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Routinized Innovations -

Dynamic Capabilities in a Simulation Study

by

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1. Introduction

Joseph Alois Schumpeter (1942) has been among others prominent for emphasizing that innovative activities of firms are to be considered as active and intended search processes for new technological possibilities and opportunities rather than solely accidental events. Although this statement has been a first attack on neoclassical general equilibrium theory it has been the neoclassical camp itself who presented an approach to formalize these ideas; the *new industrial economics* (Arrow (1962), Dasgupta/Stiglitz (1980), Reinganum (1985)) was bom. Within a traditional cost-benefit framework the conditions for an optimal allocation of R&D resources are derived. For doing so, however, this approach has to rely on several strong assumptions where infinite technological opportunities, perfect capabilities, perfect foresight and full information combined with weak uncertainty are the most crucial ones. Only on this basis optimal solutions can be obtained and respective firm strategies derived.

This neoclassical development, however, has been critized by modem innovation theory, which claims that the neoclassical assumptions on opportunities, information and uncertainty do neglect the very nature of the innovative process: opportunities are not abundant, information is far from perfect, uncertainty is strong, capabilities are heterogeneous and far from perfect. On this basis, the strategic behaviour of firms is not only to be seen as a response to other firms' actions - a play against competitors as in traditional industrial economics - but also as a device to play a *game against nature.*

Within this context, where strategies are not readily computable, one has to ask according to what rules do firms behave, how do they shape their strategies. The concept of *procedural rationality* (Simon (1976), Dosi/Egidi (1991)) explains the behaviour of actors in only very weak computable environments with a high degree of uncertainty. Accordingly, actors do not globally optimize their decisions but they follow certain *routines* which provide for satisficing outcomes. In order to cope with this kind of behaviour the decision-theoretic approach of neoclassical innovation theory has to be replaced by an alternative theory, the *behavioural approach.*

On this basis our paper investigates how different routines of innovative behaviour perform. The design of those routines is derived from the technological environment a firm faces, i.e. opportunities, uncertainty and appropriability conditions, from economic factors such as profits and sales, as well as from the individual capability and willingness to cope with (technological) uncertainty. Principally, the ‘constructed’ routines contain fixed and flexible components, where the former are labbeled *strategies* and the latter *learning rules.* Three different strategies are investigated: the *absorptive strategy* where the ability to use technological spillovers plays the central role, the *conservative strategy* which acts rather in isolation and relies only on own R&D, and the *imitative strategy* which, contrariwise, relies not on own R&D but tries to catch up by imitating best-practice technologies.

With a routine-based modelling of innovative activities our analysis cannot look for equilibrium solution but relies on simulation experiments in the tradition of Nelson/Winter (1982). Under different conditions and different flexible routines we show that the absorptive strategy is very likely to dominate other strategies in the long-run. Moreover, we find that learning rules focussing on technological rather than economic performance accelerate the speed of technological progress considerably.

Our analysis proceeds as follows: In section 2 we discuss the theoretical foundations where we explicitly introduce and explain the different strategies and the motives behind them. Section 3 describes the simulation model. Section 4 shows the most important results of different simulation runs. We close our discussion with some concluding remarks in section 5.

2. The Design of R&D-Srategies

One of the major attempts of modem innovation theory is to provide new insights in the process of technological change by dismissing the simplifying assumptions of traditional economic theory. There the assumption of abundant technological opportunities, appropriablity conditions, perfect capabilities, information and foresight combined with an only weak uncertainty provide that innovative activities are boiled down to an optimal R&D allocation game against competitors. Here, technological progress banned into a *black-box' is designed in a way to allow for optimal cost-benefit calculations. Dissmissing with these assumptions and taking into account that technological progress is also *a game against nature,* it is not at all clear how firms design their R&D policies.

In the following we investigate how different innovation strategies as found in the literature perform in a comparative analysis. For this purpose we first briefly discuss the technological environment firms are facing. Based on this, the second step provides a characterization of different R&D-strategies.

2.1. Supply-Side Factors Influencing Innovation

The saying that innovative activities are (also) a *game against nature,* and thus against the unforseeable, suggests that firms invest resources mainly in order to acquire more information which allows for better decisions and improved performance. This is done in a technological environment which is not a 'black-box', but which has its own structural and dynamic features. Since the 80's modem innovation theory has been mainly engaged in investigating those environments which show the following main features:

- *technological uncertainty*

The search for new technologies and even the improvement of existing technologies are risky and uncertain endeavours. This uncertainty intrinsic to the innovation process makes it impossible to predict innovative results: on the one side firms try to find new technological solutions in their production processes with ex-ante not anticipated consequences, on the other side, new unforeseen discoveries external to a firm open totally new combinations of different and seemingly unrelated technologies.

- *technological opportunities*

The developmental potential of a single technology is increasingly exhausted with progress on this technological trajectory. According to 'Wolff's Law' these 'intensive technological opportunities' (Coombs (1988)) are depleted step by step. Therefore, technological as well as scientific boundaries more and more come into effect which make further improvements increasingly difficult and sometimes even impossible to achieve.

Besides intensive opportunities characterizing a single technology there are also 'extensive technological opportunities' which arise out of *cross-fertilization* of different technologies (Mokyr, J. (1990)). New technical solutions are often created by new combinations of several already existing technologies. Sometimes the amalgamation of ex-ante unrelated technologies leads to totally new technological fields, mechatronic or bionic are points in case. Therefore 'structural tensions' (Dahmen (1989)) between complementary technologies may be solved in the course of time providing for new technological opportunities and a continuous although uneven technological development.

Those mutual interdependencies have quite a number of different sources: Besides new ideas and findings in academia the manifold effects between up- and downstream productions between firms within branches as well as between different industries are potential sources of such *cross-fertilization.* Those mutual influences come mainly into effect by technological spillovers. These spillovers are possible whenever new technological know-how is not a purely private good and thus not entirely appropriable by the innovating firm.

- *appropriability conditions*

A successful inventor should realistically anticipate receiving something less than the total benefits arising out of his innovation.[1] Imperfect appropriability conditions are responsible for the benefits of other firms from his innovative efforts. Whereas in mainstream economics this is the reason for a suboptimal innovative activity[2], modem innovation theory regards imperfect appropriability conditions in a totally different way by emphasizing the *idea-creating* features of knowledge spillovers.

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[1] See e.g. Winter, S.G. (1989).

[2] The fundamental reference is Arrow, K. (1962).

