MANUFACTURING'S ROLE 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 properly 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 de-
cay in prices characterize this market. Its extraordinary pat-
terns are, of course, illustrative but not representative for
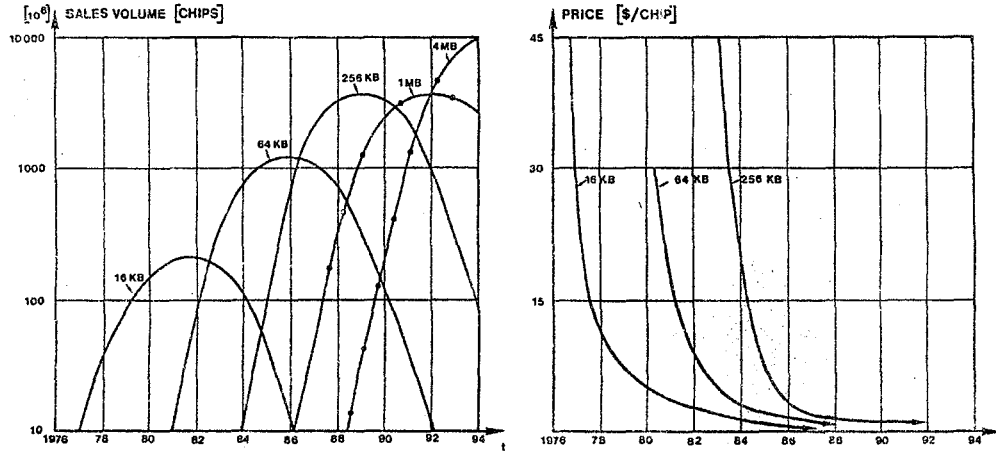innovative goods in general.

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 pen-
etration, 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, pri-
ces 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 mar-
kets.

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 devel-
oped[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 pro-
jected 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 pene-
tration, prices charged, and product quality[2].

Besides the demand projection, the firm's willingness to ac-
cept risk is explicitly considered in the investment decision.
A tendency toward a cautious strategy will reduce, a more ag-
gressive attitude will increase the indicated change in capi-
tal investment.

Quality Assurance

Total investment serves two purposes, it provides the capaci-
ties required for production purposes and those allocated to
quality assurance. Investment comprises all factors (capital
goods and human resources) needed in their respective propor-
tions 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 man-
ufacturing 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 pro-
vided 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 ef-
fort worth to be considered.

Cost Management

Although short term pricing decisions can be made without ex-
plicitly 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, de-
fining 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 calcu-
lated from the respective standard value modified for pro-
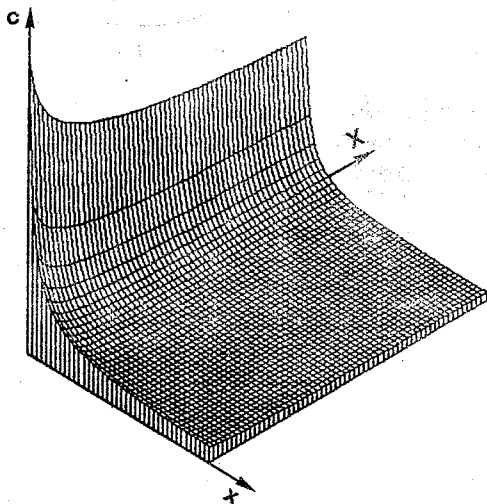duction volume variances.

Figure 2   Graph of the dynamic cost function.

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

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[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 $\le$ 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 in-dustry 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.

