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Absorptive Capaticies and Technological Spillovers II

Simulations in an Evolutionary Framework

von

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1. Introduction

Received modem innovation theory focusses primarily on the endogenous generation of new technological knowledge under the conditions of population heterogeneity and the notion of a technological progress which is pushed forward collectively The concepts of heterogeneity and of collective progress are, however, in a somewhat tensionary relation because technological heterogeneity implies that firms or individuals differ in their technological approaches and technological knowledge whereas a progress pushed forward collectively requires at least some common understanding and the ability to combine individual knowledge assets. In this respect the concept of absorptive capacity gains importance because it allows firms to understand and use knowledge generated elsewhere and transferred by technological spillovers. This absorptive capacity is, however, something which is not (entirely) given by God but has to be build up continuously by investing resources and which is - contrary to specific R&D projects - not immediately targeted onto a specific research purpose. In a way investing in absorptive capacity is done for some precautionary motives allowing to be prepared for some unforseen technological developments generated outside the firm.

In Cantner/Pyka (1995) it has been shown that although acquiring absorptive capacity is costly, in the medium and long run this strategy is superior to a strategy - called conservative - which invests in understanding the knowledge generated elsewhere only when the own technological opportunities seem to be depleted. However, the analysis there is undertaken on quite simplifying terms. First, the spillover effects have been taken as exogenously given in an unchanged quality and quantity. Second, the analysis there is based only on technological terms rendering the economic conditions and consequences as - in a first approximation - not essential. Especially the resource using process of building up absorptive capacity is assumed to be entirely independent of the economic success of the firm.

As the title already indicates, this paper is a "natural" extension of a our previous paper. We try to resolve some of the restrictions posed there by extending the analysis to a techno-economic framework where technological and economic performance influence each other and where firms compete on economic as well as technological terms. For this purpose we use a standard economic model which helps to cope with the economic competition of firms, a model of heterogeneous oligopoly. There competition determines the economic success of firms which in turn determines the financial means available to engage in R&D projects and in building up absorptive capacity. The degree of interfirm heterogeneity is to a certain degree determined by the relative innovative success of those firms, where forging-ahead and falling-behind processes are the normal way of life. Moreover, the degree of spillover effects depends on the technological heterogeneity of firms. Thus, the main ingredients for a collective technological progress, absorptive capacity and technological spillovers, are modelled endogenously.

Within this general techno-economic framework we investigate, how different firm strategies with respect to consciously building up absorptive capacity perform in the medium run. For this purpose we use a simulation model where three alternative settings are investigated. Starting with a model calibration with a (relatively) high degree of economic competition and a large spillover pool, a calibration with low economic competition and a calibration with small spillover possibilities are run alternatively. For all three settings the success or failure of different strategies for building up absorptive capacity are analysed.

Our simulation results show that a firm strategy aiming on absorptive capacity and direct R&D is by and large superior to a strategy focussing entirely on direct R&D. Only in technologically homogeneous environments or with perfect patent protection the latter strategy might be superior.

Our analysis proceeds as follows. In section 2 we dicuss the theoretical foundations where we explicitely focus on the role of absorptive capacity. Section 3 describes the simulation model. Section 4 shows the most important results of different calibrations. We close our discussion with some concluding remarks in section 5.

2. Technological Opportunities, Spillovers and Absorptive Capacities in a Techno-Economic Framework

Economic science has rendered technological progress for a long time as a phenomenon the dynamism and direction of which could be explained nearly completely with the help of economic factors. The strong demand-pull approach points at changes on the demand side, a more weakly demand-pull approach focusses additionally on the role of changing relative factor prices (Dosi (1984)). Questions on the special features of technology and technological progress have broadly been declared as economically irrelevant and they were knocked into the well-known "black box". However, this rough picture of unconstrained technological opportunities and of an ownly reactive behaviour of innovators - as "painted" by this theoretical approach - cannot be convincing at all. And even more, any discussion of innovation strategies as persued by highly dynamic firms is irrelevant in a modelling context were a reactive behaviour is quite sufficient for survival.

To provide in this respect for a more satisfactory analytical basis two important developments seem to be of special interest:

First, the purely reactive innovator has been replaced by an active entrepreneur who can only acquire technological knowledge by investing resources in R&D activities. The most important problem in this respect concerns the possibilities to appropriate the returns from those R&D activities. An innovator is willing to invest in R&D only if he can earn an appropriate share of the respective innovation profits. So-called appropriability conditions are from an economic point of view the most important prerequisite for technological progress to be driven by private activities.

A second development in the theory of technological progress critizises the concept of the "black box". Since the 80's the economic discussion more and more takes into account that technological opportunities are not unconstrained and that technological progress develops along quite certain paths, that it has its own structural change and that it is often constrained by physical and chemical laws.

Both, the appropriability conditions as well as the technological opportunities are supply-side factors which do influence the innovative behaviour as well as the result of innovative activities (fig-1).

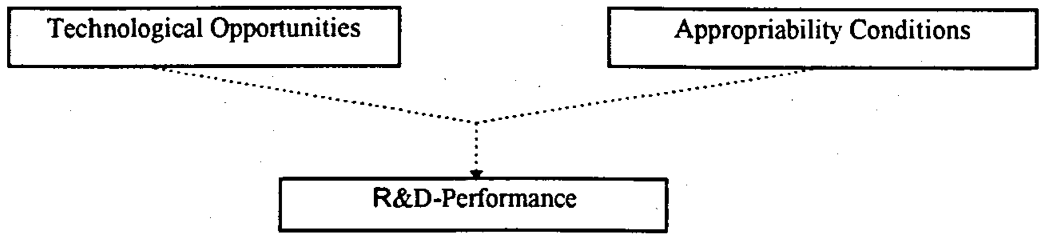

Fig. 1: Supply-side factors and R&D-performance

In the following we will briefly discuss the relation between technological opportunities and appropriability conditions. The role of absorptive capacities as an often necessary connecting device will show up accordingly.

2.1 Technological Opportunities

The notion of technological opportunities is quite closely related to the epistemological concept of a paradigm often refered to in modern innovation theory.[1] Accordingly, "normal" technological progress develops incrementally and cumulatively along certain trajectories within the "frame" provided by a paradigm. Each trajectory represents certain technological opportunties which are determined by the technological potential and degree of exhaustion. They give therefore an account of the easeness by which future innovations can be accomplished or in other words "... which may be thought of as how costly it is for the firm to achieve technical advance in a given industry."[2]

A quite important feature of technological opportunities represented by a certain trajectory is that they decrease continuously; this means that with any further development along a trajectory, it becomes more and more difficult to succeed with further improvements. Most often scientific laws constrain the development within certain technologies. As the respective technological potential becomes more and more exhausted, the successful research results become increasingly difficult to achieve.[3] This relationship is known as "Wolff's Law".[4]

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[1] Dosi (1988, p.1127) describes a technological paradigm as follows: "Both scientific and technological paradigms embody an outlook, a definition of relevant problems, a pattern of inquiry. A technological paradigm defines contextually the scientific principles utilized for the task, the material technology to be used."

[2] See Cohen/Levinthal (1989, p. 572).

[3] See Mensch (1975).

