environment of their evolution. They may also heavily influence each other, like relations of symbiosis or parasitism, but they do not constitute cases of co-evolution, unless the reciprocity of the fitness function can be determined.

The system above described is formed by the two populations of producers and buyers. While the consideration of demand as a fitness function for selecting successful producers is rather obvious, the opposite deserves further consideration. In fact, a producer offering a bad product is eliminated from the market, but it is difficult to imagine a similar mechanism for buyers. The system proposed represents buyers as having "basic needs", to which they must provide adequate satisfaction by using their preferences to choose on the market the “fittest” product. The “genetic code” of buyers is then composed by the set of preferences used to identify adequate products: a buyer with the “wrong” preferences is not eliminated, but it is more likely to change preferences than another buyer. Thus, the buyers population is “selected” according to its preferences. We can imagine that, as an extreme example, buyers having preferences on characteristics no longer present in any product offered are actually “selected out” from the market.

In order to build a model for the co-evolution of supply and demand, there is no need to represent in detail the “genetics” governing the evolution of firms and buyers. These constitute respectively the theory of the firm and the psychology of consumers. In order to keep the system as simple as possible, it is necessary to consider the main results from these two areas[3] and concentrates on the interaction among the two populations, which is supposed to form the dynamics of the market. Hence, the system should endogenously “explain” the dynamics of products’ technological evolution as emerging from assumptions on agents’ behaviour.

Dynamics

The standard tools, derived from Physics, to study the dynamics of a system are based on a fundamental assumption: the entities maintain a constant nature. For example, a planet in a Newtonian model of the solar system is constantly represented by its mass, position and velocity. The equations link these three variables and the whole model can be solved by describing the relations of the values of those variables for the set of all planets. In other words, the entities are “cancelled” in the model and substituted by a (constant) vector of variables, whose values modifications provide the explanation for the phenomena of interest.

To study the evolving populations in Biology (or Economics, Organic Chemistry, Sociology etc.) it is impossible to use a constant set of variables to represent both the nature and the properties of the evolving entities under study. As Fontana and Buss (1996) noted, the so-called complex systems cannot rely on the assumption of a fixed representation and call for an “Objects’ Calculus” in the place of numerical calculus.

[3] In particular, we will refer to the evolutionary theory of the firm (Nelson and Winter, 1982) and to the reason based choice model (Shafir et al., 1993), and other literature to account for the particular needs of the model.

The relevant aspects of an evolving population cannot be captured by a constant vector of values: its relevant qualities are modified along time, and hence we need to adapt accordingly its representation. Unless drastic simplifications are used, the number and variety of qualities of an evolving population is enormous and unpredictable[4]. From this descends that there is no way to use a constant number of variables in place of entities, but it is crucial to give a detailed representation for their characteristics. For example, there is no way to aggregate producers status' to provide an aggregate supply function to be matched with an aggregate demand function, if we allow for differentiated agents.

If we cannot use a (static) numerical representation for the qualities of a population it is not possible to "solve" a system in terms of relations among variables. Rather, it is necessary to build a bottom-up model including the basic "mechanics" of the elements and study the high level characteristics of the model as "emergent properties" (Lane, 1993) of the system. That is, to apply the methodology of simulations where the model is determined in terms of description of basic entities (i.e. genotype and rules governing its modifications) and the mechanism of interactions among them. The results are obtained not in terms of relations among a fixed set of variables' values, but in terms of qualitative aspect of semi-stable emergent entities That is, the system will be described not only in terms of numerical values, but also in terms of which variables become relevant.

The methodological challenge is too difficult to be matched by a general tool. The solution is to be found in the decomposition of the problem and the gradual aggregation of the different components of the whole model. It is anyway necessary to carefully build any component in such a way to ensure the future compatibility of the different components. For this reason, in the following we propose a model of the supply side of a market for innovative products. This model does not only provide useful results on the mechanism of this type of competition, but it is also built in such a way to easily "plug" it in a model with a demand side more elaborate than the one here used.

[4] In fact, it depends not only on the number of its elements and of its possible states, but also on their combinations. Hence, the number of possible status's of a population increases exponentially with the number of the individual components.

Time

Time is a crucial logical element of evolutionary models used to resolve apparent inconsistencies of dynamical systems. We have already discussed how time allows to evolution to take place, notwithstanding the reciprocal dependency between genetic and demographic dynamics. Another example of the importance of time is given by the relation between aggregate entities and their components. In fact, consider a model made of differentiated low-level entities that form higher-level organisations. The low level entities depend on the status of aggregate entities, because the latter constitute the constraints for their behaviour; but, on the other hand, the aggregate entities depend on their components for their very construction. As an example, consider a market where producers set their prices and the market shares are determined as a result of the choice of buyers, whose preferences include also the price. In turn, individual prices are determined by a function that includes also the market shares. Logically, there is a circularity that is not solvable, unless a time causality is introduced. In some cases, the choice of precedence of the causality is crucial for the results of the model, but it seems rather irrelevant in the real world that the model wants to represent

Co-evolutionary models are even more sensible to the use of time. In fact, assume that, in the example above, buyers modify their preferences according to the product they are consuming. The reactivity in price changes have an impact not only on market shares, but also on the future evolution of preferences. That is, a crucial aspect in describing agents' behaviour in co-evolutionary models is not only what they do, but also when.

The solution for this problem relies on the temporal dimension of the variables and of the activities considered. The same variable, for example price, actually assumes different meanings depending if we are thinking of a single purchase, of the dynamics of market shares or of price level of a market. The difference depends not only on the way the variable is constructed, but also on the time extent it is referred to.

The model here presented treats explicitly the time dimension. In particular, the model does not contains only "virtual" agents, but also a "virtual" time, which, as much as agents' representation, is modelled to represent its real world related concept.

Richardson's Dynamic Equilibrium Model

The model is designed on the basis of the suggestions contained in Richardson (1996). This paper considers markets where competition co-exists with high rates of innovation and increasing returns. That is, many producers compete for the same market (does not consider cases of monopolist competition); each producer is engaged in research providing higher quality products (research in product development); investments in research are high in respect of production costs (causing the increasing returns). Richardson underlines that traditional (static) models cannot consider such markets: either monopolistic competition is considered (but producers do not compete for the same markets) or perfect competition prevents to consider increasing returns and product innovation. In fact, in perfect competition models "producers are unable to improve their existing products" and, in case increasing returns or product innovation occur, there is no reason for the economy to immediately turn in a monopoly.

Richardson proposes to explicitly consider the time extension along which agents actions take place. His main hypothesises are that:

1) demand is "slow" to switch from one currently preferred product to a new better one.

2) research takes time to provide its outcomes.

As a result, different products can co-exist on the market competing for the same buyers, though with differentiated increment rates (proportional to the relative quality). The author suggests that in such conditions could emerge a sort of "dynamic equilibrium": producers routinely bring on the market innovative products, which enjoy a temporary advantage over competitors'. During this periods, the "innovative" producers obtains an increasing market share and correspondingly higher profits, but the competitors have time to finish to develop their own new product, which eventually is brought to the market and will allow its producer to recover the development expenses. The dynamic equilibrium is caused by average rate of profit being equal among producers, when computed over the all "product cycle".

This model, besides its own intrinsic interest, is perfectly compatible with the description of producers given in the first chapter. In particular, it considers a market for somewhat differentiated products and underlines explicitly the role that time plays in economic interactions. Therefore, it provides a perfect environment to experiment the mechanisms governing the strategies of firms not directly related to the choices on the directions of technological increment. In particular, the model described in the next section proposes a mechanism for pricing and for the management of introduction of new versions of products, which can provide the results suggested by Richardson. A particular attention is paid to how a discrete time simulation program can deal with dynamical variables, in such a way to respect the considerations made in the sections above.

Model Description

The model is composed by two entities: Demand and Supply. In turn, both entities contain a set of sub-entities: the Producers and Buyers. Since the model does not differentiate among buyers (for example for their preferences), the Demand side is extremely simplified. An aggregate amount of quantity demanded is determined, and then it is distributed according to the functions defined in the following. The producers take their decision exclusively on the basis of their own variables, that is, there is no external co-ordination mechanism. The only interaction among competitors is confined to the computation of market shares and to the determination of the technological frontier.

Demand

Market Dimension

The total number of potential customers of a market is determined by the quality of the products offered and by their prices. The quality is here intended in a very general sense, that is, the capacity of the innovative product to replace other (former) means to satisfy the basic needs of buyers. By setting the values of price and quality, a demand function (with two arguments: price and quality) returns the total dimension of the market, that is, the total number of products that can potentially be purchased.

Given that there are, in general, many producers, there can be many prices and many qualities different for each brand on the market. The demand function refers to the minimum price and to the maximum quality, assuming that the dimension of the market is determined by the most attractive among the product offered. The dimension of the market is obtained by the following function:

$$MaxQ=ConstQ*MinPrice^{ElsPr}*MaxQuality^{ElsQlt} \quad \text{with } ElsPr<0, ElsQlt>0$$

We can imagine that the demand is composed by individuals who have different types of familiarity with the technology or the sector from which the innovation is derived. Other people, while attracted by the innovative product, prefer to wait for a sufficient number of people to test it, before committing themselves in the purchase. More in general, we can easily imagine that the very information about the availability and the trust of the reliability of innovative products take time to reach all the potential buyers. Hence, the number of products sold at any time is only a fraction of the potential total number, depending not only on the limit value, but also on the number of products sold during the previous time step. Hence the actual number of products sold on the whole market at time t is given by:

$$TotQ_t=TotQ_{t-1} + SpeedGrowth*TotQ_{t-1}*(MaxQ_t-TotQ_{t-1})/MaxQ_t \quad 0<SpeedGrowth<1$$

where the inverse of SpeedGrowth determines the number of periods necessary to the market to be saturated, at any given level of market dimension.

