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Working Paper

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Wirtschaftswissenschaftliche Diskussionspapiere // Ernst-Moritz-Arndt-Universität Greifswald, Rechts- und Staatswissenschaftliche Fakultät, No. 10/2000

Provided in cooperation with:
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Suggested citation: Werker, Claudia (2000) : Market performance and competition: A product life cycle model, Wirtschaftswissenschaftliche Diskussionspapiere // Ernst-Moritz-Arndt-Universität Greifswald, Rechts- und Staatswissenschaftliche Fakultät, No. 10/2000, http://hdl.handle.net/10419/48900

Market Performance and Competition:
A Product Life Cycle Model

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Diskussionspapier Nr. 10/00
August 2000

MARKET PERFORMANCE AND COMPETITION: A PRODUCT LIFE CYCLE MODEL*

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Abstract

The paper introduces a new simulation model of market dynamics by integrating several concepts of evolutionary economics. In the course of market evolution various changes take place of which the emergence of consumers' preferences and of the knowledge that is needed to meet these preferences with appropriate products are the most important ones. In order to model the market evolution and the resulting changes, Dosi's concept of technological paradigms and Winter's concept of technological regimes are integrated into a product life cycle model. The simulations performed with this model help to understand how the dynamics of market evolution shapes market performance and competition. The results of the simulation runs show a much more differentiated picture than economic intuition suggests. Moreover, it gives useful hints for innovation policy.

Keywords:
Market Evolution, Product Life Cycle, Technological Paradigms, Technological Regimes, Simulation Model.

JEL-Classification

L10, O33

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* The simulation results presented here were improved by stimulating discussions with Rainer Voßkamp and Joachim Schwerin. I like to thank them as well as Sindy Holschumacher, Maja Mende, Tilman Schmidt, Frank Stummer, and Berit Wende who helped me with the time-consuming and tedious process of generating the simulation results. All remaining errors are of course my own.

1. Introduction

Markets provide a variety of different environments that seem to influence competition and performance in different ways. Detailed knowledge of how market environments affect competition and performance is crucial for firms as well as for policy makers. Whereas firms can derive their strategies from this knowledge stock, e.g. to make profit and to survive competition, policy makers are enabled to identify problems with regard to the nature of competition, especially situations in which the exploitation of consumers is likely. Although existing theoretical and empirical results provide a very confusing picture about the differences between markets, the following analysis shows that it is possible to gain a differentiated picture of how market environments affect competition and performance within an evolutionary model of market dynamics.

One promising starting point is to look at the way in which innovation is generated and organized in markets. The most prominent analysis of the generation and organization of innovation was provided by Schumpeter. In his book "Theory of Economic Development", published first in 1911, Schumpeter described a person who is at the core of the emergence of innovation: the entrepreneur. Usually this entrepreneur is not the person who invents something but the one who implements new combinations in markets (Schumpeter, 1911/1987, 124-139). Interestingly, Schumpeter changed his mind in his book "Capitalism, Socialism, and Democracy", published first in 1942. Here, he claimed that due to the automation of innovation processes, entrepreneurs do not play an important role in these processes anymore (Schumpeter, 1942/1980, 213-216). And yet - Schumpeter seems to be wrong in 1911 as well as in 1942, because neither do we face an economy of only small innovative entrepreneurs nor do we only see big firms with automated innovation processes. At the beginning of the 21st century, small, medium-sized and big enterprises widely coexist. Therefore, the question has to be answered why we face a variety of firms that differ, especially with regard to their innovation procedures. At the outset of an answer is the insight that Schumpeter's different opinions in 1911 and 1942 show *two different states* of firms that emerge in the course of market evolution. Although the automation of innovation processes is not a feature of a mature economy, it seems to be a feature of a mature market (see Chapter 2.).

Thus, the question at the core of the analysis of market performance and competition is: Why does the generation of innovation become automated during market evolution, so that the market turns from a new into a mature one, and what do the resulting changes mean for market performance and the nature of competition. In order to answer these questions, the paper is organized as follows. First of all, the concepts of technological regimes, technological paradigms, and product life cycles are integrated (Chapter 2.). In Chapter 3., the idea of the model and its structure are developed. As the model is solved by simulations, the specification of the parameters and the results are summarized in Chapter 4. Some policy implications as well as implications for future research round the paper (Chapter 5.).

2. Product Life Cycles, Technological Regimes, and Technological Paradigms

The simulation model developed in the following is based on three theoretical pillars: product life cycles, technological regimes and technological paradigms. The well-known *product life cycle* approach describes the changing features of markets during their evolution. It may therefore serve as the theoretical framework within which the automation of innovation as a market phenomenon can be explained. In the beginning of a product life cycle, the consumers' preferences are not yet clearly defined. Moreover, firms have not yet agreed upon the kinds of knowledge that should be used to meet these blurred preferences. Therefore, many firms with a variety of knowledge enter the market in this stage. In the course of time, the consumers' preferences become clearer and the knowledge used to generate innovation is relatively agreed upon, so that the generation of innovation finally becomes automated.

There exists a lot of empirical evidence that underpins this concept. Geroski shows that market entries occur in waves that typically have their maximum in early stages of the product life cycle (Geroski, 1995, 425f). In the analysis of Klepper/Graddy most of the analysed 46 products show the regularities predicted by the product life cycle (Klepper and Graddy, 1990, 28-35): The number of firms starts from a low level and then increases considerably. Subsequently, a sharp shakeout-stage of firms follows, so that the number of firms acting in the market decreases. The industry output displays the highest growth rates in the beginning of the product life cycle; these growth rates decrease and ultimately become zero when the market matures. The industry price decreases with high rates at the beginning of the product life cycle. Afterwards the price decrease slows down and becomes zero when the market matures. This pattern is also supported by several other studies (cf. Klepper, 1997, Agrarwal, 1997, Klepper/Simons, 1996, Utterback, 1994, 79-99, Utterback/Suárez, 1993, and Carroll/Hannan, 1989, 417-423).

