Innovation and Management: International Comparisons

Editors
Kuniyoshi Urabe · John Child · Tadao Kagono

Walter de Gruyter · Berlin · New York 1988

Management of Change in the Firm – Theoretical Analysis and Empirical Evidence

Horst Albach

1. Introductory Remarks

A comparison of the list of the "top 500" in the United States in 1965 (Fortune Magazine 1965) with the respective list of the 500 largest corporations in 1985 (Fortune Magazine 1985) reveals significant changes in rank ordering. Some companies have dropped out the list completely, others have come in.

During the industrial revolution no less than 151 firms produced dyestuffs in the Rhine provinces. No more than eight of them have survived (Pohl/Schramm/Schönert-Röhlk 1983).

Of the 133 companies that produced information processing equipment in Cologne in the period from 1881 to 1914 not a single one exists in its original legal form, and only four of them can be associated with the names of existing companies (Wessel 1983).

After the Second World War the Oberhausen Steel Works were twice the size of the Thyssen Steel Company. When the two firms merged in 1968, the relationship in size had reversed. Thyssen was twice the size of the Oberhausen Steel Works (Wenz 1976).

Development of firms in a market economy is obviously a process which shows substantial differences between companies. Discontinuities are omnipresent in the population of firms. New firms are set up, some firms disappear through merger or closure, and others undergo spectacular bankruptcies.

The questions of how to explain such development processes in the framework of economic theory, how to improve the chances of survival and success, and how to minimize the risk of bankruptcy have been to the fore of research in business economics for some time now.

It was Alfred Marshall who suggested that the life of firms is closely related to the fate of the entrepreneur's family. The father builds the business, the son maintains it, and the grandson cannot avoid the ultimate collapse. Of course, this is not an explanation that satisfies the economist. Stages of family vitality are not a category in economic theory. Even Alfred Marshall himself pointed out that firms can avoid their third generation doom by changing legal form and becoming a corporation.

Robert Gibrat, on the other hand, assumed that the development of firms is the outcome of stochastic processes. A multitude of random factors impact on the firm and determine growth or decline. The growth rate of firms is independent of firm size, and the distribution of firm sizes that emerges from a population of firms of equal size after undergoing these stochastic influences closely approaches the distribution of firm sizes observed in an economy. This again is an explanation that does not satisfy the economist. It neglects the impact of entrepreneurial and managerial decisions on the growth of firms. Managers try to equal marginal cost and marginal revenue over time.

Baumol suggested just that: the growth rate of firms is determined by the equality of the marginal returns from growth and the marginal cost of expanding the firm. This sounds, however, more like a tautology than like an explanation of firm growth, and even control theory which has shed theoretical light on such dynamic processes in the more recent past has so far not contributed to our empirical understanding of the development of corporations in a more than thought-provoking way.

On the other hand, the behavioral theory of the firm has much to say about workers' (and managers') resistance to change, and the theory of organizational development has studied intensively the implications of Levin's stages of organizational change. But these studies borrow more heavily from Karl Lorenz' analyses of animal behavior than from economics.

In this paper the topic of management of change in the firm will be addressed in the traditional vein of business economics. In particular, an answer will be given to a question which the late Erich Gutenberg, the most famous German business economist in the post-war-period, has left unanswered: "How can we explain the transition from one production function of the firm to the other?" (Gutenberg 1983: 73).

The outline of the paper is as follows. In section 2 some empirical facts will be presented. Sections 3 and 4 then develop the empirical analysis of change in firms. In section 3 change is taken to be exogenous to the firm. The environment changes, and the firm has to adapt to the change in the environment. Adaptation is realized by a change in the firm's production function. The cost of changing the production function may be low (3.1.) or may be high (3.2.). In section 4 it is assumed that the firm has some impact on its environment. Innovation changes the environment of the firm, in particular, product innovation brings about changes in consumer demand, and process innovation changes the competitive position of the firm. Management of change is thus understood as an active approach to changing the firms' environment through the firms' innovative effort (4.1.) as well as through the whole array of the marketing instruments of the firm (4.2.).

A methodological remark seems appropriate at this point. Management of change in the firm may be studied on a micro-level: the object of research is the individual innovation. Product innovations and process innovations are investigated (Albach 1983). A second approach starts from the overall result of the many innovative processes in the firm, and studies the overall efficiency of the firm in its competitive environment (Albach 1980). Efficiency is measured by the firm's total output in relation to the best possible output in the relevant branch of industry. Analysis is thus carried out on the macro-level.

In this paper the second approach is taken. The firm is considered as a production function. Management of change is understood as deciding on innovation in the firm in order to change the inputs (process innovation) or the outputs (product innovation) of the production function.

The validity of the approach taken here, to study management of change in competitive firms, lies in its explanatory power. The facts to be explained will be presented in the next section.

2. The Empirical Facts

The basis for the empirical analysis of the theoretical answers is provided by the financial statements in the "Bonn data bank". The Bonn data bank contains all the data of the financial statements of 295 German industrial corporations quoted on the German stock exchanges. The data cover the period from 1960 to 1984. All in all there are roughly half a million data on the computer tapes of the Bonn data bank.

Quoted stock corporations are in general and with some exceptions big companies. Medium-sized companies do not have to report financial data. The Bonn Institute for Research on Medium-Sized Firms has a data bank with data from 463 companies. The data extend over a period from 1978 to 1982 (Albach/Bock/Warnke 1985). The theoretical answers are tested against the data from this data bank as well.

Needless to say that each of these 758 companies has had a unique fate

Table 1 Growth Rates
Industrial Corporations 1979–1983; Medium-sized Firms 1978–1982

Group	Sales	Employees
All companies		
corporations	5.44	– 2.04
medium-sized firms	6.20	– 0.05
Top companies[1]		
corporations	9.67	1.59
medium-sized firms	9.84	1.79
Chemical industry		
corporations	5.89	– 1.97
medium-sized firms	9.10	0.74
Machinery and equipment		
corporations	4.88	– 0.30
medium-sized firms	7.08	– 0.03

[1] "Top Firms" are the 30 top-ranking firms in the sample. Rank is determined by weighted averages of six growth and profitability criteria.

and a unique course of development. However, for presentation some condensation of information is necessary. The empirical facts are therefore first presented as averages over all the firms for the last 5 years. Then averages over time for the individual firms are given to show differences between firms. Finally, growth paths of individual firms and of the average German firm will be shown.

During the years from 1978 to 1983 employment was increased only by those firms that managed to attain high growth rates of sales. A growth rate of sales between 8% and 9% was critical for changes in employment. Companies with lower growth rates reduced their staff, while firms with higher growth rates added to their work force. Table 1 provides some data on rates of change in sales and employment.