[4] Ayres (1988, p.96) refers in this respect to an example out of the aircraft industry: "It was once assumed that aircraft flight speeds would increase more or less smoothly as engine power was increased. Not so. Again a discontinuity was found. Near the speed of sound (Mach I) turbulence increases sharply, and power required to exceed sonic speed rises in a sharply non-linear fashion."

Based on this concept all technological opportunities which can be explored on a specific trajectory are refered to as "intensive technological opportunities" (Coombs (1988)). According to Wolffs Law those opportunities will be exhausted step by step.[5]

This, however, does not imply that progress comes to rest. Specific technological trajectories and their technological opportunities do not co-exist unrelatedly but they are connected by several influencing devices and feedbacks. Improvements in one technology can create totally different applications of other technologies or even totally new technological opportunities. Nearly exhausted trajectories can then be influenced by other innovation or technology fields so that new opportunities are opened up[6] In this context one additionally has to mention that new technological potentials can even be created by simple re-combination of certain already existing products and processes.[7] Contrary to intensive technological opportunities represented by a certain trajectory, technological opportunities which arise out of cross-fertilization are called "extensive technological opportunities". Those external influences have quite a number of sources: new ideas and findings at universities and other research institutes; the manifold effects between up- and downstream productions between firms within branches as well as between industries. In this context, the idea to describe technological progress as a collective process becomes evident.

Those very much emphasized sources of external technological know-how come into effect by so-called technological spillovers. However, these effects are possible whenever technological knowhow is not a purely private good and thus not entirely appropriable by the innovating firm, and when the receiving firm is able to understand their information content, i.e. the firm has some absorptive capacity. In the following section we will discuss these concepts accordingly.

2.2 Appropriability Conditions

For costly innovative activities to be undertaken by private firms the appropriability conditions are of paramount importance. Applying a rationally maximiring agent and complete information

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[5] For example, scientific laws do not allow a further miniaturization combined by an acceleration of microprocessors because a certain distance between the specific elements is necessary according to certain requirements of quantum physics. Whenever those distances and speeds are achieved, the intensive technological opportunities of this technology were exhausted.

[6] Referring back to our example of the microprocessor in the previous footnote, a switch from electronic to optical data transfer is just a point in case.

[7] Kaufmann (1988) states in this respect: "This process can lead to a new product by means of the combination of parts of existing products. For example, the Wright brothers built an airplane by combining bicycle wheels, airfoils, and petrol engine."

framework neoclassical innovation theory has highlighted this point by stating that it is just the occurrence of technological spillover effects which reduces the appropriability conditions of the innovators. In fact, according to this approach technological spillovers and appropriability conditions are a trade-off relation: Large (small) possibilities for spillovers imply that firms are able to appropriate a small (large) part of the respective innovation rent. Consequently, spillovers are seen as reducing the incentives to innovate, resulting in a from a social point of view sub-optimal level of innovation expenditures.[8]

Modem innovation theory, however, states that those negative effects indeed do exist but that they are compensated for by the opportunity to use technological knowhow of the competitors[9] This argument is 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 a slightly unique trial-and-error process where specific cumulative experiences, knowledge and capabilities as well as historical circumstances and contingencies as well as lock-in effects play an important and determining role. The resulting heterogeneity of innovators (and imitators) implies that the R&D activities of firms within a branch do not follow a single unique technological path, i.e. the specific R&D projects are not only substitutes but often they are complements. The transfer of knowledge and spillover effects between firms can help to create new technological potentials - technological progress becomes collective with beneficial effects for all participating innovators.

On this basis it is obvious that firms sometimes initiate consciously technological spillovers: In order to get access to the knowledge of other firms they have to behave cooperatively.[10] Therefore, strategically it might even be an advantage to reveal own R&D results to competitors.[11] Although this will increase the competitors R&D performance, the own performance will also improve.

This argument for the beneficial effects of technological spillovers becomes even stronger the less the economic competition between firms. For the most extreme case in this respect one might think of so-called inter-industry spillovers. Here the incentive reducing effect of spillovers has to be considered as nil because competition between firms of different sectors is by and large negligable.

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[8] The fundamental reference is Arrow (1962).

[9] This aspect has also been sustained by several new game theoretical models. Those models focus on the effects of technological spillovers to increase the incentives to innovate. See d'Aspremont/Jacquemin (1988) and Katz/Ordover (1990).

[10] See von Hippel (1990).

[11] See DeFraja (1993).

This brief discussion of appropriability conditions for technological knowhow has shown that technological spillovers do have a negative effect on the willingness to innovate whenever different firms apply identical technologies. The more these firms, however, differ in this respect, the less problematic is the transfer of firm-specific knowhow. This applies even the more when firms are located in different economic sectors. This reversal of the neoclassical argument should not lead to the conclusion that technological spillovers are no problem anymore. This would fail to recognize another important aspect: Spillovers can come into effect only when the recipient of that knowledge satisfies certain requirements. This leads us directly to the concept of absorptive capacity.

2.3 Absorptive Capacity

It is far-fetched to believe that technological spillovers can always be used by firms without any own contributions. Cohen/Levinthal (1989, p.128) focus on this point: "The ability to exploit external knowledge is ... a critical component of innovative activity." What are the theoretical foundations of this statement?

Whenever technological knowledge is of a specific type it cannot be transferred without constraints.[12] In this respect knowledge loses its feature of being a poorly public good and has to be treated as a "latent public good"[13], as ideosyncratic knowhow or even as a good which comes close to a private good.[14] In this cases it is the very nature of the respective knowledge that makes also imitation a costly endeavour or as Nelson (1990b, p.197) puts it: "In such cases 'technology transfer' may be as expensive and time consuming as independent R&D."

In order to understand and apply such specific know-how, firms must have already gathered experience in other related fields and must have the capabilities to anticipate and appropriate potentially useful other technological developments. Cohen/Levinthal (1989, 1990) emphasize this point: "... we argue that while R&D obviously generates innovation, it also develops the firm's ability to identify, assimilate and exploit knowledge from the environment - what we call a firm's

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[12] Technological knowledge can be firm- as well as technology-specific.

[13] See Nelson (1990a).

[14] In cases where patent laws prohibit the use of certain technological knowledge by potential innovators even unspecific know-how becomes a latent public good. For specific knowledge, however, the protection by patents is not necessary for appropriation.

`learning` or 'absorptive' capacity. ..., 'absorptive capacity' also includes the firm's ability to exploit outside knowledge of a more intermediate sort ... ."[15]

Whenever firms want to apply knowledge transferred by technological spillovers, they have to invest in their absorptive capacities - even when these are to some degree given by god. Of course, one can imagine that investment in own R&D does help to imitate comparably quick the innovations of competitors on the same technological trajectory. Absorptive capacities are then a side-effect. Firm-owned research institutes are a point in case.[16] However, firms do also invest directly in their absorptive capacity which then is no by-product.[17] Consequently, investment in absorptive capacity is not different from other investment: It is to be considered also as a time-consuming and costly process. Therefore the R&D budgets no longer provide only resources for more or less one-directional improvements within a certain technology but are also spent partly for screening the rather global technological developments. This allows the firms to use the potential effects of technological spillovers from other firms which then might help to create new technological opportunities.