A crucial characteristic of the product life cycle approach is that markets change from being favourable for entrants to being favourable for established firms. The aim of this paper is to show how this phenomenon can be modelled endogenously.[1] In order to do so, two additional concepts will be used here: the concepts of technological regimes and of technological paradigms. Two *technological regimes* which characterize different market environments can be distinguished: Under the entrepreneurial regime, innovative market entry is favoured by the fact that there exists a number of specific opportunities to exploit the profit opportunities of markets (Winter, 1984, 297). These profit opportunities are limited because only specific firms have access to the knowledge that is relevant for the market. This is due to the fact that innovative market entry does not only require knowledge about technology and products but also about the specific circumstances of the respective market. For this reason, suppliers of inputs or consumers of outputs appear relatively often among those companies which enter the market. In contrast, the market environment under the routinized regime is totally different. Here innovation by established firms is favoured because the cumulative character of the market relevant knowledge becomes crucial which result in increasing returns to scale. Moreover, knowledge is protected by secrecy or patent protection, so that potential entrants face growing difficulties to gain access to the relevant knowledge and to compete with the established firms (Winter, 1984, 296).

This distinction of markets according to the environment for innovation by different types of firms is corroborated by empirical studies as well. Using the data of 4.5

[1] Product life cycle models already exist. Yet, in these models the change of environment from a new to a mature market is usually modelled exogenously (see e.g. Jovanic/MacDonald, 1994). An exception is the model by Klepper where "(t)he advantage of size in process R&D causes firm process R&D to rise over time and eventually puts entrants at such a cost disadvantage that entry is foreclosed" (Klepper, 1996, 580). Klepper's takes the view that the product life cycle is driven merely by the supply side (Klepper, 1996, 562). In contrast, the model presented here is not only a simulation model but it also provides a view that allows to integrate supply and demand side.

Mio. firms in the US-Small Business Data Base from 1976 until 1986, Audretsch was able to show that significantly more firms entered the markets that could be defined as entrepreneurial than markets that could be defined as routinized (Audretsch, 1995, 15f and 62). Similar results were derived by Malerba/Orsenigo. Using patent data of US-American, German, French, British, Italian and Japanese firms in 49 different sectors in the period between 1978 and 1991, they reached the conclusion that in some industries innovation by market entrants were favoured whereas in others more innovation were generated by established firms (Malerba/Orsenigo, 1996, 454f).

The notion of technological regimes can very well underpin the product life cycle approach. By integrating both regimes a whole market evolution can be derived, because the entrepreneurial regime shows the evolution of a new and the routinized regime that of a mature market. This means that the entrepreneurial regime is a market stage that is followed by the routinized regime. As a consequence, the question why and how markets change from an entrepreneurial regime to a routinized one has to be solved. This explanation can be provided by the third pillar of the model derived here: the concept of *technological paradigms*. A technological paradigm can be characterized by some basic artefacts and a couple of technological paths that provide information on future research possibilities (Dosi, 1988, 1127, and Dosi, 1982, 151-153). It does not only define a research field but also gives directions for the search for new solutions as well as for appropriate tools. These directions of research are called technological paths. When firms follow these paths, new possible solutions can be found. Therefore, innovations *within* a paradigm are generated in an ordered and accumulative way. These innovations are called incremental, because an ex-ante idea about their possible outcomes and implications exists. In contrast, radical innovations are connected with intrinsical uncertainty, because they always cause a change of paradigm, so that even experts are not able to prognosticate their possible outcomes and implications. In the following, it is assumed that whereas in the beginning of the entrepreneurial regime there exist a couple of possible technological paradigms that may contribute to meet consumers' preferences, at the end of the entrepreneurial regime consumers do only accept products manufactured under one paradigm; this is called the dominant paradigm. Due to the emergence of a dominant paradigm, the market changes from the entrepreneurial to the routinized regime; a switch which can thus be explained here

Figure 1

endogenously within the model, the details of which are described in the following chapter. The integration of the three theoretical pillars into the model is depicted in Figure 1.

3. The Model

3.1 The idea of the model

In order to derive concrete results for market performance and competition in the following a model is developed that produces patterns of market evolution according to the *product life cycle approach*. The model is formalized by integrating the concept of *technological regimes* with that of *technological paradigms.* To do so, a totally new innovation mechanism is introduced here into the basic model by Winter (1984). This new mechanism uses Dosi's idea of technological paradigms (Dosi, 1982 and 1988).

Winter (1984) distinguished between innovation and imitation to model differences in innovation efforts and outputs. However, a pure imitation takes only place exceptionally, because it always requires adaptations to the specific situation and environment of the firm. Consequently, imitations usually also have innovative elements. Compared with Winter's approach the new innovation mechanism that is based on Dosi's concept of technological paradigms (Dosi, 1988 and 1982) has two advantages: First, it provides an endogenous mechanism that explains why the market changes from the entrepreneurial to the routinized regime: Only when a considerable part of demand is satisfied by the production from one paradigm, this paradigm is established as the dominant one and the market becomes mature. The second advantage of this new innovation mechanism is that it explains better why the entrepreneurial regime is favourable to innovative market entry whereas the routinized regime is favourable to innovation by established firms. Within the entrepreneurial regime, innovative market entries can easily take place with the help of a radical innovation. In contrast, within the routinized regime market entrants have not only to generate a radical innovation but they also have to find the dominant paradigm with a productivity level that is competitive. Therefore, it is much more difficult for them to enter under the routinized regime and most innovations are generated by established firms.