The main argument for imperfect appropriability conditions are the 'latent public good' features of newly generated technological know-how. To a great extent this knowledge is only partly excludable and non-rival, making R&D laboratories of firms the potential source of mighty spillovers. Accordingly, this has different impacts on the incentives for R&D. On the one hand, other firms can eventually use the new knowledge, and this will of course reduce the respective incentives to undertake costly innovative endeavours. On the other hand, this leakage of own know-how is compensated for by the opportunity to use know-how of other firms. The latter argument underlines the complementary character of R&D and is also based on the assumption of bounded rational behaviour of agents which leads to the perception that innovative activities do not follow a common optimizing concept but they are to be taken as local search processes where specific cumulative experiences, knowledge, and competences as well as lock-in effects play an important and determining role.

Even within a branch this neccessarily leads to a significant heterogeneity of firms applying fuzzy sets of technologies. Because of this 'technological pluralism' specific R&D projects are not only substitutes but often they provide for synergies and complementarities. Exploring new technical combinations with unforseen impacts and uncertain results could help to overcome restrictions imposed by Wolff's Law. Here, however, technological constraints, heterogeneity and uncertainty leads to the impossibility of an globally optimizing behaviour. Instead firms have to try to struggle in other ways in competitive environments characterized by a continuously changing technological framework. In order to do so, firms design certain strategies which will be discussed in the following.

2.2. Firm Strategies to Cope with Innovation

The rate of technological progress is not God given but driven by uncoordinated behaviour of firms which try to improve their technologies or to introduce new ones. The restrictions raising out of technological heterogeneity, uncertainty, and constraints are -as just mentioned- indeed responsible for an abandonment of the global optimization principle. This, however, does not imply that there are no longer regularities in firm behaviour. In their decisions firms do not randomly allocate R&D budgets and select by chance certain research directions. Instead they are guided in a cumulative manner by their past experiences and their already built up capabilities. The resulting behaviour is consequently neither unique nor optimal and can be described by the concept of routines.

- routines

Strong regular patterns in the innovative activities of firms suggest to describe the innovative behaviour as 'routinized' (Nelson, Winter (1982)). Firms are operating in environments characterized by an increasing spectrum of market and technological possibilities which make it possible to overcome single technical restrictions. Although there exists technological uncertainty with respect to the results of their actions, firms have economic expectations. Hence, within the above restrictions and constraints firms are able to design different strategies (Freeman (1982)) in which they decide how to use their technical skills and their resources for different options to cope with the innovation process.

These strategic decisions are guided by a 'procedural rationality' (Simon (1976)). Not abstract questions how to measure the marginal productivity of R&D expenditures are on the agenda of firms, but questions on reasonable procedures for fixing these quantities are to be answered. Therefore, we simply regard R&D decision rules as behavioural patterns which cannot be explained by optimization, but by reference to historical circumstances and evolutionary development. Firms design and adjust their routines by the means of learning and adapting towards their changing environments. In this perspective firms are learning organizations, constrained by their cognitive capabilities (Heiner (1988)). They do not completely know the set of actual and future opportunities open to them and therefore cannot choose the best alternative but are constrained to more or less local opportunities.

- exploitation vs. exploration

The introduction of new technologies, the improvement of existing ones, learning how to adjust behaviour according to changed circumstances, and imitation of other successful actors are the most important components of improving the firms' performance and strengthen the competitive advantage. Modem organizational theory treats this as a trade-off problem between the exploitation of existing, and exploration of new opportunities (Winter (1971), March (1991)). Typically included in exploration are behaviours like search, variation, risk taking and experimentation, whereas exploitation means refinement, production, efficiency and execution. This is also reflected in the comparison of the returns from exploration which are less certain and more remote in time with respect to the returns from exploitation. In the following we introduce three general behavioural patterns and show that exploration and exploitation find a variety of expressions in different routines.

- *the conservative strategy*

One possibility to struggle in the innovation process is a self-sufficient 'conservative' strategy[3] which concentrates all innovative efforts exclusively on own research. This strategy neglects external technological developments in so far as it only invests in the refinement of its own opportunities. Thus, the technology and know-how it requires for growth and competitiveness are generated in isolation. Nevertheless, the impact of Wolffs Law is paid tribute to in directing the innovative efforts in exploitation of the existing technology i.e. process improvements and in exploration of new technologies i.e. product innovation.

- *the imitative strategy*

Firms applying the imitative strategy[4] do not devote resources in explorative search. Their main goal with respect to introducing new technologies is the attempt to imitate the most successful methods generated elsewhere instead of trying to innovate by themselves (Winter (1986)). The principle behind this strategy is to be seen in the exploitation of external knowledge and opportunities with respect to process as well as product technologies. This strategy does not imply the absence of R&D expenditures. Contrariwise, imitative firms can be as research intensive as other firms. But they are not willing to explore risky new opportunities. They want to avoid failure and even more learn from failures of competitors. Therefore they are confident with not being technological leaders but keeping up with the technological pace. According to Freeman (1982) the imitative strategy is a kind of insurance for the respective firms. It enables them to react and adapt to technical change introduced by competitors.

Imitation becomes possible whenever new technological know-how is not completely appropriable by the innovating firm. Under regimes of total non-appropriability of the know-how of products possibly to be imitated, an imitative firm has the advantage of knowing and learning ex-ante that the aim of its imitative efforts is a workable solution. But technological knowledge typically is characterized by specificity, tacitness as well as by cumulative learning. "In such cases 'technology transfer' may be as expensive and time consuming as independent

[3] In the literature, for this strategy the notion 'go-it-alone strategy' is used alternatively. See Fusfield, HI., Haklish, C.S. (1985).

[4] Freeman, C. (1982) alternatively uses the notion 'defensive or dependent strategy'.

R&D"[5]. Therefore, it is the very nature of technological knowledge that makes also imitation a costly endeavour. In these cases of limited access to the technology being imitated, it is very unlikely that imitation yields the same technological results as the original innovative technology[6].

- *absorptive strategy*

Firms applying the absorptive strategy decide to use a sophisticated mixture of explorative and exploitative search. On the one hand they undertake research endeavours aiming at two goals which are also targeted by conservative firms: they exploitatively improve their production processes and exploratively introduce product innovations. On the other hand, they additionaly exploit external knowledge sources which are available in technological regimes characterized by at least not perfect appropriability.

Above the potential beneficial idea-creating effects of spillovers have been introduced. Despite these potential effects it is far fetched to believe that spillovers are no problem anymore and can always easily be integrated in the knowledge stock of a receiving firm. Just contrary, firms with an absorptive strategy do not devote the whole R&D budget in direct research endeavours, but invest a significant share for the purpose of scanning the general technological development[7]. Doing this, they expect synergistic benefits which help to overcome restrictions imposed by Wolffs Law.