The particular functional form used provides the typical s-shaped market function. It means that the rate of increment of the market dimension is low at the early stages of the industry and when it is close to saturation, while it is higher in the intermediate phase. Since the models here presented are meant to study the effects of a mechanism to represent the of strategies of producers, we can assume exogenously such demand behaviour. Few experiments, not presented here, have been tried to determine under which conditions such demand function can be obtained. There are many justifications that can be used. First, we can assume that the number of buyers deciding to purchase a new good is a function of the number of people who had already bought it, on the basis of the way the information about the availability and reliability spread .

Another reason can be found considering that most of the products on these markets are durable. It means that buyers can either be new entrants or former users who replace their older product. The share of market due to replacement increases with the number of users, until reaching its “physiological” value, motivated by the demographic composition of the demand. Thus, in the early stage of the market there is only the share due to new buyers, while in the last part there is only the replacement factor. Hence, during the intermediate phases, there are both factors that, summing together, provide the s-shape curve.

Market Sharing

The total number of products sold at each time step is distributed among the different producers according to the relative attractiveness of the products. Each producer is able to gain a share of the available market as a function of its product characteristics. Each product is assigned an indicator of its "attractiveness" computed as follows:

$$\mathbf{Attr_t^i = WghtP * (MinPrice_t / Price_t^i) * WghtQlty * (Quality_t^i / MaxQuality_t)}$$

The actual share of the market for each product depends both by each attractiveness and by its current share of the market. The idea is that the current share influences partially the number buyers in the next period. In the long run, two identical products will have the same market share, but more commonly used products keep on a enjoying higher market share in the short term. The long run market share for producer i at time t is computed as follows:

$$\mathbf{LongRunMS_t^i = (Attr_t^i)^{ElsMS} * / [\Sigma_j (Attr_t^j)^{ElsMS}]}$$

The actual market share is obtained by adjusting the current market share to get closer to the long run market share:

$$\mathbf{MS_t^i = MS_{t-1}^i * CoefMS + LongRunMS_t^i * (1-CoefMS)}$$

The demand representation above described has the property to allow the modeller to tune not only the absolute dimensions of the market, but also the speeds of adjustment both of market dimensions and of market distribution. Note that, while being rather simplistic, the demand function allows easily to implement extensions to include models with products differentiation. For the purposes of this work, we still assume either homogeneous products or differentiation along one given dimension. In fact, the goal of the models is to study the properties of markets with homogeneous demand. Further developments of these models will easily allow for demand segmentation, given the type of model structure here described.

Supply

The model of firms here presented is aimed at testing mechanisms for the strategies of firms in a market for innovative products. As an extreme hypothesis, we don't consider variable costs, as if these were negligible. This hypothesis, which could anyway been removed for later versions of the model, underlines the fact that we consider markets where the fixed costs in research and development are of overwhelming importance in respect of production costs. Or, which brings to the same conclusion, that the production costs are equal for every producer, while they can (and do) differentiate for the R&D costs, providing differentiated levels of technological improvements to their respective products.

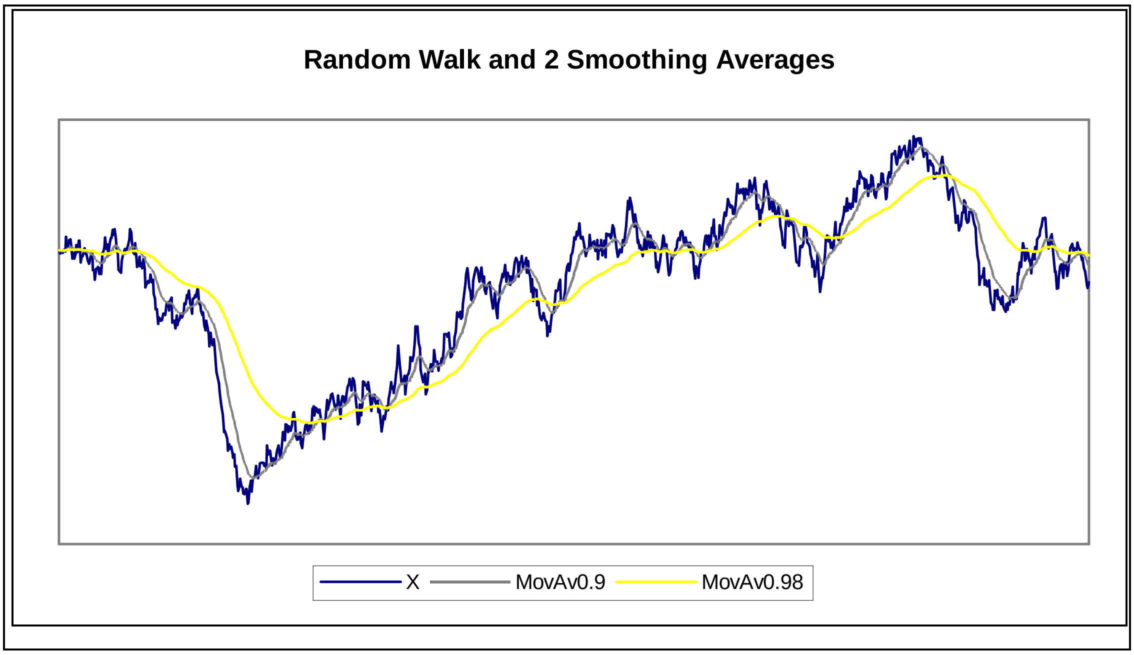
Firms are modelled as having different time lengths for their activities. The unitary time step in the simulation represents the "day" of the simulated market, during which firms collect data on the situation of the market. The second activity is the price decision; at time intervals (the "months") firms consider whether to modify their prices, according to the data collected in the previous time steps. The last activity is the R&D: at longer time intervals ("semesters"), the laboratories provide innovation allowing firms to offer higher quality products. At the end of these intervals, firms decide also the levels of R&D for the next periods. The model does not consider production activities, as if these were common to every producer, and hence do not affect the market relations. In the following, we will discuss the implementation of the price and R&D strategies used by firms.

Firms collect the values of variables on daily basis, but consider for their decisions a transformation of those variables aimed at eliminating the short term volatility.

They refer to sort moving averages of the variables: that is, in place of any variable X whose value is collected every day, firms use for their decisions smoothed proxies, obtained as:

$$\mathbf{MovAvX_t = MovAvX_{t-1} * \alpha + X_t * (1-\alpha) = X_0 * \alpha^t + \Sigma^t_{i=1} X_i * (1-\alpha) * \alpha^{t-i}}$$

where the rightmost equation holds considering $MavAvX_0=X_0$. The value of the smoothed variable is a sort of average of the time series of the original variable, where the weights decrease exponentially with time. The effects of using a moving average instead of the raw variables is shown in the following graph. It plots the values of an example variable (a random walk from a standard normal random variable) and the results of two moving averages with different values of α. The moving averages register with a lag the trajectory of the underlining variable and provide two different references for the interpolation of the random variable.



Pricing Decisions

As we have seen in the previous chapter, the demand react slowly both to the expansion of the market and to modifications of the characteristics of the competing products. Hence, we need to define what are the "medium term" strategies of firms in order to take the decisions not related to the technological competition, that is, the price decisions.

There are two mechanisms parts of the price decisions: the definition of when the price needs to be modified; the direction and the amount of the price variation. In fact, whether the price needs to be increased or decreased is a decision aimed at resolving the trade-off between high profitability or high market shares. An increase of price improves the profits in the short run by charging a higher margin on the (slowly decreasing) existing market share, at risk of lower market share in the long term if other conditions don't change; on the other hand, lowering the price allows to enlarge the base of the contribution to the profits in the future, at cost of diminishing profitability in the short run.

Firms in the model are supposed to ignore the parameters governing the growth of the market and the distribution of customers among the producers. Moreover, they also ignore (or neglect for the price decisions) every aggregate statistics of the market, like average price, average profits, competitors' products characteristics etc. This is done because the model is built for considering products as qualitatively different, hence their comparison cannot be made directly, but is only reflected by the demand behaviour.

The price decisions are taken by considering only variables internal to each firm, namely the ongoing revenues and own market share. According to the same representation used for the demand, both the monitoring of the market by producers and their actions are bounded to the time extent necessary to explicate their effects. The price of a firm can be altered only if enough time is expired from the last price modification, so to be able to observe the effects of the last price decision. If a firm is allowed to modify its price, it considers, orderly, three cases that can trigger a price modification: decreasing revenues, decreasing growth of revenues, and unexpected changes in market shares.