In the remainder of this chapter, the idea described above is transferred into equations. The formal model consists of a static and a dynamic system. Chapter 3.2 describes the static system of the model within which output and profit of the firm as well as industry output and price are determined. The dynamic system in Chapter 3.3 deals with the entrepreneurial decision routines which determine the development of important industry variables such as average productivity, average capital stock, industry output, and price.

3.2 The static system

The static system of the model is based on the following assumptions: Single product firms alone manufacture the product; their only input is capital. As soon as firms enter a market, they achieve the minimal optimal scale, so that their production function is subject to constant returns to scale. The technique of a firm is represented by its productivity A_{it} (all variables are listed in Appendix 1). The capital use and production technique of a single firm are given for every single period. The firms produce at full capacity. Hence, the output of firm i in period t Q_{it} can be obtained by multiplying its productivity of capital in t A_{it} by its capital use in t K_{it}:

$$Q_{it} = A_{it} * K_{it}. \tag{1}$$

The industry output Q_t consists of the output of all firms in the market taken together. The industry price P_t is determined by the demand curve, which is a function of the industry output Q_t. This demand curve is normal in shape and constant in time.

$$Q_t = \sum_i Q_{it}, \tag{2a}$$

$$P_t = D(Q_t). \tag{2b}$$

The profit per unit of capital Π_{it} made by a firm can be calculated by subtracting the costs per unit of capital from the productivity A_{it} and by multiplying the result with the price P_t. The costs which occur here are the depreciation rate d, the production costs per unit of capital c and the expenditure for innovation activities per unit of capital r_{it}.

$$\Pi_{it} = P_t * (A_{it} - d - c - r_{it}). \qquad (3)$$

3.3 The dynamic system

Equations (1) to (3) describe the short-run system of the model in period t. The following equations of the dynamic system connect the different periods by modelling the influences of entrepreneurial decisions on the market evolution. On the one hand side, the market evolution depends on the entry and exit decisions of the firms (Chapter 3.3.2). On the other hand side, the decisions of the established firms on the employed technology, on the capital stock, and on innovation expenditures also shape the dynamics of the market (Chapter 3.3.1).

3.3.1 The innovation decisions of the established firms

In the model, successful innovation activities result in a rise of capital productivity, A_{it}, whereas the production costs per unit of capital, c, remain unchanged. This means that innovation success leads to increases in the efficiency of production. Yet, this kind of modelling would only account for process innovations. Therefore, the production costs per unit of capital c are standardized in the following by quality units.[2] Consequently, the efficiency increases can as well be interpreted as product innovations. As process and product innovations are usually impossible without supporting organizational innovations, these are also mirrored here in the efficiency increases.

Every firm uses the percentage r_{it} of its capital for innovation activities. The firm's past innovation expenditures are summed up to form the total knowledge stock of the firm R_{it}:

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[2] This modelling follows Klepper/Graddy, 1990, 37.

$$R_{it} = \sum_{t} r_{it} * K_{it}. \tag{4}$$

The knowledge stock represents the organizational and technological knowledge of the firm. From this follows, that the probability of innovation success increases when a firm invests in innovation activities, even if it is not presently successful in generating a concrete innovation. The dependency of innovation success on the total knowledge stock is proven by the observation that firms accumulate internal (Arrow, 1962) and external knowledge whenever they pursue innovation activities (Cohen/Levinthal, 1990, 129, and Cohen/Levinthal, 1989, 570f). The higher a knowledge stock already is, the easier it is for firms to absorb external knowledge and to combine internal and external knowledge in a new way.

In order to model the connection between innovation activities in period t and the potential increase of the firm's productivity in t+1 a two-stage random process is applied. In the first stage, it becomes clear whether the firm's activities lead to an innovation. The generation of innovation is modelled in the following way: For every market there exist some paradigms that provide technological and organizational solutions to meet the consumers' preferences. With the help of radical innovations a firm can gain access to a new paradigm. The probability to generate a radical innovation consists of two elements. First of all, it is influenced by the autonomous parameter RI^{aut}. This term represents the fact that firms are able to discover a new technological paradigm by mere chance without relying on their knowledge stock. Thus, even a firm without a knowledge stock can generate a radical innovation. The second element is represented by the parameter a_{it}^{rI} multiplied by the level of the firms' accumulated knowledge stock. a_{it}^{rI} denotes the probability to generate radical innovations depending on the level of the knowledge stock. To illustrate this latter element by a metaphor, the higher the firm's knowledge stock R_{it} is the more often the firm is allowed to draw from the urn that contains the different paradigms. The entire probability to generate a radical innovation is shown by the probability variable pr $[d_{it}^{rI}]$:

$$pr\,[d_{it}^{rI}] = RI^{aut} + a_{it}^{rI}\, R_{it}. \tag{5a}$$

Furthermore, every paradigm in itself represent an urn which contains information about one technological path.[3] On this path, a firm can generate innovation which results in different levels of productivity A_{it}. If it gets access to a paradigm with the help of a radical innovation, it draws its initial productivity on the respective technological path simultaneously. The probability to draw initial productivities on a path is equally distributed. This distribution as a whole is limited by a best practice productivity of the respective path, as the possibilities to increase the productivity with the help of technological and organizational innovations are not endless within the paradigm. As soon as a firm establishes itself on a technological path, any incremental innovation results in a small increase of productivity within the respective paradigm.

