Innovation Diffusion Models for Decision Support in Strategic Management

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Abstract

The diffusion of innovations over time is a highly dynamic problem that is influenced by various factors like price, advertising, product quality, competition and among others the time of market entry. The traditional models of innovation diffusion – like the Bass model and the further developments on that basis – ignore those factors and the complexity and dynamics underlying the process of diffusion. Usually these models consider only one influencing, but exogenous element, e.g., price or advertising, and seek for strategies to optimize the cumulated profits. Their aim is normative decision support in this field, but they use models, which do not appropriately represent the structural fundamentals of the problem because the methodologies the models are based on are inadequate to build complex and interdependent models.

The use of the system dynamics methodology allows the development of more complex models to investigate and analyze the process of innovation diffusion. These models can enhance the insight in the problem structure and increase understanding of the complexity, the dynamics and the impact of the influencing factors. The paper discusses in a systematic view different model types. In the beginning the coarse structure of a model that generates the process of innovation diffusion in monopolistic markets is shown and discussed in detail. It is also described how management policies and the structures of corporate models can be integrated to the model. Further developments of this core model then describe different ways of mapping competition among existing and potential competitors in innovation diffusion models. These models then allow – among others – the analysis of market entry timing, pricing or advertizing, and research and development strategies.

Decision Support with Models of Innovation Diffusion

The continous improvement and renewal of a company's range of products is essential for survival in competition. Strategic management has, among others, the task to seek for strategies to guarantee and to increase the competitive advantages of a company. The development and introduction of new products in literature usually is summarized with the term innovation management. It comprises all activities of the process of innovation. This includes the phase of research and development as well as the real innovation activity: introducing new products to a market and controlling the process of innovation diffusion. Innovation management has to take care of R&D activities and therefore it is responsible for the technical know how and the potential product quality. It has to seek for adequate market entry strategies, regarding the whole spectrum from capacity planning, pricing, advertising, or the problem of market entry time. Innovation management has to deal with two stages of the same process: the process of invention -- bringing technology into being -- and the process of innovation -- bringing invention into use (Schon 1967). This paper concentrates on model to support decisions that deal with the activities of the process of introducing new products to the markets. From that point of view the process of bringing technology into being is controlled by the invention management, or R&D management.

Even though the process of invention is very complex too, especially the process of innovation diffusion is highly dynamic and not easy to understand. Management science has developed a plenty of descriptive or normative methods, models and instruments to support decisions in the process of introducing new products. A variety of models have been developed to model the diffusion of innovations over time. The research reaches back to 1960 with the models developed by Fourt/Woodlock, Mansfield and Bass (Fourt/Woodlock 1960; Mansfield 1961; Bass 1969). These models regard the diffusion of an innovation over time as a quasi natural process -- like the spread of a disease -- neglecting variables that allow to control the speed of innovation diffusion through corporate decisions. However, these fundamental models have been the basis for a variety of developments in this particular field, but only a few of them consider the variety of influencing elements of the innovation diffusion (for an overview see e.g., Mahajan/Peterson 1985; Mahajan/Wind 1986; Mahajan/Muller/Bass 1990; Maier 1995). They concentrate only on one or a combination of a few of the decision variables. E.g., some models have been developed to seek for the optimum pricing or advertising strategies. Some models are simple in structure, regarding only monopolistic markets and neglecting important management decision variables. Some models are more complex, considering oligopolistic or dynamic market structures. However, management decision variables are mostly exogenous inputs into the model, no feedback between management decisions and the spread of a new product in the market exists. These kinds of models are sufficient for description and sometimes for optimization, but not for the understanding of complex and dynamic feedback structures and therefore insuffiecent for decision support.