Base Run (with Market Growth & Substitution)
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           ─────────  SALES.BS(0.,80,e6)      ·········· RDEL.BS(.5,1.5)
    80.e6 ─ ── ─ ── ─ ORES.BS(-10.e6,30.e6)  ─·─·─·─· QUAL.BS(.5,1.5)
    30.e6 ────────── MDEV.BS(-150.e3,150.e3)
   150.e3
     1.5
    60.e6
    20.e6
    75.e3
     1.25
    40.e6
    10.e6
     0.
     1.
    20.e6
     0.
   -75.e3
     .75
     0.
   -10.e6
  -150.e3
       .5 0.        12.         24.        36.        48.         60.
                                   TIME
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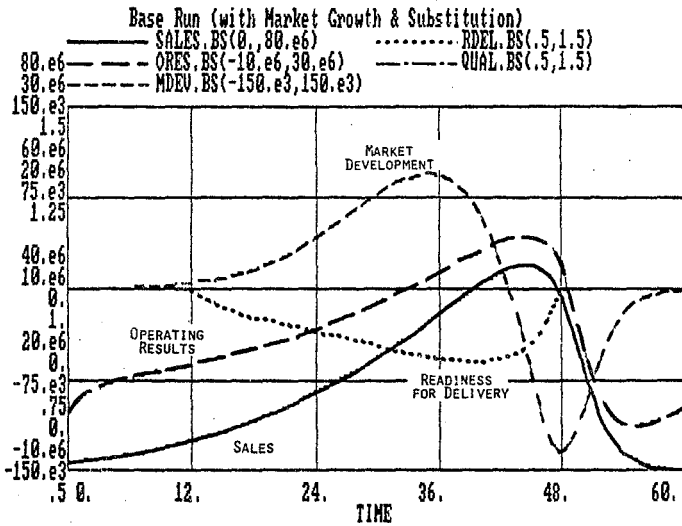
Figure 3   Reference mode of the innovation diffusion model.

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 po-tential 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 neg-ative 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 suc-
cessful launch and the profitable performance of the inno-
vation. 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 technol-
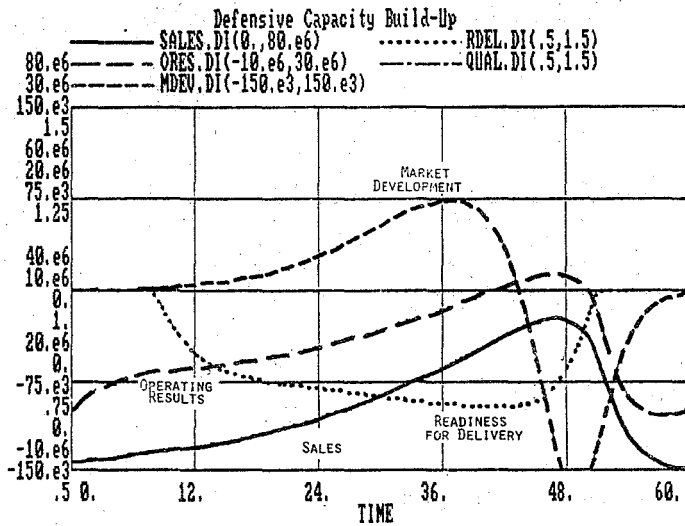ogy and causes an accelerated loss of potential customers.

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
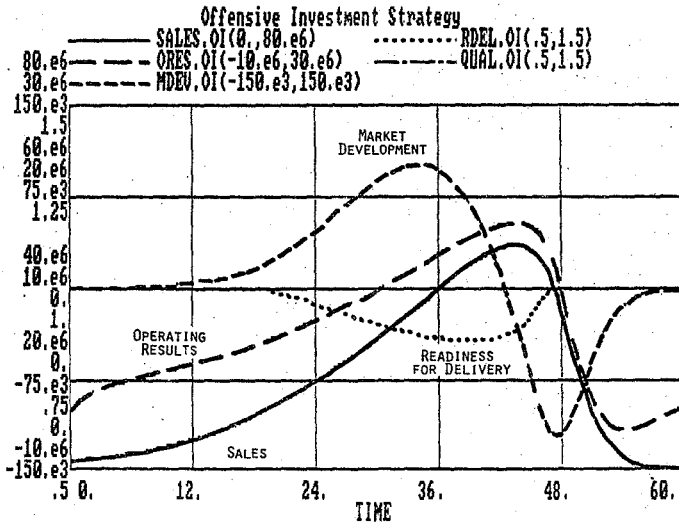newer technology and their demand is permanently lost.

