Innovation and market structure in the dynamics of the Japanese IT-sector: an empirical analysis from 1978 to 2000

Monika Friedrich-Nishio*
Burkhard Schade

Institute for Economic Policy Research (IWW)
Section System Dynamics and Innovation
UNIVERSITY OF KARLSRUHE (TH)
GERMANY

Abstract

The paper presents a sectoral evolutionary simulation model that combines the Schumpeterian approach to innovation and imitation with the simpler but very powerful results of evolutionary theory of Nelson and Winter (1982). According to that, competition is a process wherein firms try to survive in the market by innovations and imitations. Based on the behavioural theory of the firm and Simon's work on bounded rationality, which investigates rationality assuming that the resources of the decision maker are limited, the evolutionary theory enables to focus on the definition of firms as a set of competencies that the firms control, and the evolution of firms by searching new routines. Feedback between strategies and selection through the market entails endogenous industrial dynamics. The analysis of the outcomes of competitive dynamics is computed with a simulation model developed with Vensim, and tested on the basis of the Japanese IT-industry case, represented by the companies NTT, NEC, Toshiba, Hitachi and Fujitsu.

JEL Classification: E17, L11, O32

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*Corresponding author. Phone: +49 (0) 721 608-7694, Fax: +49 (0) 721 608-8429, E-Mail: friedrich-nishio@iww.uni-karlsruhe.de

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1 Introduction

Innovations are the driving force behind economic development. With the developments in IT (information technology) and the spurt in cross-border corporate activities, the world economy is facing a period of mega-competition. The utilization of IT has dramatically reduced the time and expense associated with distribution of information. From the history we know that innovations based on revolutionary technology bring about large economic benefits.

The activities referred to as "innovation" which create new value by creating and utilizing knowledge, the artefact of the capabilities of mankind, provide benefits not only to companies, but also to society and economy as a whole. The process innovations (innovations in the manufacturing process) which Japan has taken full advantage of its strengths in, must be upgraded in order to support Japan's key industries and to ensure international competitiveness. Since the structural recession in the 1990's, the Japanese economy is being gained upon rapidly by other Asian countries in the field of process innovation.

The process by which innovations are generated is related to a variety of factors, inside and outside of the companies, and the combinations of these are referred to as innovation systems. The influence of environmental conditions on innovations is being analyzed in a lot of works concerning the so-called "National Innovation System" (NIS).

In the first part, in section 2, we will shortly describe the theoretical framework (ecolutionary economics as the base theory), the concept of National Innovation System, and the role of innovation in Japanese Economy.

Next, in section 3, we will describe the development of innovation processes by introducing an evolutionary model. For the interpretation of industrial dynamics and the development of innovation processes the seminal work of Nelson and Winter (1982) and the following developments until today provide a useful framework. Based on the behavioural theory of the firm (Cyert and March, 1963), the evolutionary theory enables to focus on the definition of firms as a set of competence that the firms control, and the evolution of firms by searching new routines and transforming secondary routines into principal routines.

Theoretical and empirical analysis of the development inside innovation processes have often paid insufficient attention to the important issue of dynamics. In section 4, a dynamic simulation model is developed, aimed to overcome some of the weaknesses of the comparative static approach and to achieve improved specifications of the dynamic relationship between input and output factors in-between an innovation process on the one hand and economic performance on the other hand.

A simulation study requires well-designed methods of model development, validation and verification. The construction of a model of real phenomena is always simplified because of the aim to understand and explain the given phenomena. In addition, by the simplification of the model, the most essential attributes of the innovation process become apparent: the non-linearity of the R&D function linked to the marked diffusion process.

In this paper we will develop a evolutionary model, following a system dynamics approach. Important elements of the models are the process of technology and product development which contain a learning process (firms learn over time according to their accumulated knowledge), and the linkage between the outcome of R&D process and market development. The objective of this study will be the dynamic relationship between the structural elements of the (sectoral) innovation system and its innovative performance.

The next step would be to test the model with real data. In this paper we will focus on the Japanese IT-sector which is represented by five Japanese IT-firms (NTT, NEC, Hitachi, Toshiba and Fujitsu). The data of these firms cover: net sales, net income, R&D expenditure, capital expenditure, number of employees, patents and publications.

2 Innovation as a Driving Force

2.1 Theoretical Framework

2.1.1 Organizational innovation in evolutionary economics

The level of analysis in evolutionary economics (Nelson and Winter, 1982 [10]) is normally the firm, where tacit and explicit forms of knowledge interact and are selected in the basis of choice made by individuals, according to some utility emerging from the historical and economic context. Evolutionary economics extend the behavioral theory of firm (Cyert and March, 1963 [4]) and draws on the Schumpeterian idea of capitalism as an evolutionary process, which regards industry structure as constantly evolving and firms as adapting over time in a "process of creative destruction" (Schumpeter, 1934 [16]).

Evolutionary economics focusses on intensity, direction, and strategy of search activity and their causal factor. Organizational search leads to dynamic environmental changes and selection, and changes in business strategies and search activities lead to dynamic changes at the aggregate firm level, since profitability, investments and rates of expansion are affected. Theses changes int turn effect to dynamic changes at the industry level. Firms behave different concerning their strategies, and these differences are assumed to result in performance outcome variations. Less successful firms tend to imitate strategies of other firms by reducing their strategic diversity. Only a few successful firms will be able to find pioneering new technologies in order to generate innovations. They can obtain above average returns until the imitators dissipate away these temporarily high returns. Firms, unable to overcome internal structural inertia, might fail to adapt to the environmental changes, so that they eventually will not survive,: a selection process through the market (Schumpeter, 1934 [16]).

Organizational adaption and strategy evolution is considered to be path-dependent (Nelson, 1995 [11]), i.e. firms make decisions according to their accumulated knowledge of technologies. In that sense, the differences of firms in the ability to generate innovations are grounded more in organizational factors and their accumulated knowledge rather than in the possession of certain technologies. Nelson and Winter (1982) refer to organizational routines as the "organization's genetic material, explicitly embedded in bureaucratic rules, as well as implicitly in the organization culture". The learning process and the speed, how fast firms do learn from their past, is therefore an important point which will have to be integrated in the modelling industry development. To describe the system in which these interactions are taking place, it is necessary to introduce the concept of a National Innovation System.

2.1.2 The concept of National Innovation System

The concept of National Innovation System (NIS) has been the center of interest in a lot of works. But we cannot talk of the existence of a single concept of National Innovation System, because this concept covers different realities, and the interpretations differ depending on the author[1]. These concepts differ in their methodological point of view (micro- or macro-economical), the conceptualization of the technology, and the role of institutional frameworks.

Freeman (1988) emphasizes that economic success is often related to major institutional changes in the national system of innovation, as well as to big increases in the scale of professional research and inventive activities and new clusters of radical innovations. Considering the situation in Japan he notes:

> "[When we consider Japan's economic success,] this is related not simply or even mainly to the scale of R&D, but to other social and institutional changes. (...) Japanese trade performance in the 1970s and 1980s is further indirect evidence of this success, based as it is on new product and process design, and high quality."[2]

He defines the National Innovation System as "the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies". All the concepts of National Innovation Systems have

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[1] Freeman (1988), Lundvall (1988, 1992), Porter (1993) or Nelson/Winter (1982) are some of them, to mention a few.

[2] Freeman (1988), p. 330

one thing in common: they try to understand regional innovative capabilities in relation to the various institutions that set up the frame within innovation processes and competitions are taking place. Regarding the Japanese National Innovation System the role of government, especially MITI, the role of firms, in terms of *keiretsu*, and social and educational components have an impact on economic performance. Regarding the IT-sector, we can also consider the regulation as one of the components in the National Innovation System in which firms develop their strategies.

The conceptual diagram of a National Innovation System is shown in figure 1.

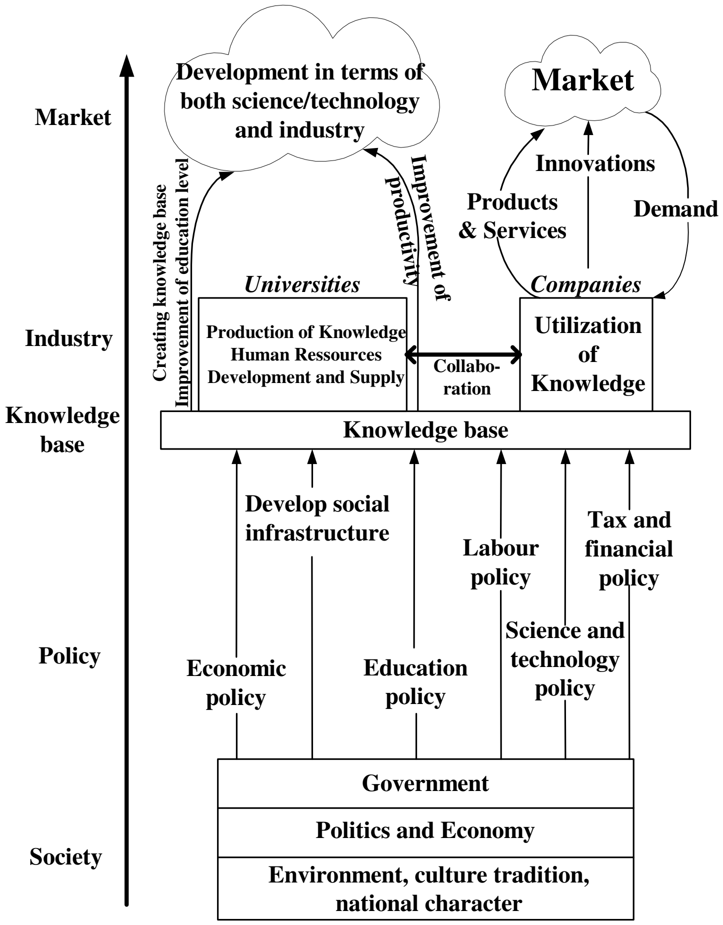

Figure 1: The concept of National Innovation System.