The probability to generate an incremental innovation is determined by the parameter of probability a_{it}^{iI} multiplied by the knowledge stock. This means that the frequency of innovation draws depends on the level of the knowledge stock and the probability parameter a_{it}^{iI}. The probability of generating incremental innovations is represented by the random variable pr $[d_{it}^{iI}]$:

$$pr\,[d_{it}^{iI}] = a_{it}^{iI} R_{it}. \tag{5b}$$

The probability parameter a_{it}^{iI} is here assumed to be higher than the parameter of probability a_{it}^{rI}, because it is more probable to generate an incremental innovation than to generate a radical one. The different probabilities reflect the different character of radical in contrast to incremental innovation. Whereas a firm can work directly on incremental innovation - as there exists an ex-ante idea about it - the generation of a radical innovation cannot be pursued concretely - as the way to find it as well as its outcome are totally unclear ex-ante.

In the second stage of the random process within the model, the technology and organization structure of the firm for period t+1 are chosen. The firm can either stick to the old technology and organization structure or it can choose new ones if they correspond to a higher productivity level:

$$A_{i(t+1)} = \max\,(A_{it};\, A_{it}^{iI};\, A_{it}^{rI}). \tag{6}$$

[3] For simplification it is assumed that one technological paradigm contains only one technological path.

If the firm achieves its highest productivity level by a radical innovation, the knowledge stock will be depreciated by (? * 100)%, because any decision to use the technique connected with the radical innovation means entering a new paradigm. The value of the accumulated knowledge decreases, because it can only be used to its full extent in the context of the old paradigm. And yet, the value of the knowledge stock partly remains because some elements of this knowledge are market relevant and because other parts of it contribute to the firm's ability to generate radical innovation and to change paradigms.

$$R_{i(t+1)} = (1-?)\ R_{it}, \tag{7}$$

if $A_{i(t+1)} = A_{it}^{rI}$.

The determination of the output of the firm in t+1 does not only require a decision on the productivity level that represents the technology and organization structure of the firm but also one on the capital stock used in period t+1:

$$K_{i(t+1)} = (1-d) * K_{it} + i * K_{it}, \tag{8}$$

if $?_{it} > 0$, then $i = d + g$ with $g = (?_{it} - ?_{i(t-1)})/?_{it}$,
if $?_{it} = 0$, then $i = d$,
if $?_{it} < 0$, then $i = 0$.

The capital stock in period t+1 equals the sum of the capital stock of the former period, depreciated by d and the investment which results from the multiplication of the capital stock of the former period by an investment rate i. The level of i is determined by the growth rate of the firm's profit per unit of capital. If this term is zero, the investment rate will equal the depreciation quota; i.e., the firm's capacity remains unaffected. If the profit per unit of capital is greater than zero, the investment rate will equal the depreciation rate plus the profit growth rate g. If the profit per unit of capital is negative, the investment rate will be zero. This means that in period t+1 the firm produces with the depreciated capital stock of t.

3.3.2 Market entry and exit decisions

The market entry and exit decisions of the firms play a crucial role for the evolution of the market because they influence the levels of output and price and the average productivity as well as the number of firms. *A firm decides to exit a market* if its capital stock falls below the minimum capital stock, K^{min}, necessary to continue the business. A firm would also exit the market in t if its profit has been negative over a specific period of time.

$$K_{it} = 0 \quad \text{for all} \quad t > t, \tag{9}$$

if $K_{i(t+1)} < K^{min}$
or if $\Pi_{it} < 0$ for some periods.

A firm enters a market if it can exploit profit opportunities. On the one hand side, there are profit opportunities for a number of potential entrants because of the technological and organizational knowledge already accumulated outside the industry. On the other hand side, such profit opportunities occur when the potential entrants can use the industry knowledge in a more efficient way because of their different knowledge stock. Market entrants serve the market evolution in a specific way because "… (e)ntrepreneurs may start new firms not merely to replicate the incumbent firm, but rather to do something different. In this sense, new firms can be viewed as 'agents of change'." (Audretsch/Mahmood, 1993, 27). This holds true for the model developed here if a market entrant produces under a paradigm that has not been discovered yet. The decision to enter a market depends on how the potential entrant measures his/her profit opportunities in the market:

$$\Pi^{en} > B^{en}, \tag{10}$$

with $A_{it}^{en} = A_{it}^{en}(R_{it}^{en})$.

The profits an entrant expects to have must exceed the entry barrier B^{en}. This entry barrier may contain all kinds of causes which may keep entrants outside an industry (Winter, 1984, 304). In this model, the entry barrier is interpreted as a lump-sum payment for the establishment of the organization required for business activities (Klepper/Graddy, 1990, 37). As has been modelled above with regard to the established firms, the productivity level of an entrant A_{it}^{en} depends on his/her accumulated knowledge stock R_{it}^{en}.

The market evolution can be represented best by the development of the variables that are computed with the help of equation (2): industry output and price. Moreover, the development of the number of firms mirrors the market evolution. The number of firms in period t consists of firms which were in the market in the former period plus market entries minus market exits in the current period:

$$N_t = N_{(t-1)} + En_t - Ex_t. \tag{11}$$

4. The Simulation Results

4.1 The Reference Specification

The numerical specification of the model does not intend to describe a specific empirical situation. Instead it aims to show how market performance and competition are influenced by a variety of factors. Nevertheless, the parameters are chosen at an empirically plausible level. The market evolution is shown for 100 years.[4] Usually, the dominant paradigm is established during this period of time, and the industry consolidates.[5] Every market is founded by the first market entrant with a capital stock of 5 and an initial productivity of 1. The supply of the first market entrant is expressed by the inverse demand equation $P_t = 2000 - Q_t$ that provides the connection between the level of market output and market price. The firms have to face production costs per

[4] The simulation runs show 400 periods of 3 months.