Capacity expansion by business investment in plant and equipment plays a major role in theoretical explanations of firm growth. Return on capital is a good indicator for profitable investment. Table 2 presents data on the rate of gross investment and on the average rate of return on equity.

It seems at first sight that adequate rates of return on investment lead to high rates of business investment, and this in turn requires additional personnel. It should be noted that rates of return show a skewed distribution. Some top-earning firms influence the mean of the distribution substantially and pull it upward.

Table 2 Investment and Profits
Industrial Corporations 1979–1983; Medium-sized Firms 1978–1982

Group	Gross Investment (percentage of total fixed investment)	Return on Equity	
		Mean	Median
All companies			
corporations	27.15	6.01	6.14
medium-sized firms	24.14	12.18	7.80
Top Companies			
corporations	33.58	13.09	9.63
medium-sized firms	27.61	27.13	13.56
Chemical Industry			
corporations	27.10	6.59	6.85
medium-sized firms	26.37	8.67	10.01
Machinery and equipment			
corporations	25.79	3.93	3.86
medium-sized firms	23.20	9.30	8.49

Tables 1 and 2 present, in addition to the averages over all firms, data for the top companies and for the firms in two different branches of industry. This is to show that the patterns of development differ according to legal form, type of company, and branch of industry. The data give rise to the question whether a general theory of the management of change is sufficient or whether specific theories of the development of the firm have to be developed.

So far, average growth rates over time have been presented for all the firms and for specific subsamples. These figures do not show the great differences in growth rates between firms. The distribution of average growth rates over periods of five and of twenty years, respectively, is given in Figures 1, 2, and 3. There were corporations in Germany which lost sales at a rate of 15% annually and reduced their staff by 20% annually. At the other extreme there are firms which managed to attain a 40% annual increase in sales and a 25% annual increase in employment. The picture is only slightly altered when medium-sized firms are considered.

It is rather amazing that the average growth rates over a period of 20 years should differ as much as shown in Figure 3. This indicates that adaptability of the firms to a changed environment is not only different, but also rather slow. Inflexibilities within the firm and in its legal and institutional environment may account for this phenomenon. On the other hand, forces

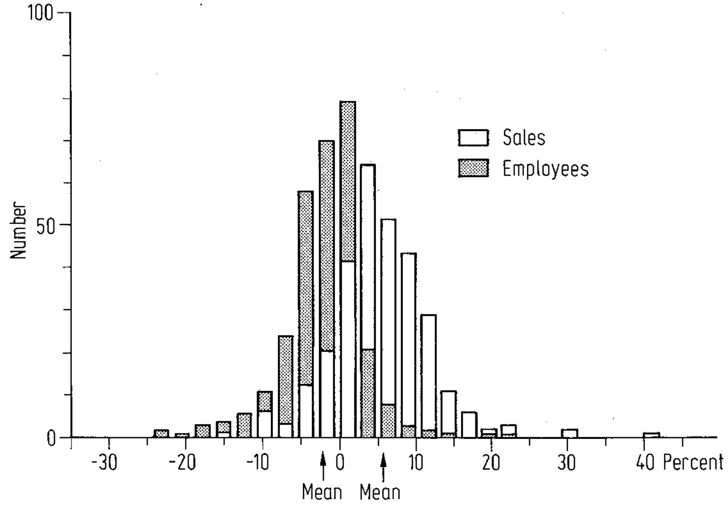

Figure 1 Distribution of Growth Rates
Industrial Corporations, Averages Last Five Years

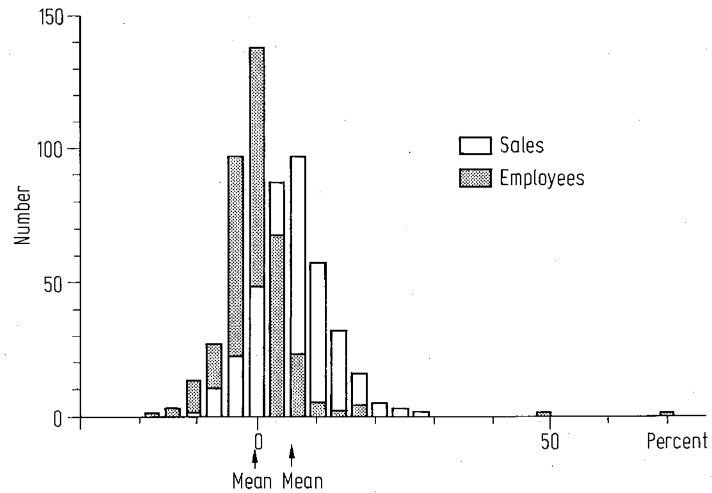

Figure 2 Distribution of Growth Rates
Medium-Sized Firms, Averages Last Five Years

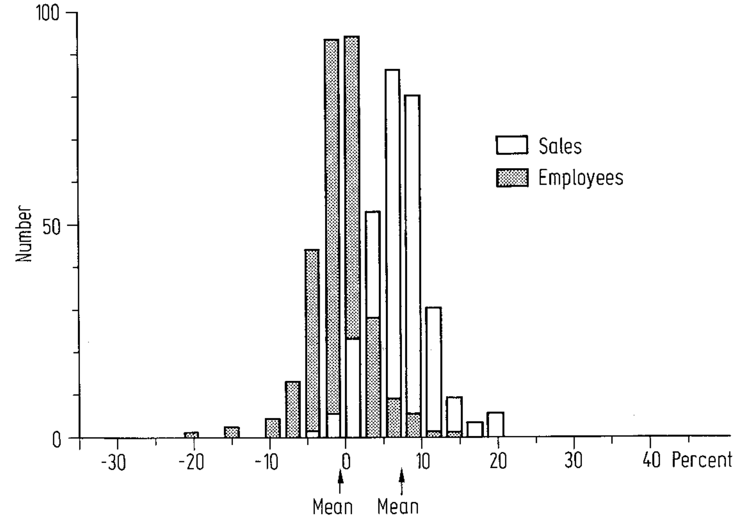

Figure 3 Distribution of Growth Rates
Industrial Corporations, Averages Over 20 Years

of competition in the market place are obviously not strong enough to overcome these rigidities. This is all the more remarkable, as economic theory assumes high flexibility of the market economy and high speed of adaptation of the firms to changed relative prices of the productive factors and products.

The firms in the sample earned remarkably different rates of return on equity. Some of the corporations have made more than 15% on their equity annually over a period of 20 years, while others have averaged a negative rate of return on equity over this very long period of time. Of course, the rates of return show a wider distribution over the shorter period of 5 years (Figures 4–6). Even if the rate of return on equity is computed not on book, but on the market value of equity, the averages for the firms differ significantly. This is another piece of evidence that the German capital market is far from being a perfect market.