On this basis the concept of absorptive capacity is to be seen as the connecting device between technological opportunities and the appropriability conditions. In fact, the absorptive capacity provides that technological spillovers can be exhausted which may help to create new technological opportunities.

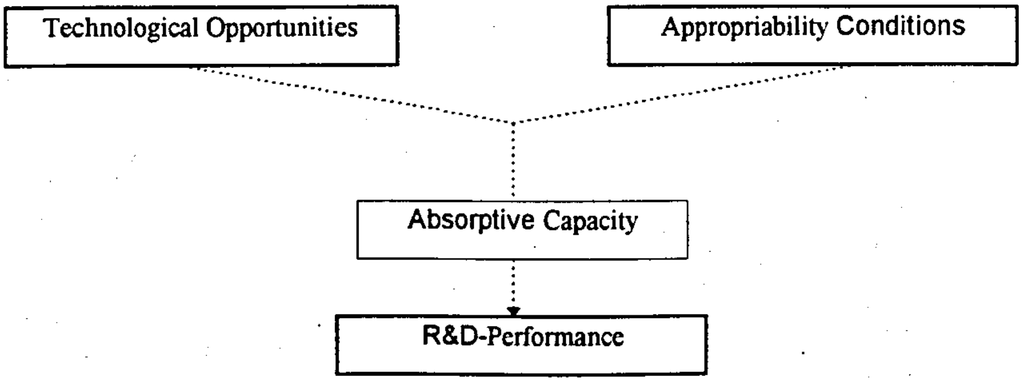

Fig.2: Absorptive capacity as a connecting device

[15] See Cohen/Levinthal (1989, p.569).
[16] See Mowery (1983).
[17] Cohen/Levinthal (1989, p.129) 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 effort exclusively to creating 'absorptive capacity' (i.e. 'absorptive capacity' is not a by-product)."

To state this in somewhat different terms, the absorptive capacity is also the connecting element between the heterogeneity of agents providing for different new ideas and the notion of a collective progress where some common understanding of the various ideas is necessary. Spillovers come only into existence when there is heterogeneity but the common use of their knowledge content requires some reciprocal understanding. Absorptive capacities facilitate this understanding.

2.4 Market Competition

Innovative and imitative activities of firms are undertaken in an economic environment which is characterized by a certain degree of competition among firms. This competition in the end provides for an economic evaluation of those activities compared to those of the competitors. The economic success of firms is then not only dependent on their ability to push forward its own technological know-how but also on the kind of competition taking place and therefore on the technological performance of the competitors. Seen in a dynamic context, this economic success is a necessary requirement for the firm's ability to finance further innovative activities in order to survive - or to put it differently success breeds success.

Concerning a technological progress collectively pushed forward by several firms the issue of competition attains a special importance because the situation where firms are in a competitive relation is different to a situation were there is no competiton. Refering back to our previous distinction between inter- and intra-industry spillovers, market competition is only relevant in the latter case. On what terms does this competition take place when we take into account that the very nature of technological progress does lead even to intra-industry heterogeneity?

Based on the behavioural assumption of bounded rationality providing for firm-specific abilities, experiences and knowledge levels the empirical fact of an heterogeneous industry structure finds even a theoretical foundation. Within such an economic environment competition between firms is not the textbook perfect price competition with a homogeneous output. Competition has rather to be considered in an oligopolistic setting where besides price competition - which is still important - one has to consider some kind of quality competition which refers to either vertical or horizontal product differentiation as well as additional services attached. Since these quality differences are the outcome of innovative activities the label "technological competition" seems adequate.

3. The Simulation Model

In the preceding section the absorptive capacities of firms have been identified as an important factor influencing the collective technological development. In the following we will present a model of a dynamic oligopoly in which firms compete not only on the market, but also do influence each other by their innovative activities. The firm under consideration apply different R&D-strategies which are in between two extremes: The first is the so called conservative strategy, where the firms' R&D results are only dependent on their own efforts. On the other side firms try to absorb research results created elsewhere in order to enlarge their own technological opportunities. For this screening and adoption of externally created know-how it is necessary to build up absorptive capacity, which is a costly process in the sense that the respective investment would otherwise further direct R&D efforts.

(a) Market

Market competition is modelled as a heterogeneous oligopoly. There every firm faces an individual linear demand function[18]:

$$(1)\qquad p_i(t) = a_i(t) - \eta x_i(t) + \frac{h_i(t)}{(n(t)-1)} * \sum_j p_j(t-1)$$

$i, j \in \{1,2,..,10\}$; $i \neq j$;

$p_i(t)$:= price of firm i at time t

$a_i(t)$:= prohibitive price of firm i's product

η := price elasticity of demand

$h_i(t)$:= demand switch variable for firm i's product

$n(t)$:= number of firms at time t

$x_i(t)$:= output of firm i at time t

The prohibitive price $a_i(t)$ will be used later on to model the consumers' assessment of product quality in the presence of product innovations. Consequently $a_i(t)$ is to be considered as dependent on the innovative activities in the sector.

Regarding the production process we assume constant returns to scale. Consequently the unit costs $c_i(t)$ are independent of the produced output. Besides the mere production firms devote

[18] see Kuenne, R.E. (1992).

periodically investments $r_i(t)$ to research and development (R&D) which help to reduce unit costs. Therefore the profit function $G_i(t)$ of the firm i reads as follows:

(2) $$G_i(t) = [p_i(t) - c_i(t)] * x_i(t) - r_i(t)$$

With respect to market behaviour of firms we rely on the Betrand-assumption. In our context this has two implications: First, the firms believe that there will be the same number of competitors in the market like in the preceding period, and second, firm i will expect the prices of its competitors j to be unchanged in the current period.

Based on this we assume profit-maximizing behaviour for the short-term decisions, i.e. for one period. Under this assumption it is straightforward to develop the firms' reaction functions

(3) $$p_i(t) = \frac{a_i(t) + c_i(t)}{2} + \frac{h_i(t)}{2(n(t-1)-1)} * \sum_j p_j(t-1)$$

and the corresponding output level

(4) $$x_i(t) = \frac{a_i(t) - c_i(t)}{2\eta} + \frac{h_i(t)}{2\eta(n(t-1)-1)} * \sum_j p_j(t-1)$$

(b) Technological progress I: Process and product innovations

To secure and even to enlarge their market shares firms try to improve on their technologies. Therefore they are engaged in R&D endeavours aiming at two goals. On the one hand these innovative efforts are directed to process innovations which make production techniques more efficient (gradual improvements). Consequently process innovations can be represented by unit cost reductions. The innovative success is transformed to an economic one by the enlargement of the production through lower unit costs. On the other hand the innovative efforts of firms are directed to create new products. These product innovations attract additional demand.