Pricing: Decreasing Profits

To monitor the possibility of decreasing revenues the firms keep track of two moving averages, MARevShort and MARevLong. Both variables have the same structure:

$$\mathbf{MARevShort_t = MARevShort_t * \alpha + (1-\alpha) Revenues_t}$$

and

$$\mathbf{MARevLong_t = MARevLong_t * \beta + (1-\beta) Revenues_t}$$

where $Revenues_t$ is the daily value of revenues (price times units of product sold). The two variables differ in the two parameters, that is $\beta > \alpha$ so that if MARevShort<MARevLong this indicates a decreasing level of profit[5].

In case a price change is triggered by the acknowledgement of decreasing revenues, firms need to determine the direction and the amount of price modification. They are

[5] That is, the decreasing levels of ongoing revenues in respect of the "historical" ones. The use of the smoothed proxies for the revenues avoids firms to be deceived by sharp modifications taking place during their decisional time step.

not directly aware of competitors' behaviour or of demand elasticity, hence they apply a simple rule of thumb, to determine whether the reason for the falling profits is a too low or too high price. They compare the values of two variables, reflecting the modification of the market shares. Again, the two variables of the market shares are two moving averages of the past values of daily market shares. If the market shares are decreasing, then the price is lowered, while it is increased in the opposite case. The level for the price change is proportional to the difference between long and short term profits: higher differences will cause higher changes in prices.

Pricing: Decreasing Rate of Revenues

In case of stable or increasing revenues, firms can still decide a price modification as an early move to counter a potential future decreasing revenues rate. To monitor this event, the firms keep track of two variables:

$$DRevLong_t = DRevLong_{t-1} * \gamma + [MARevLong_{t-1} - MARevShort_{t-1}] * (1-\gamma)$$

and

$$DRevShort_t = DRevShort_{t-1} * \delta + [MARevLong_{t-1} - MARevShort_{t-1}] * (1-\delta)$$

where $\delta<\gamma$. In case DRevShort < DRevLong, firms induce that, though still increasing, the revenues are lowering the rate of increase and hence a reaction is due. The same system used for absolute levels of revenues is used to determine the direction and the amount of price changes. Though simple, this price change triggering system provides firms with a (limited) capacity to pre-empt potentially negative situations.

Pricing: Market Shares Modifications

The two price changing mechanisms above described are mainly defensive, since they trigger a reaction in case the absolute levels or the rate of revenues are falling. A third mechanism allows firms to modify their price, both as an "aggressive" or defensive move, as a response to unexpected modifications of market shares. We have seen that firms keep track of their historical market shares (that is, a "long term" moving average of daily market shares) and to compare this value with a short term market share indicator (a moving average with a lower coefficient value). A difference between the two is interpreted either as the possibility to exploit a short period of higher volumes of sales or the necessity to defend the historical levels of market shares. The underlining hypothesis is that firms regard the historical market shares as the attractor of the fluctuating short term values. They do not consider permanent a short term market share value higher than the historical one (which is then valuable to exploit), and react promptly to recover any decrement of market shares (below the level of historical market shares). The amount of price modification is proportional to the relative difference between the two market shares proxies.

Note that the use of “short term” and “historical” proxies for different variables assumes firms to have a sort of internal representation of “normal” satisfycing situation. In case of detection of a modification in respect of the normal situation, firms both react trying to return to the historical state, but also adjust, to some degree, their internal representation of the state of world.

Research and Quality Changes

The model considers products as having one single dimension of quality. Each firm performs R&D during its daily activities, that is, they spend a (constant) amount of resources for R&D. From time to time, they are able to introduce a new version of its product, as a result of their research. The time lenght necessary to develop a new version of the product is constant and equal for every firm, while the amount of quality improvement depends on the cumulated expenses in R&D.

The relation between R&D and quality increments is modelled as firms could “buy” quality points using their R&D investments. The costs of such points differ depending whether other products exist on the market with higher quality (that is, the firm is “catching up” by imitating) or if the firm is introducing an absolute new product (that is, the firm is innovating). While the cost of imitating is constant, the cost for innovation increases with the quality level, so that it is more and more expensive to obtain the same quality increments.

IF($RDImit_t > RD_t$)

$Quality_t = Quality_{t-1} + RD_t/CostImitation$

ELSE

$Quality_t = MaxQuality_{t-1} + (RD_t - RDImit_t)/CostInnovation_t$

with $RDImit_t = (MaxQuality_{t-1} - Quality_{t-1}) * CostInnovation$, and

$CostInnovation_t = InitCostInnovation + MaxQuality_{t-1}^{ExpInn}$, $ExpInn > 1$

The levels of spending is decided as a fixed percentage the "normal" levels of revenues, estimated during the recent past. Of course, there is no guarantee that the same levels of revenues can be obtain in the future. That is, the actual level of R&D spending will be a lower percentage of actual revenues in case of increasing revenues and a higher level in case of decreasing revenues.

The amount of R&D expenses is decided at the beginning of the "research" period and is computed by considering the "historical" levels of revenues, that is, a "slow" moving average for revenues. To determine the daily amount for R&D they take a (constant and equal for every firm) share of this moving average. Thus, if revenues keep on increasing, the actual percentage R&D is lower, while it is higher in case of falling levels of revenues.

Comments on the Model Structure

Note that the model describes the firms as purely reacting to changes in their state, as compared to their "memory" of the past. Hence, providing the model with initial values of "equilibrium" (that is, that do not trigger any modification and are mutually compatible among the producers), no change will ever occur. But it is enough to provide firms with slightly "wrong" values of the historical time series, that firms will start trying to adjust their current situation to the one recorded in their "memory" by the modeller when setting the initial values. In the same time, firms also modify the levels of the "historical" variables used as comparison with the current state of affairs.

The length of the triggering periods is fixed and equal for each firm, and initialised so that to only one firm modifies its price or product quality during one single time step.

Note that there are no stochastic elements in the model, thus the results cannot be caused by random events.

The results of the model are not easily forecastable, given the high number of interactions. It is anyway important to note since now that no part of the model explicitly aiming at any convergence of the model, apart the weak tendency to maintain invariant the market shares. And even this latter mechanism is applied only when the other mechanisms do not suggest a different behaviour.

Given the strategy applied by firms (without considering the possibility to modify the characteristics of the products), there are three types of results that can be expected at aggregate levels: price war, emergence of a monopolist, convergence to an “equilibrium”. In the first case, firms act aggressively to gain market shares, but none can succeed, so that they bring their prices to zero, with market shares highly volatile. In the second case, one firm succeed in conquering the whole market and competitors cannot but tend to zero market shares. The last case entails all the competitors having the same shares and the same profits.

Simulations Results

The results presented below allow to observe the pattern followed by the different variables along the development of a market. Therefore, the interest is not on the absolute values reached by the variables, but on the comparative patterns followed by the entities in the model. The values for parameters and initial values have been chosen tentatively partly by trying to resemble real world values, partly by adjusting the values according to the results obtained in the former trials. Therefore, the results presented below do not have any claim of generality The aim of these model is not to show that such systems do always produce some kind of configuration. The interest is focused on the determinants of particular conditions that may occur. Hence, even in the case that only one single particular parameterisation provided a specific result, the use of simulation methodology is to allow a detailed observation of the causes that brought such results (or why such configuration could not emerge). This does not mean that any simulation run is always a useful one. A “bad” simulation run is one where the causes of particular configurations are motivated by specific initial values or specific functional forms that cannot be soundly justified on economic reasons. That is, we want to obtain a “story” that have clear explanation in terms of economic reasons.

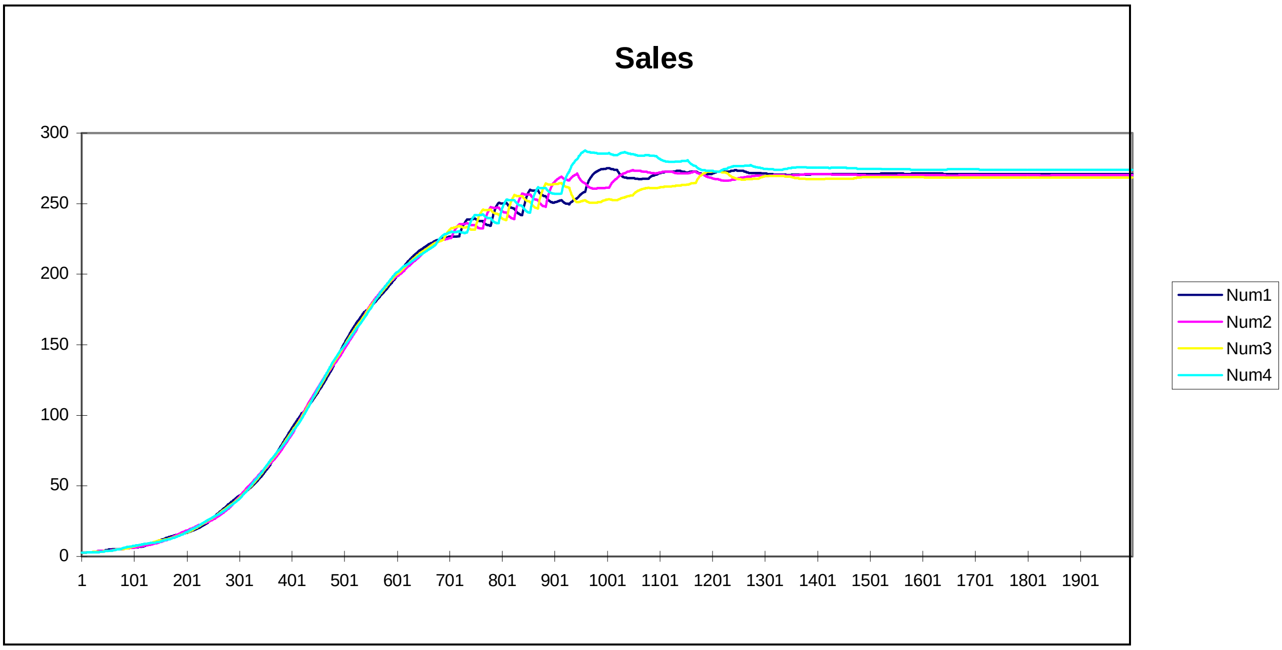
Market Emergence with Identical Products

As a first experiment, let’s consider the model with a number of identical firms producing a new product (that is, the market is still to be saturated) but they do not make any further innovation. Therefore, all of the producers offer an identical products and the demand can only discriminate on the basis of the prices. This experiment allows to determine the results provided only by the pricing mechanism.