The empirical facts presented indicate that lags in adaptation to changed environmental conditions, rigidities, and inflexibilities play a significant role in the process of change. Management of change thus means to help people within the firm to change rigid patterns of behavior, to effect structural changes within the companies, and to interchange with political and social groups for a more flexible and adaptable environment.

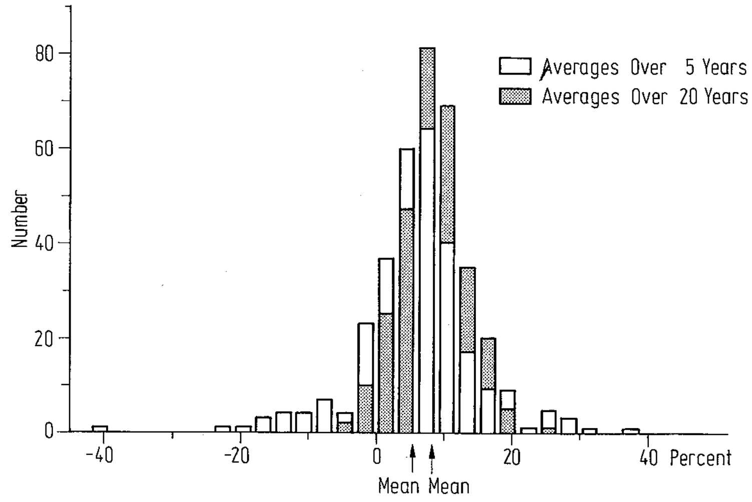

Figure 4 Distribution of Return on Equity (After Tax), Book Values Industrial Corporations

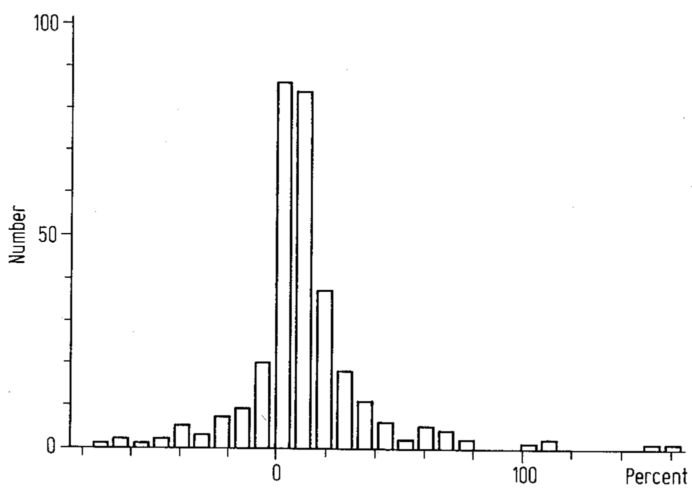

Figure 5 Distribution of Return on Equity (After Tax), Book Values Medium-Sized Firms, Averages Over 5 Years

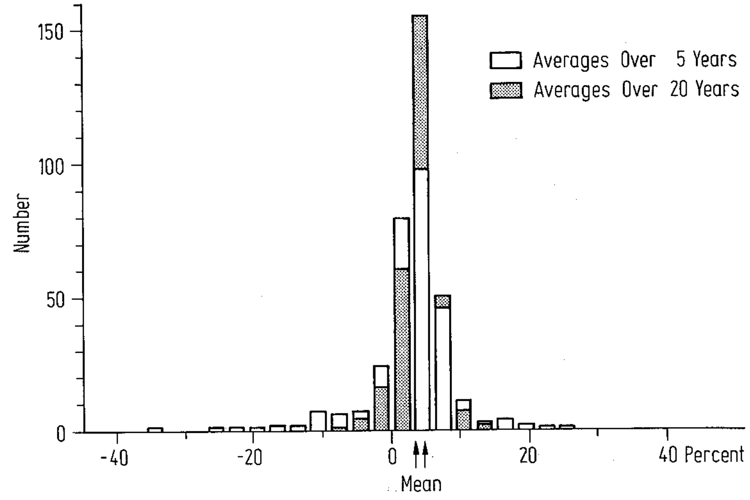

Figure 6 Distribution of Return on Equity (After Tax), Market Values Industrial Corporations

3. Adaptation to Changes in the Firm's Environment

3.1 Low Cost of Adaptation

3.1.1. The Cobb-Douglas Production Function without Technical Progress

Economic theory describes the firm as an institution that maximizes profits, given relatives prices of commodities and factors of production subject to an input-output-function. Capacities can be adjusted easily to changed demand conditions, and the employees readily adapt to new technological conditions of production. There is no cost involved in hiring and firing personnel. This highly unrealistic situation may well be used as a starting point for an analysis of change.

The firm maximizes the profit function

(1) $\quad G = px - cK - wL$

subject to the production-function

(2) $\quad X = a_0 K^{\alpha_1} L^{\alpha_2}$

with

- G – profit
- p – sales price
- c – user cost of capital
- w – user cost of labor
- K – capital input
- L – labor input
- X – production
- α_1, α_2 – elasticities of production
- a_o – parameter

The optimal production function is determined by the relative prices p, c, and w and the technological conditions of production. Change depends on change in the output required by the market and is immediate.

Technological change is determined by the relative prices only. As long as prices do not change, the production function remains the same. Growth may be determined by an increase in demand, but will be carried out on the basis of the same technology. If prices change, however, the production function is altered immediately. There is no management of change in the sense that management is in itself a scarce factor of production.

3.1.2. The Cobb-Douglas Production Function with Technical Progress

If now the environment is described not only by the existing technological knowledge and by relative prices but also by technological progress, then investment means incorporating new technology in the production function of the firm. It is assumed that employees are readily available to man the new machines.

The firm maximizes profits again subject to a production function which is the aggregate of all machinery purchased in different years in the past and still in existence. Machinery purchased in year v produces output in year t according to the production function

(3) $$X_{tv} = a_0 e^{\mu v} K_{tv}^{\alpha_1} L_{tv}^{\alpha_2}$$

with

- v – period of investment
- t – current period
- μ – rate of technological progress.

Total capacity is then given by

(4) $$X_t = a_0 \left[\int_{-\infty}^{t} e^{\mu v} K_{tv} \, dv \right]^{\alpha_1} \left[\int_{-\infty}^{t} L_{tv} \, dv \right]^{\alpha_2}$$

Using an approximation by Nelson we have

(5) $$X_t = a_0 e^{\alpha_1 \mu (t - \bar{g}_t)} K^{\alpha_1} L^{\alpha_2}$$

with g_t the average age of machinery in period t.