The influencing elements of the diffusion of innovations can be classified into four groups (Maier 1995): These factors are:

(1) different types of market structure e.g., monopolistic, oligopolistic or markets which change from monopolistic to a competitive structure;

(2) the factors directly influenced by the decision variables of a company, such as pricing or advertizing strategies, the quality of a product as influenced by the quality of the manufacturing process, the technical know how incorporated into a product through

research and development as well as the delivery delays caused by insufficient capacity investment;

(3) general aspects of innovation diffusion processes, like negative word of mouth, substitution among successive product generations, potential repeat purchases and the market potential; and

(4) the process of innovation diffusion itself through, e.g., carry over effects from ealier periods.

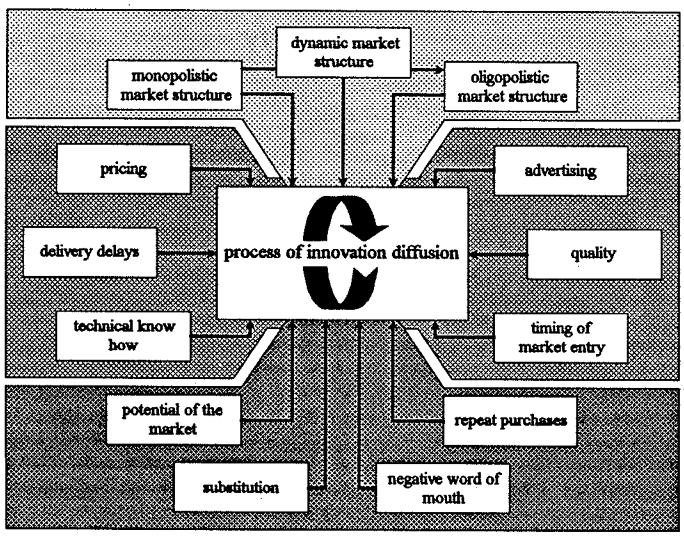

Fig. 1: Influencing elements of the process of innovation diffusion

Figure 1 comprises the main influencing factors of diffusion processes. Although these elements have to be considered for the conceptualization and development of models for decision support in the field of innovation management, the models discussed in literature fail caused by methodological restrictions. Particulary, models based on the system dynamics methodology could be suitable instruments for decision support because their objectives are to improve the effectiveness of decision making through the understanding of the underlying feedback structures. System dynamics models consider all factors that causes the behavior of a system as endogenous elements. They explain the behavior of a system through the feedback relations of its elements. How the diffusion of innovations can be modeled using system dynamics models will be shown for some exemplary problems in the following.

Approaches to Model the Diffusion of Innovations

The Basic Models

The so called model of externel influence (Fourt/Woodlock 1960) models the diffusion of innovation as shown in equation (1). The sales of a period x_t are calculated as the product of the probability of a purchase α and the remaining market potential of period N_t.

$$x_t = \alpha * N_t \tag{1}$$

with:

α	probabilty of a purchase
x_t	sales in period t
N_t	remaining market potential of peridod t

The remaining market potential N_t is calculated as the difference of the initial market potential N and the cumulated sales X_t.

$$N_t = (N - X_t) \tag{2}$$

with:

N_t	Remaining market potential in period t
N	Initial market potential
X_t	Cumulated sales in period t
	$= \sum_{t=1}^{n} x_t$

The model of internal influence (Mansfield 1961) explains the process of innovation diffusion through the communication of the members of the remaining market potential $(N - X_t)$ and the persons who have already bought the product X_t and a factor β which represents the probabilitiy that the communication leads to a purchase of the product.

$$x_t = \beta * X_t * (N - X_t) \tag{3}$$

with:

β	probabiltiy of a product purchase initiated by communication

The Bass model of innovation diffusion (Bass 1969) summarizes the external and internal influence model. For this reason it is a so called mixed influence model. Bass interprets external influenced buying behavior as innovative buying and internal influenced buying behavior as imitative purchasing. The demand of a periode is calculated through addition of innovative demand $(\alpha * (N - X_t))$, and imitative demand $(\frac{\beta^*}{N} * X_t(N - X_t))$ according to equation 4. The constants α and $\frac{\beta^*}{N}$ are interpreted as the coefficient of innovation and the coefficient of imitation[1].

$$x_t = \alpha * (N - X_t) + \frac{\beta^*}{N} * X_t(N - X_t) \tag{4}$$

These three models which do not consider the influences resulting from corporate decisions generate the behavior as shown in figure 2.