In order to accomplish technological progress firms have to invest in R&D activities. Since the development of a new technology, even the improvement of an existing technology is a risky and uncertain endeavour, the R&D-decisions of firms are not guided by the maximization principle ('bounded rationality'). Instead entrepreneurs apply certain routines[19] for their decisions, which are deduced mostly from past experience and future expectations. As an approximation of an entrepreneurial R&D-routine firms invest a fixed share γ, $\gamma \in \{0,1\}$ of their turnover from the preceding period:

(5) $$r_i(t) = \gamma[p_i(t-1) * x_i(t-1)]$$

Already in section 2 cumulativeness was identified as an important characteristic of technical progress along a certain technological trajectory. To reach a certain technological level the preceding levels have to be passed through, because otherwise the relevant technological understanding cannot be achieved. Representing this feature periodical R&D investments sum up to a R&D capital stock $R_i(t)$ representing the accumulated technological know-how:[20]

(6) $$R_i(t) = \sum_t r_i(t)$$

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 physical and chemical boundaries and bottlenecks. In order to take account of this effect we assume positive but decreasing innovative success $ie_i(t)$. To take account of technological uncertainty, the occurrence of such a success is determined stochastically. An equally distributed random number Ψ_t reflects the uncertainty inherent in process innovations.

(7) $$ie_i(t) = 1 - Exp[-\alpha_1 * R_i(t)] \text{ and}$$

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

α_1 := bending of the innovation success

$\Psi_t \in [0,1]$:= equally distributed random number

[19] „The broad ideas that shape the most critical high-level decisions of a business enterprise may also be viewed as heuristics - they are principles that are believed to shorten the average search to solutions of the problems of survival and profitability.", Nelson, R.R., Winter, S. (1982), p. 133.

[20] Here we assume no obsolescence of know-how.

$$\frac{\partial f}{\partial R_i} > 0; \quad \frac{\partial f^2}{\partial^2 R_i} < 0;$$

Since the innovative success comes into effect only with a time lag of one period, the R&D efforts of the period t-1 influence the unit costs of period t. Additionaly we assume a periodical increase in unit costs by π which is caused by inflation of factor costs[21]. Unit costs of firm i develop as follows:

$$(8) \qquad c_i(t) = c_0 * (1+\pi)^t * [1 - ie_i(t-1)]$$

c_0 := initial value of unit costs

Besides improving production processes firms are assumed to engage in product innovations. The uncertainty envolved in those endeavours is quite different from the one we assumed 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[22].

The R&D efforts devoted to product innovations are again represented by the stock of R&D capital $R_i(t)$. In the course of time the firms accumulate a success probability $pr_i(t)[.]$, which approximate asymmtotically the mean value of the poisson distrtibuted random number. The growth of the success probability is characterized by positive, but decreasing rates:

$$(9) \qquad pr_i(t)[PDI = 1] = 1 - Exp[-\alpha_2 * R_i(t)]$$

PDI := binary variable, which takes the value 1 in the case of success

α_2 := bending of the innovation probability

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[21] This assumption is always neccessary when modeling process-innovation as cost-reduction. Without this assumption the paradox situation of producing everything with no input could be achieved.

[22] see Granstrand, O. (1994).

If the accumulated probability in period t is equal to or even bigger as the poisson-random number the firm undertakes successfully a product innovation.

Whenever a firm succeeds with 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.

The effect of a product innovation is reflected by a quality improvement which shows up on the demand side. Here they have a twofold effect on the economic sphere. First, the demand switch variable $h_i(t)$ will be influenced. With higher heterogeneity this demand switch will decrease and this will affect the competitors by different degrees. The effect will be the largest for those firms whose quality distance towards the innovating firm decreases measured with the absolute (normalized) distance $|Q_i|$ of firm i towards the other firms.

(10) $$h_i(t) = h_0 * (1 - \frac{|Q_i|}{n(t)})$$

h_0 := initial value

Q_i := measure for the relative qualitiy deviation with respect to the average quality

Secondly, successfull product innovations change the prohibitive price $a_i(t)$. Here the innovating entrepreneur produces a higher quality and the consumers' assessment of his product will increase. Other firms experience a decrease of their $a_i(t)$ value, because the product innovation decreases their respective measure Q_i of the (normalized) distance of firm i in the quality space. Consequently we get:

(11) $$a_i(t) = n(t)^{Q_i}$$

(c) Technological progress II: Spillovers and absorptive capacity

As already mentioned at the beginning, an essential feature and determinant of a collectively pushed forward research process are technological spillovers, which come into existence because of some public good characteristics of new technological knowledge. In order to use the information content of spillovers a minimal amount of understanding the other's technologies is neccessary. This understanding of the knowledge created outside the firm has to be acquired actively and is institutionalized in the firms' so called absorptive capacities.

In the model we explicitly distinguish process and product spillovers. The first category affects the technology used by the firm and helps to improve this technology. The latter category of spillovers is increasing the probability for product innovations. They contend either technical information about new product opportunities or information concerning the connection of different knowledge elements[23]. Spillovers neccessarily can only arise when there is some heterogeneity among firms. In this respect we assume that the relevant spilloverpool increases with increasing heterogeneity.

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. For product spillovers the variance $s_{a,t}^2$ of the quality measure $a_i(t)$ serves as the relevant figure describing the product- resp. quality-heterogeneity.

Building-up absorptive capacity to use technological spillovers is not a costless endeavour, on the contrary resources are to be invested which are then no longer available for direct R&D-efforts. A firm which decides to build up absorptive capacity $ac_i(t)$ invests a share σ_i , $\sigma_i \in [0,1]$ of the periodic R&D-budget in the understanding of technological spillovers. The absorptive capacity of a firm has to be accumulated like the stock of R&D-capital:

$$(12) \quad ac_i(t) = \sum_t \sigma_i * r_i(t)$$

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[24]. In the model this is reflected by a non-linear process, which

23 „.. successful product development requires two types of knowledge. First, it requires component knowledge, or knowledge about each of the core design concepts and the way in which they are implemented in a particular component. Second, it requires architectural knowledge or knowledge about the ways in which the components are integrated and linked together into a coherent whole.", Henderson, R., Clark, K. (1990), p.11.

24 „... 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.

should show the threshold effect of the impact of additional information, if the necessary basis is already built-up[25].

The function of the innovative success for process innovations of firms which decided to build up absorptive capacity is modified by adding a term representing the absorptive capacity and containing the pool of process spillovers:

(13) $ie_i(t) = 1 - Exp[-\alpha_1 * R_i(t)] + \mu / (1 + Exp\{\tau_1 * [d_i(t) - s_t^2 * ac_i(t)]\})$ *and*

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

(14) $d_i(t) = [1 - \varepsilon * ac_i(t)^2] * (1 + \theta)^t$

μ, ε := scaling parameters

τ_1 := difficulty in building-up absorptive capacity

θ := learning-parameter

$d_i(t)$:= impact of absorptive capacity

When building-up an absorptive capacity a learning process will take place in the course of time: On the one hand there are experiences with respect to the value of different spillover sources ('learning-by-interacting') and on the other hand an advantage in experience with the integration of external knowledge should be expected ('learning-to-integrate')[26] through repeated integration. In the model this learning effect as well as the accumulated absorptive capacity determine the term $d_i(t)$, which describes the specific increase in the impact of the absorptive capacity.

The probability of a product innovation is also positive influenced through the possibility of using product spillovers. In this case the stock of R&D-capital of the firms is weighted with the size of the absorptive capacity, which is in magnitude again dependent on the variance of qualities as a measure for product spillovers. This should reflect the idea-creating feature of technological spillovers in connection with product innovation ('cross-fertilization').

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[25] „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).