Now relative prices and technological progress embodied in a new vintage of machinery determine change in the firm.

Average Production Function

The model of change given by equations (1) and (5) was tested against the data of the Chemical Industry for the period from 1960 to 1975 (von Maltzan 1978). In this context it may suffice to show the results for an individual company, Hoechst Chemical Corporation.

From equation

(6) $$X_t = a_0 K^{0.44}_{(5.42)} L^{0.61}_{(7.84)} e^{0.035\,t}_{(9.85)} \; ; (R^2 = 0.99; DW = 1.79)$$

one can derive that the average rate of technical change that Hoechst realized in its capital equipment averaged 8% over the 15-year-period from 1960 to 1975. Estimation of equation (5) for the period from 1960 to 1983 did not produce econometrically satisfactory results. The reason is a structural break between 1973 and 1975 which will be considered subsequently. However, it may be said that the rates of technical change that Hoechst realized in the periods following the oil price hike of 1973 were significantly lower than the 8% derived from equation (6).

Frontier Production Function

The firms in the Chemical Industry (as well as in other branches of industry not explicitly treated here) show remarkable differences in efficiency. They manage change in their inputs of labor, capital, and technological know-how differently. Two groups of firms emerge from analysis: the "pioneers" and the "laggards".

The pioneers produce at the front of technological progress. They require less capital and less labor for a unit of real output than their competitors. The laggards have to struggle to keep up with the pioneers in order not to be eliminated by competition. Empirical evidence for the German Chemical Industry shows that laggards have remained laggards, and that pioneers have been able to maintain their leading position during the long period from 1960 to 1983.

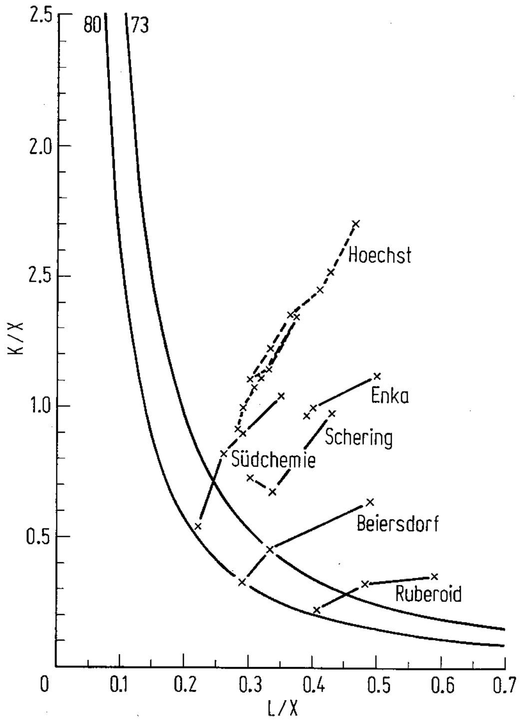

Figure 7 Frontier Production Functions and Corporate Development Chemical Industry 1968–1983

The frontier production function technique is used to identify the pioneering firms. Figure 7 gives results for 18 chemical companies and the period from 1968 to 1983. Two frontier production functions are represented in Figure 7. The paths of development of some pioneers and some laggards are also indicated in Figure 7.

The frontier production function

(7) $X_t = .827\, K_t^{.401}\, L_t^{.599}\, e^{.030t}$

is determined by Südchemie Company in 1973 and in 1979 and by Beiersdorf in 1980. Ruberoid, Schering, and Hoechst are also highly efficient, while Enka Corporation is a constant laggard with great structural problems.

The development of Hoechst Corporation is given in greater detail in Figure 7. There is a clearly noticeable structural break of the firm's development towards more und more efficient production between 1973 and 1975.

These years mark the impact of the oil price hike on the company. Hoechst experienced great rigidities in adapting to the new relative prices. Inflexibilities were particularly important in the chemical fibers division. Adjusting obsolete equipment and relocating and retraining employees took roughly three years. In 1976 Hoechst was back where it had been on the efficiency path in 1973. In the meantime adjustment meant higher inputs of capital and labor for a given unit of real output.

Two conclusions may be derived from this simple explanation of change within the companies:

- two groups of firms have to be distinguished for an analysis of the management process of change: pioneering firms and firms trailing behind;
- firms with different degrees of efficiency may exist side by side. Markets do not eliminate lesser efficient companies but leave room for firms that operate on different levels of efficiency.

It seems plausible to associate the pioneers in this analysis with the Schumpeter entrepreneur and the laggards with the "static firm" in Schumpeter's analysis of economic development. The pioneering firms are then innovators that market new products and invest in new production processes. However, this distinction leaves open the question why the laggards do not react faster to technological advances of the pioneers. Difficulties in adapting to changes in market conditions and in technology seem to account for this. These difficulties are not adequately represented in a model with low cost of change. In fact, rigidities are just another expression of the fact that it is highly costly for some firms to react fast and properly to changes in the environment.

3.2. High Cost of Adaptation

3.2.1. The Putty-Clay Production Function

A first approach to the analysis of rigidities in the development of firms may be to assume that the cost of change in the existing machinery is infinite, whereas the cost of installing new equipment and of training additional personnel to work on these machines is zero. Existing machinery cannot be displaced freely. It is dismantled according to a given survival function. Thus

- existing machinery is displaced according to the survival function for the individual vintages of equipment;

- new machinery can be installed rapidly and easily as is economically justified, given the rate of technological progress and the relative prices prevailing in the market place at a given moment in time.

A formal description of such an assumption of changing technological conditions in the firm is given by equations (8–11).

