MANUFACTURING'S RÔLE IN INNOVATION DIFFUSION AND TECHNOLOGICAL SUBSTITUTION

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ABSTRACT

Successful innovation management depends upon both, the intrinsic attributes of the new product to be marketed and the firm's internal performance like cost management, timely delivery and quality assurance. The impact of these latter aspects is frequently neglected in the design of models for supporting decision making in innovative firms.

A model is outlined to study the market response of different manufacturing policies for innovative goods. It allows e. g. the evaluation of an aggressive strategy with large production capacities from the outset, or a more tentative behavior to avoid the pressures stemming from high fixed cost and the risks of eventually idle capacity.

ENDOGENOUS FACTORS SHAPING THE PRODUCT LIFE CYCLE

The concept of a product life cycle serves as a prime heuristic for innovation management. The portfolio approach to strategic planning, for example, focuses on the different growth stages of a product in the market. Most models generating the cycle's characteristic logistic curve, however, do not reflect propeṙly the factors causing this behavior. They are based upon biological or physical analogies and fail to take sufficiently into account the economic environment of cost and price effects, quality and in-time delivery, etc. Purchasing decisions do not follow the same natural laws as do the spread of a disease, the dissipation of particles or similar processes.

Furthermore, most of these models show the diffusion, not the evolution of a phenomenon. They concentrate on - and thereby isolate - the short term dynamics of an innovation; they do not reflect the substitution processes between a sequence of products which take place as technology advances. Exactly these factors are to be considered and represented endogenously in a model if it is to be used as a meaningful tool for improving the quality of managerial decision making.

Due to the dynamics of innovative markets, substitution between technologies can occur rather rapidly, leaving only little time for the firm to earn an adequate return on its investment. Figures 1a and 1b show an example: the sales and price development of subsequent generations of memory chips. Each new generation brought with it a quadrupling of respective capacity. Very short life cycles and a dramatic decay in prices characterize this market. Its extraordinary patterns are, of course, illustrative but not representative for innovative goods in general.

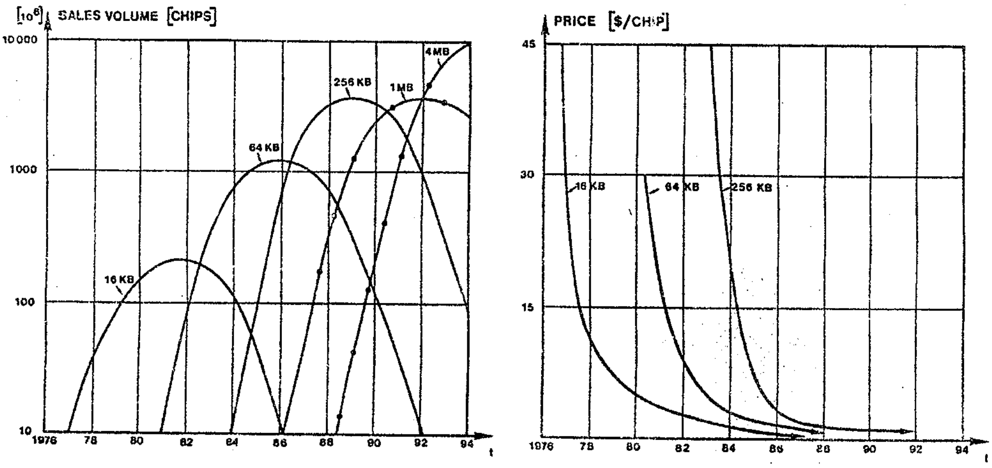

Figure 1 Sales volume and price development of memory chips.

The graphs indicate how vital it might be for firms in this business to build up in time the production capacity required to assure immediate delivery when demand gains momentum. It is only in the very early stages of the life cycle that high prices can be charged to compensate research and development expenditures.

This might suggest a strategy of high pricing together with an early investment in production capacity. This, however, also implies high fixed cost and consequently little flexibility if demand was overestimated or the market is already in its downswing. Furthermore, a policy of skimming prices during the introduction of a new product may lead to slow market penetration, impeding the rate of diffusion. Without rapidly expanding sales volume little benefits can be drawn from the experience curve.

The rate of innovation diffusion and the hazards of an early appearance of substituting products with an even higher level of technical sophistication are influenced by the behavior of the firm. Too cautious investment, small production volumes or poor quality are factors which determine delivery delays, prices and profit margin, customer satisfaction, etc.