Contrary to imitative firms absorptive firms do not simply copy a successful technology, but try to integrate external knowledge in order to create additional technological opportunities. Contrary to conservative firms, not the total R&D budget is spent in improving the own technology. Absorptive firms have to trade off short-term benefits of exploiting own opportunities with a mixture of a long-ranged exploring and exploiting of external technological possibilities. In this respect, those firms can avoid, at least in a dynamical perspective, the consequence stated by organization theory that 'exploitation of existing knowledge reduces the capabilities and the speed with which new alternatives can be explored* (Levinthal, March (1981)).

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[5] Nelson, RR. (1990), p. 197.

[6] See Winter, S.G. (1986).

[7] Cohen, W. and Levinthal, D. (1989) state in this respect: "When a firm wishes to acquire and use new knowledge that is unrelated to its ongoing activity, then the firm must dedicate exclusively to creating 'absorptive capacity* (i.e. 'absorptive capacity' is not a by product)." p. 129.

Following the above characterization of the innovative process, investing in absorptive capacity in technological heterogeneous environments is done in order to exploit extensive technological opportunities by understanding the content of knowledge spillovers. Therefore, investing in absorptive capacity is not immediately targeted towards a specific well described research purpose. In a way, investing in absorptive capacity is done for some precautionary motives allowing to be prepared for some unforeseen technological developments. In this context Cohen and Levinthal (1994) refer to the words of Louis Pasteur *"Fortune Favours the Prepared Mind."*

In reality a clear discrimination between the stylized strategies introduced above clearly is not possible. This is due to several reasons: building up absorptive capabilities is sometimes a kind of by-product to normal R&D activities, especially with respect to technologies which are characterized by small technological distances. In these cases conservative as well as imitative firms acquire the capabilities to understand and use know-how connected with these neighboured technologies. But with increasing technological distances the God-given absorptive capabilities decrease and direct efforts to acquire complementary knowledge become unavoidable. Unexpected and therefore not already realized synergetic benefits out of the combination of quite close technologies are less probable than those arising out of the combination of seemingly different technologies. Of course, in reality firms will apply an opportunistic mixture of these strategies, some with more emphasis on conservative attitudes and others emphasizing more absorptive or imitative attitudes. For analytical purposes we will, however, distinguish those strategies clear-cut.

3. The Simulation Model

In this section we present a model of dynamic oligopoly in which firms do not only compete in the market, but also influence each other by their innovative activities. The firms under consideration belong to three 'camps' each characterized by a fixed strategy: one group is applying the conservative strategy neglecting technical development created outside the own firm boundaries. The next group behaves according to the imitative strategy, does not innovate itself, and tries instead to imitate the most successful technologies of the competitors. The third group are the absorptive firms which attempt to integrate research results created by others to support own R&D endeavours.

In order to represent market relationships we choose a model of heterogeneous oligopoly as found in Kuenne (1992). Here n firms (indexed with i, i = {1,..,n}) differ in their production processes and in their produced qualities. Despite firms are continuously confronted with uncertainty and myopically try to improve their technologies, they are assumed to be able to optimize their purely economic decisions statically. In this respect they know the demand functions and can construct reaction functions based on the economic decisions of their competitors. This modelling strategy allows to focus on the technology side of behaviour whereas the economic decisions are represented by a well understood oligopolistic setting[8]. The model of heterogeneous oligopoly is standard and described in more detail in Cantner/Pyka (1995). Regarding the production techniques we assume constant returns to scale, consequently unit costs $c_i(t)$ are independent of the produced output. Concerning the technology side of the model the following building blocks are relevant:

- *R&D investment decisions and learning rules*

Besides mere production firms devote periodically investments $r_i(t)$ to research, development and imitation in order to secure or even to enlarge their market shares. Since the development of a new technology and even the improvement of an existing one is a risky and uncertain endeavour, R&D decisions are guided by 'procedural rationality' allowing firms to learn and adapt their routines to changed environments. The respective routines determine a share of turnover $\gamma_i(t)$ which firms invest in R&D.

In our model we distinguish two different methods of adjusting those routines. The first learning rule uses as a reference criteria an economic indicator, the return on turnover $\beta_i(t)$.

(1a) $$\gamma_i(t) = \gamma_0 + \omega\left(\frac{\overline{\beta}_t - \beta_i(t)}{\overline{\beta}_t}\right)$$

γ_0 := initial value; ω := exogeneous rate of adjustment;
$\beta_i(t)$:= rate of turnover; $\overline{\beta}_t$:= average rate of turnover;

Whenever the own return on turnover is lower (higher) than the market average rate the firm does rise (reduce) its share $\gamma_i(t)$. The second learning rule does not look at an economic indicator but uses relative technological positions with respect to process technology $RP_i^{PC}(t)$ and product technology $RP_i^{PD}(t)$. Both indicators are restricted to]0,1] with a value of 1 indicating the leading position.

[8] Keeping in mind our investigation goal the market framework should be not too complicated. Of course there are more realistic and in an evolutionary sense better suited market representations (e.g. mark-up pricing models etc.), which, however, are not in the center of interest of this paper.

(1b) $\gamma_i(t) = \gamma_0 + \omega[1 - \frac{RP_i^{PC}(t) - RP_i^{PD}(t)}{2}]$

The share $\gamma_i(t)$ determining R&D efforts is increased or decreased according to the respective technological position. In a sense both learning rules represent a kind of satisficing behaviour. If the own position, whether economical or technological, is unsatisfactory an adjustment mechanism with respect to the periodical R&D investments should ensure the catching up. We are comparing the effects of these different learning rules in the following simulations.