The model starts at the very beginning of the market, and the only modification is the change in the absolute dimension of the demand. Firms (there are always four firms in all the experiments presented) start with identical market shares and are allowed to modify their prices according to the criteria described in the previous chapter. The simulation covers 2000 of time steps; if no price modifications were decided by firms, the market would be saturated after 1000 time steps. That is, the initial price, and the rate of entry of demand, allows the market to increase through the early 1000 time steps and then to keep the same dimension for the remaining 1000 time steps.

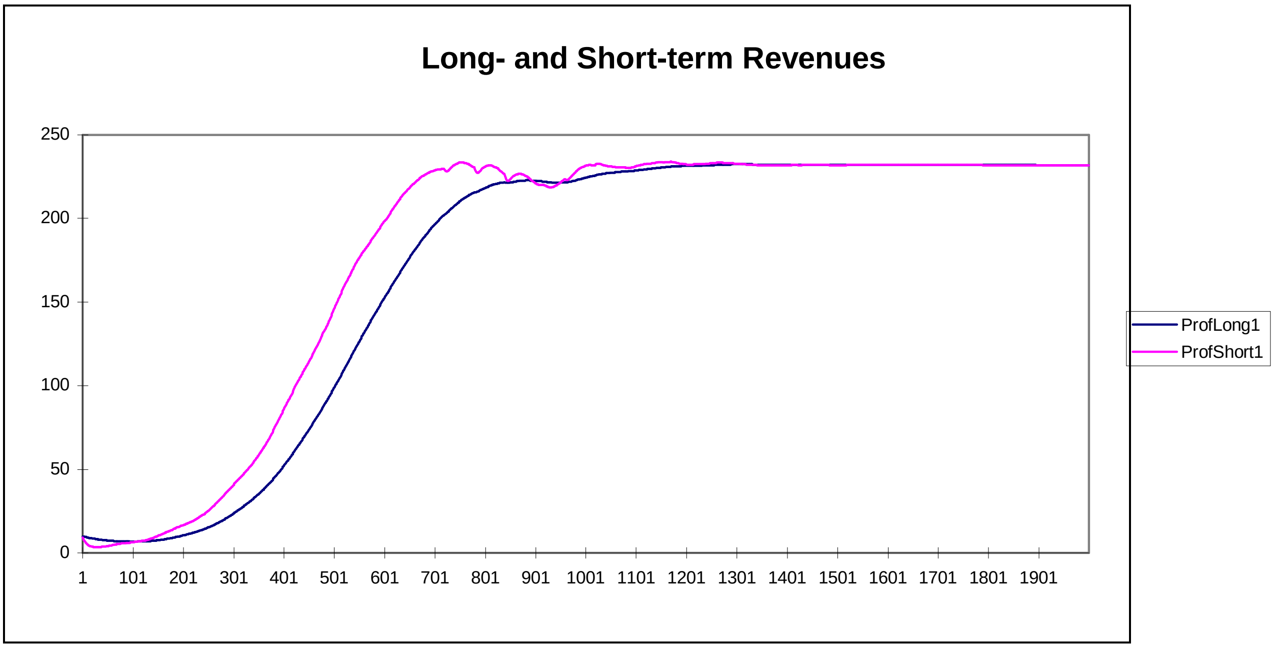
The initial values of the historical time series recorded for the firms (i.e. market shares and profits, both long and short period) are slightly "wrong", so that firms have the incentive to modify their prices in the very early periods. Any change in price is reflected in the corresponding modification in market shares.

The graph below shows the values of sales per firm during the simulation run. In the first stage of the market development firms slightly differ in their amount of sales, but they are extremely close, with prices compensating for arising differences.



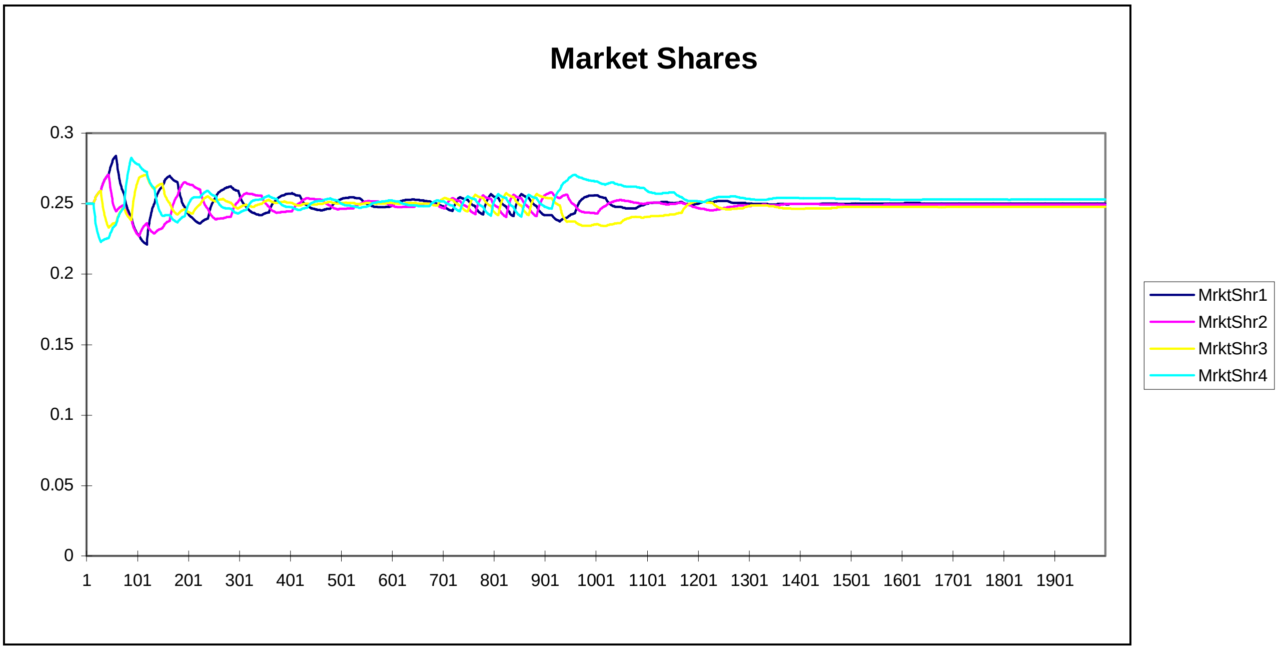
When the dimension of the market is approaching the maximum, and hence the rate of increase of the market is diminishing, firms start to modify wildly their price to adjust to this new situation. In this phase, prices are modified because of the second mechanism triggering a price modification, that is, because of a decrease in the rate of increase in revenues, caused by the ending of the expansion period of the market.

This turbulent period is terminated by the adjustment in the time series tracking the long term values of the variables. In the graph below is showed, for only one firm, the relation between the long and the short term revenues record.