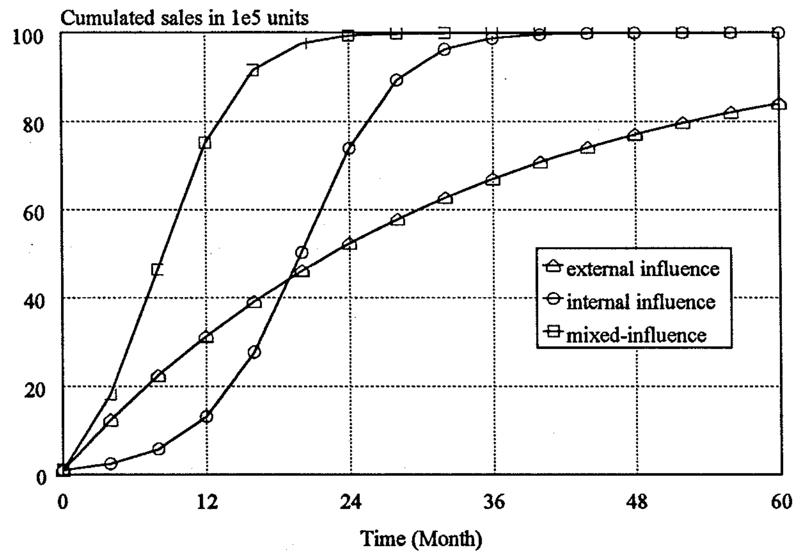

Fig.2: Cumulated sales in the basic diffusion models

For decision support these models are not sufficient. They have to be extended through variables that consider corporate decision making as endogenous elements which regard the sales and the various decisions variables to be interrelated through several feedback loops.

Integrating Decision Variables in Innovation Diffusion Models

Looking at the Bass model from a system dynamics point of view the remaining market potential $N_t = (N - X_t)$ and the cumulated sales $X_t = \sum_{t=1}^{n} x_t$ are the state variables of the system, the so called market potential, and the adopters of a product. The sales of a period which consist of innovative and imitative demand reduce the market potential and increase the number of adopters. The coarse structure of a mixed influence diffusion model is shown in the centre of figure 3. Various models have been developed at the basis of the mixed influence model. These models added price or advertizing as decision variables, but exogenous elements (Robinson/Lakhani 1975; Simon/Sebastian 1987).

Milling firstly applied the system dynamics methodology to model the process of innovation diffusion for a monopolistic market, considering decision variables as endogenous elements. The model is structural identical to the mixed influence model developed by Bass. However, in contrast to the basic models Milling explained imitative purchases through a combinatorical analysis and added a corporate model to map elements like experience curve depending costs, price depending market potential, delivery delays caused by insufficient capacity investment, and substitution processes (Milling 1986a).

The calculation of innovative and imitative demand as used in the model developed by Milling can be derived from equation 4.

$$\textit{innovative demand} = \textit{coefficient of innovation} * \textit{market potential} \qquad (5)$$

$$\textit{imitative demand} = \frac{\textit{coefficient of imitation}}{\textit{init. value market potential}} * \textit{total adopters} * \textit{market potential} \quad (6)$$

This core model of the product life cycle serves as the fundamental basis for a series of different models to analyze the consequences of varying decision variables like pricing policies, capacity investment, or production policies (see e.g., Milling 1986b; Milling 1987; Milling 1989).