If we talk of the main players in the innovation system, we have to look for the characteristics of the innovation systems in terms of science and technology activities. For this we are using indicators of innovation processes, like indicators of input into research and development (R&D expenditures, human resources), indicators of output (number of patents, number of scientific papers), indicators of results of innovations (technology trade and exports of high-tech products, including the relationships between universities and companies).

The interaction of a number of firms with different characteristics in terms of their propensities to innovate, imitate and invest in R&D, implies a modelling of a system, which is characterized by a high level of complexity. Since the degree of complexity of this stochastic modelling makes it difficult or even impossible to solve it analytically, computer simulations and agent based modelling are used in the analysis of emerging properties in such an environment. The empirical evidence, so far, is quite limited. In this paper we will put the sectoral innovation system of the Japanese IT-sector in the center of our analysis.

2.2 The Current State of Japan's Innovation System

Since World War II Japan has achieved high economic growth, especially through progressive technical innovations, centering on process innovations.

Following the 1985 Plaza Accord, the yen rose sharply in value over the next few years to three times its value in 1971, in the fixed exchange rate system. With the increase in the price of Japanese exports, competitiveness was decreased overseas, while government financial measures increased demand domestically. During the 1980s, a lot of credit for Japan's success was aimed at their management techniques, their educational system, their trade policies – even the harmony of their traditional culture.

When Japan's powerhouse *bubble economy* of the late 1980s burst on the last day of 1989, it signaled the end of phenomenal growth and more than two decades of rapid overseas business expansion. From 1975 to 1994, Japan enjoyed an inflation rate of only 2%, the lowest in the industrialized world.

Corporate investment rose sharply in 1988 and 1989. New equity issues rose in value as a result of higher stock prices, thus making them an important source of financing for corporations. In the meantime, banks sought for funds in the outlet of real estate development. In turn, corporations used their real estate holding as collateral for stock market speculation. A direct result of this was the doubling of land value prices and a 180% rise in the Tokyo Nikkei stock market index.

In May 1989, the government tightened it's monetary policies to suppress the rise in value of assets, such as land. However, higher interest rates sent stock prices on a steady spiral down. The Tokyo stock market had fallen 38% by the end of 1990, thus effectively wiping out 2.07 trillion dollars in value. Steeply dropping land prices burdened financial institutions with bad debts and some of them even went bankrupt. Others attempted to improve internal finances and managed to stay afloat by limiting the supply of capital to private businesses by being cautious in granting loans. In October 1993, the recession bottomed out, but has been recovering slowly since then.

After the bursting of the economic bubble, Japan's economy showed signs of recovery from around 1999, but that recovery has already ended, deteriorating once more, and companies are holding back on capital investment. Now Japan's economic growth is at the lowest level among developed nations. Meanwhile, other Asian countries have achieved to overcome the currency crisis of the late 1990s, with some recording unprecedented levels of economic growth.

If we compare Japan's innovation indicators with the indicators of various countries, we get the following table (see table 1).

Category	Indicator	Japan	USA	Germany	France	UK	Average
Input	Number of researchers (10,000 people)	72.8	111.4	25.5	16.0	15.9	48.3
Input	R&D expenditures (trillion yen)	16.3	28.5	5.0	3.0	2.9	11.1
Degree of cooperation between industry and academia	Percentage of university research expenditure borne by industry (%)	2.5	7.7	11.3	3.4	7.1	6.4
Output	Number of patent applications (10,000)	79.2	220.6	60.5	25.9	40.0	85.2
Output	Number of scientific papers	74,050	242,216	66,420	48,006	68,391	99,817
Achievements	Value of technology exports (100 mill. $)	102.3	380.3	28.4	23.2	62.3	119.3
Achievements	Export market shares for high-tech products (%)	13.2	25.5	10.0	7.1	8.7	12.9

Table 1: Innovation indicators, taken for the year 2002. (Source: Ministry of Education, Culture, Sports, Science and Technology, Japan.)

It is evident that the same input doesn't consequently lead to the same output and achievements. The input indicators in Japan such as R&D expenditure and Human Capital (number of researchers) are much higher compared to the other nations, but the output of innovation like number of patents and publications, and especially the achievements (value of technology exports, export market shares for high-tech products) are lagging behind the other major countries. The reason for the different developments are finally founded in the different structure of each national innovation system. The importance of identifying regional innovation systems and its framework which is surrounding the system becomes apparent.

Exemplified, let us regard one of the output indicators: Let us regard the patents (table 2).

YEAR	Japan	USA	Europe
1988	(37.0)		
1991	(30.0)		
1995	(24.0)		
1996	22.0	10.1	15.6
1997	21.0	10.4	15.8
1998	19.0	12.6	18.3
1999	19.7	12.8	19.8
2000	21.1	13.0	20.7

Table 2: First Action Period for Patents (in months) Source: Japan Patent Office. "Trilateral Statistical Report," examination period: "Japan Patent Office Annual Report".

In contrast to the United States, where the first action period[3] is around 13 months, in Japan in recent years, it takes on average 21 months after placing a request for examination.[4] The Patent Office is therefore working to strengthen the framework by increasing the number of examiners and utilizing external examination capacity for prior art examinations, in a bid to achieve rapid and accurate examinations.

If we consider IT-products with short times before other companies will catch up, the increasingly long times required for settlement of disputes concerning patents and so forth is a major problem. Although the average trial times in Japan have been halved over the past ten years, further steps to strengthen the framework concerning intellectual property cases will be necessary. We can see that this factor is to be taken into account if we model the Japanese IT-sectoral innovation system: a lag function for the effect of patents on the firm's performance is therefore integrated.

In the next section we will describe an evolutionary industry model suited for the Japanese IT case.

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[3] the period of time from patent application to when the first notification is sent from the examiner to the applicant

[4] Notes: 1. Japan Patent Office, US Patent and Trademark Office, European Patent Office 2. Figures in parentheses are the examination period, which is calculated in a different way from the first action period.

2.3 Necessary modifications to the traditional evolutionary industry models

Following the evolutionary industry model of Nelson and Winter (1982 [10], part V, chapter 12) we will now describe a simplified version of it, a dynamic discrete-time Marcov model, i.d. the state variables at time t determine the state variables at time $t+1$ through a set of transition rules that at least partially are of stochastic nature. The variables of the models can be interpreted as economically relevant stocks like the firms' capital and productivities based on knowledge.

On account of simplification only new elements in the model will be emphasized. The intersection with the well known Nelson & Winter model (NW-Model) will first be outlined. Main differences between this model and the NW-Model consist in the investment behavior: investment in physical capital and investment in R&D.

In the tradition of the NW-Model and also in most the evolutionary industry models, learning is not taken into account in the behavior of the firms, i.e. the R&D decision rules rely on fixed rules. So these firms' decisions concerning the amount of R&D investment are not influenced by their learning about their past experience and their environment.

If we consider the R&D decision rules more realistically, they are characterized by a strong uncertainty concerning the return on investment. This uncertainty is stronger for R&D investment than for other types of investment. In contrary to the neoclassical theory, Herbert Simon (1958 [17]) pointed out that the "new" theory of the firm as a "satisficing" as opposed to "maximizing" agent has begun to take hold in industrial organization. Despite Simon's nominal shift to Artificial Intelligence and cognitive science 40 years ago, the central question underlying all of his research has never changed: How do people make decisions? In general, Simon's theories of bounded rationality have become an integral part of the so-called "New Institutionalist Economics". According to Simon innovation often result from what he calls "nonprogrammed decisions", a situation where the alternatives of choices must be discovered by firms and the connections between choices and consequences are imperfectly known.

So if we involve the fact that R&D decisions are generally associated with uncertainty, and that this uncertainty strongly limits the ability of firms to form expectations about the return on their R&D investment, we have to allow a modification: firms cumulate experience, and through their experience they must be able to improve their perception of the relationships between competitiveness and R&D investment and also to adapt according to their R&D decisions. Since we have individuals with bounded rationality, firms do not necessarily search for the globally best solutions, they just learn from their own (past) experience and this learning allows them to improve their R&D behavior. Firms effectively use each rule in order to evaluate its fitness. At the industry level and from the point of view of competitive power, learning process is a source of efficiency. This individual learning is a modification compared to the NW-Model: we have a learning process which will be implied by introducing a variable indicating the productive efficiency level of applied technologies. By taking this into account firms can change their routines (their R&D decisions) over time.