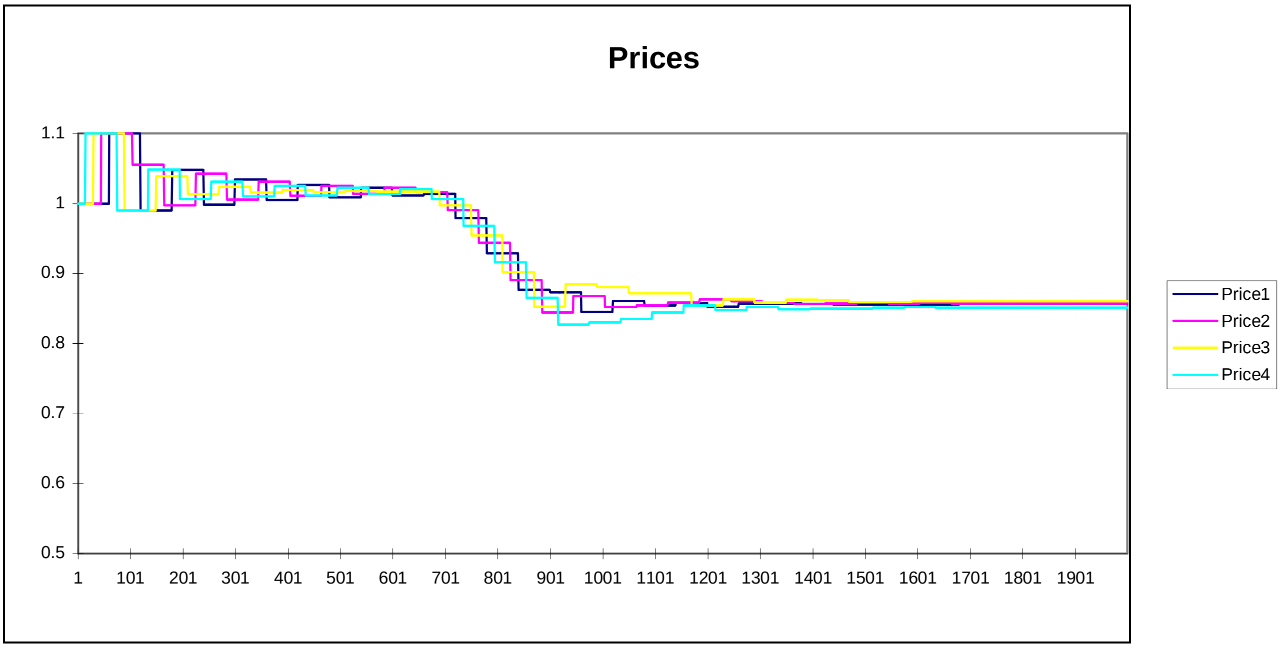
The cyclical turbulence along the final part of the market increase (around period 700) starts because the difference between "historical" revenues and short term ones begins to decrease. The cycles are due to the alternate changes of firms. When the two series converge (around period 1200), they stop to cause new price modifications.

To better consider the "emergent" equilibrium provided by this model, consider the following graph, reporting the values of the market shares for all the firms.



Again, the market shares confirm the tendency of the firms to reach a stable state after the two “shocks” of the model, that is, the initial values and the reaching of the market saturation.

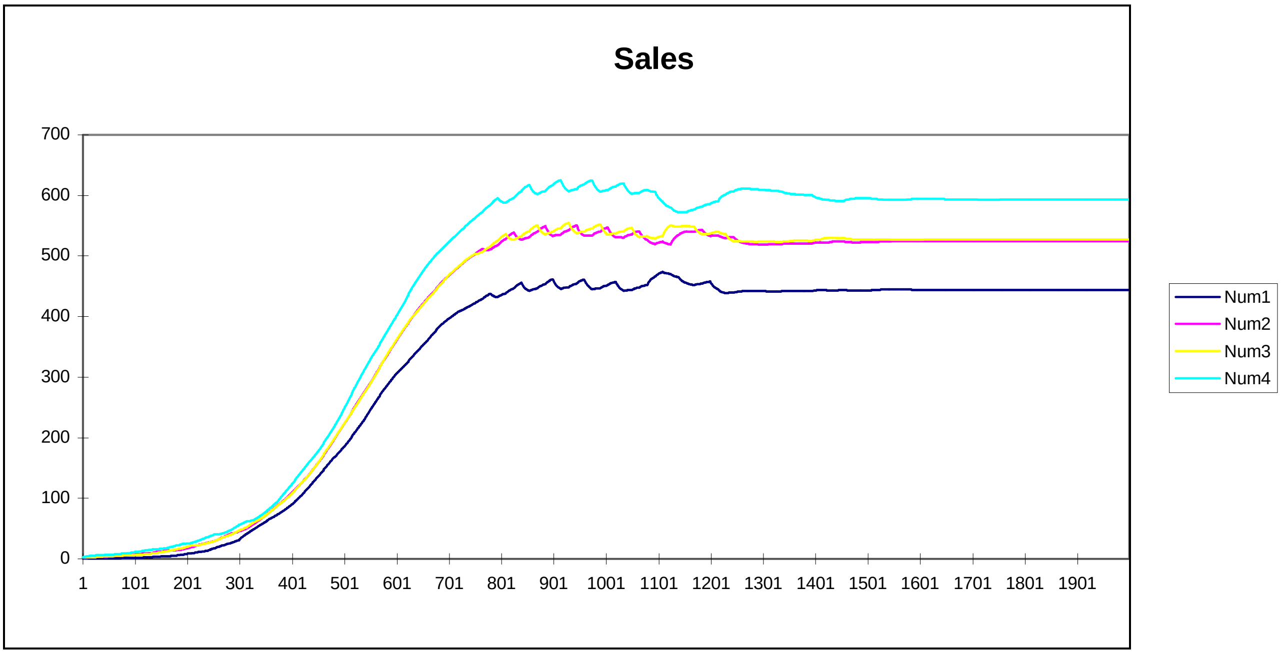
The last graph below shows the values of prices for all the firms. As seen in the previous chapter, the price modifications can take place only every a fixed number of steps (always 60 in all the simulations presented), thus causing the graph to be a sequence of segments. Here it is possible to see that firms started a price war, which intensity is anyway decreasing until an “agreement” is found, and no firm finds advantageous to change the price.



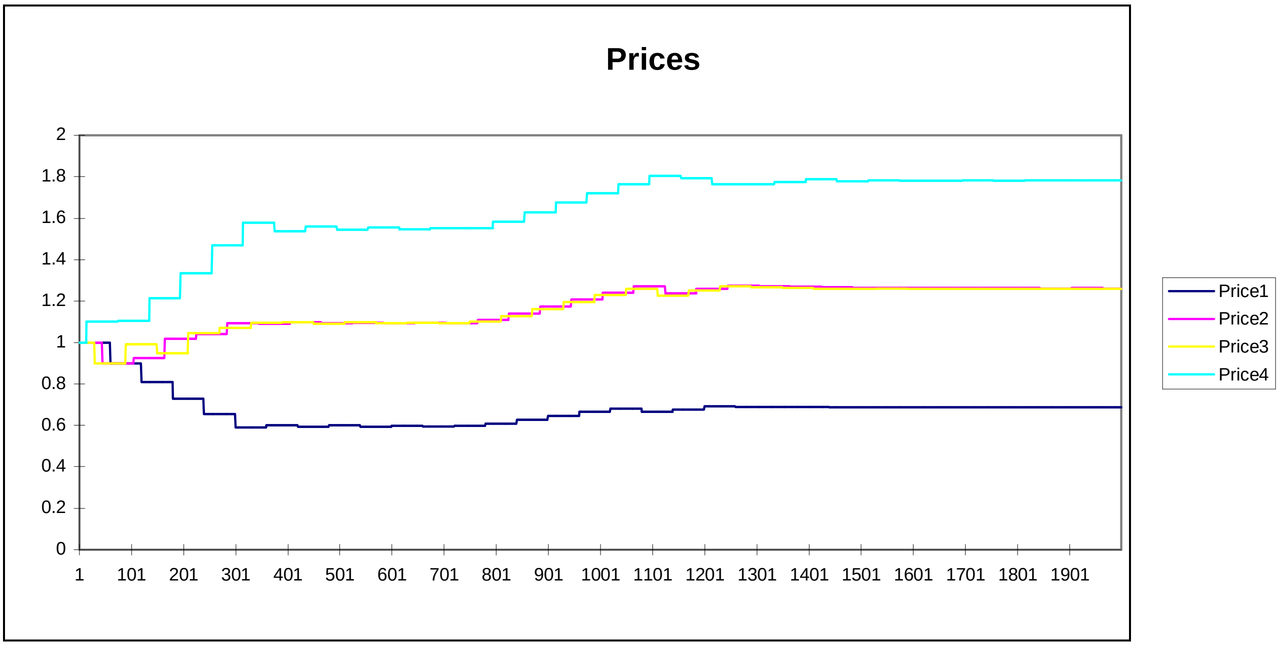
Again, note that such situation is not motivated by a comparison with a firms' individual price with, for example, the average price, but it is an endogenous property of individual price strategies. This early experiment shows that, for firm sharing the same identical product, they tend, with time, to converge to (almost) identical situation of market shares, profits and price, by using this price strategy. Temporary "bursts" of price changing can occasionally be triggered by particular conditions, but then they tend to fade away as firms adjust both their prices and their historical records.

Market Emergence with Differentiated Products

As a second experiment, we present a simulation using the same set up as in the previous chapter, but products' qualities are different, and so remain during all the simulation. This time, the levels of absolute sales differ from the very beginning, and the firms are able to exploit to different degrees the increase of market volume.