Firms deciding to implement the absorptive strategy additionally have to decide on the respective share $\sigma_i(t)$ of the R&D-budget they invest in building up absorptive capacity $ac_i(t)$. It is plausible to assume that firms on the technological frontier cannot learn much from their competitors. Accordingly, they adjust their investment in absorptive capacity due to their relative technological position. Equation (2) formally describes this decision rule:

(2) $\sigma_i(t) = 1 - \left[RP_i^{PD}(t) * RP_i^{PC}(t)\right]$ $\quad 0.05 \leq \sigma_i(t) \leq 0.2$

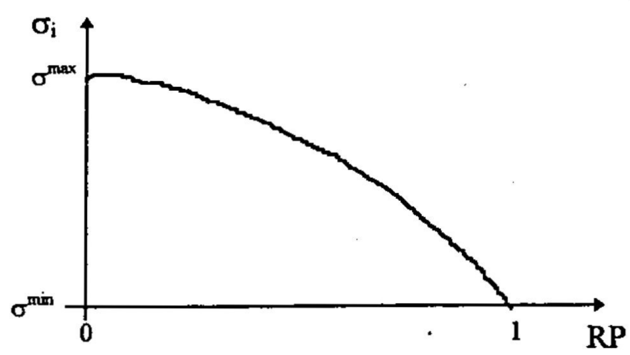

Fig. 1

There are upper and lower bounds for variable $\sigma_i(t)$: a minimum level, at which firms always invest in absorptive capacity due to exogenous spillovers from sciences and inter-industrial spillovers, and a maximum level, because firms do not reduce their own R&D below a certain level. Figure 1 shows this decision rule in a simplified way ($RP_i^{PC} = RP_i^{PD}$).

- *Process innovation*

On the one hand the R&D and imitative endeavours of firms are directed to process innovations in order to make production techniques more efficient. Therefore process innovations are represented by unit cost reductions. To reach a certain technological level the preceding levels have to be passed through, because otherwise the relevant technological understanding cannot be achieved. Therefore, to represent the cumulative feature of technological progress the periodic R&D investments $r_i(t)$ sum up to a R&D capital stock $R_i(t)$. Besides R&D activities the rate of technological progress depends also on the degree of exhaustion of the intensive technological opportunities. According to Wolff's Law every further development of a single technology is increasingly confronted with technical boundaries and bottlenecks. To model this feature we assume positive but decreasing innovative success $ie_i(t)$. To take account of technological uncertainty, the occurence of such a success is determined stochastically by an equally distributed random number ψ_t. The innovative success $ie_i(t)$ translates with a time-lag of one period in unit cost reductions.

(3) $$c_i(t) = c_0 * [1 - ie_i(t-1)]$$

c_0 := initial value of unit costs

For the <u>conservative</u> firms the equation describing process innovation looks as follows:

(4) $$ie_i(t) = 1 - \mathrm{Exp}[-\alpha * R_i(t)] \quad and$$

$$ie_i(t) = \begin{cases} ie_i(t) & for \quad f(R_i(t)) \geq \psi_t \\ ie_i(t-1) & for \quad f(R_i(t)) < \psi_t \end{cases}$$

α := bending of the innovation success; $\quad \frac{\partial f}{\partial R_i} > 0; \quad \frac{\partial f^2}{\partial^2 R_i} < 0; \quad f(R_i) = 1 - e^{-\alpha R_i}$

For the <u>absorptive</u> strategy spillover effects and the ability to use them are relevant. In our model the spillover effects are generated endogenously. For process spillovers the variance of the unit costs $s(t)^2$ of the different firms is taken as a proxy for spillover potentials. The absorptive capacity $ac_i(t)$ neccessary to integrate the knowledge content of spillovers has to be accumulated like the stock of R&D-capital:

(5) $$ac_i(t) = \sum_t \sigma_i(t) * r_i(t)$$

Of course, the adoption of externally created technological know-how in the form of spillovers is also a cumulative process. This implies that the potential impact of spillovers is increasing with the accumulation of absorptive capacity and the increasing informational content of the spillovers already integrated[9]. In the model this is reflected by a non-linear process, which should show the threshold effect of the impact of additional information, if the necessary basis is already built-up[10].

Additionally, for using spillovers the technological distance to the leader is relevant[11]. For small distances, there is not much new a firm can learn, it masters the technology on its own. On the other side, firms which fall very far behind are not able to keep up with the pace of technological leaders, the respective knowledge becomes too specific. But for inbetween gaps the spillovers have the highest impact because these firms need and could use the respective information. In the model we distinguish between technological gaps with respect to product $G_i^{PD}(t)$ and process $G_i^{PC}(t)$ technologies.

The impact of technological spillovers on the innovative success $F[G_i^{\bullet}(t)]$ is described by equation (6)[12] and graphically depicted in figure 2.

$$(6) \qquad F[G_i^{PC}(t)] = RP_i^{PC}(t) * Exp[-\frac{RP_i^{PC}(t)}{ac_i(t)}]$$

$F[G_i^{PC}(t)]$:= spillover function (process technologies);

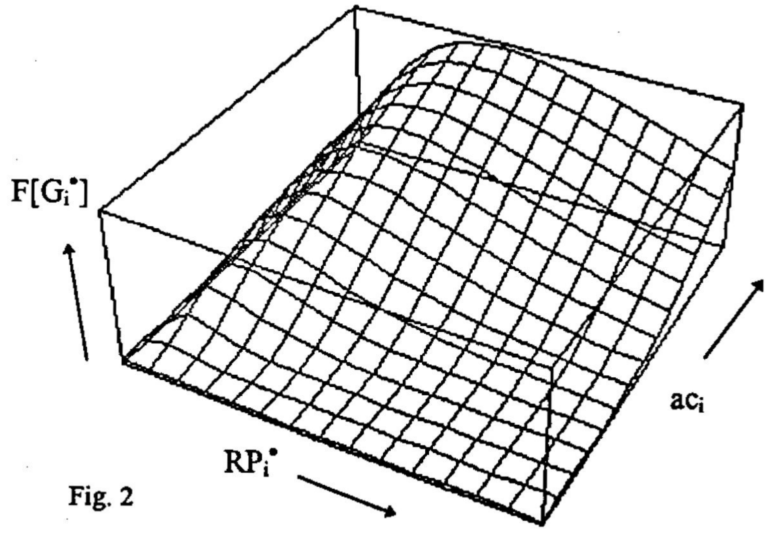

Fig. 2

[9] „... limited competence is caused by the imperfect ability to use information, which is to be distinguished from the usually considered case of imperfect information.", Pelikan, P. (1992), p. 383.
[10] „Learning is a process by which repetition and experimentation enable tasks to be performed better and quicker and new production opportunities to be identified.", Dosi, G., Teece, D.J., Winter, S. (1992).
[11] There is empirical evidence that the technological gap determines the capability to internalize spillover effects. Verspagen (1992) and Cantner (1995) found a bell-shaped relation between the technological gap and the ability to integrate knowledge spillovers.
[12] If in the spillover function (6) the technological gap G_i^{PC} is substituted with the gap in product technology G_i^{PD} we get the spillover function with respect to product innovation.