A possibility of exit from the industry is also included in the model: In the long term competition selects the firms that outperforms their competitors: the firms can only finance their investments by their profits and they have to leave the industry when their physical capital vanishes. The exit of the market is however restricted, more inertial than in usual evolutionary industry model in that way, that we allow the firms to keep *alive* though their economic performance is negative. This is necessary to represent the actual situation in the Japanese IT-sector. As described above, because of the different patent system in Japan the first action period of patents must be cared and integrated in the model. This is be done by a introduced variable which measures the actual and delayed performances, and forces the firms to exit the market not until a certain duration of negative performance has occurred.

3 The Structure of the Model

We consider an industry evolving in discrete time $t = 0, 1, 2, \ldots, T$. At time $t = 0$ there are no firms ready to manufacture, but a random number of firms are drawn which will start to manufacture at $t = 1$. At time $t = 1$ the industry consists of n_t firms which are involved in manufacturing. At each time t the economy is endowed with two factors of production: labour, which is provided by the employees of firms, and physical capital. At the beginning of each period the firm i is characterized by the productivity of its technology (A_{it}), its labour employed in production (L_{it}) and its capital stock (K_{it}). The production technology is characterized by fixed input coefficient and constant scale economies. Each firm produces the same homogenous good. We have constant returns to scale and the productivities are modified by technical progress.

A technology of a firm can never be degraded but only improved. An improvement is possible either through successful innovations or through adopting a better technology of another firm (imitation).

3.1 Productive efficiency level and learning process

Firms learn different from the past. The capacity of changing the organizational routines varies across firms, and the relative position of a given firm is unstable.

The variable u_{it} indicates the productive efficiency level at time t. Changes in A_{it} are a function of technical progress via R&D strategy. Firms can also change their total factor productivity by improving the efficiency of their organizational routine u_{it} (Cohendet et al (1999) [3]). This is possible through learning and adopting over time. But routines are very hard to change, so they are responsible for inflexibility and inertia in organizational behavior. The learning process has two characteristics:

1. Learning effects are limited, and
2. the organizational knowledge is technology-specific: If a new technology is introduced, a new learning process begins and the firm enters into a different "learning curve".

The firm's efficiency at time t is

$$u_{it} = \left(1 + \omega_i \cdot e^{-z_i \cdot (t-\tau_i^e)}\right)^{-1} \cdot \left(u_{max} - e^{-\nu_i^k \cdot (t-\tau_i^k)-k}\right) \ , \tag{1}$$

with $0 < u_{min} \leq u_{max} \leq \infty$, $u_{min} \approx 0$ but $u_{min} \neq 0$.

$z_i \ , \ \nu_i^k$: learning speed,
the higher the value the faster the learning process
τ_i^e : period where firm i enters in the industry
τ_i^k : period where technology k is selected
$(t - \tau_i^e)$: age of the firm i, number of periods during
which firm i uses technology k
$k \in \mathbb{R}$: position of the learning curve

The first term $(1 + w_i \cdot e^{-z_i \cdot (t-\tau_i^e)})^{-1}$ is a logistic function and expresses the learning process associated with the age of the firm i. The second term $(u_{max} - e^{-\nu_i^k \cdot (t-\tau_i^k)-k})$ is a modified exponential function. It characterizes the specific learning process of technology k.

The production cost per unit of output of firm i at time t (unit costs of this technology) is given by:

$$c_{it} = \frac{1}{u_{it}} \cdot \frac{v}{A_{it}} \tag{2}$$

where v is variable costs per unit of output, assumed constant over time, and for a given plant or technology, the efficiency of input utilization is kept unchanged with the amount produced.

Differences in firms' unit costs arise from improvements in efficiency u_{it} and from technical progress A_{it}. When the total productivity A_{it} increases, the unit costs decreases.

Each technology has a specific design, and according to the usual assumptions in economic studies concerning the behavior of learning curves, the productivity increase of a given technology tends progressively to exhaust (Possas 2001, [14], p. 10). As a new technology is introduced, lagging or handicapped firms have the opportunity to catch up or even to go beyond the leaders in the former technology or in the old equipment. This can be imagined as a firm's sudden jump to a new learning curve, bringing itself in a position of equality or even superiority to others5).

3.2 Market behavior

The individual supply for firm i at time t is then according to a Cobb-Douglas-production-function:

$$Q_{it} = A_{it} \cdot K_{it}^{\gamma} \cdot L_{it}^{1-\gamma} \cdot u_{it} \ . \tag{3}$$

with $0 < \gamma < 1$ and u_{it} is the productive efficiency level at time t, $0 < u_{min} \leq u_{max} \leq \infty$ (for details about u_{it} see section 3.1).

The total supply for the whole industry is:

$$Q_t = \sum_{i=1}^{n_t} Q_{it} \ . \tag{4}$$

The demand and short term equilibrium price is:

$$p_t = \frac{D}{Q_t^{\frac{1}{\eta}}} \ , \tag{5}$$

with $D(Q_t)$: demand, and η: demand elasticity. The demand function $D(Q_t)$ denotes the quantity demanded at time t, with $\lim_{Q(t)\to 0} D(Q_t) < \infty$ and $\lim_{Q(t)\to\infty} D(Q_t) = 0$.

The capital stock depreciates at rate δ at each period. Unit using cost of capital is m with

$$m = \delta + r_{nat} \ , \tag{6}$$

where r_{nat} is the natural interest rate.

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5) This phenomenon can be seen e.g. in sectors like semiconductors, aircraft, and especially computers (rapid technological obsolescence of product design), see Scherer and Ross (1990), [15] p. 372.

The profit of firm i at time t is equal to total sales minus production and non-production (R&D) costs. Hence, the gross profit on capital of the firm i at time t is given by:

$$\Pi_{it} = p_t \cdot Q_{it} - (m + c_{it}) \cdot K_{it} - R_{it} \tag{7}$$

where R_{it} indicates the R&D expenditures (more in section 3.3).

The state of each firm will change from one period to another in consequence of the R&D decisions, which modify its technology and hence its productivity, and the investment behavior, which modifies its capital stock. The market share (MS) of each firm is given by

$$MS_{it} = \frac{Q_{it}}{Q_t} \; . \tag{8}$$

3.3 Technical progress and R&D

Due to the technical progress firms are able to modify their productivity. In each period firms invest an amount of resources: They have R&D expenditure and capital expenditure, so there are two stages: the search stage (search for innovation or imitation) and the production stage.

The allocation of the new investment in R&D R_{it} is a random amount to be endogenously determined during the search process. Though the R&D expenditures have a character of fixed costs, for the increase of output not consequently increases the R&D expenditures, but we assume here that firm's R&D investment is based on a (short-term constant but) long-term evolving behavior function. That means, the ratio of R&D investment to the output is proportional. Thereby the firms have to decide

1. whether they imitate their successful competitors, i.e. they adopt a default technology which is used in the previous period,
2. or they innovate, i.e. they invest in search for a better technology.

In other words, more productive technologies can be obtained either by introducing new production processes or by mimicking the old ones. Therefore we also introduce here the according R&D ratios, r_{it}^{inno} for the innovation costs, and r_{it}^{imi} for the imitation costs per unit of capital. The total innovation costs R_{it}^{inno} and imitation costs R_{it}^{imi} for firm i at time t is therefore:

$$\begin{aligned} R_{it}^{inno} &:= r_{it}^{inno} \cdot K_{it} \\ R_{it}^{imi} &:= r_{it}^{imi} \cdot K_{it} \; . \end{aligned}$$

The R&D expenditure rate per unit of sales is r_{it}, with $0 \leq r_{it} < 1$. A minimal investment is necessary to keep alive the R&D potential (i.d. research equipment and R&D personnel). We therefore require $r_{it} \geq rd_{min}$. With r_{it} firms invest in each period a fixed proportion of their sales in R&D (in addition to the minimal amount of R&D). Since a firm can choose to innovate or to imitate, R&D expenditures are assumed to be a function of sales and can be either innovative (R^{inno}) or imitative (R^{imi}):

$$\begin{aligned} R_{it}^{inno} &= \alpha_i \cdot (r^{it} + rd_{min}) \cdot p_t \cdot Q_{it} \\ R_{it}^{imi} &= (1-\alpha_i) \cdot (r^{it} + rd_{min}) \cdot p_t \cdot Q_{it} \end{aligned}$$

with $0 \leq \alpha_i < 1$.

The R&D expenditure of firm i at one time t is then:

$$R_{it} = \begin{cases} R_{it}^{inno} & \text{in case of innovation} \\ R_{it}^{imi} & \text{in case of imitation} \end{cases} \tag{9}$$

Since firms can only either innovate or imitate at one time t, one of the values R_{it}^{inno} and R_{it}^{imi} is always equal to Zero. So we also can write equation (9) as follows:

$$R_{it} = R_{it}^{inno} + R_{it}^{imi} \ . \tag{10}$$

Innovation means firms search for a better technology which doesn't exist or isn't applied in the economy so far. Since the production techniques are embodied and there are no switching costs, the capital of the firm can be converted without any costs from one technology to another. So we only consider process innovation and no product innovation. The innovating firm does not replace its capital stock but uses is more efficiently. An innovation is therefor interpreted as a better knowledge of the production process. In other words, with innovation firms can only modify their efficiency parameters but not for instance the qualitative attributes of the output.