[26] „The capacity to reconfigure and transform is itself a learned organizational skill. The more frequently practiced, the more easily accomplished.", Teece, D.J., Pisano, G. (1994), p. 545.

$$(15) \quad pr_i(t)[PDI=1] = 1 - Exp\{-\alpha_2 * \{\frac{\xi + s_{at}^2}{1 + Exp[\tau_2 * (d_i(t) - ac_i(t))]}\} * R_i(t)\}$$

τ_2 :=difficulty in building up absorptive capacity

ξ := interindustry spillovers and feedbacks from the sciences

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 10 enterprises. These enterprises only differ in their R&D-strategies with respect to their decisions upon building-up absorptive capacity. The first firm plans to invest the largest share $\sigma_i = 0.2$ of its periodic R&D-budget in accumulating absorptive capabilities. Firms 2 - 9 also invest in these capabilities but by decreasing shares. Firm 10 follows the conservative strategy and therefore only invests in direct R&D efforts with the consequence of despensing to use information provided by technological spillovers.

In presenting our simulation results we only show the development of the two extreme firms, 1 and 10, as well as of firm 5 with a medium incentive to invest in absorptive capacity. Whenever there are remarkable results by other firms they are stated in the text.

For each run we assume that all firms start with identical unit production costs and product qualities which are assessed equally by consumers. Each simulation is run for 200 periods. To avoid distortions due to several stochastic elements, all the simulation runs were performed 30 times and the respective averages were calculated. For the following discussion we first investigate the effect of absorptive capacities on the firms' performance in process and product innovations respectively. In a second step the respective development of profits in three different scenarios is analyzed.

(a) The effects of absorptive capacity on process innovations

Process innovations reduce the unit costs of production. In the following we illustrate only their development for 85 periods because within this time-span comparability of the different curves is given, since there no product innovation occur. Consequently, all firms are moving along the original technological trajectory. Figure 3 shows the development of the respective unit costs.

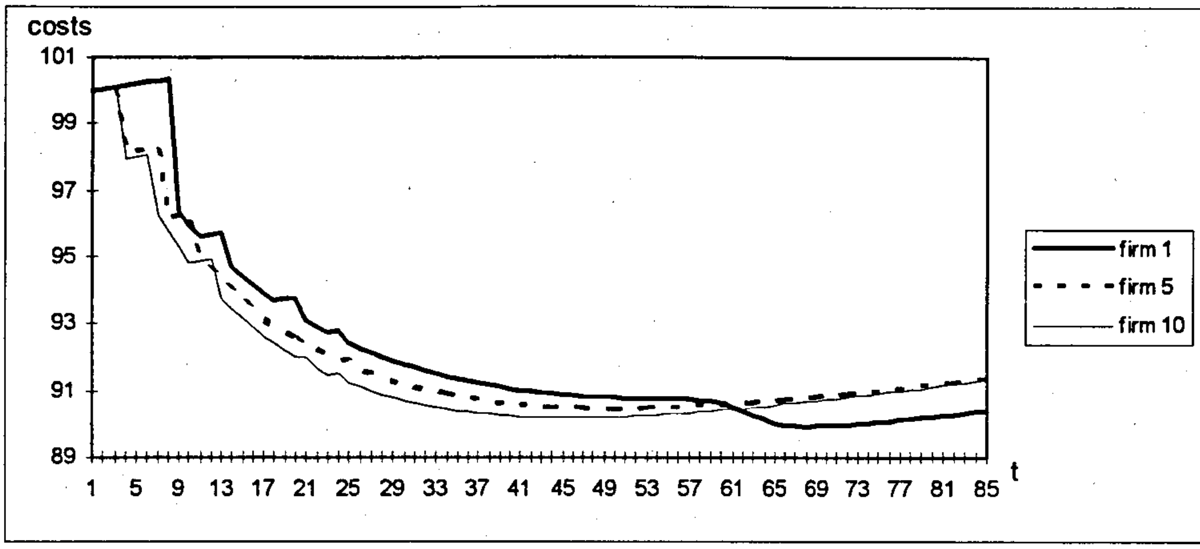

figure 3

Generally the unit costs of all firms decline at least in the first half of the investigated period where this development is sometimes interrupted by unsuccessful attempts to innovate. Exhausted technological opportunities are responible for the inflation driven increase of costs in later periods. Considering the first 60 periods, it can immediately been seen that the conservative firm 10 is most successful in process innovations. The respective unit costs are clearly below the others', who invest in absorptive capacity. However, at the end of this period the technological opportunities of the conservative firm are nearly depleted and further successes in process innovations can just cover the inflation. Finally unit costs of firm 10 increase again. A quite similar cost-development characterizes firm 5. Any advantages of investment in absorptive capacity do not show up here and therefore compared with the conservative strategy firm 5 is in a worse position.

Considering firm 1, in the early periods the endeavours to reduce unit costs have not been very successful. Because of investing a large amount in building-up absorptive capacity, the direct investments in R&D are the lowest compared to the other firms. Since the technological differences between firms are quite low in the beginning spillover potentials are quite low. But about the period 57 absorptive capacity and the spillover pool are large enough to make additional technical improvements and the related cost reductions possible. Contrary to its competitors, struggling with nearly depleted opportunities, firm 1 is able to explore new technological potentials with the help of know-how created outside the own laboratories. Allthough the respective information is freely available, only firms, which were actively engaged in developing the neccessary absorptive capabilities are able to use this knowledge.

(b) The effects of absorptive capacity on product innovations

Looking at the probability to introduce product innovations, figure 4 shows that the conservative firm 10 again is the fastest to accumulate success-probability in the first periods. The respective probability increases periodically but with decreasing rates and approximate asymptotically the mean value of the poisson-distributed random number. The effect of decreasing rates can be compensated by additional potentials, whenever firms have the absorptive capacity to use them. After about 60 periods firm's 1 absorptive capacity, built-up through continuous investment and learning, is large enough to open new promising research possibilities with the help of the externally generated know-how. Finally product innovations of competitors are responsible for the growing pool of externalities, and this again supports the positive effects of the absorptive capacities. At about period 60 these effects even allowed firm 1 to get ahead of firm 10.

