R&D Strategies and the Diffusion of Innovations

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ABSTRACT

Various factors like price, delivery delays and product quality influence the diffusion of innovations. This paper discusses - among other aspects - the impacts of research and development (R&D) strategies on the technical know-how of a product as a strategic factor. To investigate the interrelations of R&D, market performance of products, pricing and profits and to draw conclusions for corporate strategy, an innovation diffusion model is needed, which represents the underlying problem structure adequately. This paper presents such a model.

A COMPREHENSIVE MODEL FOR INNOVATION DIFFUSION

PROBLEM- AND MODEL STRUCTURE

Most existing innovation diffusion models concentrate on price and advertising as the only variables controlling the product life cycle. However, especially in markets for consumer durables, the technical know-how and, therefore, the product quality is a very important competitive element controlling the diffusion of innovations. The technical know-how is a variable highly influenced by corporate research and development (R&D). It is responsible for the marketability and the competitive advantage of a product. "Time to Market" and "Time to Volume" are essential elements of corporate strategy (Milling 1990, 1991a). Empirical studies have shown, for instance, that a six month delay in market entry time will cause a 33% profit loss; a 50% R&D budget overrun produces only a 3,5% decline of profits (Dumaine 1989).

Time to market and time to volume are variables that are not independent of each other. There are close interrelations between a new product's development cycle and market cycle - the two stages of the integrated product life cycle (Pfeiffer et. al. 1989). For example, the process of R&D requires resources derived from the sales volume and the realized profits of older products. Market entry time, sales volume, competitive strength and the risk of substitution of a product are influenced by the technical know-how. Technical know-how itself is responsible for sales volume, cost situation and finally for the profits of a new product.

Models that separately analyze the two stages are insufficient. For effective decision support in the field of innovation management they must fail, because they do not properly reflect the complex structure of this highly dynamic and complex problem. In view this, it is necessary to develop a model that links the process of corporate R&D with a model which represents both the diffusion and substitution processes of new products, as well as the corporate strategies. Such a model is presented below.