Those endogenous variables, influencing the pattern and the time frame of a product's market performance, must be included in models designed as decision support systems for innovation management. They represent the very aspects which decide over success or failure of the corporations venturing in these markets.

PRODUCTION'S IMPACT ON INNOVATION PERFORMANCE

To analyze the impact of intra-firm factors, especially those in the production sector, on the market response of innovative products a general model of innovation diffusion was developed[1]. The basic structure of the market penetration processes is derived from the classic deterministic epidemics model. This core model is extended to include - among others - such aspects as investment decision, cost performance, and quality control.

Capital Investment Decision

In the model, investment is based on a comparison between projected demand and available production capacity, both measured in units per period. Three categories of new product buying behavior and the respective shift in dominance between them are taken into account: innovators, imitators, and - in the later stages - repeat or replacement purchasers. They react differently with respect to the already achieved market penetration, prices charged, and product quality[2].

Besides the demand projection, the firm's willingness to accept risk is explicitly considered in the investment decision. A tendency toward a cautious strategy will reduce, a more aggressive attitude will increase the indicated change in capital investment.

Quality Assurance

Total investment serves two purposes, it provides the capacities required for production purposes and those allocated to quality assurance. Investment comprises all factors (capital goods and human resources) needed in their respective proportions according to an implicitly assumed production function. At the investment stage, no distinction is made between the two functions, the facilities can either be employed for manufacturing new products or for assuring the desired quality level of the process.

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[1] A description of the model structure and its main equations is provided in Milling, P.M. (1986b), pp. 55ff.

[2] For this categorization cf. Rogers, E.M. (1983); Jeuland, A.P. and Dolan, R.J. (1982); Bass, F.M. (1980), (1969).

Resource reallocation between both ways of capital usage is monitored by a decision rule based on the firm's readiness for delivery. In a market with short life cycles and the constant threat of upcoming new products making the currently available ones obsolete, delivery delays can cause a permanent loss of demand. Thus, the strategy of immediate delivering capability - even at the cost of less careful quality control - is an effort worth to be considered.

Cost Management

Although short term pricing decisions can be made without explicitly striving for full cost coverage, in the long run such a policy is not sustainable; prices must be related to cost. Manufacturing's performance influences cost, prices and demand which feeds back on cost. These interdependencies, their structure and their consequences for pricing new products, have been analyzed elsewhere[3]. A central tenet for innovation management is the control of average unit cost.

The model uses a dynamic cost function with two variables, defining the long term and the short term behavior (Figure 2). The long range standard cost per unit are derived from an experience curve, the actual cost for each period are calculated from the respective standard value modified for production volume variances.

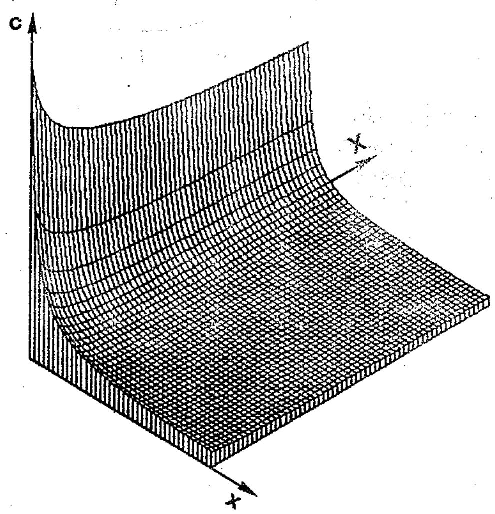

Figure 2 Graph of the dynamic cost function.

The experience curve assumes a direct relation between cumulated production X (which incorporates a firm's experience) and average unit cost c^p, adjusted for inflation; every

[3] Milling, P.M. (1986a).

doubling of X is associated with a cost reduction by a constant and predictable percentage:

$$c^p(t) = c_n \, [\, X(t)/n \,]^{-\delta} \qquad (1)$$

where c_n stands for the cost of unit n ($n \leq X$) and δ represents a constant which depends on the experience rate[4].

The dynamic cost function generated in the model determines actual unit cost in each period

$$c(t) = \Phi \, [\, X(t), \, x(t) \,] \qquad (2)$$

on the basis of gained experience X(t) which gives the standard unit cost and the variance resulting from the level of capacity utilization achieved with the output volume x(t).