The function of innovative success for process innovations (4) by applying the absorptive strategy is modified by a term containing the spillover pool $s(t)^2$ and the spillover function $F[G_i^{PC}]$ as a weight for the R&D capital stock:

$$\text{(7)}\qquad ie_i(t) = 1 - \mathrm{Exp}[-\alpha \frac{\xi + s(t)^2}{1 + \mathrm{Exp}\{\tau * d_i(t) - F(G_i^{PC}(t))\}} * R_i(t)] \quad \textit{and}$$

$$ie_i(t) = \begin{cases} ie_i(t) & \textit{for} \quad f(R_i(t)) \geq \psi_t \\ ie_i(t-1) & \textit{for} \quad f(R_i(t)) < \psi_t \end{cases}$$

$$\text{(8)}\qquad d_i(t) = [1 - \varepsilon * ac_i(t)^2] * (1+\theta)^t$$

ε := scaling parameter; τ := difficulty in building-up absorptive capacity;
θ := learning-parameter; $d_i(t)$:= impact of absorptive capacity;
ξ := interindustry spillovers and feedbacks from the sciences;

When building up absorptive capabilities a learning process will take place: On the one hand there are experiences with respect to the richness of different spillover sources and on the other hand an advantage in experience with the integration of external knowledge should be expected. In the model this learning as well as the accumulated absorptive capacity determine the term $d_i(t)$, which describes the specific increase in the impact of absorptive capacity.

Imitative firms try to improve their production processes by imitating the most successful technologies ie_{t-1}^{max} of their competitors. Because they are imitating already workable technologies their endeavours are not confronted in the same way with risk and uncertainty like the innovative efforts of other firms. Nevertheless, at least some degree of appropriability suggests a stochastic determination of their imitative success. Equation (9) describes the imitative success $pcimit_i(t)$ of those firms:

$$\text{(9)}\qquad pcimit_i(t) = ieit_{t-1}^{max} * \mu_t^{PC} * [1 - \mathrm{Exp}(-\alpha * R_i(t))]$$

$ieit_t^{max}$:= max of innovation success of innovative firms;
μ^{PC}_t := equal distributed random number; $\mu^{PC}_t \in [0.8,1]$

- Product innovation

Besides improving production processes firms are assumed to engage in product innovations. The effect of a product innovation is reflected by a quality improvement, which shows up a twofold effect: First, the mutual price dependence of the oligopolists decrease with higher heterogeneity in quality levels. Second, successfull product innovations change prohibitive prices $a_i(t)$. The innovating entrepreneur produces a higher quality connected with an increase in consumers' assessment. Other firms experience a decrease of their prohibitive price, because this innovation decreases the relative qualities of their products.

The uncertainty envolved in those endeavours is quite different from the one we assume for process innovations. Whereas the direction and impact of process innovations along certain trajectories can be roughly expected, this does not apply to product innovations. In the literature this context is described with the notion of 'intrinsic' uncertainty: If somebody knows the results of innovative endeavours ex ante, it is no longer a product innovation. In order to model this quite different feature of product innovations we use a poisson-distributed random number. This probability distribution, which in the literature is often called 'the distribution of the low probability for happenings with a low probability', seems to be adequate with respect to product innovations.

The R&D efforts devoted to product innovations are again represented by the stock of R&D capital $R_i(t)$. By this stock firms accumulate success probability $pr_i(t)[.]$, which approximates asymtotically the mean value of the poisson distributed random number. The increase of success probability for <u>conservative</u> firms is characterized by positive, but decreasing rates:

$$(10) \quad pr_i(t)[PDI = 1] = 1 - Exp[-\alpha \ * R_i(t)]$$

$$PDI = \begin{cases} 1 & \text{for } pr_i(t) \geq \rho_t \\ 0 & \text{for } pr_i(t) < \rho_t \end{cases}$$

ρ_t := poisson distributed random number
PDI := binary variable, which takes the value 1 in the case of success

<u>Absorptive</u> firms take into account the idea-creating effects of spillovers. Their probability for a product innovation is supported by learning from product spillovers. The respective spillover pool is given by the variance $s_a(t)^2$ of the prohibitive prices $a_i(t)$. The stock of R&D-capital is again weighted with the spillover function $F[G_i^{PD}(t)]$ and the spillover pool. This should reflect

the cross-fertilization possibility of technological spillovers in connection with product innovations.

$$(11)\quad pr_i(t)[PDI=1]=1-Exp[-\alpha*\frac{\xi+s_a(t)^2}{1+Exp[\tau*d_i(t)-F[G_i^{PD}(t)]}*R_i(t)]$$

$F(G_i^{PD}(t))$:= spillover function (product technology);

<u>Imitative</u> firms do not face the same uncertainty when they attempt to introduce a new product. They engage in imitation only, if one of the competitors successfully introduced a new product. Then they accumulate a success probability in the following manner:

$$(12)\quad pdimit_i(t)[PDI=1]=[1-Exp(-\alpha*R_i(t))]$$

$$PDI=\begin{cases}1 & \text{for } pdimit_i(t)\geq\mu^{PD}_t\\ 0 & \text{for } pdimit_i(t)<\mu^{PD}_t\end{cases}$$

μ^{PD}_t := equal distributed random number; $\mu^{PD}_t \in [0.95,1]$

- *Obsolescence*

Whenever a firm succeeds in introducing a product innovation the knowledge to master the old technology is assumed to become irrelevant. Therefore the old stock of R&D capital will be totally depreciated every time a product innovation occurs. The new technology shows full technological opportunities and consequently a large potential for new process innovations.

For an enterprise which decides to invest in absorptive capacity a product innovation bears two additional consequences: The absorptive capacity like the stock of R&D capital becomes obsolete and will be depreciated. Also the learning variable $d_i(t)$ will be set back to the initial value.

4. Simulation Results

In our simulation experiments we are dealing with an oligopoly containing 15 firms[13]. According to the three different strategies these enterprises are subdivided into three 'camps'. For each simulation run of 200 periods we assume that all firms start with identical unit production costs and product qualities which are assessed equally by consumers. To avoid distortions due to the several stochastic elements we run all simulations 30 times and calculate

[13] The different parameter values are listed in the appendix.

the respective averages. Additionaly, we only present average results of the different groups. For the following discussion we first investigate the performance of the different strategies. In a second step we compare the impacts of the two different learning rules[14].

- The strategies' performances

The following figures show the development of profits for the different strategies[15]. In figures 3a and 3b firms behave according to the technological learning rule (1a) and the economical learning rule (1b) respectively.