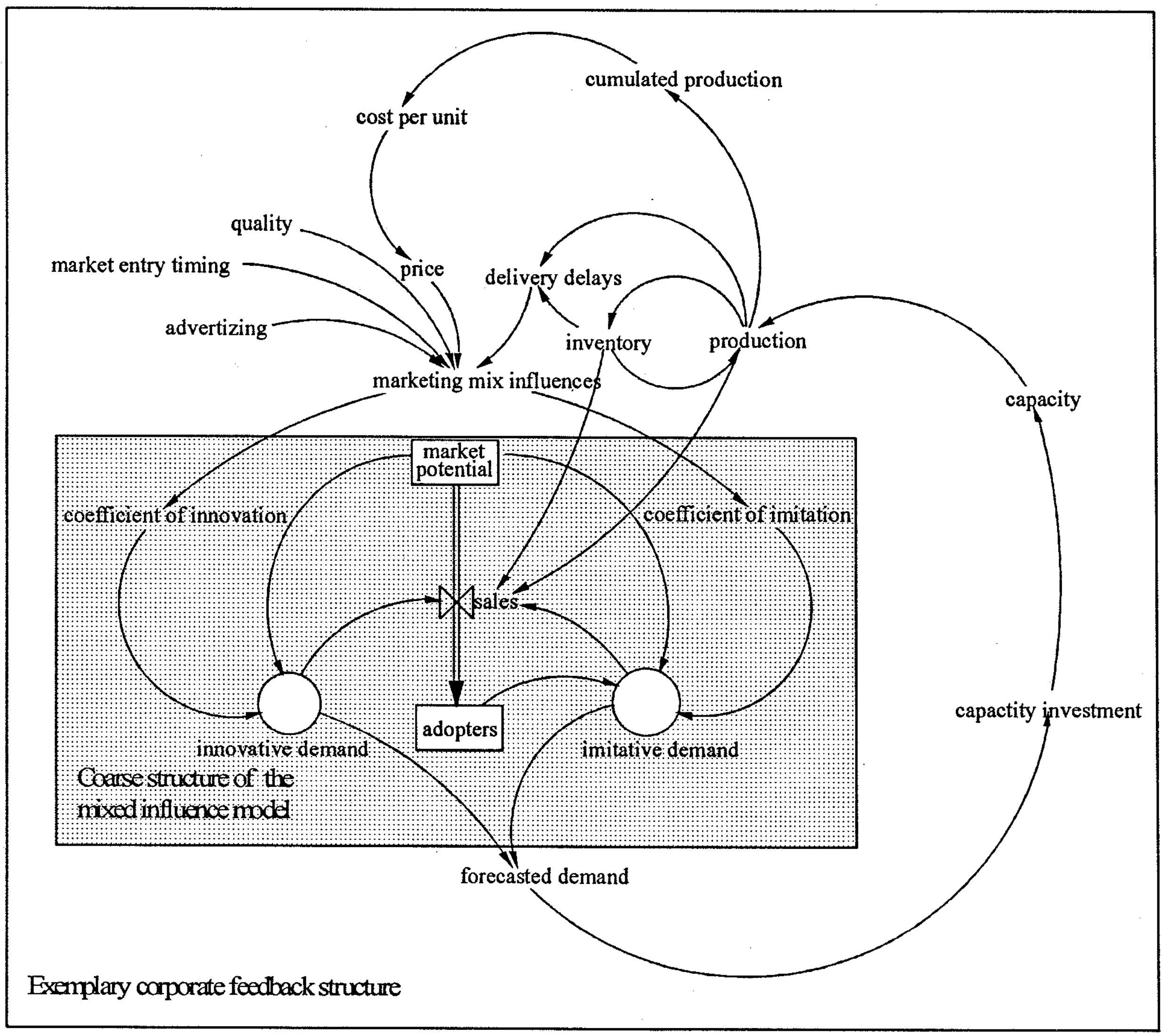

Fig. 3: The monopolistic mixed influence model in feedback perspective

Figure 3 also shows exemplarily how corporate decision variables may be integrated into the coarse model of innovation diffusion and how they may be influenced through the feedback structures. Variables like pricing, quality, advertizing or delivery delays influence the coefficients of innovation and imitation and therefore the probability of a purchase. This means that the coefficients have to be seen as a function of the endogenously influenced decision variables.

$$\textit{coefficient of innovation / imitation} = f(\textit{pricing, advertizing, quality, ...}) \quad (7)$$

The actual sales of a periode have to be defined as the minimum of the innovative and imitative demand and the production and inventory of period t.

$$sales_t = \text{MIN}(innovative\ demand_t\ +\ imitative\ demand_t,\ production_t\ +\ inventory_t) \quad (8)$$

A model developed in this manner can serve as a simulator to analyze the consequences of different strategies. It is not suitable for optimization, but it allows an enhanced understanding the influencing elements. It shows e.g., how pricing strategies and investment strategies influence each other, or how the impact of intensified quality control is for production and sales of a period.