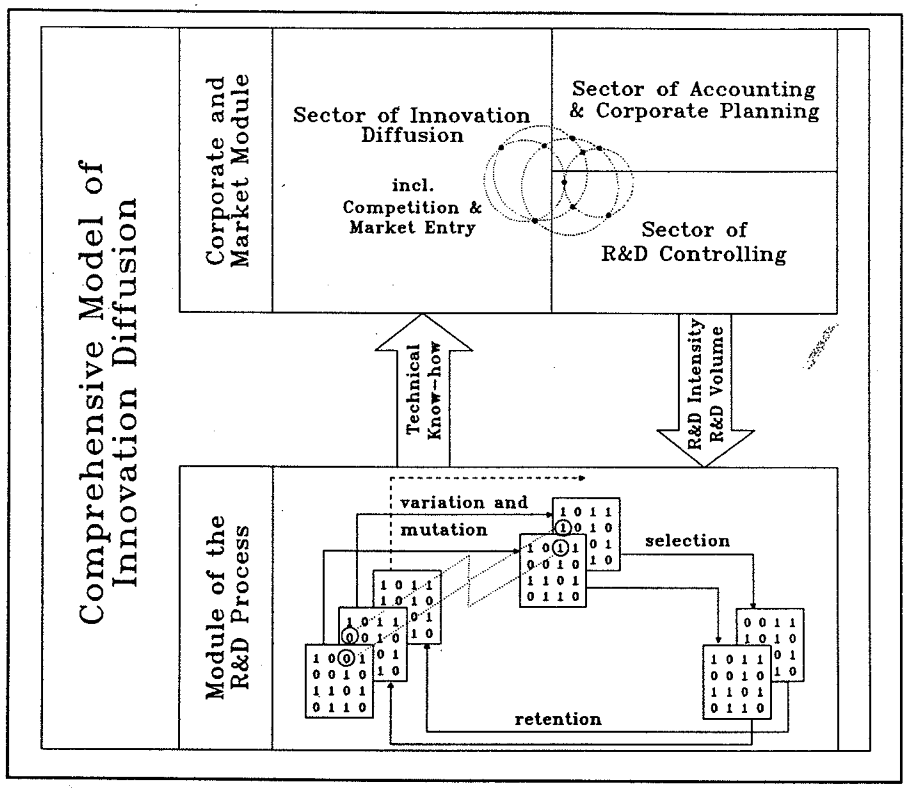

Fig. 1: Structure and Linkages of the Comprehensive Innovation Diffusion Model

As shown in figure 1 the model consists of two components. The first component is a C-written algorithm modeling the stochastic processes of creating new knowledge through corporate R&D. Under the assumption that biological evolution theory is applicable to the R&D process, an evolution algorithm was developed that represents the stochastic nature of creating new knowledge.

The second component, a DYNAMO-based model, maps the corporate policies for R&D budgeting and pricing, as well as the structural fundamentals of market dynamics for competitive and substituting goods. The information about R&D budgets and the allocation of the resources to the different R&D projects derived from the DYNAMO component. As input for the algorithm, this information influences the intensity and volume of the R&D activities. The evolution algorithm itself delivers the information about the technical know-how back to the corporate and market model.

BASIC PRINCIPLES OF THE R&D PROCESS MODULE

All attempts to use a production function (similar to those which model the production of material goods) with R&D resources as input factors, in modeling the process of generating new technological knowledge, must fail. The reason is in the highly stochastic nature of the input-output relation of the underlying process. This results from the commonly observed uncertain outcome of industrial R&D. Also, because of the extremely heterogeneous output, there are many problems with measurement of the R&D process output (Schröder 1973).

Due to the stochastic elements of R&D and the consequent failure of deterministic models, the process of corporate R&D is modeled with an evolutionary algorithm, considering the principles of variation, selection and retention (see Figure 1). The technological systems are represented through binary matrices with the entries "0" or "1". Each matrix can be interpreted as a basic invention that "opens" a new technology. The size of the matrix represents the maximum technological potential. It expresses the importance of a technology. The number of columns of the binary matrix is limited to 8; the number of rows is limited only through the technical restrictions of the computer system used to run the model. Currently matrices with 1250 - 3000 rows are in use. The element "0" is interpreted as basic knowledge in the field of the technology; the element "1" means applied knowledge. The worth of a matrix – and therefore the worth of the technical know-how – depends on the amount of elements with the value "1".

For the modeling of the R&D process, the evolution algorithm selects randomly an element of the matrix and changes the value of the element from "0" to "1" and vice versa (variation and mutation). The number of variations and mutations of the matrix in each period depends on the intensity and the volume of the R&D process. With each evolutionary step, selection takes place. The overall value of the matrix is then compared to its prior value before starting the variations (selection). If the value is higher, the new matrix is retained; otherwise, it is rejected and the old matrix is the basis for the next evolutionary step (retention) (Milling 1991b). The technological system with the higher number of elements with the value "1" is the superior one. It determines the technical know-how of a product. The difference between the maximum possible number of elements witch could have the value "1" and the actual number characterizes the technological potential.

ELEMENTS OF THE CORPORATE AND MARKET MODULE

The corporate and market module maps the structural fundamentals of three competing companies and the markets of four substituting successive goods. The parameters and initial values of the model have been adopted from studies of the personal computer market. The module is structured into three different sectors that are linked together through a large number of interrelations and feedback loops (see Figure 1). The fundamental basis of the sector of innovation diffusion is an innovation diffusion model (Milling 1986) that is extended to include competition among existing firms and substitution of successive products.