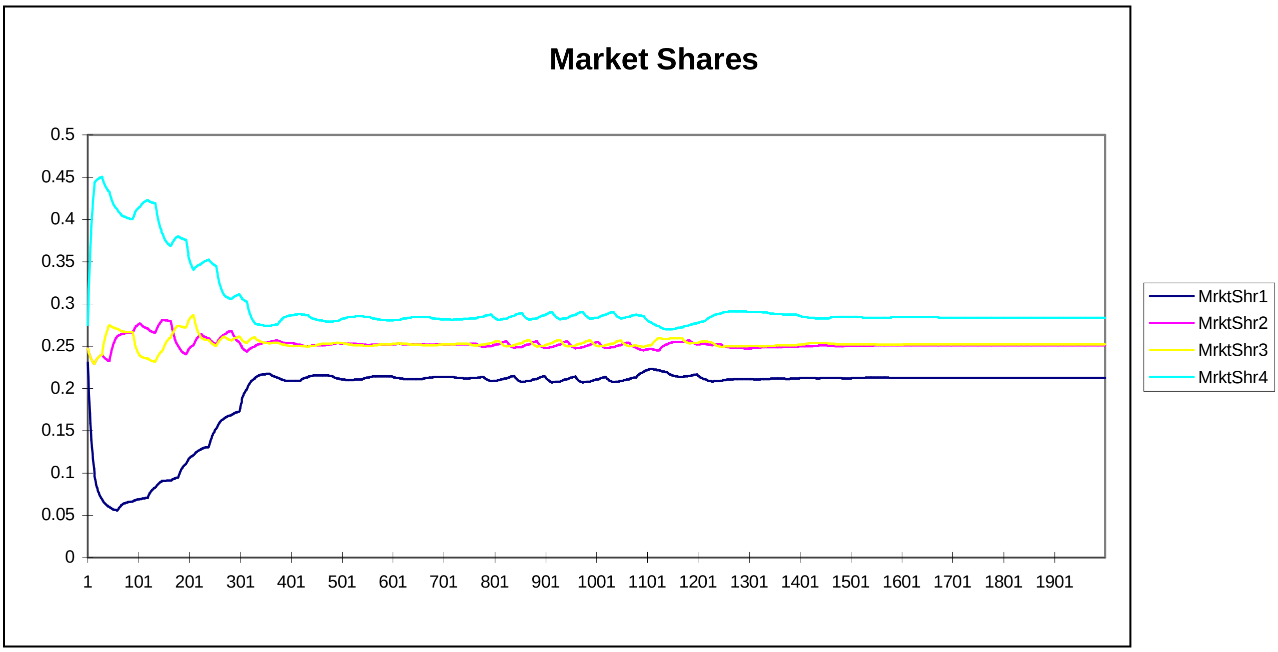


The initial values assign the product number 1 with the lowest quality, then the firms 2 and 3 with the same intermediate level of quality, and the fourth product with the highest quality. In order to understand whether the highest performance is due to a pure quality effect or also to a price effect, let's consider the prices of the products.



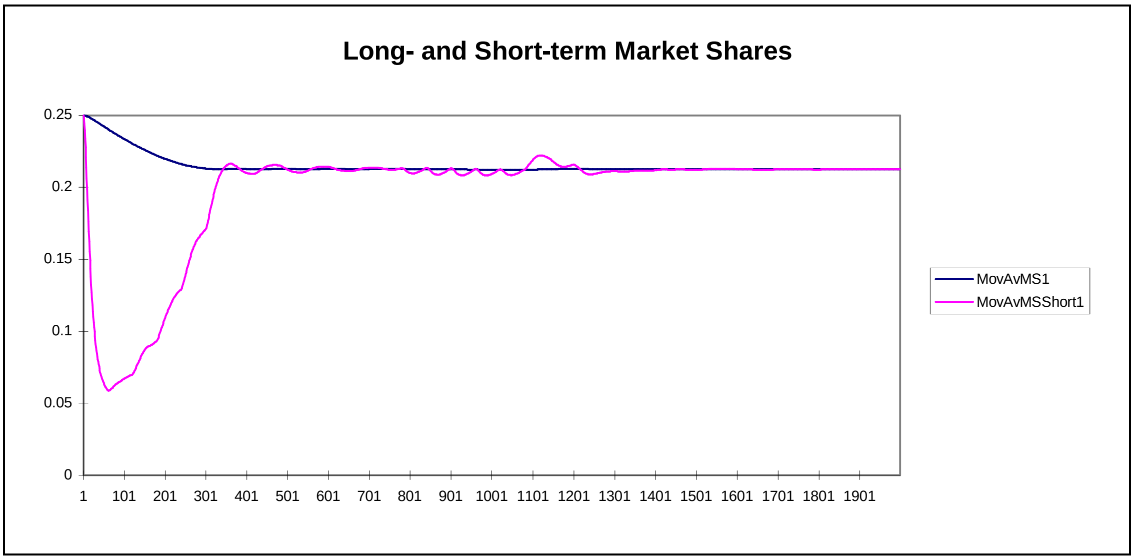
The firms adjust the prices only partially to compensate for their different qualities. The highest quality product can also keep higher sales volumes notwithstanding higher values of price. Note also that all the time series for the prices of the firms reflect the general modification of market, by showing the same tendency observed in the previous chapter to change in the initial phase of the market, remain relatively constant during the phase of expansion, then having a new turbulent phase when the growing period ends, and finally they stabilise on a constant path.

The market dynamics can be better observed looking at the market shares.



It is possible to see how fast the initial market shares (all equal by initialisation) reflect the different quality level. Until almost the 400th time step, the product number 1 tries to "catch up" by reducing its price, and the firm 4 to exploit its privileged position by raising its price. To see why they stop at a given level, and (for example) don't continue till reaching the initial value, we need to observe the variables used by firms for their price decisions, that is, the long and the short term moving averages of market shares. As you can see in the graph below, the firm number 1 stops to decrease the price when the long term moving average of market share meets the short term one. At that moment, the firm is "satisfyced" and does not regard valuable further increases in market share. This happens because the principal goal of increasing profits can be easily achieved, being the market in a general expansion. Hence, the firm's pricing strategy aims at defending its market shares.

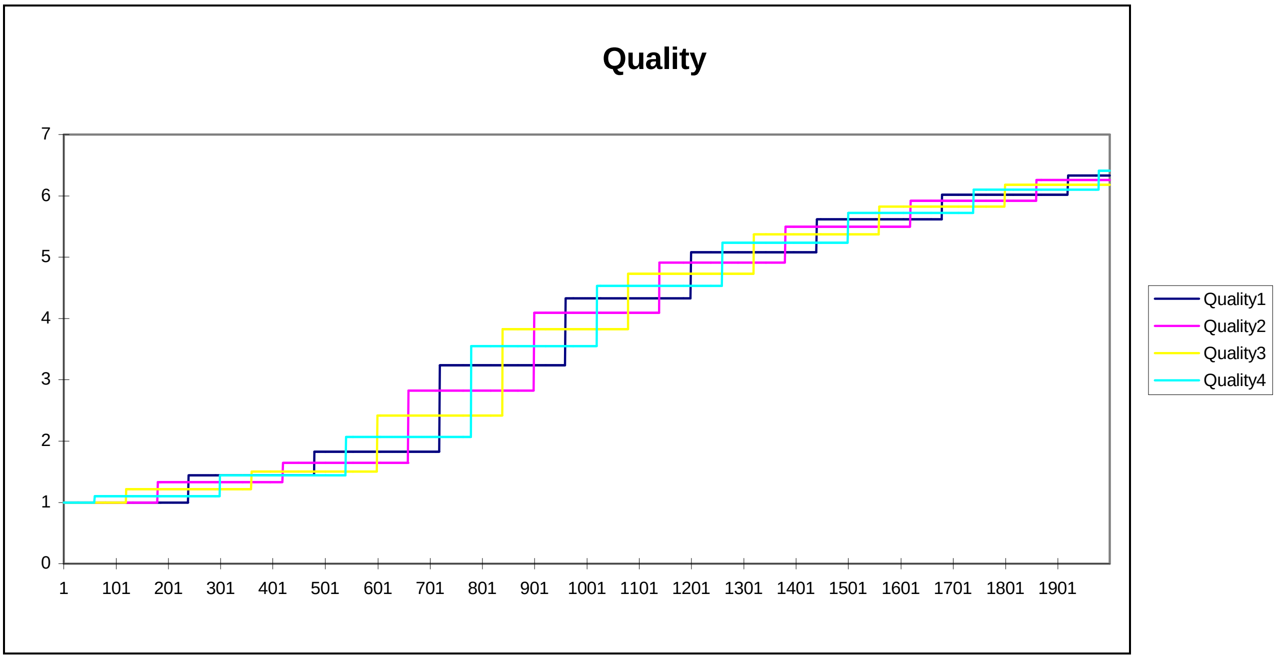
Note also that the presence of higher quality products favoured the increase in dimension of the market for two reasons. In fact, the demand curve returns higher values because the quality of the best product is higher. But there is also the increasing effect due to the fact that lower quality products are forced to reduce the price, in order to keep a minimum of competitiveness. Hence, the demand curve provides still higher values because of the lower price products available on the market.