Imitation means firms regard the technologies applied in the economy, and if they found a better one, which grant them more productivity, and if they do not innovate, they adopt this technology in the next period.

Innovation

Innovation is a two-stage stochastic process. A first draw determines if the R&D investment has been successful and resulted in an innovation. The probability of such a draw is

$$Pr(d_{inno} = 1) := 1 - \exp^{-a^{inno} . \hat{R}_{it}^{inno}} \ , \tag{11}$$

whereby a^{inno} stands for the efficiency parameter for innovative R&D. This calibration parameter projects R_{it}^{inno} on $[0,1]$, is constant over time and identical for all firms. a^{inno} is industry-specific and an exogenous parameter of technological opportunities of innovative success. $\hat{R}_{it}^{inno}$ is the innovative research level of firm i at time t with

$$\hat{R}_{it}^{inno} = \psi_{inno} \cdot \hat{R}_{i,(t-1)}^{inno} + (1 - \psi_{inno}) \cdot (1 + r_{it}) \cdot \hat{R}_{i,(t-1)}^{inno} \ , \tag{12}$$

whereby ψ_{inno} can control the balance between the continuity of the research level and the research expenditure increase, $0 < \psi_{inno} < 1$.

The effective result of the innovation is found in the second draw. There are two possibilities concerning the result of innovation:

If we consider that innovation is a **cumulative process** and firms with higher productivities have a better chance to obtain higher productivities. The productivity in this case is:

$$A_{it}^{inno-cum} \rightsquigarrow \Theta_{lognorm}(A_{i,(t-1)}, \sigma^2) \ ,$$

whereby $\Theta_{lognorm}$ denotes the log normal distribution, with log mean given by $A_{i,(t-1)}$ and standard deviation σ. Log mean $= A_{i,(t-1)}$ means that innovative draws are based on firms' previous input productivity levels. Therefore we call this innovative process "cumulative". In this case, each firm is allowed to follow its own technological trajectory according to its R&D strategy.

In the case of **science based innovations** we have an evolution of latent productivity λ which comes from the R&D activity realized outside of the industry. The productivity in this case is:

$$A_{it}^{inno-sb} \rightsquigarrow \Theta_{lognorm}(\lambda_{it}, \sigma^2) \ ,$$

whereby the latent productivity λ_{it} is given by $\lambda_{it} = \lambda_{i,t-1} \cdot (1 + g_{it})^{a_{it}^{inno}}$, and the growth rate g_{it} associated with innovation.

The ***rule for innovation*** is described as follows:

For the case **"cumulative innovations"**:

```
    If     $\Theta_{binary}(Pr(d_{inno} = 1)) = \text{TRUE}$
    then   $A_{it}^{inno} := \Theta_{lognorm}(A_{i,(t-1)}, \sigma^2)$
    else   $A_{it}^{inno} := 0$
```

For the case **"science based innovations"**:

```
    If     $\Theta_{binary}(Pr(d_{inno} = 1)) = \text{TRUE}$
    the    $A_{it}^{inno} := \Theta_{lognorm}(\lambda_{it}, \sigma^2)$
    else   $A_{it}^{inno} := 0$
```

$\Theta_{binary}(\ldots)$ is a binary probability function and takes the value TRUE with the probability which has been putted in this function.

Imitation

Analogously we discuss the imitation process. At this we install the bounded rationality assumption: firms do not "see" all the possible existing alternatives. They only discover a subset of the total alternative set. This can be imagined as follows: only a certain number of technologies are "visible" to the firms and the others are accordingly "invisible". Only the visible technologies can be imitated by firms. If the firm is successful in the imitation draw, the best of the "visible" practices in the industry is obtained.

The probability for a imitative draw is given by:

$$Pr(d_{imi} = 1) := 1 - \exp^{-a_{imi} \cdot \hat{R}_{it}^{imi}} \ . \tag{13}$$

$\hat{R}_{it}^{imi}$ is the imitative research level of firm i at time t with

$$\hat{R}_{it}^{imi} = \psi_{imi} \cdot \hat{R}_{i,(t-1)}^{imi} + (1 - \psi_{imi}) \cdot (1 + r_{it}) \cdot \hat{R}_{i,(t-1)}^{imi} \ , \tag{14}$$

whereby ψ_{imi} indicates the balance between continuity of the research level and the increase of the expenditure rate, $0 < \psi_{imi} < 1$.

The ***rule for imitation*** is as follows:

If $\Theta_{binary}(Pr(d_{imi} = 1)) = \text{TRUE}$
then $A_{it}^{imi} := \Xi(\text{visible technologies } 1_t, \ldots, \#_t)$
else $A_{it}^{imi} := 0$

$\Xi(\ldots)$ is a function, which selects one technology of all applied technologies in the industry which are visible to the firm. The probability of selecting one technology is proportional to the capital which has been invested in this technology.

New productivity

The new productivity of firm i for the next period $t + 1$ is:

$$A_{i,(t+1)} = \max\{A_{it}, A_{it}^{inno}, A_{it}^{imi}\} \ . \tag{15}$$

3.4 Changes of the "routines"

In case of the Japanese economic situation from 1978 to 2000, we have the exceptional phase of the so-called *Bubble Economy*: Japan's extraordinary speculative boom of the 1980's and the dramatic bust of the 1990's (section 2.2).

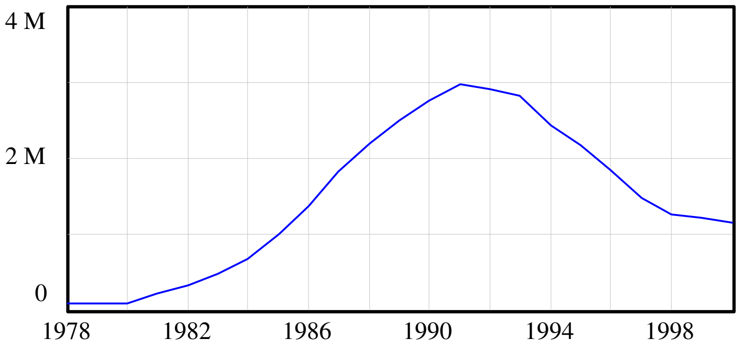

Figure 2: Development of total demand, from 1978 to 2000.

According to this, the demand function has the shape as shown in figure 2.

The beginning of the bubble economy is set in the simulation model for the year 1988, the end of this phase at the year 1993. This is done by introducing a status variable to indicate the changing of the economic situation. The firms react differently to this changing of the states.

The firms can change routines, i.e. their R&D expenditure rate per unit of sales, over time. This is one part of their strategies whereby each firm differs in it: We have individual strategies to define the dimension of the R&D expenditure rate depending firstly on a multiplier F related to the actual available human capital stock (Step 1) and secondly to the innovative behavior in the period before (Step 2).

Step 1: *R&D expenditure rate depending on Multiplier F*

The R&D expenditure rate is depending on their human capital stock, i.e.:

$$r_{it} = L_{it} \cdot F \ . \tag{16}$$

In times of an economic revival firms decide to increase their factor F about a multiple of s, individually determined, and in times of a cyclical downturn they reduce it analogously.

Step 2: *R&D expenditure rate depending on the previous innovative behavior*

The decision in $t+1$ concerning the modification of the R&D expenditure rate is also depending on their innovative behavior in the period t.

If the firm innovates in t, they achieve its highest productivity by performing a radical innovation, which means, they are entering a new technological paradigm. But their accumulated knowledge till t is concentrated to the old technological paradigm. Consequently, the firm cannot benefit from their full accumulated knowledge. They start at a more or less new position in the field of research, so that they have to spend more for R&D, i.e. they increase their R&D expenditure rate about the factor ϵ.

On the other hand, if the firm decides to imitate at t, the level of their capital stock will be kept, since they can profit of their accumulated knowledge. The R&D expenditure rate will be decreased about ϵ.

In the case of neither innovation nor imitation, the R&D expenditure rate will not be changed.

So we have for the change of the R&D expenditure rate:

$$r_{i,(t+1)} = \begin{cases} (1+\epsilon)\cdot r_{it} & \text{if } A_{i,(t+1)} = A_{it}^{inno} \quad \text{(e.g. in case of innovation)} \\ (1-\epsilon)\cdot r_{it} & \text{if } A_{i,(t+1)} = A_{it}^{imi} \quad \text{(e.g. in case of imitation)} \\ r_{it} & \text{if } A_{i,(t+1)} = A_{it} \quad \text{(else)} \end{cases}$$

Changes of the unit production costs

The unit production costs of the applied technology will also be changed according to the imitative and innovative steps.

A successful imitation means that the firm is able to imitate the best and visible practices in the industry. In this case, the firm chooses the technique with the lowest unit production cost:

$$c_{it}^{imi} = \min\{\tilde{c}_{1t}, \tilde{c}_{2t}, \ldots, \tilde{c}_{nt}\}$$

where analogously to eq. (2) $\tilde{c}_{it} = \frac{1}{u_{max}} \cdot \frac{m}{A_{it}}$ is the unit cost associated with the technique with the maximum efficiency within the set of visible technologies. Finally, the firm chooses between the existing technique and the best alternative resulting from the R&D effort according to:

$$c_{i,(t+1)} = \min\{\tilde{c}_{it}, c_{it}^{inno}, c_{it}^{imi}\} \tag{17}$$

3.5 Investment in physical capital

Investment in physical capital is the other source of dynamics in the model. Capital investment results directly from the arbitrage of firms between R&D investment and capital expansion.