[5] In the following analysis, the results of simulation runs in which a dominant paradigm is not established are not taken into consideration, because these runs would ultimately also reach a dominant paradigm and would produce the same patterns if the duration of the run is longer. For the specification of the variables

unit of capital of 0.1, depreciation rate per unit of capital of 0.1, and innovation expenditures per unit of capital of 0.007.

All established firms and all potential entrants can generate innovations.[6] The probability to generate a radical innovation depends on the one hand side on the autonomous parameter RI^{aut}, which is 0.0025, and on the other hand side on a_t^{rI}, 0.0025 as well; the latter is multiplied by the level of the accumulated knowledge stock. If a radical innovation has taken place, the respective firm has the possibility to change the paradigm. In this specification of the model, ten different paradigms are at hand. The worst paradigm renders possible productivities between zero and one, the best paradigm productivities between zero and 5.5.[7] Within the paradigms, the probability to draw an initial productivity is distributed equally. Because of this specification it becomes possible that a firm draws a radical innovation and gets access to a better paradigm, but that the initial productivity there is lower than the productivity of the old technology and organization structure, so that the firm still sticks to its old technology and organization structure as well as to its old paradigm. If however a radical innovation has led to a higher productivity, the firm changes the paradigm and half of the so far accumulated knowledge stock R_{it} is depreciated. A firm that generates an incremental innovation gains a productivity increase of 0.1. The probability to find such an incremental innovation is determined by a_{it}^{iI}, which is here 0.1, multiplied by the knowledge stock of the firm. Every firm enters with an initial knowledge stock of 1. The knowledge stock increases in the run of time by accumulating the innovation expenditures of the firm. As formerly successful firms have higher knowledge stocks, their probability to be successful in the future is also higher. Nevertheless, less successful firms always have the chance to reach or to exceed the productivity of their competitors – especially due to the parameter RI^{aut} that mirrors the probability to generate a radical innovation independent of the accumulated knowledge stock.

In every period the firm determines its capital stock for the following period. The level of the capital stock depends on the firm's profit growth rate. If the profit growth

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see Appendix 2.

[6] In order to simplify the runs, the number of potential entrants N_t^{max} is limited to twenty. The potential entrants for every period t Pen_t are also limited to twenty; this means that all potential entrants can enter the market in one period.

[7] Thus, the best practice productivity of each paradigm increases with 0.5, respectively. This means that

rate is positive, the capital stock increases accordingly. If it is zero, the capital stock remains constant. If it is negative, investment in the capital stock is zero, so that the latter decreases with a depreciation rate of 10%. Moreover, if the profit is negative for more than 5 periods the firm exits the market. It also exits the market if the capital stock falls below the minimum of 2.5.

In the model, a dominant paradigm that causes the change from the entrepreneurial to the routinized one is established if half of the demand is satisfied by this paradigm.[8] From this point in time the consumers will only buy products that are produced within the dominant paradigm. Consequently, the output of the firms that produce within the other paradigms becomes zero. This means that these firms will have to draw a radical innovation which will give them access to the dominant paradigm or they will have to exit the market within the next five periods according to the specification of the exit routine. If the firms which produce within the dominant paradigm have already reached a high level of productivity at this point in time, the chances for the other firms are even worse because they not only have to generate a radical innovation that gives access to the dominant paradigm, but they also have to draw a high initial productivity level to be competitive immediately.

With the help of the numerical specification of the model the patterns of the product life cycle which were derived by the theoretical and empirical analyses can be reproduced (see Chapter 2). This basic pattern can now be analysed with the help of the time sequences of some important variables. Figure 2 contains one example of a typical run. There, the changes in time of average productivity, output of the industry, price, and the number of firms on the market are depicted. At the very beginning of the market evolution, only one firm is active, later the number of firms increases to a maximum of ten firms. Then, the dominant paradigm is established in period 240, so that seven firms have to exit the market, because they are not able to produce under the dominant paradigm. After this point in time the number of firms remains stable. The average productivity reflects the innovation activities of the firms. Unless the innovation activities are successful, the average productivity stagnates. Radical innovations of large

the best practice productivity of paradigm 2 is 1.5, the best practice productivity of paradigm 3 is 2, etc.

[8] Here, the empirical result of Anderson/Tushman (1990) is applied to the simulation model. They found out that a market share of 50% is necessary to establish a dominant paradigm.

Figure 2

firms may result in a jump of the average productivity whereas incremental innovations cause a continuous increase of the average productivity. Before the dominant paradigm is reached, radical as well as incremental innovations take place. In contrast, radical innovations are exceptions under the routinized regime and are only implemented successfully provided that the dominant paradigm is drawn with a high initial productivity level. Hence, the average productivity increases partly with increasing growth rates until the establishment of the dominant paradigm whereas it usually shows decreasing growth rates afterwards and stagnates as soon as the best practice productivity of the dominant paradigm is reached. The price develops according to the productivity as the market is contestable because of the low market entry barrier. The evolution of output mirrors that of the price because the demand curve is normal in shape and constant in time: This means that output increases if price decreases and vice versa.

4.2 Market Performance and Competition under Different Specifications

Market performance and competition are influenced by various parameters. In the following, the parameters that are especially interesting for market performance and competition are systematically varied and the results are analysed.[9] Eventually, competition and market performance are measured by the most important endogenous market variables. The number of firms that are producing in the market, the price and the output at the period of the establishment of the dominant paradigm and at the period after the market consolidation has taken place are taken into account. A more detailed analysis is possible by looking at the level of the dominant paradigm and the period in which it is established. The influence of the varied parameters on the endogenous variables mentioned above are analysed with the help of regressions, the results of which are summed up in Table 1.