The firm minimizes factor cost

$$c = \sum_{t \le v} (q_t I_t + w_t L_t)\, e^{-rt} \quad (8)$$

subject to the production function

$$X_t = \sum_{\tau \le M_G} g(\tau)\, \phi_{1,t-\tau}(I_{t-\tau})\, I_{t-\tau}\, e^{\mu t} \quad (9)$$

with the input coefficients

$$\phi_{1,t} = a_0\{\delta + (1-\delta)\, \phi_{2,t}^{-\varrho}\}^{-\frac{1}{\varrho}} \quad (10)$$

and

$$\phi_{2,t}(I_t) = \left(\frac{1-\delta}{\delta}\right)^{\sigma} \left(\frac{q_t}{\sum_{\tau \le M_G} g(\tau) w_{t+\tau}\, e^{-r\tau}}\right)^{\sigma} \quad (11)$$

where

- M_G – maximal lifetime of equipment
- I_t – real investment in plant and equipment in period t
- $\phi_{1,t}$ – capital coefficient of machinery purchased in period t
- $\phi_{2,t}$ – labor/capital coefficient
- σ – elasticity of substitution of a CES-production function
- ϱ – paramater of CES-production function
- q – purchasing price per unit of capacity
- g – survival function
- δ – distribution parameter of ex ante production function.

$$X_t = a_o\,\{\delta I_t^{-\varrho} + (1-\delta) L_t^{-\varrho}\}^{-\frac{1}{\varrho}}$$

Optimal factor inputs are derived from this model. Capital input is given by (12), and labor input is given by (13).

$$X_t = \sum_{\tau \le M_G} g(\tau)\, \phi_{1,t-\tau}\, I_{t-\tau}\, e^{\mu t} \quad (12)$$

$$L_t = \sum_{\tau \le M_G} g(\tau)\, \phi_{2,t-\tau}\, I_{t-\tau}. \quad (13)$$

Empirical analysis of (12) for all the chemical corporations in the Bonn data bank shows that technical progress was 5.3% on the average during the

period from 1953 to 1974, and the elasticity of employment with respect to sales was 0.61.

Again, Hoechst Corporation is used as a more specific example of such a bird's-eye view of the management of change within a particular company. The rate of technological change was 5.1% during the period from 1952 to 1974. The average rate of growth of sales was 11%, while employment increased at an average rate of 4%. Figure 8 shows actual and estimated development of sales and employment.

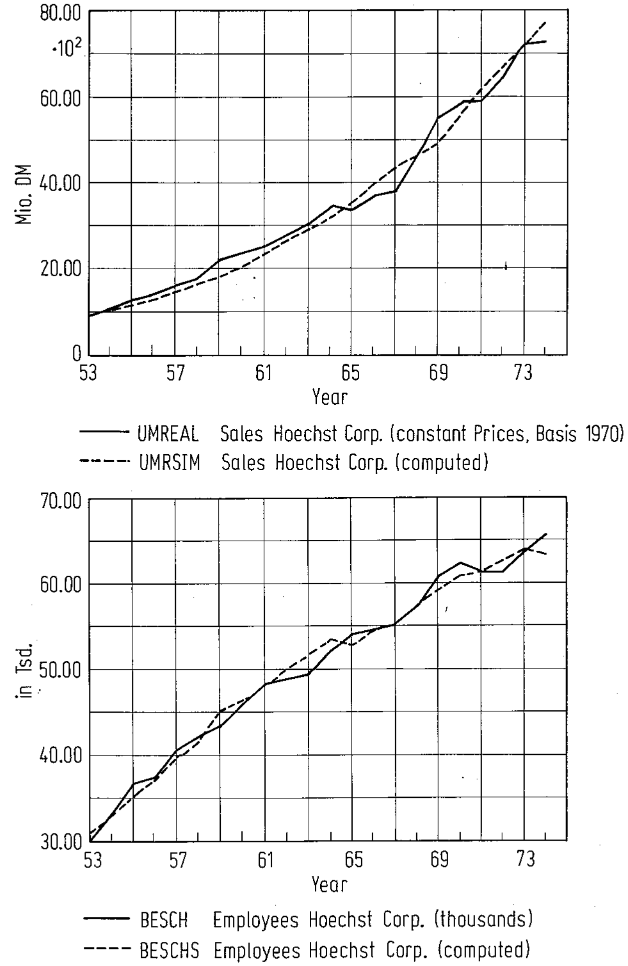

Figure 8 Empirical Estimates of Real Sales and Number of Employees Putty-Clay Model
Hoechst Corporation, 1953–74

3.2.2. The Semi-Fixed Factors Production Function

While this model describes actual development of the firm fairly accurately, the underlying philosophy seems a far cry from the actual problems of managing change. Existing equipment can be changed or replaced, and new equipment is not readily available. However, replacing existing equipment and setting up new one is a costly and time-consuming process. These costs of adapting to changing conditions in the environment and these time lags have to be taken into consideration very explicitly in order to really understand the process of managing change. Models of intertemporal profit maximization provide adequate theoretical tools for studying such processes. The models distinguish between variable and fixed factors of production. Changing variable factors is without cost, while changing fixed factors entails costs of adaptation.

The model assumes that capital and labor are fixed factors of production. The firm maximizes profit over time

$$(14) \qquad G = \int_0^\infty e^{-rt} \{pF(V,Q) - vV - \tilde{C}(I^K,Q) - qI\}\, dt$$

where

$$\dot{Q} = I - \delta Q$$

and

$$\tilde{C}(O,.) = O,\ \tilde{C}'(I,.) \lesseqgtr O <=> I \lesseqgtr O,\ \tilde{C}''(I) > O$$

where

- V – variable factors of production (i.e. materials inputs)
- K – fixed factors of production (i.e. capital and labor)
- $\tilde{C}$ – cost of adaptation
- v – purchasing price per unit of variable input.

The production function F(V,Q) is required to fulfil very general regularity conditions only. The optimal strategies I*, V*, and Q* can be computed. In order to do so, (14) is transformed into an equivalent problem of minimizing cost. Specifying the variables more specifically one has to minimize

$$(15) \qquad C = \int_0^\infty e^{-rt} \{cK + wL + mM + \tilde{C}(K,L,I^K,I^L)\}\, dt$$

with

- m – price per unit of materials input
- M – input of raw materials
- I^Q – changes in capital stock due to investment
- I^L – changes in labor force due to hiring.

The solution of this problem is given by

$$(16) \qquad \begin{pmatrix} \dot{K} \\ \dot{L} \end{pmatrix} = \begin{pmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} \end{pmatrix} \begin{pmatrix} K - K^* \\ L - L^* \end{pmatrix}$$

where

K* denotes optimal stock of capital, and L* is the optimal number of employees.

Pooled time series and cross section analysis with the data of the Bonn data bank yields the following empirical result for (16).

$$(17) \qquad \Lambda = \begin{pmatrix} -0.213 & 0.470 \\ 0.038 & -0.672 \end{pmatrix}$$

3,7 2,9 / 0,5 0,6

(17) shows that growth is determined by two conflicting forces. Investment is influenced positively by the direct capital effect (−0.213). Growth of capital is, on the other hand, retarded by the indirect employment effect (+.470). Since it takes time and is costly to hire personnel and to train it for handling the new pieces of equipment, installing machinery is slowed down. The same holds true for periods of shrinking capacity. The indirect employment effect reduces the speed of adapting to the less favorable condition significantly. High costs of laying off workers prolong the time path of change. The period required to adapt actual equipment to the optimal level is longer than one year, and it is longer for small firms than for big companies.