The desired investment is depending on the price, the costs, and the market share of each firm. But such decisions must be financially feasible, i.e. the firm must be capable of paying for new capital goods either with its own and/or with borrowed resources, subject to a given precautionary demand for liquid assets. These financial variables are a constraint to the firm's desired investment. In other words, since these decisions are depending on their actual investing capability, the firms have to compare their actual margin with the target margin reflecting its market power.

Possible investment rate

The possible investment rate is for a negative gross profit rate the sum of the depreciation and the return on investment (ROI). For the positive case the firm can finance its desired investment by profit and also by borrowing from the financial system. So we have for the possible investment rate i^P:

$$i^P = \begin{cases} \delta + \kappa_{it} & \text{for } \kappa_{it} \leq 0 \\ \delta + (1+b) \cdot \kappa_{it} & \text{for } \kappa_{it} > 0 \end{cases} \tag{18}$$

where b, $b > 0$, is the interest rate for external financing via borrowed capital, and $\kappa_{it} = \frac{\Pi_{it}}{K_{it}}$ the return on investment (ROI).

Desired investment rate

The desired investment rate is putted in that way so that the investment overcompensates the depreciation of capital, and is depending of the ratio of production cost to price, market share and the return on investment (ROI).

The desired investment rate is:

$$i^D = 1 + \delta - \frac{\rho_{it}}{\mu_{it}}$$

whereby

$$\begin{aligned} \rho_{it} &= \tfrac{p_t}{c_{it}/A_{i,(t+1)}} && \text{(actual mark-up factor)} \\ \mu_{it} &= \tfrac{2\chi - MS_{it}}{2\chi - 2 \cdot MS_{it}} \cdot \kappa_{it} && \text{(desired mark-up factor)} \end{aligned}$$

χ, $\chi \geq 0$ is the lack of aggressiveness in investment strategy. So we have for the desired investment:

$$i^D = 1 + \delta - \frac{2\chi - MS_{it}}{2\chi - 2 \cdot MS_{it}} \cdot \frac{c_{it}}{p_t \cdot A_{it}} \cdot \kappa_{it}\ . \tag{19}$$

i^D is increasing with the market share, its capital resp. return on investment (ROI), and the costs, and is decreasing with the productivity of the firm.

Firms have a minimum level for the capital stock, K_{min}, which determines the boundary for the desired investment rate.

$$\begin{aligned} &\text{If} \quad (1 + \delta + i^D) \cdot K_{it} < K_{min} \\ &\Rightarrow \quad i^D := \tfrac{K_{min}}{K_{it}} - 1 + \delta. \end{aligned}$$

To sum up the investment decision, we have:

$$I_{it} = (\max\{0, \min\{i^D, i^P\}\}) \cdot K_{it} \ . \tag{20}$$

The capital stock of the firm at $t+1$ is then:

$$K_{i,(t+1)} = (1-\delta) \cdot K_{it} + I_{it} - R_{it} \ . \tag{21}$$

No investment, i.e. $i^P = 0$ or $i^D = 0$ leads to a decrease of the capital stock in equation (21) because of the depreciation of the capital.

Market concentration

For the development of the whole industry we take the Herfindahl-Index. Nelson and Winter (1982) use the reciprocal term of it which is interpreted as "number of firms in an industry of equal-sized firms that has the same degree of concentration as the actual industry".[6)]

According to Andersen (1996 [2]) it is necessary to distinguish between the Herfindahl-index of production H_t^Q and the Herfindahl-index of capital H_t^K. Both indices display different developments.

$$H_t^Q = \sum_{i=1}^{n_t} (MS_{it})^2 \tag{22}$$

$$H_t^K = \sum_{i=1}^{n_t} \left(\frac{K_{it}}{\sum_i K_{it}} \right)^2 \tag{23}$$

3.6 Market Exit

There are three reasons for a firm to decide to exit a market.

1. If the capital stock gets very small, the firm looses all possibility of innovation and growth. So if the capital stock becomes less than the minimum capital stock necessary to keep *alive*, the firm has to exit the market.

2. If the profits of the firm get persistently low, it can loose all possibility of investment and innovation. In this case, current profits do not permit any investments, and the capital stock of the firm vanishes because of the depreciation. So if the profit has been negative for $t^{\circledast}$ periods consecutively, the firm has to exit the market.

3. If the performance of a firm

[6)] Nelson and Winter (1982) [10], p. 301)

- is either negative at t at a simultaneously decreasing market share
- or has been negative for $t^{\circledast}$ periods consecutively,

the firm has to exit the market. The performance of a firm is measured by the output indicators for innovative activities, like the numbers of patents and numbers of scientific publications, which are exogenously given.

The performance indicator of firm i at t is given by

$$Z_{i,t} = \frac{Pat_{it} - Pat_{i,(t-1)}}{Pat_{it}} + \frac{SCI_{it} - SCI_{i,(t-1)}}{SCI_{it}} \; . \tag{24}$$

$Z_{i,t}$ denotes the growths both of the patents (Pat_{it}) and the publication output (SCI_{it}), whereby the negative growth of one indicator can be compensated by the positive growth of the other one.

A firm consequently exits the industry when one of the following conditions is fulfilled.

The ***rule for market exit*** is as follows:

If $K_{i,t} \leq K_{min}$
or $\Pi_{i,t} \leq 0$ for $t^{\circledast}$ periods
or $Z_{i,t} \leq 0$ and $MS_{it} < MS_{i,(t-1)}$
or $Z_{i,t} \leq 0$ for $t^{\circledast}$ periods

then Firm i exists the market, i.e. $K_{i,t^*} := 0$ for all $t > t^*$

The artificial delay of the negative influence of bad performance in the previous years, constructed with $t^{\circledast}$, can be controlled by varying the time span. The higher $t^{\circledast}$ is set, the lower the negative influence of bad performance, the more lethargical is the reaction of the market concerning the exit of the firm.

4 The Simulation of the Model with Vensim: Implementation and Results

The analysis of the outcomes of competitive dynamics is computed with a simulation model developed with Vensim, a system dynamic based simulation tool for constructing models of business, scientific, environmental, and social systems. The conceptual structure of the model, exemplary for the level of market structure, is shown in figure 3.

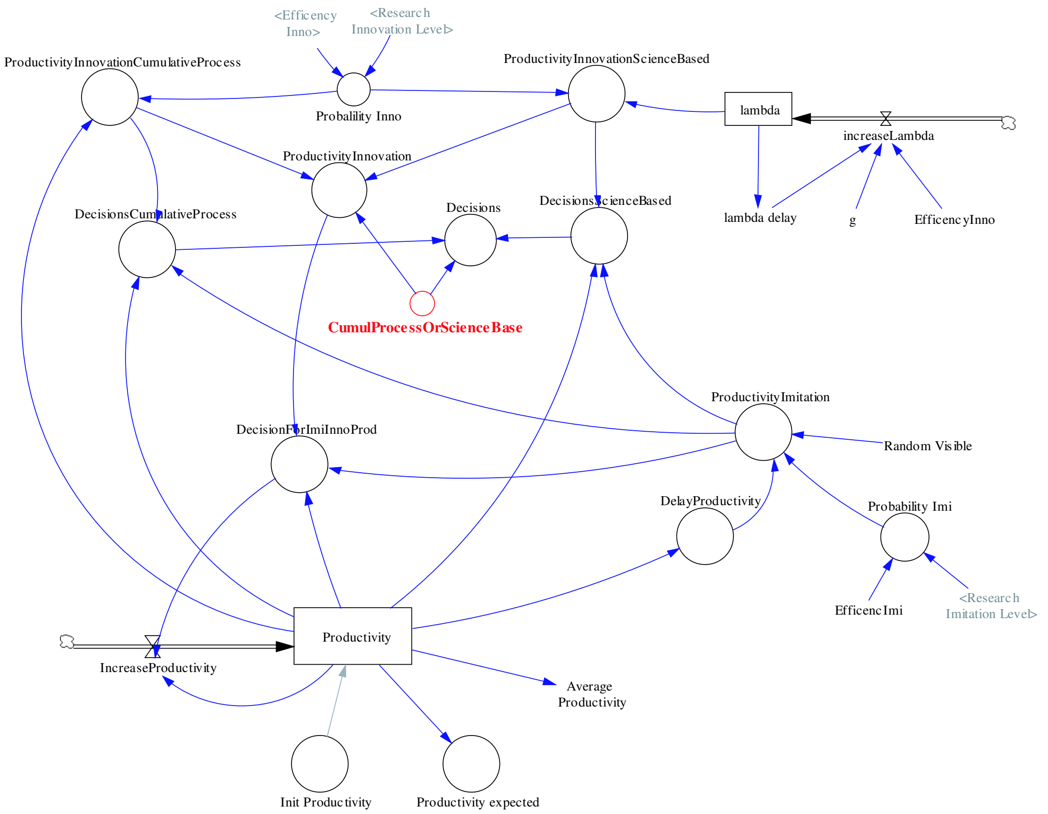

Figure 3: Implementation of the “productivity” in Vensim.