Offensive Investment Strategy

SALES.OI(0.,80.e6)   RDEL.OI(.5,1.5)
ORES.OI(-10.e6,30.e6)   QUAL.OI(.5,1.5)
MDEV.OI(-150.e3,150.e3)

Figure 5   Offensive capital investment strategy.

Still more investment in production capacity is not recom-
mendable. 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 in-
suring the desired quality level. If these resources were
partly and temporarily reallocated and used to increase output
instead of controlling quality, a significant higher produc-
tion volume with unchanged fixed cost and consequently an im-
proved return on investment could be achieved.

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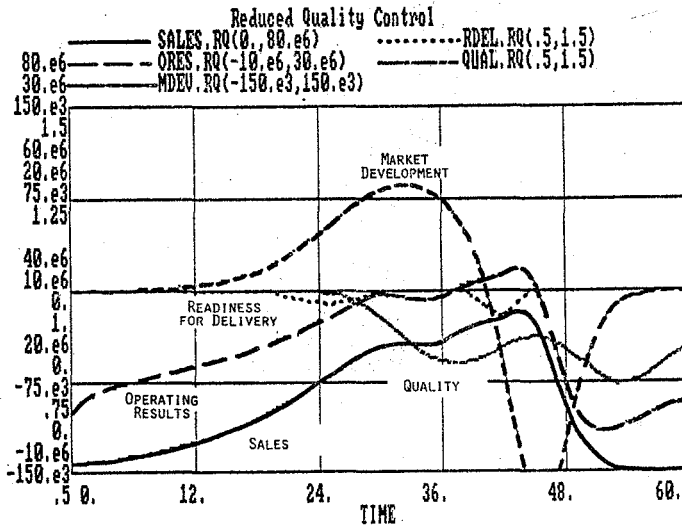surance is temporarily reduced to allow a higher rate of pro-
duction.

Figure 6 Reduced quality control.

Similar to the case of reduced capital investment, the obtain-
ed 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 de-
creases, 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 up-
coming 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 dam-
ages. In a medium and long range perspective, they cause det-
rimental 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. Oper-
ating results double approximately, compared with the preced-
ing run. Nearly all the market potential is exhausted, leaving
relatively few customers for the new technology. The reputa-
tion of the product due to its superior quality is strong
enough to compensate the negative effects of transient diffi-
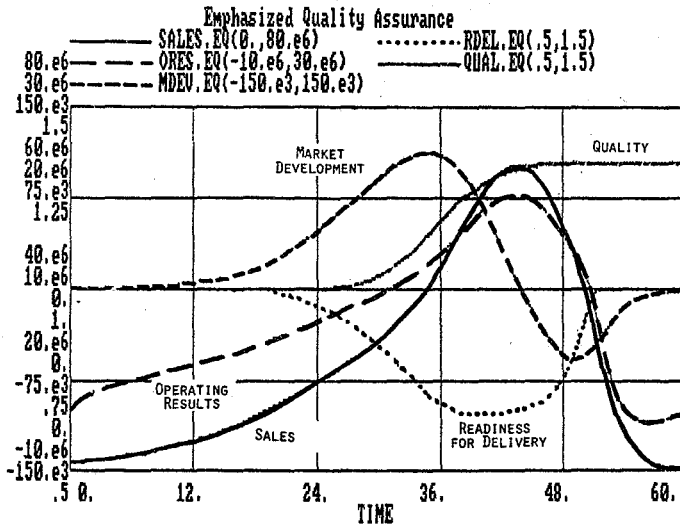culties with immediate delivery.

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 qual-
ity 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 pro-
duction 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; neg-
lected quality generates only short term advantages, the long
range negative consequences exceed them by far.

The model emphasizes that the market performance of innova-
tions is heavily influenced by intra-firm factors. Demand — in
its time pattern as well as in its absolute volume — is sig-
nificantly 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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