EVALUATION OF RESOURCE ALLOCATION STRATEGIES

The extent to which manufacturing decisions determine an innovation's market performance and how they are to be controlled is evaluated on the basis of following assumptions:

(1) The dynamics of an innovation are studied from the viewpoint of a whole industry, thereby neglecting the competition between individual firms in this branch. The product under consideration can be thought of as a technologically sophisticated consumer durable like CD players, video recorders, etc.

(2) Although competition is not included at the micro level, it can and will occur between different levels of technology. Substitution will take place when a new technology is introduced into the market.

(3) Production on stock - at least at a level significant for the analysis - is considered to be not possible. When incoming orders stay below capacity, the level of output is reduced accordingly.

(4) The price effect upon demand is kept constant for all the simulation runs presented here. Prices are set according to a policy : $p(t) = c^p(t) * \pi * (1 - a*e^{-t/T})$, where π defines the profit margin on top of long run standard cost[5].

Figure 3 shows the base run of the model simulation. It assumes an initial value of 1 million potential customers as the product is launched into the market; additionally 2 million

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[4] Empirical evidence for this relationship is especially provided by Henderson, B.D. (1968).

[5] This policy - among others - is discussed in Milling, P.M. (1986a), pp. 790-792; for a control theoretical analysis of dynamic pricing cf. Jeuland, A.P. and Dolan R. J. (1982).

customers could be gained from an untapped market as diffusion proceeds. At TIME = 15 a new firm or even a completely new industry enters the market, its competing and more attractive product offers a higher level of technical sophistication. A substitution cycle is initiated and draws potential customers away from the product under consideration.

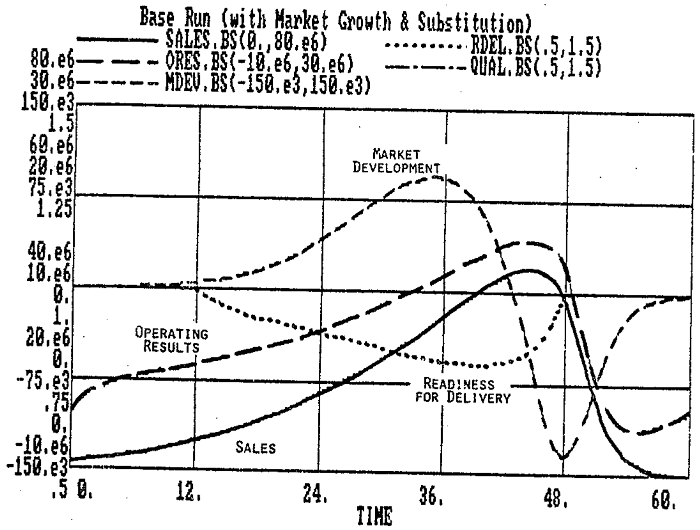

Figure 3 Reference mode of the innovation diffusion model.

The behavior of sales volume and operating results duplicates the usual characteristics of a product life cycle. In the early periods, the curve "Market Development" indicates a growing number of potential customers coming from the untapped market. This is caused by increased product awareness and falling prices. In later periods, market volume decreases as the untapped market becomes depleted and more and more potential buyers shift towards the substituting technology.

Capital Investment's Impact on Demand

The net loss in potential customers causes a sharp decline in sales which occurs so rapidly that production capacity cannot be adjusted in time. The fact that operating results turn negative during the last stage of the life cycle may suggest a more cautious strategy of increasing production capacity. Less capital investment prior to the peak of demand implies less fixed cost and - intuitively - seems to offer the opportunity for a more flexible reaction to market development.

Such a defensive investment policy, however, worsens in fact the situation significantly (Figure 4). It leads to less sales over the whole period under investigation and reduces the achieved financial results substantially. From the early stages of market introduction, unfilled orders hamper the successful launch and the profitable performance of the innovation. The curve "Readiness for Delivery" shows that, over a longer period of time, production volume reaches only 75% or even less of the demand level. This backlog in unfilled orders amplifies the upcoming trend towards the substituting technology and causes an accelerated loss of potential customers.