Although these types of models may be very useful for decision support in monopolistic markets, they do not reflect the problems that are caused by competition among existing and potential competitors. For this reason, the coarse model of innovation diffusion has to be extended through model structures to map competition.

Considering Competition among Corporations

Before competition can be considered in an innovation diffusion model some preliminaries have to be clarified. In the monopolistic diffusion model there are two different types of demand, innovative and imitative demand. Innovators purchase a product because they are interested in innovations. They are not influenced by the adopters, persons who have already bought the product. As shown in equation 5 they are calculated as a percentage of the market potential. For calculation of a company's innovative demand in a competitive diffusion model this equation has to be modified. The coefficient of innovation has to be divided by the number of competitors, in order to share the demand among the competitors. The multiplication with the factor of market presence allows to model different market entry times of the competitors. It takes the value 1 since a company is present at the market, otherwise the factor own the value 0. This causes that the demand of a company has the value 0 as long as the company is not present at the market.

$$innovative\ demand_{company\ i} = \frac{coeff.\ of\ innovation}{numb.\ of\ competitors} * fac.\ market\ presence_{company\ i} * market\ potential \quad (9)$$

The imitators observe the buying behavior of adopters or communicate with adopters, and purchase the product because they also want to own it. As shown in equation 6 the term $total\ adopters * market\ potential$ summarizes the number of potential contacts between the persons of the market potential (they have not yet bought the product) and the adopters (persons that already purchased the product) in a monopolistic market. For modeling a competitive market first it has to be clarified how do people communicate. Do adopters give information about a product form (e.g., video recorders) or do they communicate information on the product of a particular company (e.g., a video recorder of company „xy").

In the first case -- the model of product form related communication -- the term $total\ adopters * market\ potential$ gives the correct number of potential contacts. The variable adopters shows the number of the cumulated product purchases of all companies that are present at the market. However, to calculate the imitative demand of a company i an additional term has to be introduced as shown in equation (10). This term represents of company's share of the total adopters of a market.

$$imitative\ demand = \frac{coefficient\ of\ imitation}{init.\ value\ market\ potential} * \frac{adopters_{company\ i}}{total\ adopters} * \quad (10)$$
$$total\ adopters * market\ potential$$

In the second case the adopters of a particular company's product communicate information about the product they have purchased. Therefore an alternative way of modeling competition in imitative demand has to consider the number of potential contacts between the market potential and the adopters of the products ofcompany i. This model of product related communication is shown in eqation (11).

$$imitative\ demand = \frac{coefficient\ of\ imitation}{init.\ value\ market\ potential} * adopters_{company\ i} * market\ potential \quad (11)$$

It is obvious that equation (10) can be transformed to equation (11), through reduction of the variable total adopters from (10). However, if the term that represents a company's share of the total adopters of a market $\frac{adopters_{company\ i}}{total\ adopters}$ is raised to the power of γ as shown in equation (12) one can model weaker $(0<\gamma<1)$ or stronger $(\gamma>1)$ influence of a company's share of adopters[2]. In the case of $\gamma=1$ equation (12) is equal to equation (11). Equation (12) is preferred for the reason of the more advanced modeling capabilities.

$$imitative\ demand = \frac{coefficient\ of\ imitation}{init.\ value\ market\ potential} * \left(\frac{adopters_{company\ i}}{total\ adopters}\right)^{\gamma} * \quad (12)$$
$$total\ adopters * market\ potential$$

System Dynamics based innovation diffusion models as shown in (12) then can be used as a strategic decision support system for the management of innovations in a competitive environment. Therefore it has to be linked to a comprehensive corporate model that maps the relevant structures and policies of the competing companies. The influence of a company's marketing decisions for example can be connected to the coefficients of innovation or imitation as shown in figure 3. However, those variables than have to measure the relative influence of the decisions compared to the competitor's decisions. Figure 4 gives an examplary application of the competitive market model under consideration of innovative and imitative demand as modeled in equation (9) and (12). The factor λ is assumed to be 0.75.