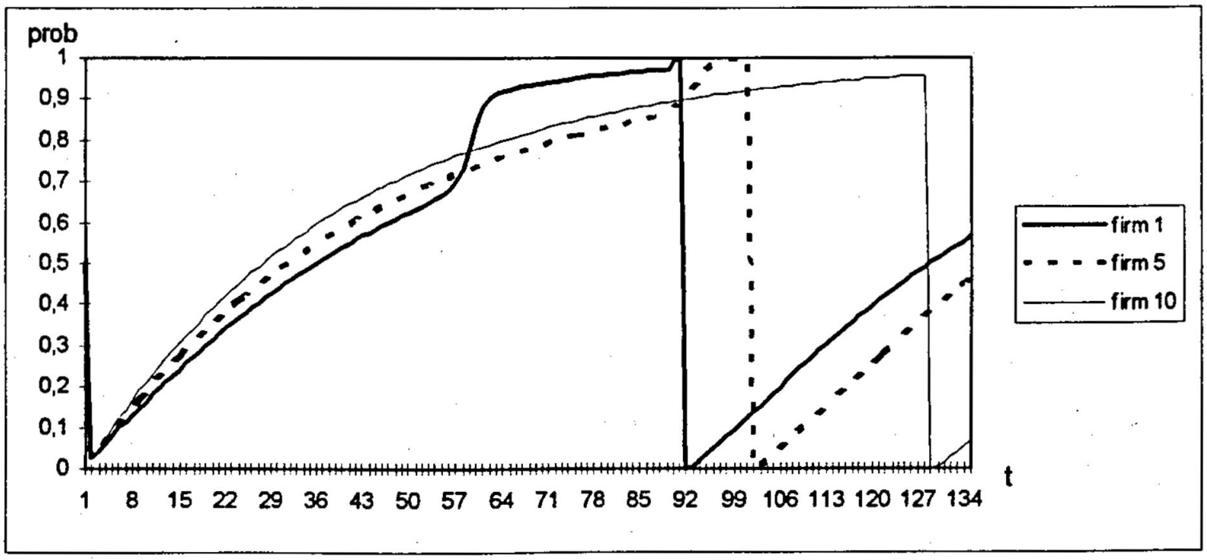

figure 4

In period 92 a product innovation of firm 1 takes place. On the new technological trajectory enterprise 1 has to build-up again the probability, because when switching on the new trajectory the old knowledge becomes irrelevant. Also firm 5 can realize gains out of its decision to invest in absorptive capacity. After about 90 periods the supporting effects of absorptive capacity help to improve the success probability and already 10 periods later the new trajectory is reached. The conservative firm relies only on own research and therefore ex-ante excludes cross-fertilization effects. Consequently after about 130 periods firm 10 is the last firm performing successful a product innovation.

The effect of product innovations on technological competition is best shown in figure 5. In our oligopoly a product innovation accompanied by a quality improvement is rewarded with an increasing prohibitive price $a_i(t)$ on the demand side, whereas the assessments of the quality of the competitors' products decrease.

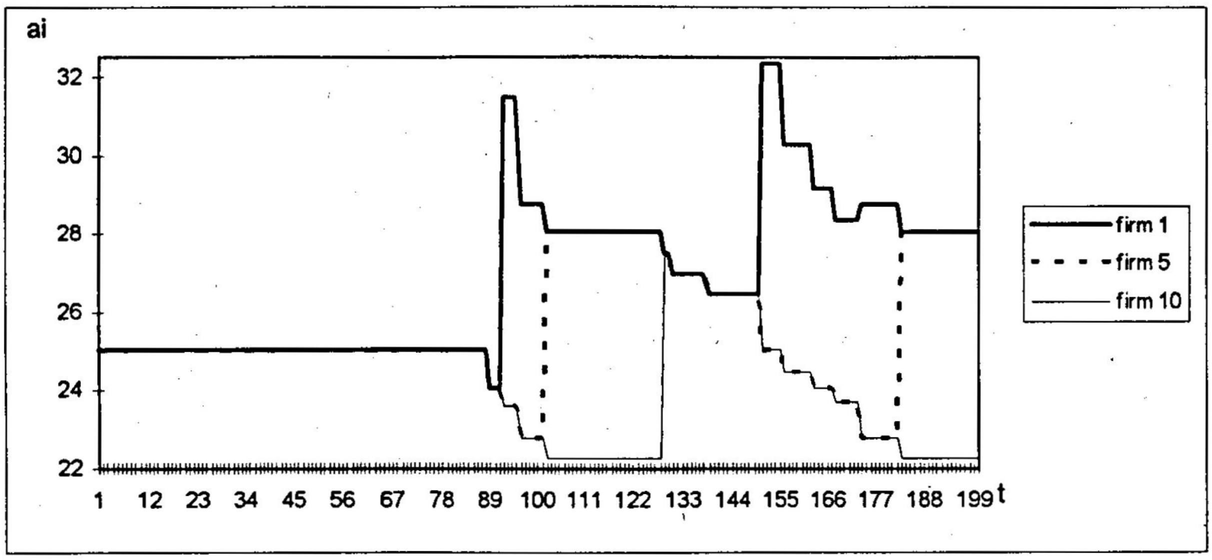

figure 5

In our simulations firm 2, not shown here, is (on the average) the first firm to successfully introduce a product innovation[27]. This is the reason why at about period 89 the respective values of our firms decrease. However, only a short time later, firm 1 succeeds in innovation and is able to reach a higher assessment of quality. Consequently the respective values of firm 5 and 10 decrease. Again the quality assessment of firm 5 is improved after its product innovation and together with the accompaning decrease for firm 1, this leads to the same prohibitive price for both firms. At last when firm 10 is able to improve quality assessment there are no longer remarkable gains. Just a short time later firm 1 starts a new innovation cycle.

[27] This reflects a trade-off relation between the investments in absorptive capacity and in direct research efforts. This relation is dependent on several influences like the size of the respective spilloverpools, the degree of competition etc.

The development of innovation cycles is illustrated in the following figure 6. We show the number of firms n which produce a product of a certain quality level, here the quality levels 1 to 3.

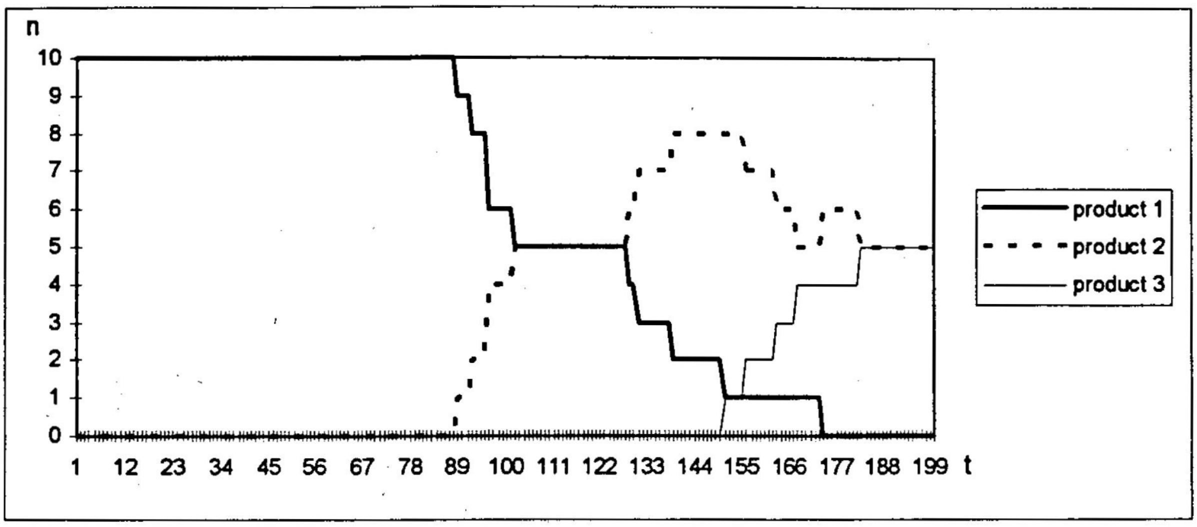

figure 6

At period 90 the share of firms staying on the first trajectory more and more diminishes (bold line). After 100 iterations half of the oligopolists switched to the second trajectory (dashed line). The third innovation cycle starts about period 150 and again grows quite fast. Regarding the preceding picture of the innovation-success-probability it is obvious that firms which invest a relative high amount in absorptive capacity initiate these innovation cycles. And the growing pool of spillovers following this development is an additional advantage supporting the absorptive strategy.