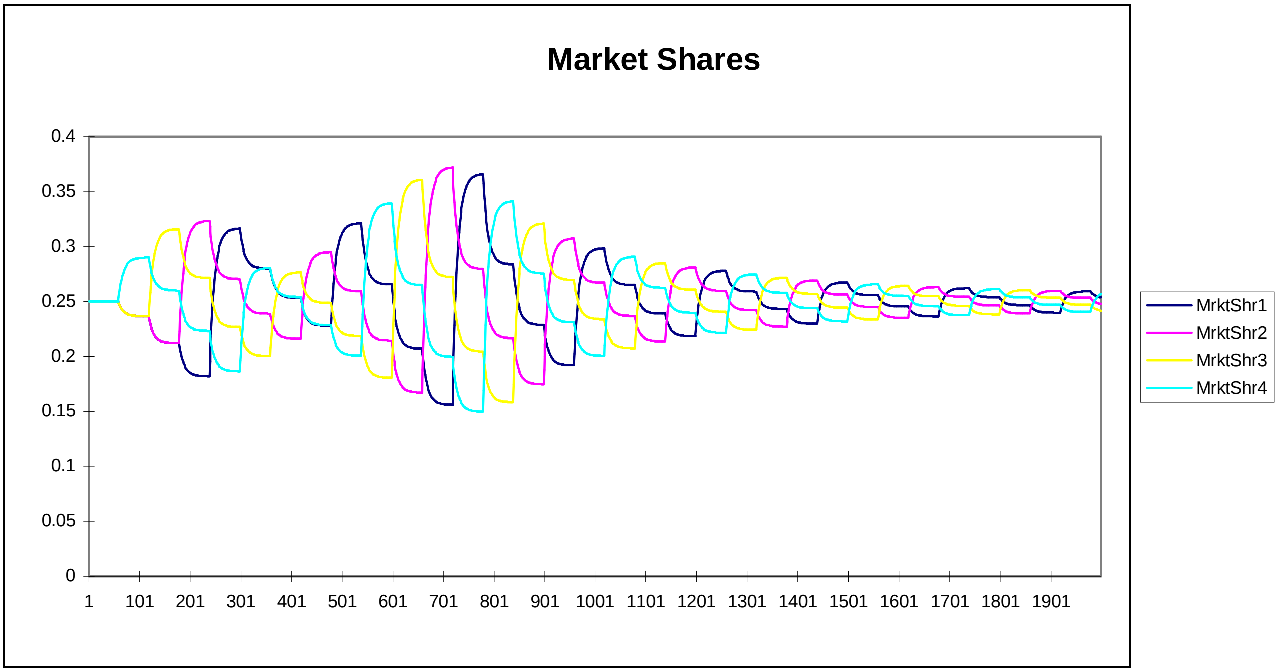
Market Emergence with Increasing Quality

In the two models above we have considered the effects of price strategies. Now we introduce endogenous modifications of products' qualities. To better observe the effects of qualitative improvements, we present first a model where price modifications are not allowed. This model setting is the most close to the Richardson's proposal.

The following graph shows the increments of the quality of products, as a result of individual R&D.

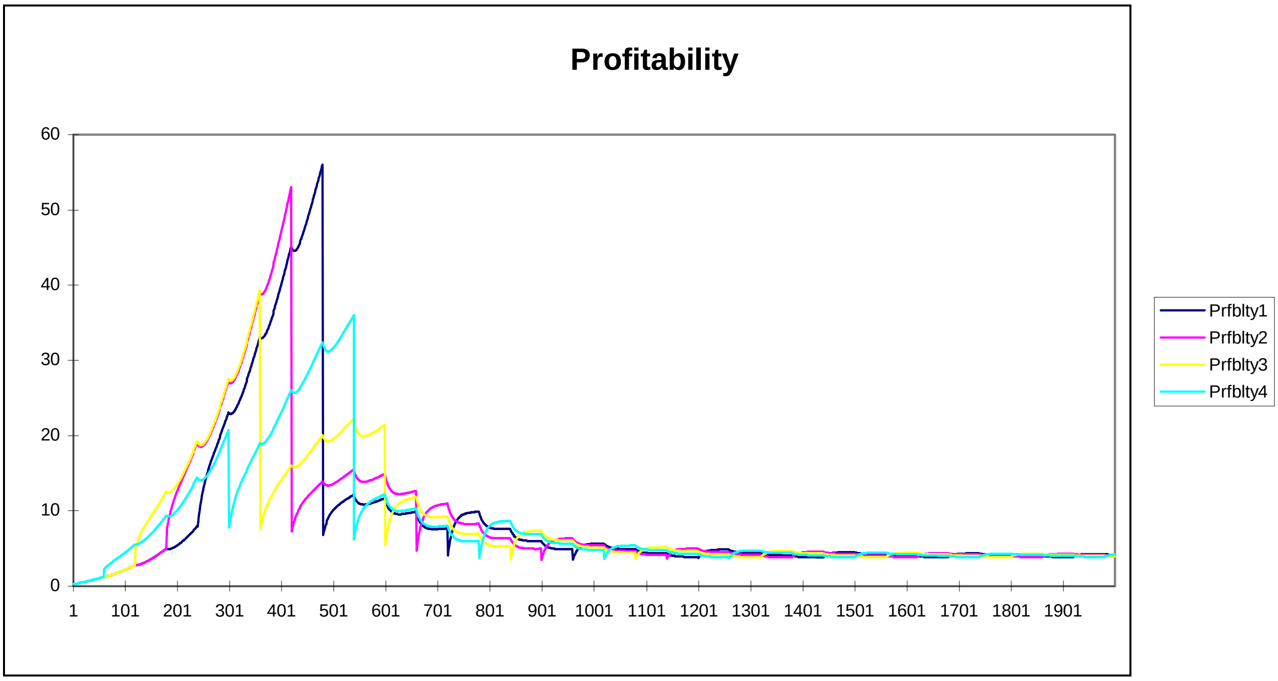


The increase in quality is low in the beginning because of the low level of R&D initially available to the firms. Then, the quality has a jump as the R&D resources become larger; note that the wide increase in R&D take place rather late, since firms need, first, to acknowledge the wider availability of resources, then employ them for R&D and only after these two "R&D steps" the research provides its fruits. The long term tendency for quality increases is diminishing because of the cost for innovation, which is more and more expensive with the absolute levels of quality.



The series of market shares show two “bursts” of volatility, besides the obvious cycle due to the alternate quality increase of the firms. They again reflect the different stages of the market development. In the beginning even a small change in quality causes a relatively high modifications of market shares, due to the relatively small dimensions of market. As we have seen above, the amount of quality increases are not too large, due to the low estimation of future revenues, and hence to the relatively scarce resources devoted to R&D. Hence, the diminishing volatility of market shares reflects the small changes in quality during the beginning of the market increase. The second burst is due to the increasing level of R&D spending and fades away as the market approaches the saturation level, so that to stabilise the amount of R&D spending. Since the cost for innovation is exponentially increasing, the rates of quality increase are diminishing, causing a dimishing width of market shares cycles.

This interpretation is confirmed looking at the “profitability” of firms, computed as the ratio between revenues and daily R&D spending. The abrupt decrements in profitability are caused by the modifications in R&D daily spendings, decided by firms every “research period”. Until the market keeps on expanding, the errors in future revenues estimations are wide, and thus the profitability is very high. While the market settles at the mature levels, the actual revenues are closer to the estimated ones, and thus the profitablity tends toward the normal level.



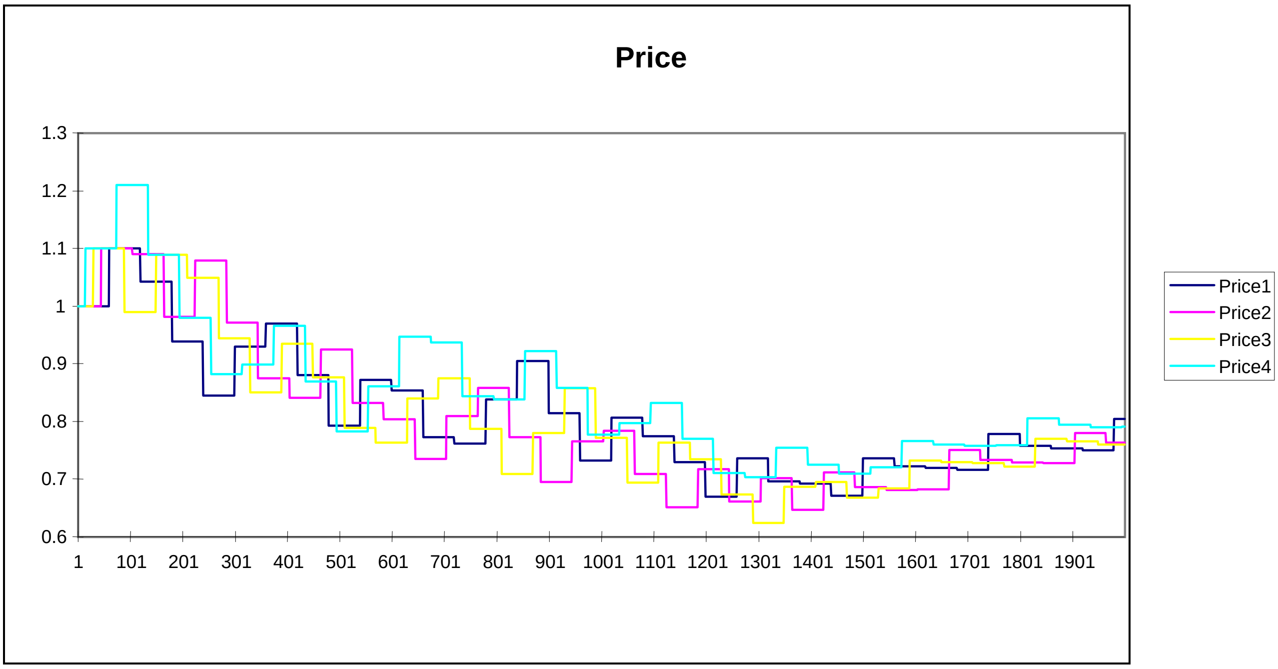
The width of the cyclical oscillations decreases because the relative improvements in quality of new products decreases, while the innovation costs increases.