Some markets are easily contestable, e.g. the ones in the reference specification where the *market entry barrier* is 1. Other markets are protected by higher market entry

[9] To show these influences exactly, only one parameter level deviates from the reference specification at each time. Beside the level that is chosen in the reference specification, four additional levels are simulated. Every specification runs 100 times, so that 500 runs per parameter are calculated altogether.

Table 1: Regressions of the variation of the parameters.

Variation of		Level of dp°	Establish-ment of dp	At establishment of dp			After establishment of dp		
				Firm number	Price	Quantity	Firm number	Price	Quantity
d	ß	0,023	0,023	0,026	0,070	-0,070	-0,072	0,129	-0,129
	R²	0,001	0,001	0,001	0,005	0,005	0,005	0,017	0,017
	t	0,455	0,450	0,518	1,376	-1,376	-1,417	2,558*	-2,558*
c	ß	-0,192	-0,186	-0,191	-0,191	-0,188	-0,174	-0,192	-0,188
	R²	0,037	0,035	0,036	0,036	0,035	0,030	0,037	0,035
	t	-3,797**	-3,670**	-3,766**	3,768**	-3,708**	-3,417**	3,801**	-3,711**
a_{it}^{il}	ß	-0,025	-0,015	-0,080	-0,434	0,434	-0,008	-0,405	-0,405
	R²	0,001	0,00	0,006	0,189	0,189	0,000	0,164	0,164
	t	-0,457	-0,273	-1,496	-8,984**	8,984**	-0,155	-8,254**	8,254**
a_{it}^{rI}	ß	0,033	-0,557	0,518	0,199	-0,199	0,336	-0,150	-0,150
	R²	0,001	0,311	0,269	0,040	0,040	0,113	0,019	0,023
	t	0,560	-11,251**	10,160**	3,412**	-3,412**	5,970**	2,546*	-2,546*
RI^{aut}	ß	0,059	-0,033	-0,047	-0,025	0,025	0,110	-0,010	0,010
	R²	0,004	0,001	0,002	0,001	0,001	0,010	0,00	0,00
	t	1,145	-0,638	-0,904	-0,490	0,490	2,144*	-0,185	0,185
r_{it}	ß	0,260	-0,066	-0,115	-0,386	0,386	0,410	-0,373	0,373
	R²	0,068	0,004	0,013	0,149	0,149	0,168	0,139	0,139
	t	5,127**	-1,261	-2,199*	-7,950**	7,950**	8,554**	-7,654**	7,654**
R_{it}^{en}	ß	-0,303	-0,642	0,437	0,205	0,205	0,087	0,202	-0,202
	R²	0,092	0,410	0,191	0,042	0,042	0,008	0,041	0,041
	t	-5,199**	-13,698**	7,963**	3,433**	-3,433**	1,434	3,385**	-3,385**
B^{en}	ß	0,151	0,159	-0,063	0,208	-0,208	0,183	0,249	-0,250
	R²	0,023	0,025	0,004	0,043	0,043	0,033	0,062	0,063
	t	3,258**	3,416**	-1,347*	4,529**	-4,529**	3,949**	5,464**	-5,494**

° dp = dominant paradigm * significant on the 5% level ** significant on the 1%

barriers, so that it is more difficult for entrants to gain access to these markets. To take these different situations into account, the level of B^{en} is varied: the entry barrier takes values of 0, 10, 100, and 1000 in the variations of the reference specification. Economic intuition suggests that the higher the market entry barrier is the worse turn competition and market performance and the less firms are producing in the market. The simulation results reveal a more differentiated picture. Whereas price and quantity show the expected patterns, the number of firms develops unexpectedly. The higher the market entry barrier is the later the dominant paradigm is established, because the firms entering the market need a longer period of time to produce half of the output under one paradigm. Due to this prolonged period which can be used for the search of better alternatives the dominant paradigm that is finally established is better. As higher market entry barriers imply a smaller number of firms when the dominant paradigm is established the innovation output is the smaller the higher the market entry barrier is. Consequently, the potential of the better paradigm is not exploited, the price is higher and the quantity smaller. Surprisingly, the number of firms after the consolidation of the market is positively influenced by higher market entry barriers. This indicates that the firms that are still able to enter the market despite the market entry barrier are fitter to survive the establishment of a dominant design. Although a higher market entry barrier is negative for consumers, it is positive for those firms that were able to enter the market because of the additional fitness a market entry barrier requires.

The costs that reduce the profit of the firm (the depreciation rate δ, the production costs per capital unit c, and the innovation expenditures per capital unit r_{it}) influence market performance and competition in different ways. The *depreciation rate* δ can vary considerably depending on the technology that is used to produce the respective output. For this reason, simulation runs were computed with different levels of δ.[10] One would expect that the higher the depreciation rate of capital is the worse is the market performance, as high depreciation rates cause a smaller capital endowment resulting in fewer efforts to innovate. Yet here, the levels of price and quantity at the establishment of the dominant paradigm are unaffected by the level of the capital depreciation rate. Only the levels of price and quantity after the consolidation of the market are clearly influenced by the depreciation rate: The higher the depreciation rate is the higher is the price and the lower is the quantity sold in the market. This indicates that higher depreciation rates enfold their effects only after the markets mature.