In the long run, capital and labor are complementary. The net effect of innovative as well as of modernization and rationalization investment was positive during the last 15 years. This conclusion may be used to analyze conditions for returning to a situation of full employment in the German economy. It is not only the relative cost of labor and capital which has to be favorable for additional employment, but also the cost of adapting to such favorable conditions. If the cost of adapting the labor force is reduced, the process of change in the work force can be speeded up.

Again, Hoechst Corporation is used as an example. Equation (18) is the demand function for capital and labor of the Hoechst Corporation. In deriving this function a pooled regression approach was used. It was assumed that the three big German chemical companies operate on different efficiency levels but show a very similar behavior with respect to environmental variables

$$(18)\quad \begin{pmatrix} K \\ L \end{pmatrix} = \begin{pmatrix} 0.808_* & 0.062_* \\ 0.636_* & 0.447_* \end{pmatrix} \begin{pmatrix} K_{-1} \\ L_{-1} \end{pmatrix} + 1.051_*^{-t}\, X \begin{pmatrix} -0.219_* & 0.010 \\ 0.040 & -0.056_* \end{pmatrix} \begin{pmatrix} c \\ w \end{pmatrix} + \begin{pmatrix} 123.6 \\ 70.9 \end{pmatrix} + 1.051_*^{-t}\, X \begin{pmatrix} .020 \\ .120_* \end{pmatrix}$$

$R^2_K = 0.930$ $DW_K = 1.562$ $R^2_L = 0.942$ $DW_L = 1.799$

* = coefficient at least twice the size of standard error

Technical progress is in this analysis assumed to be Hicks-neutral and was, on the average, 5.1%. From (18) one can conclude that capital and labor are quasi-fixed factors of production. It takes longer to adapt machinery and equipment to changed conditions than it takes to change the work force. If the wage rate increases by 10%, the work force is changed by 2.4% in the short run, while in the long run the total change in employment is 5.4%. In the short run interest rate increases have no effect whatsoever on total capacity. In the long run, however, a 10% relative increase in interest rates reduces capacity by 3.5% and employment by 1%.

This analysis shows that managing change requires a cost accounting system which informs managers adequately about the costs involved in different change processes. It is particularly interesting to note the interdependence of the processes of change. While functional interdependence between the different functional areas in the firm has been a field of study for some time, the time interdependence of change processes has not received adequate attention so far. This analysis shows, however, that there is an interdependence of time patterns of change within the firm which has to be taken into consideration by management in order to optimize time paths of change.

4. Promotion of Changes in the Firm's Environment

4.1. The Cobb-Douglas Production Function with Innovative Effort

Changes in the environment of the firm are given only in the theoretical context of classical economics. On imperfectly competitive markets the firm may exert an influence on its environment, and change environmental conditions by managerial decisions. Product innovation is a way of changing the firm's environment which has received much attention in recent years.

Innovation is generally defined by economists as putting inventions to

practical use in the market place (product innovation) or within the firm (process innovation). However, for the management scientist the definition of innovation is more complex. If the new product of an innovator proves to be a flop or only marginally successful, and if an imitator changes the innovator's product slightly to improve its marketability, then clearly the imitation may be considered a true innovation. Thus a clear distinction between innovation and imitation is hard to make. Therefore, any successful new product will be considered an innovation regardless of whether it comes out of research and development, or whether the idea originated in the marketing and consumer analysis departments.

It seems plausible on theoretical grounds to assume that innovation and imitation are substitutional. A firm which is not successful in its innovative effort may well resort to imitating successful competitors to catch up and survive. A successful imitator may well decide to add a product development department in order to gain the better over his innovative competitor. On the other hand, it seems plausible also to assume that product development is guided by market research and by the analysis of consumer demand and how it is met by competitors' products. Innovation is a process by which products on a continuous scale of novelty are offered to the market. On the one end of the scale there is a near imitation, on the other is a basic innovation (Brockhoff 1985).

If innovation and imitation are complementary, then research and development and marketing are limitational rather than substitutional, and the effect of management to change the firm's environment can be measured by the sum of R & D and marketing expenditures. Empirical analysis shows that in fact R & D and marketing are limitational rather than substitutional factors in managing change.

A simple production-theoretical model is used to analyze innovation. The firm maximizes profits subject to the production function with labor, capital and R&D expenditure, and marketing expenditure as input factors

$$(19)\qquad x = a_0\, L^{\alpha 2}\, K^{\alpha 2}\, RM^{\alpha 3}$$

with

RM – real expenditures on research and development and marketing.

This model, it is true, reverses the step as far as adapting to changed conditions in the environment is concerned. It adds a new dimension, on the other hand, by incorporating a factor that measures effort to change the environment autonomously.

4.1.1. Average Production Function

While the industrial corporations are not required to report data on R & D expenditures or on marketing cost, the medium-sized firms in the Bonn sample voluntarily made such data available.

Computing the average production function by least squares regression yields

$$(20) \qquad x' = \underset{(5.35)}{1.572} + \underset{(12.31)}{.645\,L'} + \underset{(8.10)}{.279\,K'} + \underset{(2.40)}{.055\,RM'}$$

$$R^2 = .909$$

where

()' stands for the natural logarithm of the variable.

4.1.2. Frontier Production Function

It is assumed that the most innovative firms produce on the efficiency frontier of equation (19). Therefore, a frontier production function of (19) was estimated from the data available using a linear programming approach to compute the optimal parameters a_0, α_1, α_2, and α_3. The result is given by

$$(21) \qquad x^{*\prime} = 2.126 + .635\,L' + .259\,K' + .075\,RM'.$$

One can compare the performance of the efficient firms, the "pioneers", with the performance of the other firms by computing the average production function and measuring efficiency by

$$(22) \qquad E = \frac{x'}{x^{*\prime}}.$$

The firms in the sample are on average 10% less efficient than the pioneers.

It is interesting to note that the pioneering firms have significantly higher elasticities of production of the innovative effort but slightly lower elasticities of production of capital input. An in-depth-analysis of the data reveals that the highly efficient firms spend less per unit of sales on R & D and marketing than their less efficient competitors but very significantly more on machinery and equipment.

The pioneers are product innovators but do not hesitate to imitate promising products of their competitors. This increases the efficiency of their R & D and their marketing efforts. At the same time they put high emphasis on keeping their machinery competitive by a constant flow of process innovations through heavy investment outlays.

Changing the environment by creating new markets through product innovation requires adapting the internal organization to the changed environment also. There is thus not only an interdependence between the internal processes of change, but also between the processes of product innovation and process innovation.