As in the Bass model of innovation diffusion, there are two contrary types of buyers, the innovators and the imitators (Bass 1969). The innovators are independent in their purchasing decisions; the number of innovative purchases per time period is a fraction of the actual number of potential buyers. The imitators' decisions to buy a new product depend on the experiences of people who have already purchased the product. Their behavior is imitative. So, the life cycles of different products are generated through the interactions of potential buyers and adoptors of a product. The fraction of innovative buyers and the probability of an imitative purchase are influenced by the multiplier of competitive advantage, that depends on the relative technical know-how, the price and delivery delays.

The sector of accounting and corporate planning computes variables like the costs, profits, prices, capacity and capacity expansion, timing of the market entry, market share and market growth. The variables generate the informational basis for corporate decision making. Alternative pricing strategies such as skimming- or penetration price are calculated and can be investigated for their impact on the diffusion processes and the overall profits of a product or a company.

The R&D controlling sector of this model maps the policies for the planning and allocation of capital and personnel resources to R&D process. Decisions are made about hiring and firing of R&D personnel and the allocation of available capital equipment to the R&D projects. It is the most important sector, because its decisions determine the intensity and the volume of the R&D process and finally the competitive advantage of a product. Additionally, this sector includs the policies that endogeneously control the market entrance of a new product, taking the technical know-how of a product into account. The information derived from the evolution algorithm is compiled for further use in the corporate and market module. The volume of the R&D process depends on the amount of R&D personnel allocated to the different projects; the intensity is linked to the share of allocated capital equipment per R&D person.

R&D AND MARKET DYNAMICS – FEEDBACK STRUCTURE AND MODEL BEHAVIOR

BUDGETING STRATEGIES FOR R&D

The total amount of R&D expenditures of industrial corporations depends on various factors. Due to the missing input-output relation, methods based upon marginal analysis are not useful for R&D budgeting. In practice, easier heuristics are generally used. Empirical studies have shown that in 1986 almost 60% of the investigated German companies use past-oriented values, like returns, profits or R&D budgets of earlier periods, for budgeting (Brockhoff 1988, Kern and Schröder 1977). 15.2% use the volume of returns for the calculation of the R&D budget, 30.3 % consider past R&D budgets and 6.1%, respectively 7.6%, use past profits or the budgets of competitors as a budgeting fundamental. Additionally, the empirical results have shown that more than 50% of the companies use more than one criterion for the determination of the R&D budgets.

The underlying model represented here uses a combination of the different empirically derived R&D budgeting policies. The budget for capital and laboratory equipment is determined as a percentage of the smoothed volume of past returns. The hiring and firing of R&D personnel is determined by the past number of research people, modified by a value that reflects the volume of expected change in returns. These budgeting policies are sufficient to generate the basic model behavior. In addition, the budgets of this model can be modified using a value that considers the reaching of profitability and market share objectives. This budgeting policy models the gap-oriented control of the planning and allocation of R&D resources in the process. In total, the implemented budgeting policies cover a wide spectrum of empirically established budgeting strategies.

BASIC BEHAVIOR OF THE INVESTIGATED STRATEGIES FOR R&D BUDGETING

To investigate the impact of R&D strategies on the process of innovation diffusion, the first step is the analysis of the complex and dynamic feedback structure. As mentioned before (and shown in Figure 2) the diffusion of an innovation is modeled with a diffusion model that includes innovative and imitative buying behavior.