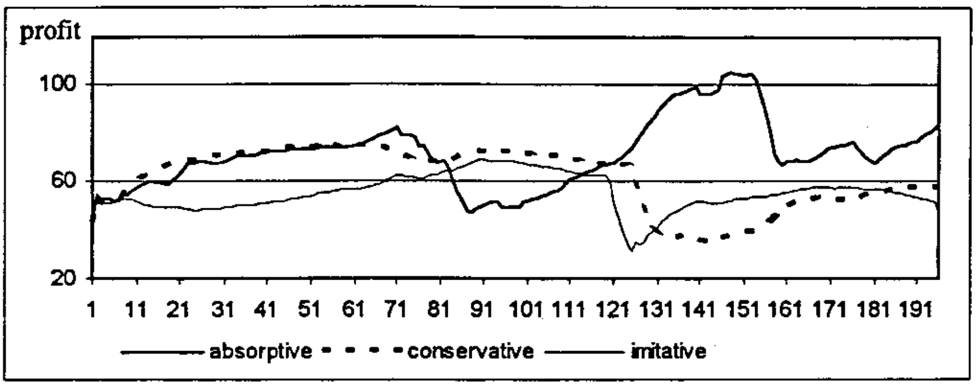

Fig. 3a

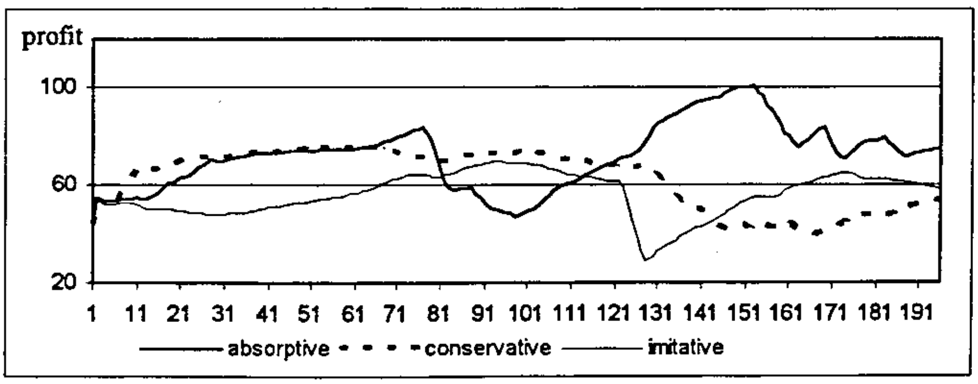

Fig. 3b

In the beginning the periodic profits of the absorptive and the imitative firms are clearly below the ones of the conservative camp. Conservative firms are able to exploit the intensive technological opportunities faster. By the ongoing exhaustion of intensive opportunities the absorptive firms are technologically catching up which soon leads to a narrowing of profits between these two strategies. Contrary to conservative competitors struggling with nearly

[14] The robustness of the different simulation results is tested in Cantner/Pyka (1995). Therefore two additional scenarios were investigated. The first scenario is a regime of high appropriability and therefore low spillover pools. In the second scenario we lower the oligopolistic interdependence. This scenario comes close to a situation where the firms can be considered as different industries technologically connected by inter-industry spillovers. Our basic results hold under these changed settings.

[15] We show 5-periods moving averages to make the respective curves somewhat smoother because they represent an aggregation over different firms and 30 simulation runs.

depleted opportunities absorptive firms finally are able to explore new technological potentials with the help of know-how created outside their own laboratories and transferred by technological spillovers. Technologically this effect is depicted in the additional sharp decrease of the best-practice unit cost frontier (I) shown in figure 4 for the technological learning rule.

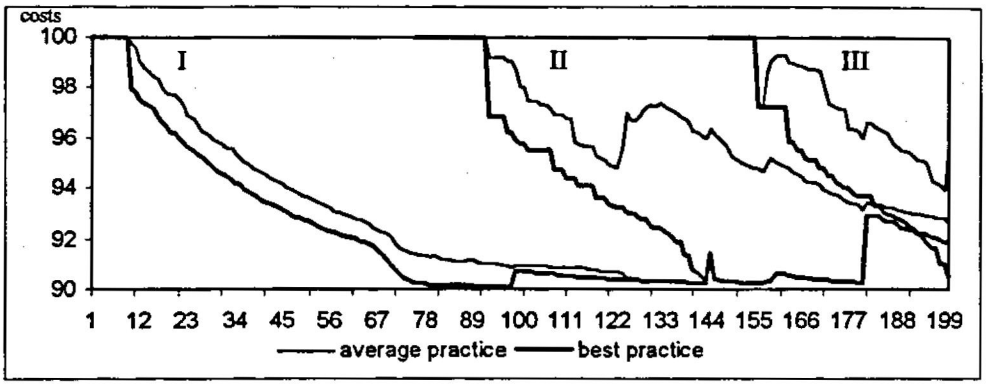

Fig. 4

With respect to periodic profits absorptive firms leapfrog their conservative competitors and are now in the leading profit position. During this period imitative firms are on the last profit position. They are confident with imitating the technological improvements of their competitors and therefore technologically lag behind. Nevertheless, due to imitation they are able to increase their periodic profits continuously.

Obviously, the ability of absorptive firms to exploit external knowledge also supports innovative endeavours aiming at product innovation[16]. Because of their capability to integrate know-how of technological spillovers these firms are the first to introduce a product innovation. On the new technological trajectory they are confronted with high unit costs depicted by the best-practice unit cost frontier (II) in figure 4. This product innovation and the corresponding jump on a new trajectory leads to an initial profit erosion which, however, does not last long. Despite the higher quality and the higher consumers' assessment of product II, in the beginning of that product cycle conservative and imitative firms are able to attract some demand of the absorptive firms because of high unit costs there. But with relatively fast cost reductions due to new technological possibilities absorptive firms are able to gain the leading profit-position again just some periods later. The technological gap of imitative and conservative firms on the second trajectory increases, because they are still lagging behind in introducing product II. These increasing technological advantages finally provide for the high

[16] The effects of absorptive capacity on product innovations are described in detail in Cantner/Pyka(1995).

profit margins of the absorptive firms. Despite introducing a third technology later on, they keep their leading profit position.

On the second trajectory the self-sufficient conservative firms technologically are lagging even behind the imitative firms who earlier introduce the new technology II. This technological advantage of the imitative strategy translates in an economic one and even with respect to profits they leapfrog their conservative competitors. Later on, however, the conservative firms are successful in catching up.