As the model developed in section 3 cannot be solved analytically due to the high degree of complexity and its stochastic character, several parameters are to be specified numerically (see appendix B). The numerical specification of the model show the intuition of the model, whereby the parameters are chosen at an empirically plausible level.

4.1 The Initial Settings for the Simulation and its construction

The simulation run is matched to the empirical data base: it contains 23 periods, from the year 1978 to the year 2000. The data are taken form the Japanese companies NTT, NEC, Toshiba, Hitachi and Fujitsu, representing the Japanese IT-sector. On account of protection of data privacy of the firms, we call them here firm 1 to firm 5. The data of these firms cover: net sales, net income, R&D expenditure, capital expenditure, number of employees, patents and publications.

At the beginning of the simulation, at time $t = 0$ (the year 1978), each firm i is characterized by the productivity of its technology ($A_{i,t=0}$), its labour employed in production ($L_{i,t=0}$) and its capital stock ($K_{i,t=0}$), which are taken from the empirical data base. The total initial values for the simulation are given in section B.

The characteristics of the five firms at $t = 0$ are:

$$\begin{array}{lcl} A_{i,t=0} & : & 0.16 \quad \forall\, i = 1, \ldots 5 \\ K_{1,t=0} & : & 45.000 \\ K_{2,t=0} & : & 70.000 \\ K_{3,t=0} & : & 106.000 \\ K_{4,t=0} & : & 200.000 \\ K_{5,t=0} & : & 1.500.000 \end{array}$$

The Development of labour of the five firms from 1978 to 2000 are exogenously determined as shown in figure 4.

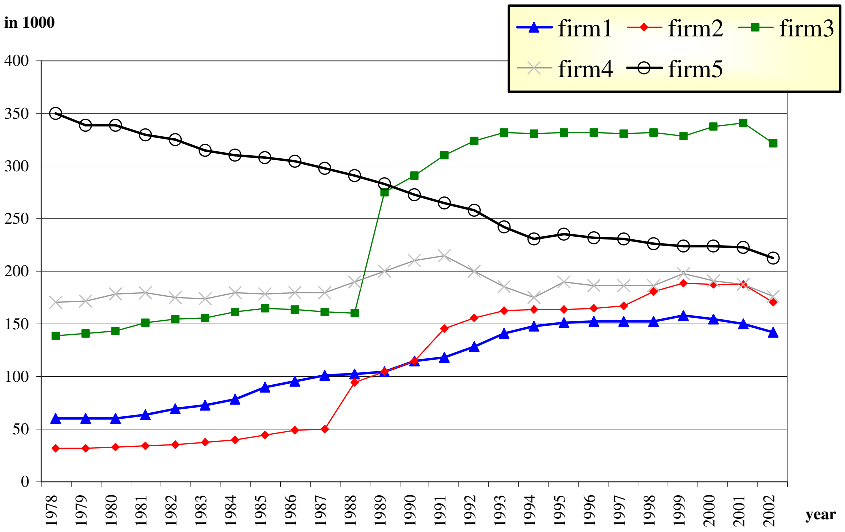

Figure 4: Development of labour of the five firms, from 1978 to 2000 (real data).

Starting here, all established five firms ($n_{t=1} = 5$) can generate innovation by searching for their best strategy.

For the setting of the R&D expenditure rate, firms can choose their individual factor F, which is related to their actual human capital stock (see section 3.4).

The individual strategies for changing the factor F depending on the actual economic situations are:

change of the factor F			
	before 1988	1988 to 1993	after 1993
Firm 1	$+2s$	$-s$	$-s$
Firm 2	$+s$	$-3s$	$-10s$
Firm 3	$+s$	no change	$-s$
Firm 4	$+s$	$+s$	$-s$
Firm 5	$-s$	$-s$	$-s$

The step s is 0.05. The initial values for F are:

	F
Firm 1	$5.41 \cdot 10^{-7}$
Firm 2	$19.72 \cdot 10^{-7}$
Firm 3	$2.43 \cdot 10^{-7}$
Firm 4	$2.94 \cdot 10^{-7}$
Firm 5	$2.31 \cdot 10^{-7}$

The construction of the research stage in the simulation model is shown in figure 5

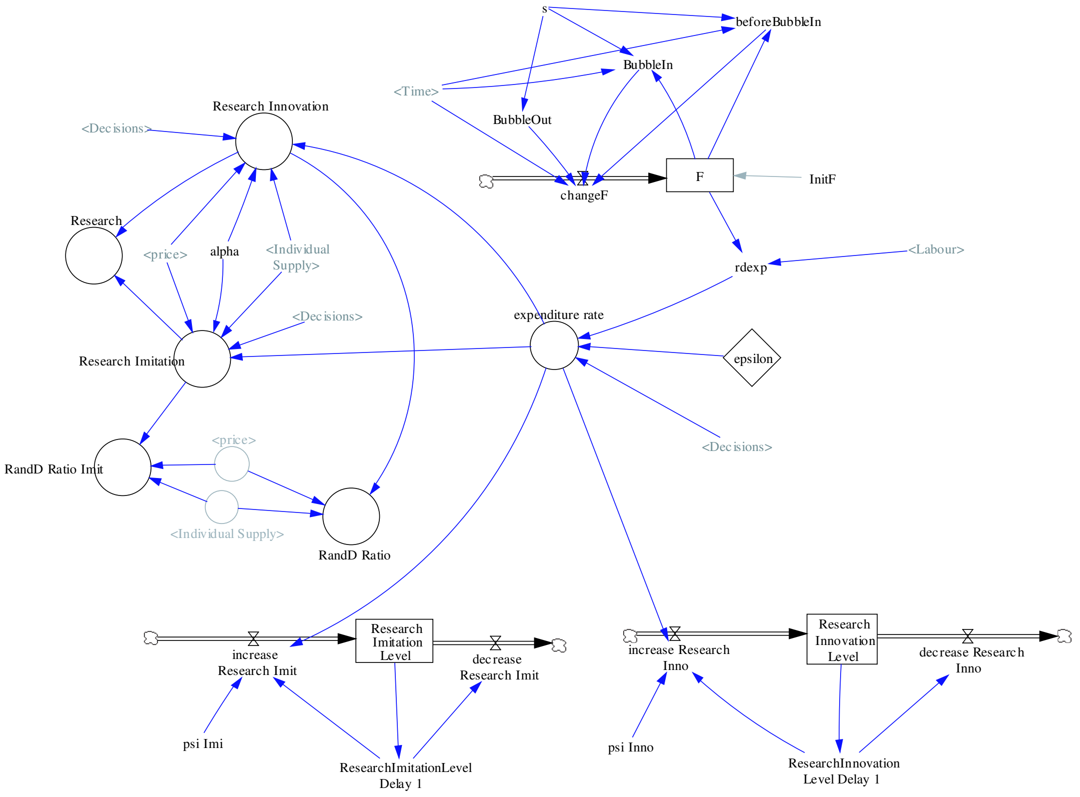

Figure 5: Implementation of the "research stage" in Vensim.

4.2 Results of the Simulation

After building up the simulation model and setting the initial values according to the real data set, we no have to ask the following questions:

Can the simulation trace the real development?

Can the simulation deliver positive results?

In this section we will look at the results of the simulation model, trying to compare these descriptively with the aim to judge the model by its qualitative results. The deeper analysis is not done in this paper, for the presented simulation model is in the fledgling stages.

For the beginning we will have a look on the development of the productivity as shown in figure 6.

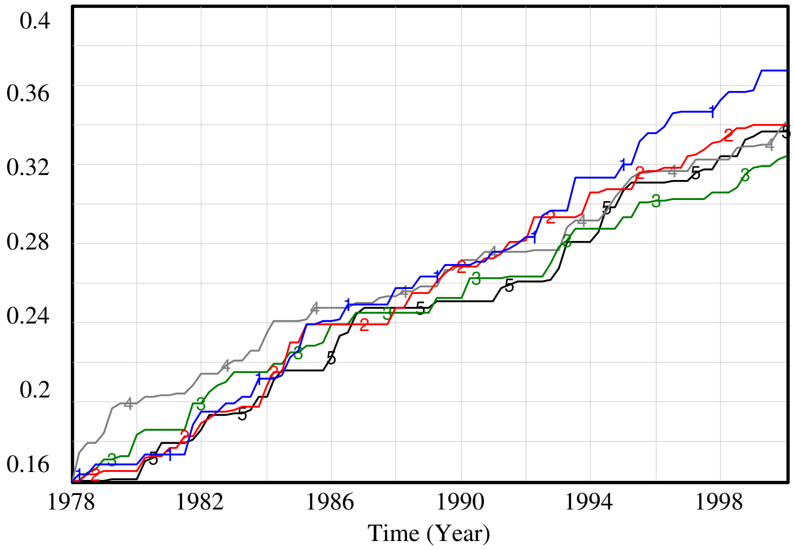

Figure 6: Development of productivity by the simulation model.

The productivity of all five firms grows as expected from the initial value 0.16 to at least 0.32 (firm 3) resp. 0.36 (firm 1).