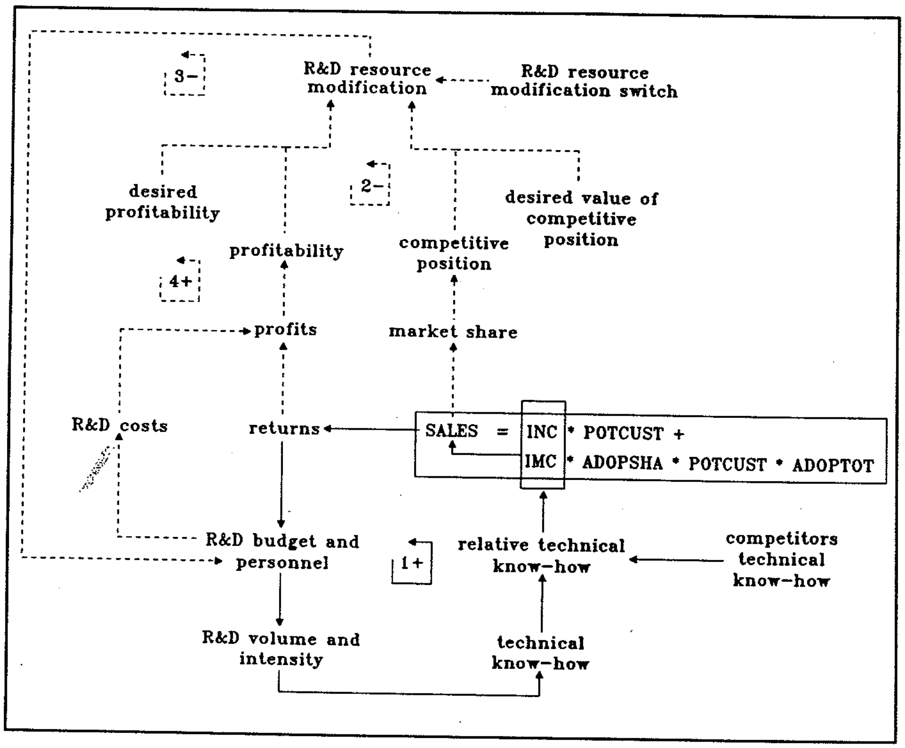

Fig. 2: Feedback structure of the implemented R&D strategies

The innovative purchases are calculated as the product of the coefficient of innovation (INC) and the number of potential customers (POTCUST). Imitative buyers are influenced in their purchasing decisions of the adoptors - persons who have already made a purchase. The product of potential customers (POTCUST) and total number of adoptors (ADOPTOT) characterizes the communication between the two groups. The coefficient of imitation describes the probability that the communication affect the purchase of a product (Milling 1986). Additionally, the share of adoptors (ADOPSHA) defines the percentage of communications allotted to each company. Indices describing the different firms and product generations are - for the sake of simplicity - omitted here. The addition of innovative and imitative purchases defines the total sales of a product in units per month.

The first loop is a central loop regarding the interrelations of R&D and market dynamics. It is implemented in all model runs. The feedback loops 2, 3 and 4 - marked with dotted lines - are only active in the strategy runs of the model mentioned later. The coefficients of innovation and imitation, which are responsible for the sales volume, are positively influenced by the relative technical know-how. Rising innovation and imitation coefficients cause the growth of sales and returns earned per month. Growing returns earned affect an increasing number of R&D personnel and growing R&D budgets. The positive linkage from R&D personnel and budgets to R&D volume and intensity finally induce better technical know-how. Compared to the competitors' technical know-how, the relative technical know-how and the coefficients of innovation and imitation increase.