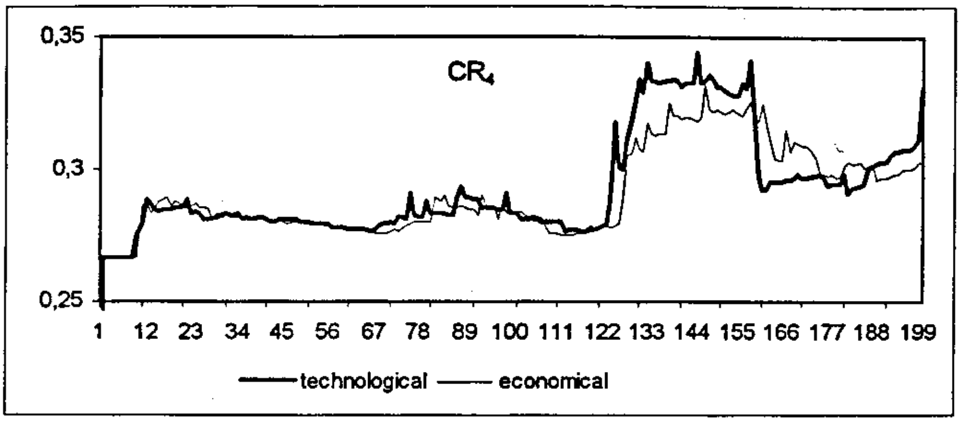

Fig. 5

These technological and economical processes are also reflected in the concentration ratio of our heterogeneous oligopoly. Figure 5 shows the development of the CR_4-index of our two learning rules. The increase in concentration in the beginning is induced by the innovative most successful conservative firms and the falling behind of the imitative firms. But very soon the absorptive firms are catching up technologically which in turn leads to a decrease in concentration. This trend changes again when absorptive firms are leapfrogging the conservative ones. In the following periods the successfull product innovation of absorptive firms is responsible for temporarily growing market shares of conservative and imitative firms. Up to this period the four largest firms are composed of both camps, absorptive and conservative. But with increasing success on the second trajectory only absorptive firms are used for CR_4. Due to their innovative success their economic success is not only dependent on higher consumer assessment connected with higher prices but also on increasing market shares.

Another possibility to compare the different strategies is to investigate the respective 'R&D effectiveness'. Here, one has to distinguish between success in process and product innovation. Concerning the latter, always firms following the absorptive strategy are the first to introduce a new product. With respect to process innovations the following figure 6 shows for the three strategies the relationship between the periodic R&D-budgets and the resulting cost-reductions. The learning rule applied here is the technological one, however, the results by and large apply also to the scenario with economic learning. To interpret these figures, observations are represented by 'sun-flowers'. The number of patels of each sun-flower gives an account of the number of observations falling in a certain intervall.

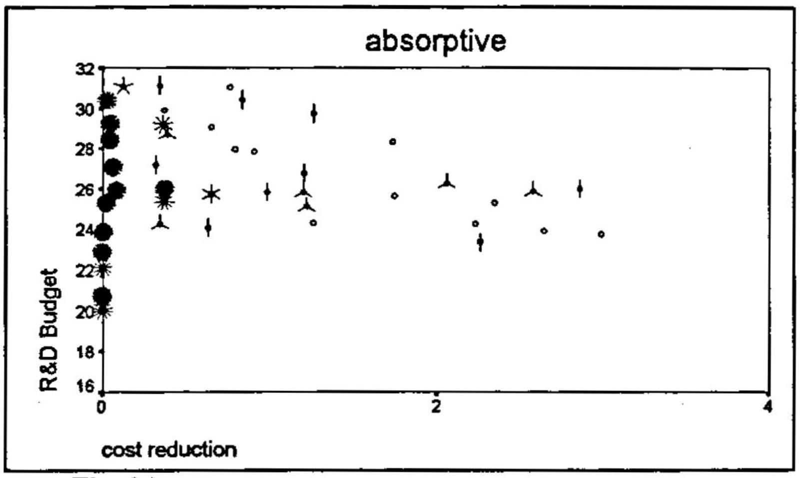

Fig. 6a)

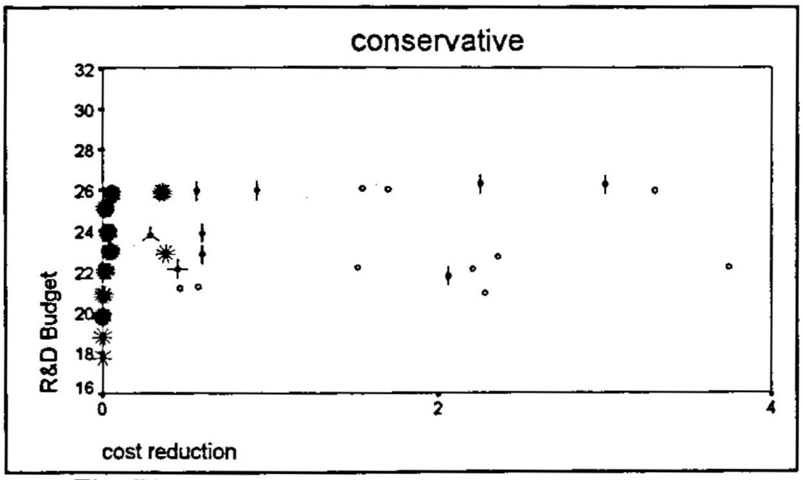

Fig. 6b)

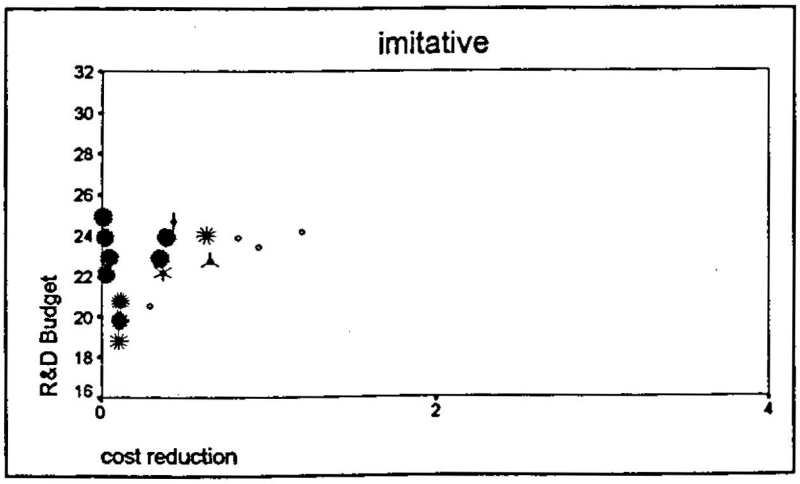

Fig. 6c)

The following results are interesting: First, the average R&D-budgets are higher for the absorptive group, because on the average they are more profitable and have higher market shares. Second, the R&D-success of absorptive firms is higher for the absorptive firms than for the other groups. This is caused mainly by three effects:

(1) Higher R&D-budgets allow for higher R&D-stocks and consequently for higher R&D-success probability.