(c)The effects of absorptive capacity on the development of profits

After switching on different (product) trajectories the figures describing the development of firms like output, unit costs etc. are no longer comparable. However, the economic success meassured by profits can be used for comparing the different strategies. In the following the investigation of the profit development will be performed within three different scenarios to test the sensibility of our model regarding different environmental conditions[28]. The first scenario serves as our reference case and contains the already used parameters. In scenario 2 we assume a higher appropriability of technological know-how. These improved property rights of new technological knowledge are responsible for lower spilloverpools. In the simulation we diminished the spillovers by factor 10. In scenario 3 the same appropriability

[28] The respective parameter values, the initial values and the modifications of the different scenarios are listed in the appendix.

conditions as in the reference case are at work; here the intensity of competition is reduced in lowering the oligopolistic interdependence between firms.

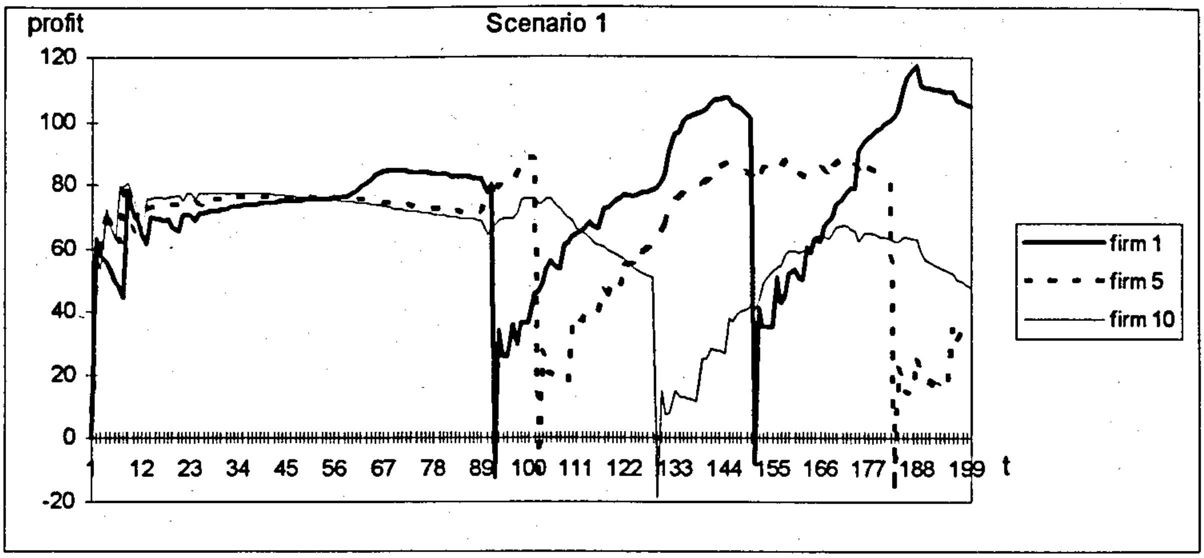

figure 7

For scenario 1 the profit development is given in figure 7. As expected in the beginning firm 1 is on the last position, because of the minor successes in process innovations. Already on the first technological trajectory this situation changes suddenly when absorptive capacity effects come into action. The advantageous integration of process spillovers then pushes firm 1 in the leading profit position.

In period 92 the product innovation of firm 1 and the corresponding jump on a new trajectory leads to a profit erosion which, however, is no long-ranged phenomenon. The large technological opportunities of the new trajectory allow again cost reductions via process innovations. At about period 110 firm 1 is again in the leading profit position and can even increase periodic profits.

After the first product innovation of firm 1 the competitve structure of the heterogeneous oligopoly allows a raise in prices and output for firms 5 and 10. Therefore they can increase their profits for a short period. Firm 5 then successfully introduces a product innovation which causes its profits to develop similar to the ones of firm 1 although on a lower level. Firm 10, however, reaches a profit peak in period 105 and then experiences steadily decreasing profits. Three reasons are responsible for this: First, firm 10's technological opportunities are nearly depleted so that further unit cost reductions are rarely possible. Second, the ongoing successful product innovations of the competitors cause consumers to rate the quality of firm 10 steadily lower leading to a decline in the product price. Third, the competitors producing new products are able to improve their production processes considerably which leads via demand switch to a further decrease of the product price of firm 10.

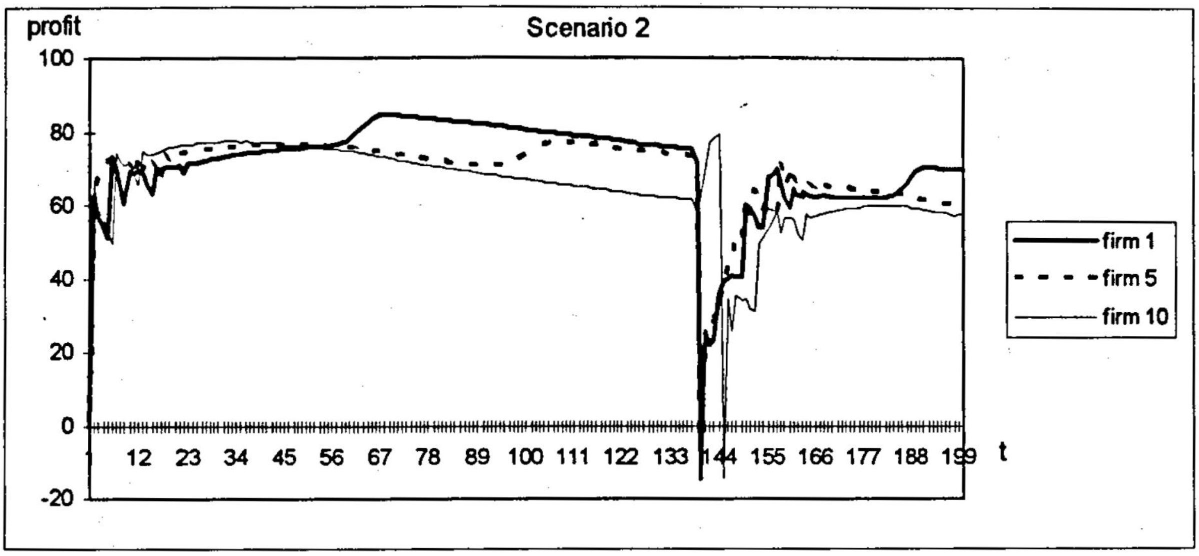

figure 8

Those results change considerably in scenario 2 where improved intellectual property rights (or a high degree of tacitness) reduce the access to external knowledge. Figure 8 shows that firms with absorptive capacities now need more time to benefit from spillovers.This applies for both, process and product innovations. Even in this scenario firms 1 and 5 are still the first to switch to a new trajectory, but only a short period later the conservative firm is able to follow. However, on the new trajectory the "absorptive" firms are from the beginning in a better profit position, although the differences are quite low. Therefore, only a low superiority of the absorptive strategies can be expected in the long-run.

Yet another important difference of the first two scenarios is the lower heterogeneity of the oligopolists in the second case. Therefore the adoption of externally generated know-how is an important factor for a relative heterogeneous development of the firms. These larger differences in the case of low appropriability conditions are also the driving force for the model's dynamic resulting in higher levels and larger fluctuations of periodic profits.