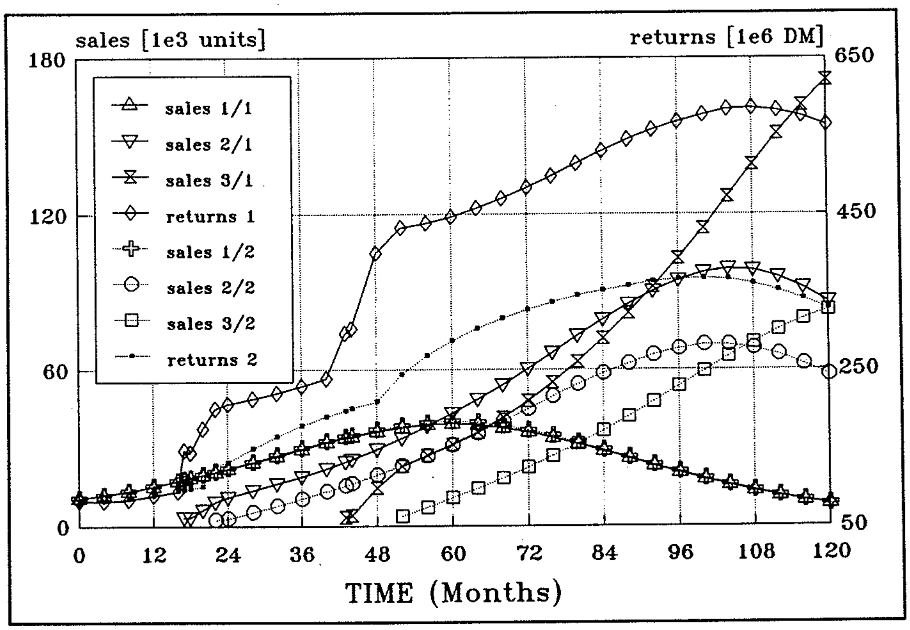

Fig. 3: Product Life Cycles and Development of Returns with Early Market Entrance of Firm 1

As with all figures to follow (including Figure 3), firm 1 is represented with solid lines and the competitors are symbolized with dotted lines, using the second company as an example. Notationally, "sales 2/1" maps the sales of the first company' s second product generation; returns 2 gives the second company' s returnes earned.

Feedback loop 1 is sufficient to produce the basic system behavior shown above. In the basic run of the model it was assumed that there is no differentiation of the products through price or technical know-how for the first product generation. The firms are assumed to be offering "identical" products. The starting point is the same for all three competitors. For the second product generation, one company reaches the needed technical know-how first and is said to have achieved early market entry. Firm 1 (the "first") appears in period 12 at the market; the second and third companies follow in period 17 (as "followers"). Although the first firm offers the products with a skimming price strategy and the followers compete at a low penetration price level, it is hard for the followers to gain market share. The followers' sales volumes are significantly lower.

Caused by the positive feedback loop 1 increasing sales affect a stronger competitive position of the first by the way of a higher R&D budget and number of R&D personnel. This leads to an earlier market entry for all successive and successful product generations. The total amount of each follower's cumulative and discounted profits is only 40% of the cumulative profits of the pioneer.

CONSIDERING THE PLANNING GAP FOR R&D BUDGETING – THE IMPACT ON THE DIFFUSION PROCESS

Considering the gap between actual and desired profitability and competitive position for R&D budgeting, additional loops with negative feedback are activated (see Figure 2). In these strategy runs of the model, loops 2 and 3 produce goal seeking behavior. Decreasing sales produce, on the one hand, a loss of market share and competitive strength and, on the other hand, a decline in returns, profits and profitability. Since the switch for R&D resource modification is activated, the descending profitability and competitive strength of a company cause improved R&D resource modification. That, in turn, produces increasing R&D budgets and R&D personnel, enhanced technical know-how and growth of sales and returns earned.

Counteracting, positive behavior generates the fourth feedback loop. A consequence of increasing resource modification and R&D resources is higher R&D costs, causing lower profits and profitability. The decrease in profitability finally induces higher resource modification. How the system behaves, depends on the gain of the loops and the strategies of the companies.

Figure 4 shows the product life cycles of three successive product generations and the development of the volume of returns. For testing of the enhanced budgeting policies it was assumed that company 1 launches the second product generation as the first in period 16. The second and third firms introduce their products to the market 6 months later. For better comparability of results, all competitors are assumed to be using a skimming price strategy. For the second generation, the pioneer' s sales volume is obviously higher than each competitor' s volume. This causes a loss in the followers' competitive positions. The enhanced resource modification and the significantly higher R&D resources enable the second and third companies to be first in launching the third product generation. Firm 1 becomes the follower. The volume of returns earned increases with the market entrance of the third product generation until the 90th period. Afterwards, a loss in the volume of returns is caused by the missing launch of the fourth product generation.