The figure shows the second company's market share depending on the market entry time. With equal market entry time both competitors share the market. In the different runs it is assumed that the second company enters the market with a delay of 3, 6, and 12 months.

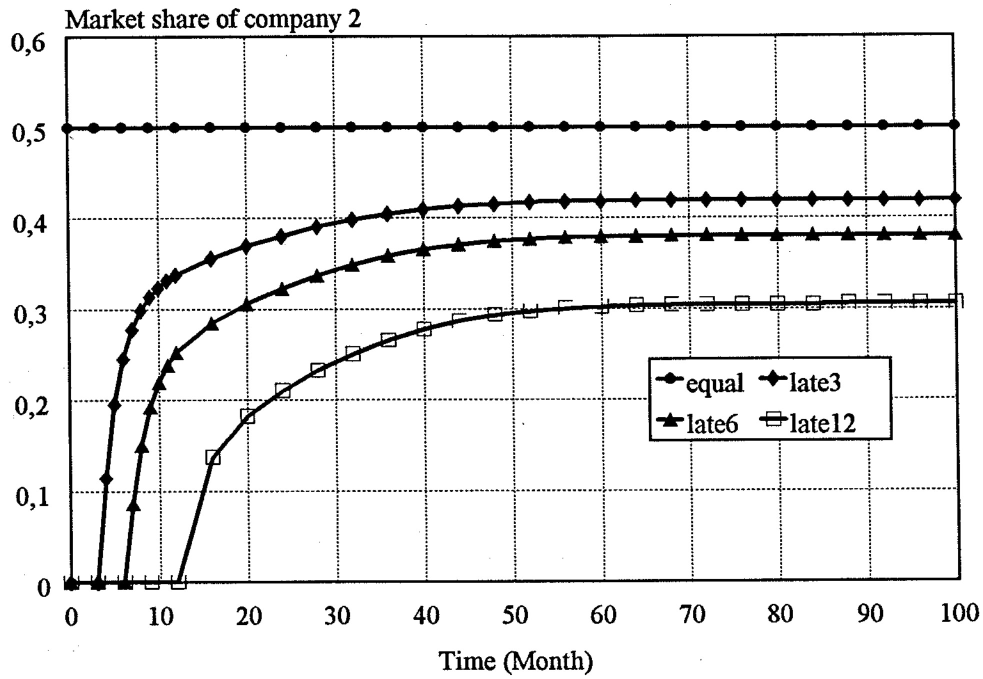

Fig. 4: Second company's market share for different market entry times

Conclusions and Research Directions

The paper discusses the applicability of system dynamics based models to innovation management. It shows how to integrate feedback depending decision variables into diffusion models and how to extend a monopolistic diffusion model to competitive structure. These models already have been used to analyze for example pricing or manufacturing strategies (Milling 1986b, Milling 1987) or strategies for research and development budgeting to develope successive product generations in a competitive market (Maier 1992). Although the models already have integrated a variety of decision variables and have been analyzed under monopolistic and competitive surroundings, they do not yet map substitution processes of successive product generations. A research project to explore the dynamics of substitution based on the example of different generations of personal computer processors already has started at Mannheim University.

Notes

1 The term $\frac{\beta^*}{N}$ in the Bass model is equivalent to the coefficient β in the Mansfield model.

2 Easingwood/Mahajan/Muller have used a similiar way to model different influences of social pressure in imitator's purchasing behavior (Easingwood/Mahajan/Muller 1983).

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