(2) A considerable share of the R&D-budgets is spent for absorptive capacity, which allows to exploit externally generated know-how (with equivalent effects on R&D-success probability).

(3) Finally, since these firms are more often opening up a new product cycle they exploit depleted intensive opportunities not too long, but they can 'enjoy' the refreshed opportunities on the new trajectory.

- *Comparing the different learning rules*

After the introduction of the first product innovation, in the scenario of the technological learning rule the share of the old technology is decreasing relative fast. This is shown in figure 7a illustrating the product cycles. Firms lagging behind the technological leaders are increasing their R&D expenditures to catch up technologically. Consequently, some periods later one after another firm quickly introduces a new technology.

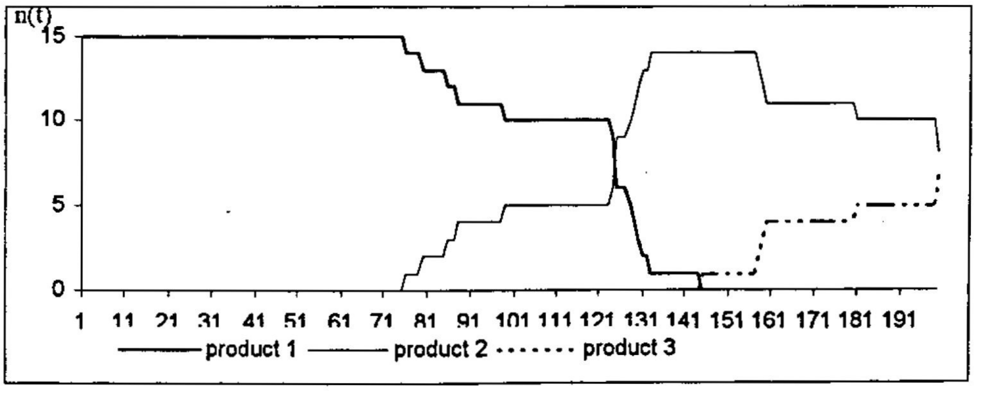

Fig. 7a)

Contrary, in the scenario of the economical learning rule firms lagging behind in jumping on the new trajectory can temporarily increase their periodic profits due to the switching problems of the successful innovators. Doing this, they are able to increase their rate on turnover with a negative effect on their R&D endeavours. This is illustrated in figure 7b showing the product cycles for this scenario. One can observe larger overlapping phases of the different product technologies. Some firms still stay on the first trajectory when their competitors are opening up the third product cycle.

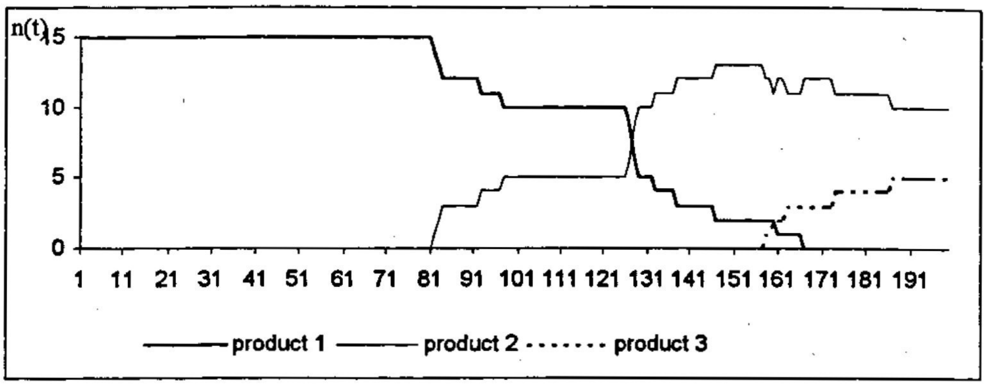

Fig. 7b)

Therefore, firms applying the economical adjustment mechanism of R&D budgets exploit their technological opportunities on a trajectory more intensely and take advantage of the short term problems of the innovating firms. Contrariwise, firms applying the technological learning rule are accelerating the speed of innovation because they attempt to close their technological gaps to the leaders as soon as they become aware of them.

5. Conclusions

In this paper we investigate the technological and economical implications of different strategies and learning rules firms apply in pushing forward technological progress. Those strategies are not designed in an optimal -'neoclassical'- way but they are more or less rules-of-thumb which have been successful in the past. The main reasons for this modelling are the inherent technological uncertainty, the technological constraints and the bounded and procedural rationality of agents.

Within this framework three different strategies are investigated, the absorptive, the conservative and the imitative strategy. Additionally we distinguish between learning rules for adapting R&D-budgets, which on the one hand are oriented along the economic success and on the other hand along the technological success of the different strategies.

Comparing the different strategies, it has been a quite robust result that in the medium and long run the absorptive strategy dominates with respect to the technological as well as economic performance.

With respect to the different learning rules a clear result is that with technological learning the rate of technological progress is comparatively higher. Applying the economic learning rule, oligopolistic competition quite often allows for sufficient economic success so that the necessesity to intensify R&D-activities is relatively low.

This result mirrors *in some way* the discussion between neoclassical and new innovation theory. In the former it is the computable economic efficiency of R&D-budgets and in some sense it is static efficiency that counts. The economic learning rule is to some degree designed in this way, although this is not to be taken literally. In the latter, however, it is the experimental character of innovative behaviour and its focus on an even only assumed dynamic efficiency. Here, it is not present profitability but the relative technological performance which drives R&D activities, the main feature of the technological learning rule.

A P P E N D I X

a) Parameter values:

bending of the innovation success	α	0.001
exogeneous rate of adjustment	ω	0.01
difficulty in building-up absorptive capacity	τ	15
interindustry spillovers	ξ	1
scaling parameter	ε	0.001
learning-parameter	θ	0.001

b) initial values:

price	$p_i(0)$	110
share of turnover for R&D	γ_0	0.025
costs	c_0	100
impact of absorptive capacity	d_0	1
prohibitive price	a_0	25
output	$x_i(0)$	10
number of firms	$n(0)$	15

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