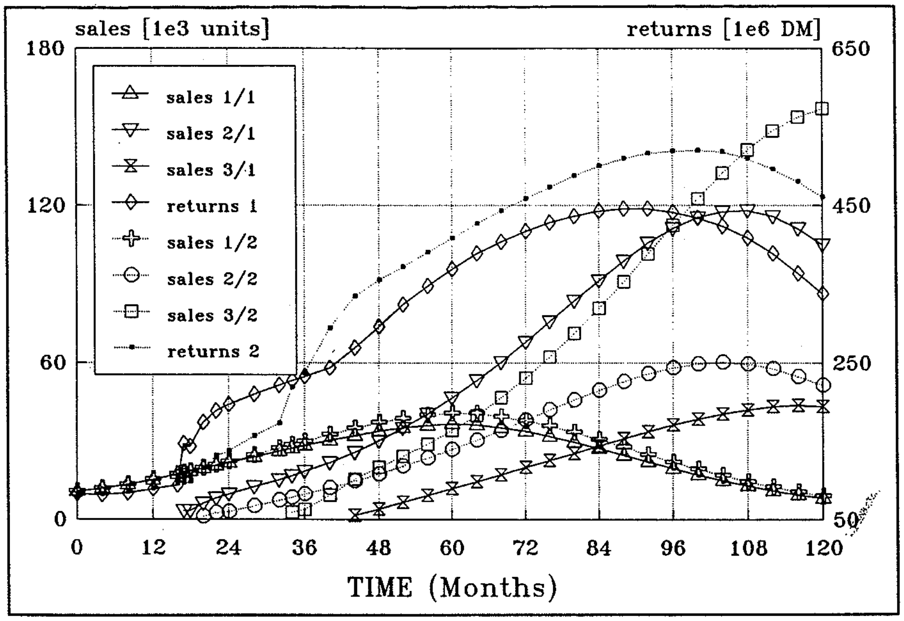

Fig. 4: Product Life Cycles and Development of Returns with Early Market Entrance of Firm 1 and Gap-oriented Budgeting Policy

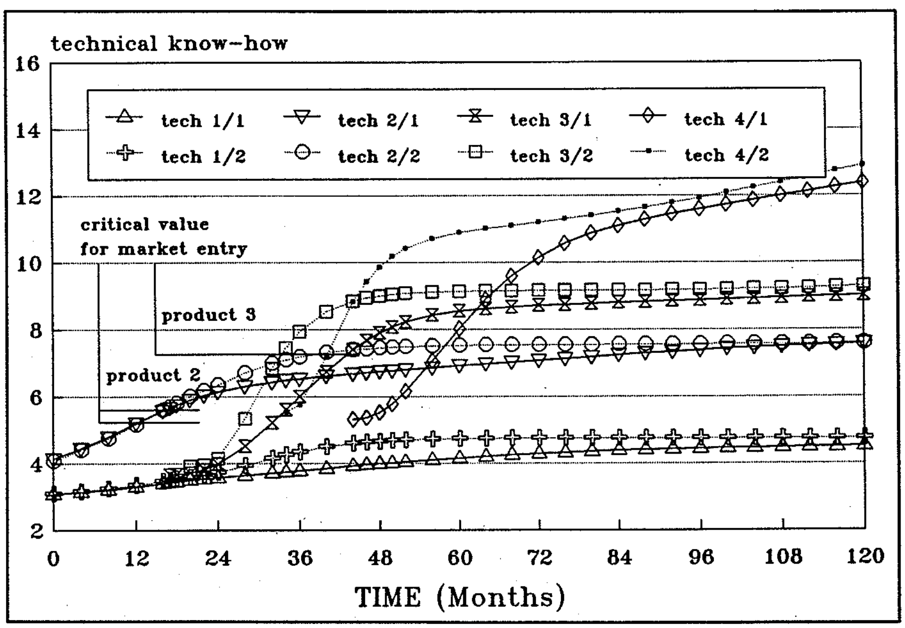

Fig. 5: S-Shaped Growth of Technological Know-how for Successive Product Generations

The time of market entry is an endogeneously made decision, which considers the technical know-how, as the output of the R&D process. Figure 5 shows the typical s-shaped growth of technical knowledge for the three successive technological generations underlying the different products of the first and second firms. The firms launch their products to the market when the technical know-how incorporated passes over a certain value (marked in the illustration).