4.2. The Interactive Production Model with Marketing Effort

Of course, management of change is more than managing adaptation and innovation in production and marketing. It means adapting the capital structure of the firm to changed conditions on capital markets, to react to changes in delivery times of raw materials, and it means taking advantage of

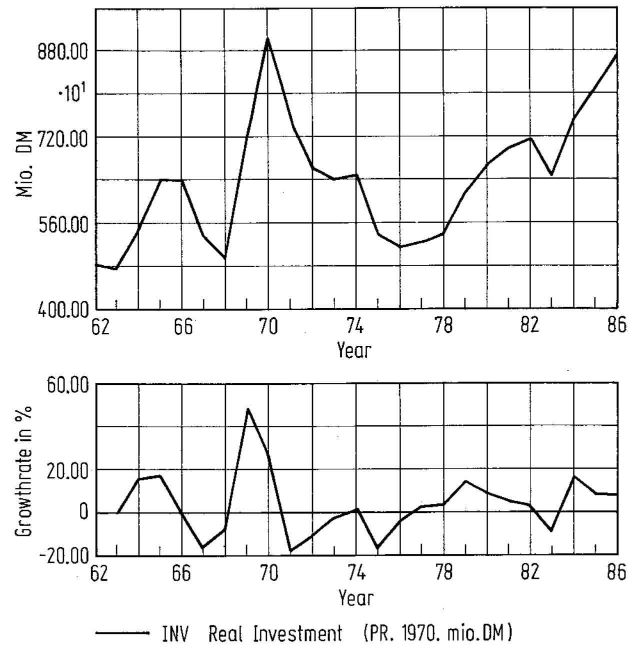

Figure 9 Investment in Plant and Equipment
Actual Development and Forecast for 1986 according to the Bonn Model of the Firm

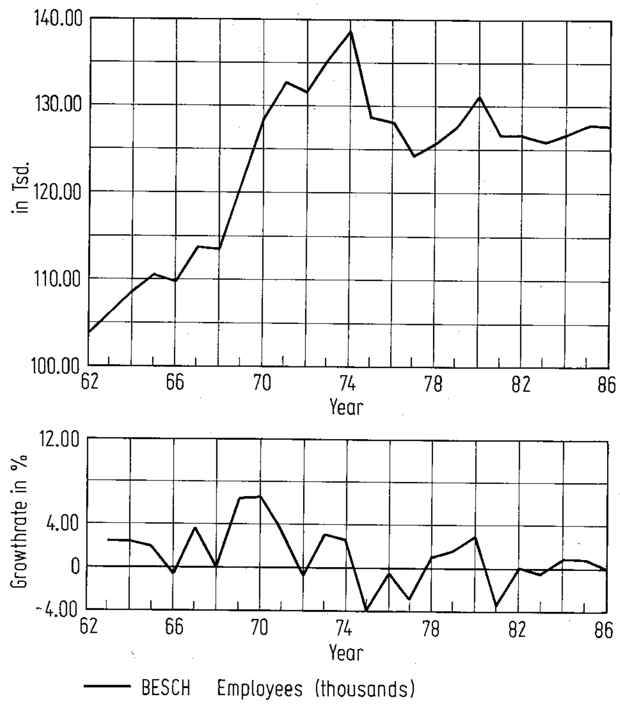

Figure 10 Employees
Actual Development and Forecast for 1986 according to the Bonn Model of the Firm

changed legislation, particularly on taxation. Work on such a model of the firm has been going on in Bonn for several years. The most recent version of the model is given in the appendix. The fit of the model to actual data is satisfactory. Rather than giving details here, it may be sufficient to show some results of using the model as a forecasting model. Using the growth rate of the economy and relative prices as exogeneous variables, managerial decisions to adapt to these data describing the environment result in a development of endogeneous variables of investment outlay and work force as given in Figures 9 and 10. The resulting return on equity is shown in Figure 11. Even though environmental conditions were quite favorable to business investment, the industrial firm in Germany did not contribute towards solving the problem of unemployment in 1986, according to the forecast.

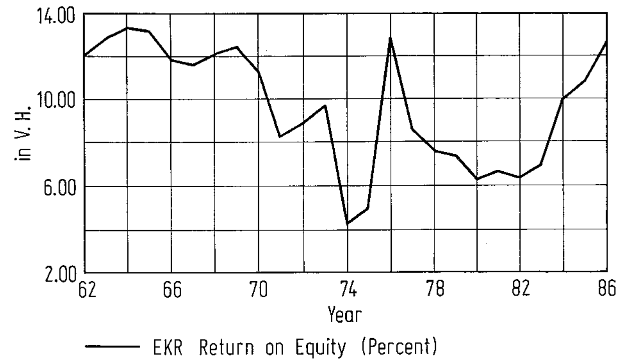

Figure 11 Return on Equity (After Tax)
Actual Development and Forecast for 1986 according to the Bonn Model of the Firm

5. Concluding Remarks

This analysis does not provide easy recipes for management how to manage the complex systems of interdependent change processes. But it helps identify the pioneers, those firms that are highly innovative and highly efficient and thus focuses analysis on the study of their behavior, and, secondly, it underscores the importance of studying the interdependence of change processes within the firm.

Management has to concentrate on managing the interdependent time paths

- of product innovation and process innovation in changing the environment;
- of capacity and work force in adapting to the environment;
- of coordinating optimally the different functional areas of the firm in their adaptation to and their actively changing the environment;

and management has to adapt to and actively influence the environment by product, process, and organizational innovations.

Appendix: The Econometric Model of the Firm

(Version 4 (1985) of the Bonn Model of the Firm)

(1) Cash flow before tax

$$CFV = pU - wL - mM - r_T FK_{-1} - SA - MA - AOE$$

(2) Cash flow after tax

$$CF = CFV - SEEV$$

(3) Taxes

$$\begin{aligned} SEEV = {} & (u51 + u4 + u51\ u4)\ (CFV - d\ SAV_{-1}) \\ & + (u52 - u51 - u52\ u51\ dks) DIV \\ & + (u4 - u51\ u4) r_T FK_{-1} \\ & + (u1 + u3 + u51\ u4\ u3 - u4\ u3 - u51\ u3) EK_{-1} \\ & + (u3 + u51\ u4\ u3 - u4\ u3 - u51\ u3) FK_{-1} \end{aligned}$$

(4) Sales

$$U = a_0 N \left(\frac{MA}{MAB}\right)^{.156} \left(\frac{I}{IB}\right)^{.052} \left(\frac{U_{-1}}{UB_{-1}}\right)^{.630}$$