The two figures 7 and 8 show the individual decisions of the firms concerning their innovative behavior. Thereby, stage 1 means to stay at their previous technological level, stage 2 to innovate, and stage 3 to imitate an existing technology. In the model, firms are not able to imitate at once the actual level of the other firms. A artificial delay of 2 years has been set.

The Strategic Decisions of the firms are to stay at their previous technological level (1), to innovate (2), or to imitate an existing technology (3).

So the three levels are:

1 staying at the previous technological level

2 innovation

3 imitation

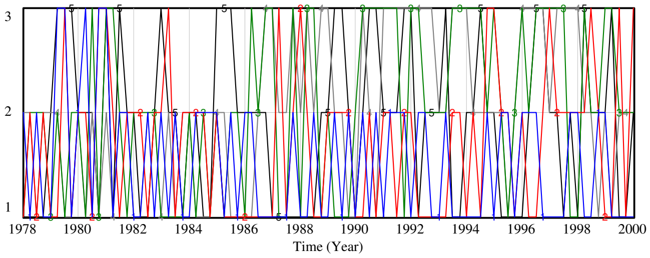

Figure 7: Strategic Decisions, for the the case of **cumulative innovations**.

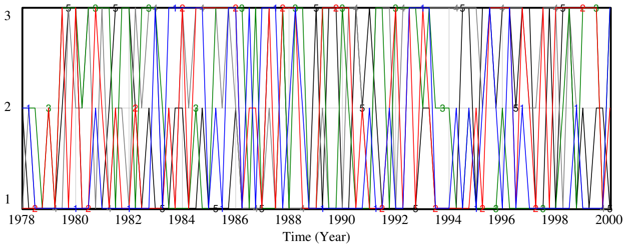

Figure 8: Strategic Decisions, for the case of **science based innovations**.

It is obvious that in the science based case, the firms imitate more compared to the cumulative case. The reason for that could be find in the growth of the latent productivity, which is not given for the first case. In the case of science based innovations we have an evolution of latent productivity λ as given in equation (13). The latent productivity comes from the R&D activity realized outside of the industry, i.e. the firms do not rely on their previous activities like in the cumulative case, but on the given λ from the market.

Now we will look at the development of the R&D expenditure rate of the five firms. As shown in figure 9 and figure 10 the simulation model is able to trace the real development. That gives us confirmation that the strategies for the simulation model as given in table 4.1 are chosen correctly.

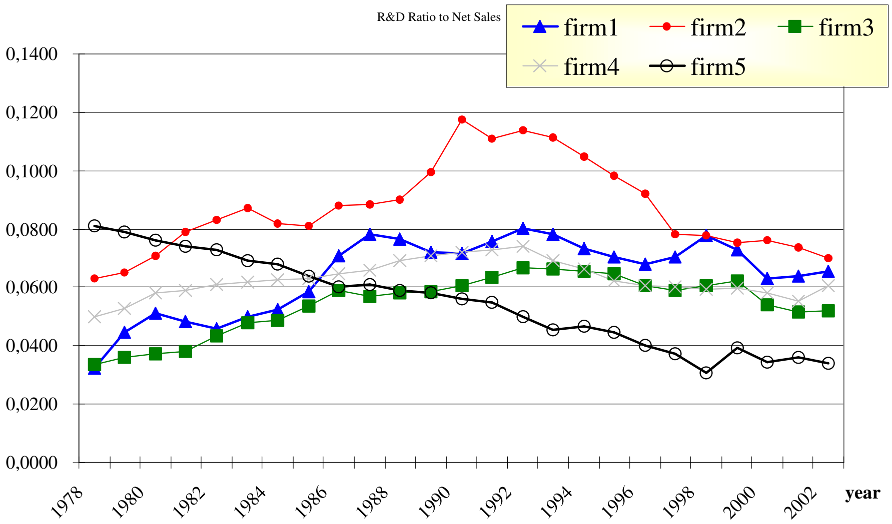

Figure 9: Development of R&D expenditure rate of the real data.

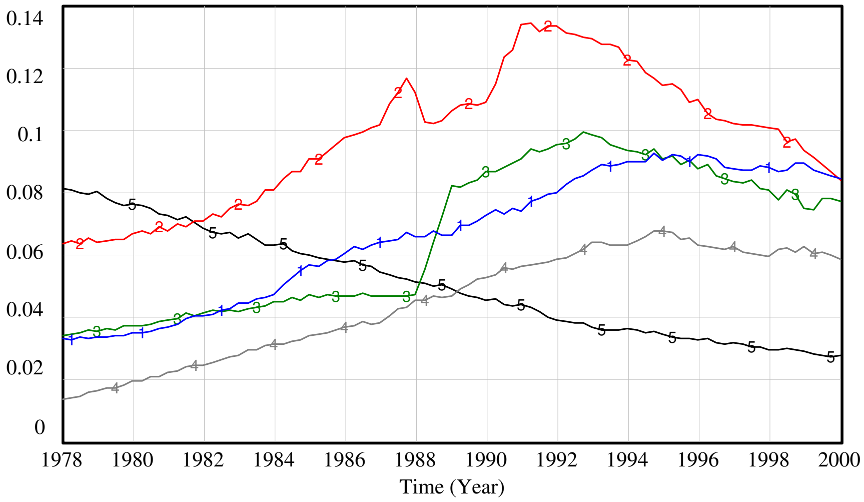

Figure 10: Development of R&D expenditure rate by the simulation model.

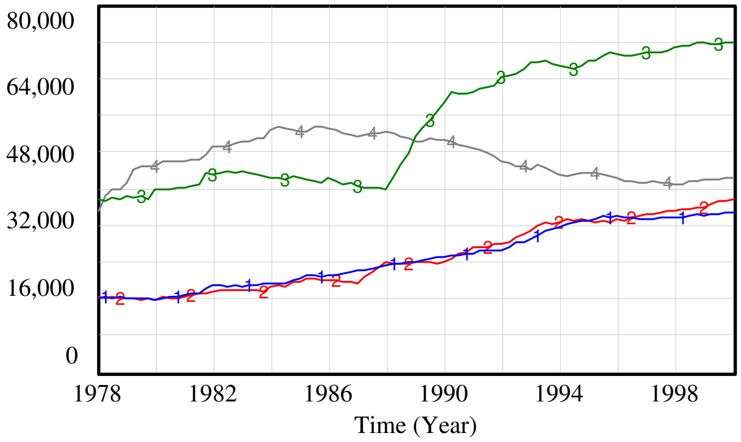

Figure 11: Development of the individual supply of the firms 1 to 4 by the simulation model.

Capital development

What happens to the development of capital of the firms?

Figure 12 shows the real development of capital of the five firms.

The figures 13 and 14 show the development of the capital for the five firms which is calculated by the simulation, here the case of **cumulative innovations**.[7]

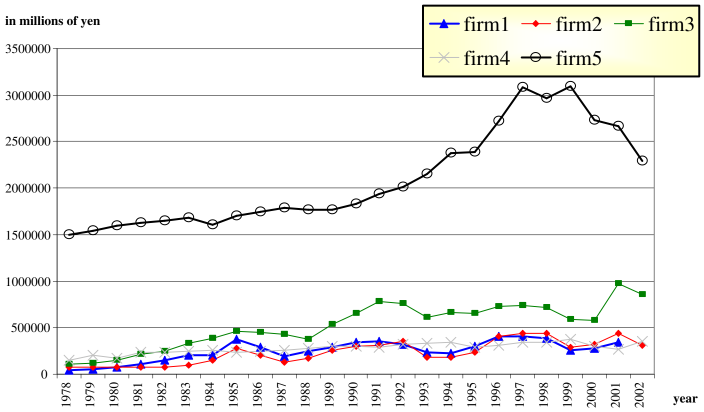

Figure 12: Development of capital with real data.

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[7] The case of **science based innovations** delivers quite similar trends and characteristics.

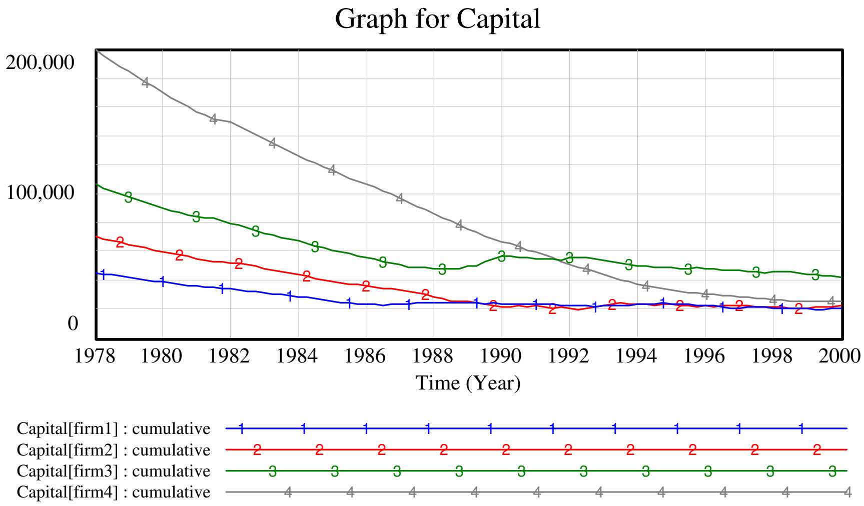

Figure 13: Development of the capital for the firms 1 to 4.