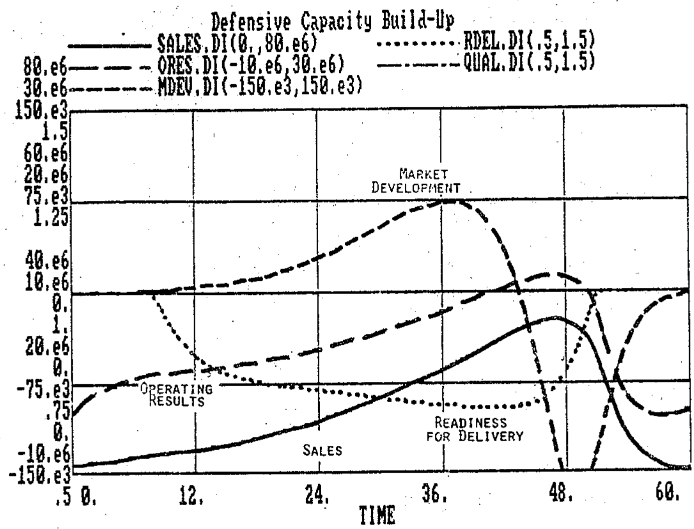

Figure 4 Defensive investment strategy.

While the tentative behavior is not promising, a different policy of more aggressive investment yields better results. Such a strategy provides sufficient production volume for in-time delivery as soon as demand gains momentum, even at the cost of a temporary excess capacity. Figure 5, in its time pattern similar to the base run, demonstrates the importance of timely capacity build-up. Production volume keeps closer up with accelerating demand, sales and operating results prosper.

Despite the overall favorable results, a thorough analysis of the combined effects of "Readiness for Delivery" and "Market Development" indicates that during the first 40 months or so the business cannot capitalize on all orders placed. Actual buyers - not potential customers - determine the success or failure of a firm. Later these potential customers move to the newer technology and their demand is permanently lost.

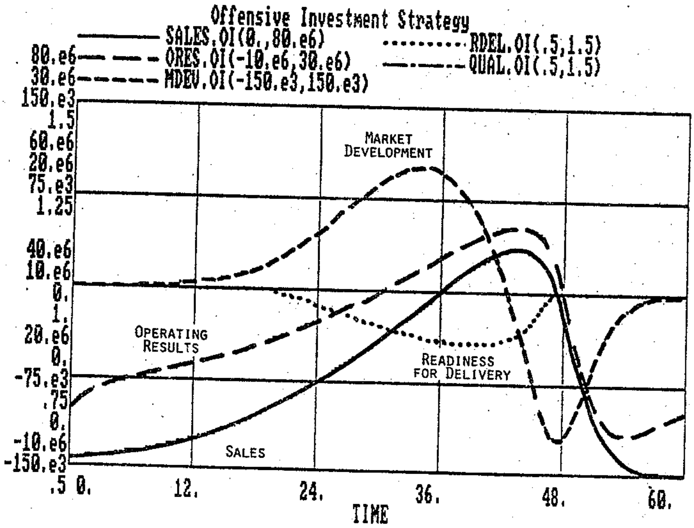

Figure 5 Offensive capital investment strategy.

Still more investment in production capacity is not recommendable. The upcoming decline in demand can be foreseen, idle capacity, the costly misallocation of resources would be the result. If, however, already available resources could be redirected for production purposes, a further improvement in the profit situation can be realized and the flexibility of the business substantially extended.

Quality Assurance - Reserve Capacity or Competitive Factor?

In the preceding runs it is assumed that a constant fraction of capital investment - for example 10% - is diverted for insuring the desired quality level. If these resources were partly and temporarily reallocated and used to increase output instead of controlling quality, a significant higher production volume with unchanged fixed cost and consequently an improved return on investment could be achieved.

This hypothesis is tested in the simulation run shown in Figure 6. In addition to the approved investment strategy, a resource allocation procedure is implemented to channel capacity between tasks devoted either to production or to quality assurance. If manufacturing capacity does not suffice to fill all incoming orders, the standard emphasis on quality assurance is temporarily reduced to allow a higher rate of production.

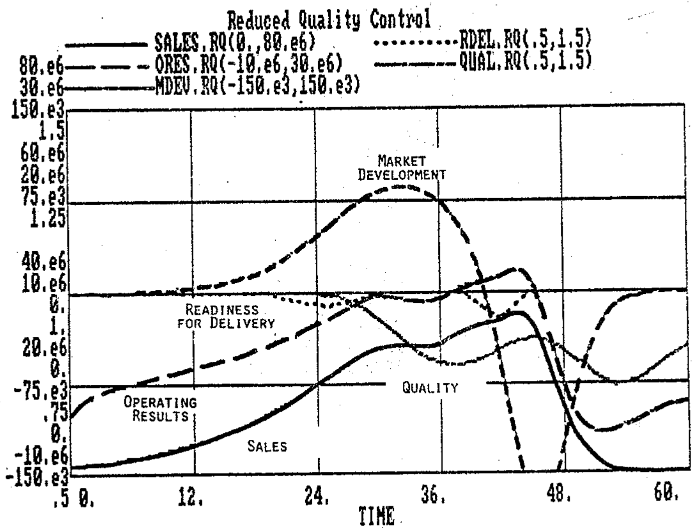

Figure 6 Reduced quality control.