The level of the *production costs per unit of capital* c depends crucially on the production process employed. In contrast to the depreciation rate that is always invested as long as the firm's profit growth rate is at least zero, the production costs per unit of capital directly affect investment in addition to the substitution of the depreciated capital stock.[11] The higher the production costs per unit of capital are the smaller is the profit, and the smaller the profit is the smaller is the growth rate of capital, ultimately resulting in a smaller knowledge stock. Therefore, one would expect that the market performance decreases with increasing production costs. This is confirmed by the simulation results. The higher the production costs per unit of capital are the earlier the dominant paradigm is established and the worse it turns out to be. Consequently, at both measurement points in time the price is higher and the quantity smaller. Not

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[10] In the reference specification, δ is 0.1 – i.e. 10% of the capital endowment is depreciated every period. In the variations, depreciation rates of 0.01, 0.05, 0.2, and 0.5 are taken into account.

[11] This parameter is varied as well: in the reference specification, c is 0.1, i.e. 10% of the capital

surprisingly, the number of firms is negatively influenced by increasing production costs per unit of capital, because the lower efficiency that can be realized in the worse dominant paradigm means that the level of demand decreases.

The *innovation expenditure per unit of capital* r_{it} differs from market to market.[12] As it influences the level of the knowledge stock that is used to generate innovation, it can be expected that an increase in this parameter leads to a better market performance.[13] The simulation runs show the expected results. The higher r_{it} is the better becomes the dominant paradigm and the earlier it is established. As r_{it} influences both the generation of radical and incremental innovation, the firms in the market are not only able to exploit their paradigms faster but they are also able to find more paradigms. Consequently, the price is smaller and the quantity higher at the point in time the dominant paradigm is established. The number of firms is negatively influenced by a higher value of r_{it}, which indicates that competition between the firms is higher. Price and quantity effects are similar after the market consolidation, but the number of firms increases with rising innovation expenditures per unit of capital. This means that the intensified competition before the establishment of the dominant paradigm. This is not only favourable for the consumers but also for the firms that survive this competition. Again here, as they are fitter they are more likely to survive the establishment of the dominant paradigm.

The level of knowledge is also influenced by the level of the initial knowledge stock of the firm R_{it}^{en} that can also vary depending on the market relevant knowledge the firm has already accumulated before entering the market.[14] Thus, it might be expected that this parameter influences market performance and competition in the way innovation expenditures do. Interestingly however, although the level of the knowledge stock is higher from the very beginning if the initial knowledge stock increases, the effects are the other way around compared with the effects of the innovation expenditures per unit of capital. This at the first glance surprising result clearly demonstrates that the point in time when a bigger knowledge stock becomes available is

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endowment. In the variations, the production costs per unit of capital are 0.01, 0.05, 0.2, and 0.5.

[12] The innovation expenditures can also vary from firm to firm. This is not taken into account here.

[13] The innovation expenditure r_{it} is 0.007 in the reference specification. In the variations, levels of 0.0007, 0.035, 0.014, and 0.035 are taken into account.

[14] In the reference specification, R_{it}^{en} equals 1; in the variations, it is 0.1, 0.5, 2, and 5.

crucial. When the initial knowledge stock increases, the dominant paradigm is established earlier, so that the firms do not have so much time to search for the best paradigms. Consequently, the dominant paradigm is the worse the higher the initial capital stock is, and this negatively affects market competition and performance.

Finally, the parameters that influence the generation of innovation are directly taken into account, i.e. the parameters that represent the probability to generate an incremental or a radical innovation (a_{it}^{iI}, a_{it}^{rI}, RI^{aut}).[15] In the regression results, one can only detect a significant influence of the autonomous probability to generate a radical innovation on the firm number after the establishment of the dominant paradigm: The higher RI^{aut} is the larger is the number of firms after the consolidation of the market. Obviously, the higher autonomous term helps firms to generate radical innovations, so that it is easier for them to reach the dominant paradigm with a competitive productivity after its establishment. This indicates that the more independently organization structure and technology can be found without having to rely on a knowledge stock the easier it is to gain access to a market - even if it is mature. This result can explain why we always find a few markets where considerable numbers of entries take place even in later stages of their development.

The two probability parameters of generating innovation that are multiplied by the knowledge stock have some influence on the endogenous market variables. The probability parameter of generating radical innovations a_{it}^{rI} can vary considerably depending on technological and organizational features of the respective market. It would be expected to influence market performance and competition in a positive way. The simulation results again show a more differentiated picture. The higher a_{it}^{rI} is the earlier the establishment of the dominant paradigm takes place. The quality of the dominant paradigm is not influenced significantly, but the market performance is worse if a_{it}^{rI} increases. This can be seen from the price increases and the quantity decreases at both points in time of measurement. This at the first glance puzzling result is caused by the fact that an increase in a_{it}^{rI} results in more changes of paradigms which is always connected with 50% depreciations of the firms' knowledge stock. Consequently, the

[15] RI^{aut} influences the probability to generate a radical innovation independently of the level of the knowledge stock. RI^{aut} equals 0.0025 in the reference specification, in the variations, it is 0.00025, 0.00125, 0.005, and 0.0125.

knowledge stock of the firms is more often depreciated, so that the market as a whole has less knowledge available and the frequency of innovations decreases.

The probability parameter to generate incremental innovations a_{it}^{iI} is also varied to show its influence on market performance and competition. The number of firms and the dominant paradigm remain unaffected by an increase of a_{it}^{iI}. But a_{it}^{iI} strongly influences price and quantity: The higher a_{it}^{iI} is the smaller is the price and the higher is the quantity at both points in time of measurement. Whereas both other parameters that influence the generation of radical innovation affect the shifts of paradigm, a_{it}^{iI} influences the efficiency with which a firm is able to produce under a certain paradigm. Therefore, as one would expect, increases in a_{it}^{iI} strongly influences the price and the quantity on the market in an advantageous way for the consumers.