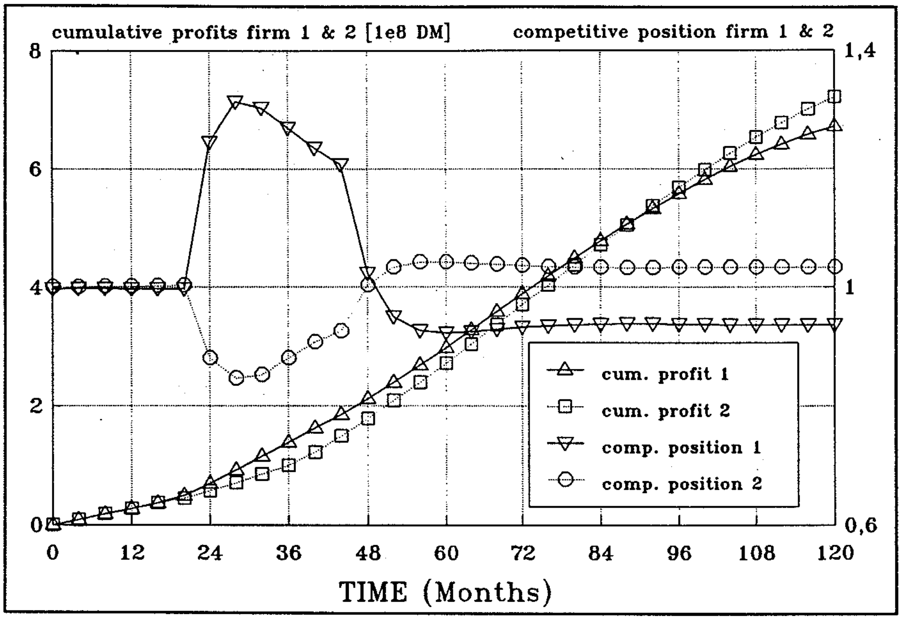

Fig. 6: Development of Cumulative Profits and Competitive Position of the Firms

Figure 6 shows the development of the indicator of competitive position for all three companies, as well as the discounted cumulative profits. The indicator of competitive position shows that the first company, with the introduction of the second product generation, gains a substantial advantage. However, with the early market launch of the third product by firms 2 and 3, it will lose all of its competitive advantage.

In view of the cumulative profits, the first firm, the pioneer with the second product generation, is the leader until the 67th month. Afterwards, firms 2 and 3 pass the first company, through earlier market entry of the third product generation. Although the R&D budgets for capital equipment are temporarily 87% higher than those of the first company, these firms will be the overall winners. Their cumulative and discounted profits are 7.5% greater. The additional R&D costs, brought about by the enhanced R&D resource modification, are made up for by the higher volume of the returns earned. Assuming, that the first company will not change its R&D strategy, it will not have the strength to become the "first" again.

CONCLUSIONS

The results of the model runs mentioned above will not show an optimal strategy for R&D budgeting. The purpose is to support decision processes in the field of innovation management - especially R&D management - and give insights into the complex structure of the problem. The model can be used to test the impact of different strategies on the market and the development of the companies.

The model clearly demonstrates that a budgeting strategy that only considers the past returns earned causes a concentration process. The pioneer firm will be the over all winner. Followers using the same strategy will not be very successful. Even strategies with low penetration prices bring no further success. Successful R&D strategies have to consider the gap between actual and desired profitability and competitive position, as a basis for enhancing R&D resources and R&D processes. This strategy can enable the followers to pass the pioneer introducing new products without ever being at his level of the older product generations.

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