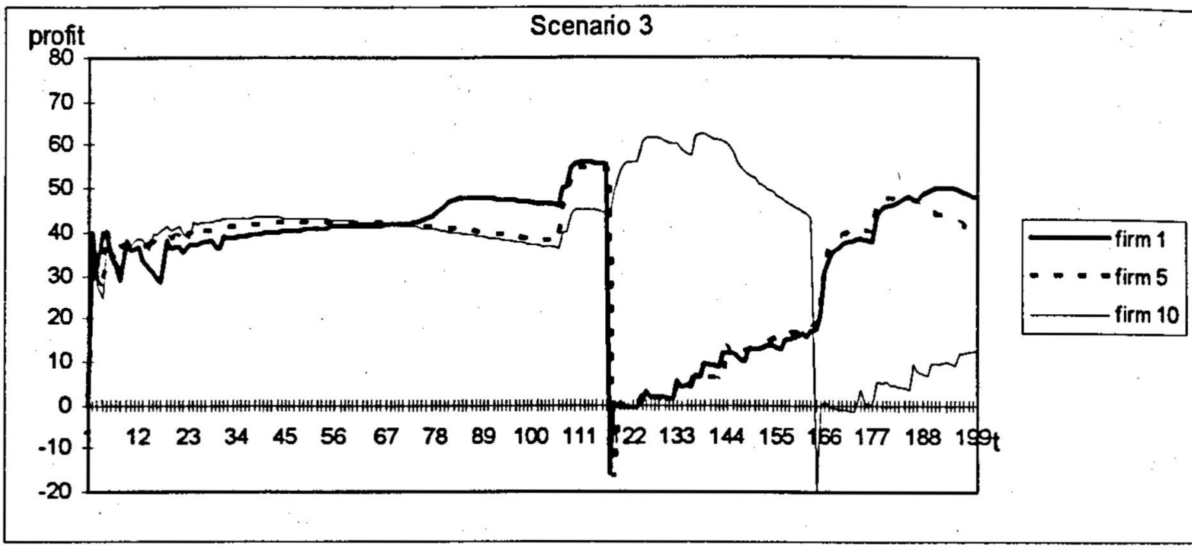

figure 9

In the third scenario the oligopolistic interdependence between firms has been reduced which implies that price-induced demand switches between firms are less severe, firms are able to act more in isolation. This constellation comes close to a situation where the firms can be considered as different industries which technologically are "connected" by inter-industry spillovers. Consequently, each firm's product price and therefore profit is less dependent on the competitors action. Figure 9 shows that here again the model's dynamic is dampened compared to our reference case. However, since here spillover effects are still on a high level, absorptive strategies are quite beneficial and clearly dominate the conservative strategies in the long run. Firms 1 and 5 are rather similar in the investigated time-range, therefore again in this scenario the heterogeneity of the actors is reduced. Finally one has to mention that the lower oligopolistic interdependence with reduced profits clearly lowers the innovative activities of all (three) firms as measured by R&D-expenditures leading to fewer and later innovations.

All the different simulation experiments show quite obvious, that a R&D-strategy relying on direct research as well as on external knowledge sources by investing the respective funds into absorptive capacity, is dominated by a conservative strategy only in the short-run. In the medium and long-run, however, the absorptive startegy comes to dominate. The cumulative features of technical progress and the latent-public-good-properties of new technological know-how are responsible for this result because they provide for technological heterogeneity leading to spillover potentials. Since to use such potentials requires absorptive capacites, strategies aiming on this tend to be superior. Only in either homogeneous situations (with identical firms) or when patent protection is perfect this result does not apply.

5. Conclusion

This paper provides a simulation analysis of firm strategies which are to different degrees set up to absorb technological know-how generated elsewhere. The success of those firm strategies is investigated in a heterogeneous oligopoly setting where firms try to introduce new products and processes. Within this framework we allow for technological spilloverpools depending on the (technological) heterogeneity of firms. The more firms differ technologically the more they can learn from each other. However, this beneficial learning effect can be accomplished only when firms have the absorptive capacity to understand and use the know-how generated elsewhere. Those absorptive capacities are the result of certain investment activities which besides direct R&D engagements belong to the strategy set of firms.

On this basis our simulation results show that building up absorptive capacities tends to be a superior strategy in technologically heterogeneous environments. Comparing those policies with a strategy not taking into account those capacities we show that the latter dominates only in the early periods. Reducing spillover effects leads to a narrowing of the success of both strategies and a slowing down of technological progress because cross-fertilization effects are of minor relevance. Reducing alternatively the market competition among firms the absorptive strategy still tends to be superior. However, the speed of technological progress is reduced because less oligopolistic interdependence provides for lower profits and therefore lower R&D budgets. This case comes close to a situation of inter-industry spillovers where market competition is nearly absent.

The concept of absorptive capacity is not an entirely theoretical one but it is a strategy which actually is relevant in reality especially in high-tech industries. An empirical study of Kumiko Miyazaki (1994) investigates in this respect the Japanese and European opto-electronic industry. There firms usually engage in basic research quite intensively and on a broad scale before they decide to follow a specific applied research trajectory. "Thus firms search over a broader horizon initially and are gradually able to narrow down their search through a painstaking learning process. In other words in the early phase of competence building, firms explore a broad range of technical possibilities, since they are not sure how the technology might be useful to them."[29]

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[29] See Miyazaki (1994), p. 653.

Although our results here are clear-cut, one has to keep in mind some shortcomings. First of all, our assumption of unchangable routines could be relaxed in order to adjust those rules in accordance with some satisfycing behaviour. Second, new products (and new processes) often require to invest in totally new plants, new machines etc. Those effects, which have not been taken into account here, could provide for longer periods of deficits with correspondingly lower innovative activities.Third and related to the last point, exit and entry to the industry should be considered. Those effects have a direct influence on the spillover pool because the firms and therefore the technological heterogeneity of the sector is affected. Finally, the spillover effects in this paper are only concerned with cross-fertilization effects. There exists, however, a considerable literature focussing on spillovers in an innovator-imitator context which should also be relevant in our context. These points provide us with an ambitious agenda for future research.

APPENDIX

a) Parameter values:

price elasticity of demand	η	1
bending of the process innovation success	α_1	0.0025
bending of the product innovation probability	α_2	1
scaling parameter	μ	0.01
difficulty in building-up abs. cap. for process inn.	τ_1	15
difficulty in building-up abs. cap. for product inn.	τ_2	25
interindustry spillovers	ξ	1
scaling parameter	ε	0.00001
inflation	π	0.0005
share for R&D expenditures	γ	0.025
learning-parameter	θ	0.0025

b) initial values:

price	$p_i(t)$	110
costs	c_0	100
demand switch	h_0	0.85
impact of absorptive capacity	d_0	1
prohibitive price	a_0	25
output	$x_i(t)$	10
number of firms	$n(t)$	10

c) different scenarios:

c1) lower spillovers

s2, sa2, ξ	diminished with the factor 10

c2) lower competition

assesment of quality $a_i(t) = (\frac{n(t)}{100})^{Q_i}$; initial value of h_0 0.825

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