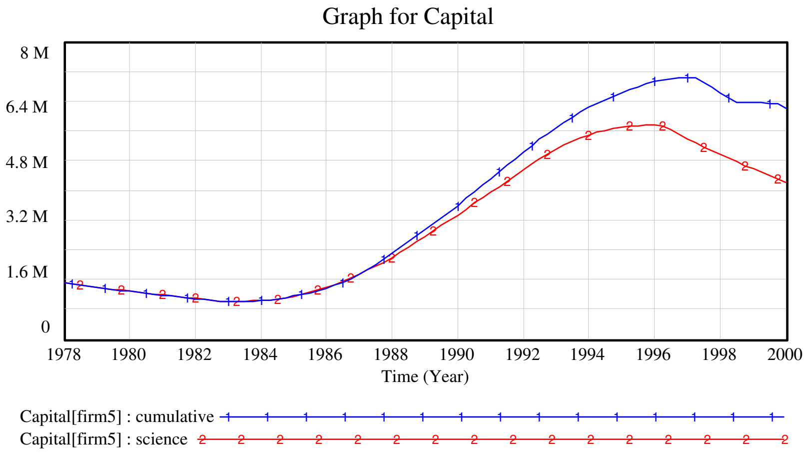

Figure 14: Development of the capital for the firm 5.

The comparison of the different developments by real data and by the simulation model draws the conclusion that the model is fitted adequate so far concerning the results of outcome of innovation and production process.

The simulation is able to trace the decision of the firms concerning their R&D investment and their innovation strategies. We have seen this in the development of the R&D expenditure rate. The routines are changed in that way, so that firm's investment behavior resembles the real behavior, at least concerning the trend. And by changing the "learning speed" the simulation can describe variants of results.

Additional conclusions cannot be made here at this point. The model presented in this paper is in its infancy so that further analysis are too early.

5 Final Remarks

In this paper we explored specific questions derived from evolutionary economics: the evolution of routines, the adaption of the R&D decisions of firms emerging from imitation and selection processes.

We have found through the simulation model that firms learn and adapt their routines, and adaptive learning can result in incremental improvements or change in existing competencies. In varying the learning speed, firms can change both their adoption and their innovation rate which has again an influence on their R&D status for the following periods. The dynamics underlying evolutionary theory is further supported by the finding that decisions at the present and also the status to stay in the market or to exit the market, is depending not only actual status but on their past development. So *history matters*, i.e. their accumulated knowledge is a base for their actual decision and economic performance.

Finally we can see with the simulation that none of the firms reported a dramatic transformation of their routines, consistent with the cultural and institutional characteristics of the organizations and environment in Japan. The persistence of the firms, i.d. the economic survival of the firms in spite of their negative performance in the past shows the typical situation in Japan, that firms with long company tradition are not automatically forced to exit the market through the selection process. So a slackness of the market reaction could be demonstrated by the simulation model.

The empirical findings reported in this paper are limited by nature of the data set available. The time series cover merely a interval from 1978 to 2000 with only five firms. We do not have complete information on the size and sector of the firms. Empirical studies of innovating firms show different patterns by size and sector (Pavitt 1984 [12], Melerba and Orsenigo (1996) [9]). So to represent the whole industry adequately, it becomes necessary to extend the time series and to combine this micro-level with macro-level data to get the dynamic impact concerning the economic outcome at the industry level.

It is obvious that more detailed analysis and adjustments of the model are necessary. The model presented in this paper is only a starting point with the very first results. Elements like market entry conditions are not included in this model. An advanced mechanisms for this must be considered. In addition, a deeper investigation, especially a more matched mechanism for the organizational routines for the firms is needed. Additional studies are required to advance knowledge of internal firm dynamics and of the structure and processes of the routines, according to these the firms are acting.

A Summary of the parameters

K_{it} : capital of firm i at time t
K_{min} : minimal capital of the firm, required for survive
L_{it} : labour of firm i at time t (Human Capital)
A_{it} : productivity of firm i at time t
p_t : price per unit of output at time t, $p > 0 \wedge p = \frac{D}{Q_t}$
Π_{it} : Profit of firm i at time t
κ_{it} : Return on investment (ROI) of firm i at time t
MS_{it} : Market share of firm i at time t
n_t : number of firms manufacturing at time t
v : variable costs per unit of output, v¿0
r_{nat} : natural interest rate
δ : depreciation rate, $0 < \delta < 1$
m : capital costs per unit of physical capital, $m > 0 \wedge c = \delta + r_{nat}$
D : demand
η : demand elasticity
Q_{it} : output of firm i at time t
Q_t : total supply of the whole industry with $Q_t = \sum_{i=1}^{n_t} Q_{it}$
i^D : desired investment rate
i^P : possible investment rate
b : interest rate for external financing , $b > 0$
c_{it} : unit production cost of the actual technology of firm i at time t
π_{it} : gross profits rate of the firm i at time t
Π_{it} : gross profits of the firm i at time t
u_{it} : efficiency of firm i at time t with $0 < u_{min} \leq u_{max} \leq \infty$, $u_{min} \approx 0$ but $u_{min} \neq 0$
z_i , ν_i^k : learning speed of the firm i at time t, the higher the value the faster the learning process
τ_i^e : period where firm i enters in the industry
τ_i^k : period where technology k is selected
$(t - \tau_i^e)$: age of the firm i, number of periods during which firm i uses technology k
$k \in \mathbb{R}$: position of the learning curve
r_{it}^{inno} : innovation costs per unit of capital for firm i at time t
r_{it}^{imi} : imitation costs per unit of capital for firm i at time t
R_{it}^{inno} : innovation costs for firm i at time t
R_{it}^{imi} : imitation costs for firm i at time t
$\hat{R_{it}}^{inno}$: innovative research level of firm i at time t
$\hat{R_{it}}^{imi}$: imitative research level of firm i at time t
a^{inno} : efficiency parameter for innovative R&D
a^{imi} : efficiency parameter for imitative R&D

ψ_{inno} : weight parameter for innovative R&D level, $0 < \psi_{inno} < 1$
ψ_{imi} : weight parameter for imitative R&D level, $0 < \psi_{imi} < 1$
R_{it} : R&D expenditure of firm i at time t
$\lambda(t)$: latent productivity int the case of science-based innovation with the growth rate g_{it}
Pat_{it} : number of patents of firm i at time t
SCI_{it} : number of publications of firm i at time t
Z_{it} : Performance indicator of firm i at time t

B Specification for the simulation

A_{i0}	$0.16 \quad \forall\, i = 1, \dots n_0$
n_0	5
L_{it}	exogenously determined $\forall\, i = 1, \dots n_0$
K_{i0}	exogenously determined $\forall\, i = 1, \dots n_0$
K_{min}	5
z	random$[0.4; 0.6]$
ν^k	random$[0.3; 0.45]$
ω	random$[60; 80]$
u_{max}	2
v	0.115=11.5%
$D(Q_t)$	according to the demand development in the industry
η	1
δ	0.08=8%
r_{nat}	$0.015 = 1.5\% \Rightarrow m = 0.08 + 0.015 = 0.095 = 9.5\%$
rd_{min}	$0.03 = 3\%$ (minimum expenditure rate)
r_{i0}	$0.02 = 2\%\ \forall\, i$ (initial expenditure rate)
ψ_{inno}	random$[0.4; 0.6]$
ψ_{imi}	random$[0.4; 0.6]$
a^{inno}	0.25
a_{imi}	0.55
Pr_{inno}^{init}	0.80 (Initial Probability for Innovation)
Pr_{imi}^{init}	0.72 (Initial Probability for Imitation, 90% of $Pr(d_{inno} = 1)^{init}$
$\hat{R_{i0}}^{inno}$	6.5
$\hat{R_{i0}}^{imi}$	0.75
g_{it}	random$[0.03; 0.1]$
ϵ	random$[0.01; 0.03]$
χ	1
$t^{\circledast}$	7
Pat_{it}	exogenously determined $\forall\, i = 1, \dots n_0$
SCI_{it}	exogenously determined $\forall\, i = 1, \dots n_0$

C Empirical data

The empirical data are based on interviews with following firms (in alphabetic order, not connected with the order of labelling the firms in the simulation model):

Fujitsu Limited
6-1, Marunouchi 1-chome, Chiyoda-ku, Tokyo 100-8211, Japan.

Hitachi, Ltd.
6, Kanda-Surugadai 4-chome, Chiyoda-ku, Tokyo 101, Japan.

NEC Corporation
7-1, Shiba 5-chome, Minato-ku, Tokyo 108-8001, Japan.

Nippon Telegraph and Telephone Corporation (NTT)
3-1, Otemachi 2-chome, Chiyoda-ku, Tokyo 100-8116, Japan.

Toshiba Corporation
1-1, Shibaura 1-chome, Minato-ku, Tokyo 105-8001, Japan.

The patent information are obtained by the Japan Patent Office (JPO), based on JAPIO (Japan Patent Information Organization database)
3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100, Japan.

The number of publications of the firms are researched at the National Institute of Science and Technology Policy (NISTEP): 1-3-2 Kasumigaseki, Chiyoda-ku, Tokyo, 100-0013, Japan.

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