The simulation, though extremely simple, is able to replicate the behaviour of the system proposed by Richardson.

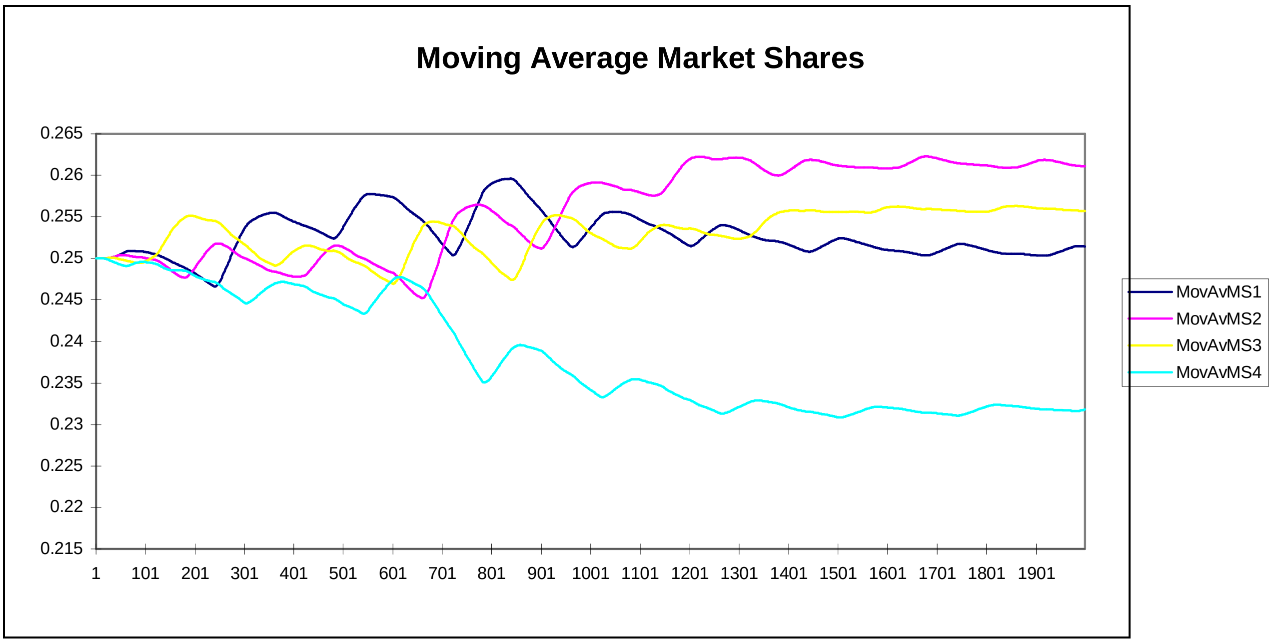
Market Emergence with Increasing Quality and Pricing

The use of simulations allows to explore the behaviour of systems even in cases of complex interactions. In the models above explored we have seen only one activity at a time (either pricing or research). Whenever only one activity is allowed, we have observed that firms behave in the same fashion, when starting with identical initial conditions. Instead, the contemporaneous actions of both activities can provide more complex results than the simple sum of the two, differentiating the firms because of the interaction between the two activities. In the simulation run here presented, besides the same configurations observed in the previous paragraphs, the result shows also new types of behaviour.

This simulation run is interesting for the "story" of the first firm which is allowed to introduce an improved product. This firm suffer from being the first because, on one hand, the initial amount of R&D is relatively low, in respect of later stages of the market, but it tries anyway to "exploit" the initial higher quality by increasing the price. As it is possible to observe also in the graph for the quality series in the previous graph (very similar to the equivalent one for this simulation in the very early stages), the first three draws for the 4th firm do not provide a high quality “discover”.



The 4th firm increases the price, loosing market shares that are later difficult to re-gain when also the competitors introduce their innovation. The second “bad luck” point for the first number 4 is a similar situation just around period 700, when the market is approaching the saturation. At this point, the firm’s “historical” series of market shares are rather low, and they cannot be recovered by dimishing the price, and relying on the general market expansion to cover the costs for this.



This causes the “long term” state of the system having the fourth firm with a sensibly lower share of the market, though the cyclical fluctuations of the Richardson’s dynamic equilibrium are still present. Given the relatively higher price, the profitability of the 4th firm is still in line with the ones of the other competitors.

Comments on Simulation Results

The results of these simulation runs show how easy a complex configuration can emerge, in particular when different activities are allowed to interact. The possibility of the simulation technique to control every single event during the simulation run avoids the risk to get lost in the mess of many interacting dynamics, and rather allows to trace back the actual causes for the observed configurations. This experiment does not want to claim that the results shown have an absolute relevance on Economics on their own. But they neverthless can help on reflecting on some real world situations. The relation between the model and the real life needs always to be carefully assessed. Given the difficulty in gathering detailed information on real economic events, we are forced to reason on such general stylised facts that can actually be “explained” by a variety of causes. It has been suggested that the assesment on the validity of different explanations should based also on their capacity to give a rationale for several stylised facts in the same time, instead of separating them (Dosi et a., 1997). Given the difficulty of considering the interactions among different parts of a complex systems, simulations provide a useful tool. In fact, they allow to “apply” some of these explanations and “re-run the tape” to test the compatibility of the model’s results with the real world observations.

Recently has been proposed a, still rather vague, methodology, called “history friendly modelling” (Malerba et al, 1996). It suggests the use of simulations together with the considerations of real worlds events. By using simple theoretical models, and considering real world events, the simulations can be “calibrated” to replicate determined configuration, with the possibility of a detailed observation of the simulated system.

Conclusions

This work has suggested that the interactions between buyers and producers have an influence on the direction of the technological change. The model to study such interactions should be a complex model for the co-evolution of the two sides of the market. In order to test the feasibility of such a model, the proposal of Richardson for a dynamic equilibrium in markets with perfect competition, increasing returns and technological change is identified as a possible representation of the supply side. This model is implemented and the Richardson's intuition on the emergence of a dynamic equilibrium in such markets is confirmed. Moreover, the model, notwithstanding its simplicity, allows to represent rather complex situations.

Extensions of the model will consider the introduction of buyers, so that, while the demand side will act as a selection mechanism on the supply through the market, the supply will "select" the buyers' preferences by offering specific types of products.

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Danish Research Unit for Industrial Dynamics

The Research Programme

The DRUID-research programme is organised in 3 different research themes:

- ***The firm as a learning organisation***
- ***Competence building and inter-firm dynamics***
- ***The learning economy and the competitiveness of systems of innovation***

In each of the three areas there is one strategic theoretical and one central empirical and policy oriented orientation.

Theme A: The firm as a learning organisation

The theoretical perspective confronts and combines the ressource-based view (Penrose, 1959) with recent approaches where the focus is on learning and the dynamic capabilities of the firm (Dosi, Teece and Winter, 1992). The aim of this theoretical work is to develop an analytical understanding of the firm as a learning organisation.

The empirical and policy issues relate to the nexus technology, productivity, organisational change and human ressources. More insight in the dynamic interplay between these factors at the level of the firm is crucial to understand international differences in performance at the macro level in terms of economic growth and employment.

Theme B: Competence building and inter-firm dynamics

The theoretical perspective relates to the dynamics of the inter-firm division of labour and the formation of network relationships between firms. An attempt will be made to develop evolutionary models with Schumpeterian innovations as the motor driving a Marshallian evolution of the division of labour.
The empirical and policy issues relate the formation of knowledge-intensive regional and sectoral networks of firms to competitiveness and structural change. Data on the structure of production will be combined with indicators of knowledge and learning. IO-matrixes which include flows of knowledge and new technologies will be developed and supplemented by data from case-studies and questionnaires.

Theme C: The learning economy and the competitiveness of systems of innovation.

The third theme aims at a stronger conceptual and theoretical base for new concepts such as 'systems of innovation' and 'the learning economy' and to link these concepts to the ecological dimension. The focus is on the interaction between institutional and technical change in a specified geographical space. An attempt will be made to synthesise theories of economic development emphasising the role of science based-sectors with those emphasising learning-by-producing and the growing knowledge-intensity of all economic activities.

The main empirical and policy issues are related to changes in the local dimensions of innovation and learning. What remains of the relative autonomy of national systems of innovation? Is there a tendency towards convergence or divergence in the specialisation in trade, production, innovation and in the knowledge base itself when we compare regions and nations?

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There are at present more than 10 Ph.D.-students working in close connection to the DRUID research programme. DRUID organises regularly specific Ph.D-activities such as workshops, seminars and courses, often in a co-operation with other Danish or international institutes. Also important is the role of DRUID as an environment which stimulates the Ph.D.-students to become creative and effective. This involves several elements:

- access to the international network in the form of visiting fellows and visits at the sister institutions
- participation in research projects
- access to supervision of theses
- access to databases

Each year DRUID welcomes a limited number of foreign Ph.D.-students who wants to work on subjects and project close to the core of the DRUID-research programme.

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DRUID-members are involved in projects with external support. One major project which covers several of the elements of the research programme is DISKO; a comparative analysis of the Danish Innovation System; and there are several projects involving international co-operation within EU's 4th Framework Programme. DRUID is open to host other projects as far as they fall within its research profile. Special attention is given to the communication of research results from such projects to a wide set of social actors and policy makers.

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