Generally speaking, the results of the simulation model correspond to economic intuition. The advantage of this is that the results seem to be valid. But if the acknowledgement of economic intuition is the only insight one can gain from the model developed here the question would arise why one has to make such an effort to get to know the known. Interestingly, the results of the simulation runs are much more differentiated than economic intuition would suggest. Therefore, they help us to understand market performance and competition much better. The implications of these insights for innovation policy are shown in the following chapter.

5. Conclusions

Three theoretical pillars, the product life cycle, technological regimes, and technological paradigms have been put together here to model the evolution of markets in time. At the first glance, the simulation results seem to show many of the expected patterns of market evolution. Yet, when one looks more closely at them, it becomes clear that they reveal a much more differentiated picture. For example large parts of the literature suggest that high market entry barriers do not only result in higher prices and smaller quantities but also that the number of firms is smaller if the market entry barrier is higher. The simulation results hold true for all of these suggestions with one exception: The firm number is positively influenced by a higher market entry barrier after the consolidation of the market because the firms that enter a market despite a high market entry barrier are fitter to survive the establishment of the dominant paradigm. Therefore, there is an additional incentive for firms to overcome market entry barriers as these market entry barriers, do not only protect them from competition of market entrants but also make them fitter for changes within the market.

Obviously, it is crucial to know which variables are relevant for the decisions about investments of firms in order to predict the market performance. The simulation results clearly show that it is not sufficient to simply have an idea of the relevant decision variables because the effects of these variables are even more important. In the model, the decision routine on investment is dependent on the profit of the firm in the current period. This profit is reduced by the depreciation rate, the production costs, and the innovation expenditures. Although all these variables have in common that they reduce the firms' profit they influence the investment decision in totally different ways. The investment routine says that the depreciation of capital is always invested as long as the firms' profit is positive. In contrast, the level of production costs are directly influencing the investments that are made in addition to the substitution of the depreciated capital stock. Consequently, the level of the production costs influences all endogenous market variables, whereas the level of the depreciation rate only affects the price and quantity after market consolidation. This result is an interesting lesson for policy makers, because it points out that policy measures must be carefully designed in order to have the desired effects.

A similar hint for policy can be drawn if one looks at the simulation results of the parameters that influence the firms' knowledge stock. Generally speaking, an increase in the level of innovation expenditures has the expected positive results for competition and market performance, i.e. smaller prices and more competitors – at least after the consolidation of the market. In contrast, an increase of the initial knowledge stocks has negative results for competition and market performance. This is due to the fact that in cases with high initial knowledge stock the dominant paradigm is established earlier and therefore the firms do not have enough time to search for better solutions than the ones provided by the then early established dominant paradigm. This result implies that policy makers should refrain from measures that lead to a relative high initial knowledge stock in new markets, because experience in the market eventually leads to much higher knowledge stocks during market evolution and consequently result in a much better market performance. This result also shows that competition and market performance are influenced in a much more positive way for the consumers if policy contributes regularly to an increase of the knowledge stock, e.g. by providing supporting contacts between firms, universities, and other innovative actors.

To deepen the qualitative analysis of evolutionary processes simulation models may be useful to derive justified economic as well as policy implications (e.g. Balmann/Reichel, 2000). In this paper, a relatively simple model was developed. Nevertheless, the results show that it is possible to derive a differentiated picture of market evolution as well as some useful hints for policy. An even more differentiated picture might be drawn if more differences between firms are taken into account (e.g. different levels of innovation expenditures) or if policy measures are modelled explicitly. Such modifications promise even more views in the functioning of markets than the insightful simulation results presented here.

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Appendix 1: Index of Variables[16]

Q_{it}	output of firm i in period t
A_{it}	capital productivity of firm i in period t
K_{it}	capital employment of firm i in period t
Q_t	output of the industry in period t
D(.)	demand curve
P_t	industry price in period t
$?_{it}$	profit per unit of capital of firm i in period t
d	depreciation rate of the capital stock
c	production costs per unit of capital
r_{it}	rate of capital spent by firm i in t for innovation activities
R_{it}	knowledge stock of firm i in period t
pr [d_{it}]	independent random variable which can equal 0 (no success) or 1 (success)
a_{it}	probability parameter
RI^{aut}	autonomous probability to generate a radical innovation
A_{it}^{iI}	productivity level caused by an incremental innovation in t which may determine the productivity of firm i in t+1
A_{it}^{rI}	productivity level caused by a radical innovation in t which may determine the productivity of firm i in t+1
ß	depreciation rate of the knowledge stock
i	investment rate
g	profit growth rate
K^{min}	minimum capital stock
t	period of market exit
Pen_t	number of potential market entrants in period t
En_t	number of market entries in period t
A_{it}^{en}	productivity level connected with market entry of firm i in period t
B^{en}	entry barrier
N_t	number of firms which produce the industry product in t
Ex_t	number of market exits in period t

[16] Variables are listed in sequence of their appearance in the text.

Appendix 2: Reference Specification of the Variables

$A_{11}^{en} = A_{11}^{en} = 1$

$K_{11}^{en} = K_{it}^{en} = 5$

$R_{11}^{en} = R_{it}^{en} = 1$

$P_t = 2000 - Q_t$

$d = 0.1$

$c = 0.1$

$r_{it} = 0.007$

$a_{it}^{iI} = 0.1$

$a_{it}^{rI} = 0.0025$

$RI^{aut} = 0.0025$

$ß = 0.5$

$K^{min} = 2.5$

$Pen_t = 20$

$B^{en} = 1$

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