Similar to the case of reduced capital investment, the obtained results differ from the expected behavior. "Readiness for Delivery" remains indeed at a very high level, but instead of gaining higher sales and improved operating performance, the actual outcome is poor. As the level of perceived quality decreases, sales and operating result stagnate, they remain in total far behind the values of other courses of action. The otherwise gradual transition of potential customers to the upcoming later technology turns now into a very steep decline of market volume.

Quality turns out to be a prime factor in the marketing mix during all phases of innovation diffusion. In the early stages, it influences market growth and penetration, in the later stages it exhibits an important impact on the rate of imitation and the speed of substitution. Short term advantages resulting from the negligence of quality, e. g. additional production capacity and reduced cost, turn into severe damages. In a medium and long range perspective, they cause detrimental effects on all relevant variables.

This suggests a strategy of emphasized - not reduced - quality control. If manufacturing cannot keep up with incoming orders, improved - not less - product quality might be appropriate. High quality standards show a strong influence on buying behavior, it can be used to balance the negative effects of delivery delays. When production volume lags orders booked, customers might be willing to accept waiting for the product if quality is supreme.

The behavior modes in Figure 7 support these hypotheses. Operating results double approximately, compared with the preceding run. Nearly all the market potential is exhausted, leaving relatively few customers for the new technology. The reputation of the product due to its superior quality is strong enough to compensate the negative effects of transient difficulties with immediate delivery.

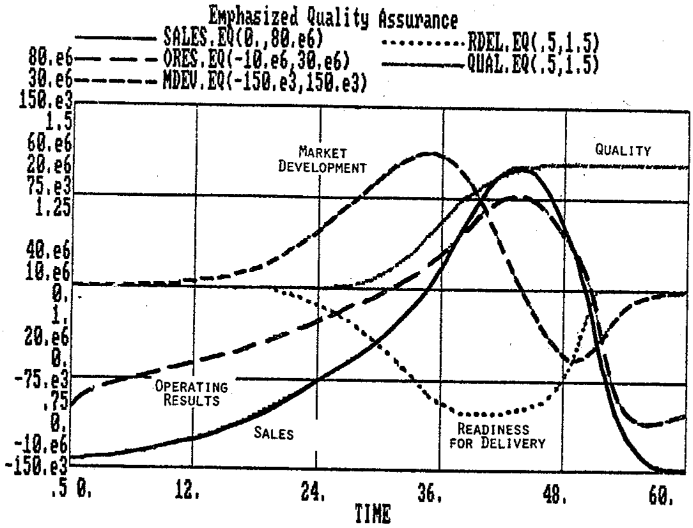

Figure 7 Strong quality performance in all innovation stages.

Especially during the last third of the life cycle, quality becomes the crucial factor. It does not extend the overall economic life time of the innovation significantly but causes demand to peak at a much higher level and to descend from it less rapidly. The profit situation is favorably influenced.

A comparison of total results, i. e. cumulated and discounted operating results, for all runs indicates that a combined strategy of offensive capital investment and high level quality assurance generates the best results. At the end of the simulation period, the business is financially approximately 30% better off than in the Base Run's reference mode.

CONCLUSIONS

The willingness to accept risk is a crucial prerequisite for the innovation business. Attempts to reduce or even to evade these hazards lead to poor results. If firms decide to launch innovative products, they have to provide the necessary production capacities to assure smooth delivery. In all phases of the life cycle, particularly, however, during market maturity and decline, quality is a prime factor of competition; neglected quality generates only short term advantages, the long range negative consequences exceed them by far.

The model emphasizes that the market performance of innovations is heavily influenced by intra-firm factors. Demand - in its time pattern as well as in its absolute volume - is significantly controlled by the corporation's manufacturing decisions. It is not only the product with its intrinsic attributes itself, nor the pricing strategy or the advertisement endeavor - to a large extent, market success is determined inside the factory.

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