(5) Output

$$X = U + VF - VF_{-1}$$

(6) Stock of finished goods

$$VF = a_0 U^{.288} \left(\frac{p}{m^{.60}\ w^{.40}}\right)^{-.130} A^{.418}\ VF_{-1}^{.602}$$

(7) Desired labor input

$$L^* = a_0 \left(\frac{c'}{m}\right)^{.200} \left(\frac{m}{w}\right)^{.629} X^{.986} e^{-.015t}$$

(8) Desired materials input

$$M^* = a_0 \left(\frac{c'}{w}\right)^{.200} \left(\frac{w}{m}\right)^{.570} X^{.986} e^{-.015t}$$

(9) Desired capacity utilization

$$A^* = a_0 \left(\frac{m}{q}\right)^{.429} \left(\frac{w}{q}\right)^{.370} \left(\frac{X^{.986}}{K_{-1}}\right) e^{-.015t}$$

(10) Actual labor input

$$L = (L^*)^{.337} (L_{-1})^{.663} (M^*)^{.108} (M_{-1})^{-.108}$$

(11) Actual materials input

$$M = (M^*)^{.680} (M_{-1})^{.320} (L^*)^{.225} (L_{-1})^{-.225}$$

(12) Capacity utilization

$$A = A^* (L^*/L_{-1})^{.360}$$

(13) Investment in plant and equipment

$$\begin{aligned} I = \Big[a_0 & + .412 \frac{CF}{q_{-1} K_{-1}} + .043 \frac{UB - UB_{-1}}{UB_{-1}} \\ & + .042 \frac{UB_{-1} - UB_{-2}}{UB_{-2}} + .031 \frac{UB_{-2} - UB_{-3}}{UB_{-3}} \\ & + .008 \frac{UB_{-3} - UB_{-4}}{UB_{-4}} + .018 \frac{k_{-1} - k_{-2}}{k_{-2}} \\ & + .021 \frac{k_{-2} - k_{-3}}{k_{-3}} + .282 \frac{I_{-1}}{K_{-2}} \Big] K_{-1} \end{aligned}$$

(14) Relative prices for capital input

$$k = \frac{w^{.40}\ m^{.60}}{c}$$

(15) User cost of capital

$$c = s\ q \left[\frac{EK_{-1}}{FBL_{-1}} \frac{\varrho}{(1 - u51)} + \left(1 - \frac{EK_{-1}}{FBL_{-1}}\right) r_L + \sigma\right]$$

(16) Real depreciation rate

$$\delta = .055 + .055 A^{1.5}$$

(17) Marginal depreciation rate of capital (dependent on intensity of utilization)

$$c' = s\ q\ A^{.5}$$

(18) Stock of capital goods

$$K = K_{-1} (1 - \delta) + I$$

(19) Fixed assets

$$SAV = SAV_{-1}(1 - d) + qI$$

(20) Inventory (raw materials)

$$VM = a_0 M^{.322} (r_K + 0.20 - in/m)^{-.102} \left(\frac{m}{p}\right)^{-.180} A^{.834} VM_{-1}^{.526}$$

(21) Total capital invested

$$GK = SAV + pVF + mVM + FINLIQ$$

(22) Equity

$$EK = a_0(-.186\varrho + .301r_L - .248r_K) + .158GK + .748EK_{-1} - .133LFK_{-1} - .088KFK_{-1}$$

(23) Long-term debt

$$LFK = a_0(.115\varrho - .489r_L + .138r_K) + .197GK - .145EK_{-1} + .687LFK_{-1} - .115KFK_{-1}$$

(24) Short-term debt

$$KFK = a_0(.070\varrho + .188r_L + .110r_K) + .645GK - .603EK_{-1} - .554LFK_{-1} + .204KFK_{-1}$$

(25) Total long-term capital

$$FBL = EK + LFK$$

(26) Industry sales

$$UB = \Sigma U$$

(27) Industry investment

$$IB = \Sigma I$$

Endogenous Variables

A = Capacity utilization
A* = Desired capacity utilization
c = User cost of capital
c' = Marginal depreciation rate of capital (dependent on intensity of utilization)
CF = Cash flow after tax
CFV = Cash flow before tax

δ = Real depreciation rate
EK = Equity
FBL = Total long-term capital
GK = Total capital invested
I = Investment in plant and equipment
IB = Industry investment
K = Stock of capital goods
k = Relative prices for capital input
KFK = Short-term debt
L* = Desired labor input
L = Actual labor input
LFK = Long-term debt
M = Actual materials input
M* = Desired materials input
SAV = Fixed assets
SEEV = Taxes
U = Sales
UB = Industry sales
VF = Stock of finished goods
VM = Inventory (raw materials)
X = Output

Exogenous Variables

AOE = Extraordinary income
d = Depreciation rate (for taxation)
DIV = Dividends
dks = Dummy variable for corporate income tax reform
FINLIQ = Financial investments
m = Materials price and liquid assets
MA = Marketing expenditures
MAB = Industry marketing expenditures
N = Total demand
p = Price of unit of output
q = Price index of investment goods
r_L = Interest rate for long-term debt
r_K = Interest rate for short-term debt
r_T = Interest expenditure per unit of debt
ϱ = Cost of equity
SA = Other expenditure
s = Ex ante tax term for capital input

u1 = Property tax rate
u3 = Franchise tax rate (on capital)
u4 = Franchise tax rate (on income)
u51 = Corporate income tax rate on retained income
u52 = Corporate income tax rate on dividends
w = Wage rate

References

Albach, H. (1980): Average and Best Practice Production Functions in German Industry; *The Journal of Industrial Economics,* 29: pp. 55–70.

–, (1983): Innovationen für Wirtschaftswachstum und internationale Wettbewerbsfähigkeit, *Technische Innovationen und Wirtschaftskraft,* Rheinisch-Westfälische Akademie der Wissenschaften, Opladen: Westdeutscher Verlag.

–, K. Bock, and Th. Warnke (1985): *Kritische Wachstumsschwellen in der Unternehmensentwicklung,* Schriften zur Mittelstandsforschung, N. F. Nr. 7, Stuttgart: Poeschel.

Brockhoff, K. (1985): Abstimmungsprobleme von Marketing und Technologiepolitik, *Die Betriebswirtschaft,* 45: pp. 623–637.

Fischer, K. H. (1984): *Die Messung von totaler Faktorproduktivität und technischem Fortschritt,* Bonn: Bonner Betriebswirtschaftliche Schriften, Band 14.

Fortune Magazine (1967): June, 15.

Fortune Magazine (1985): April, 29.

Gutenberg, E. (1983): *Rückblicke,* Köln: unpublished manuscript.

von Maltzan, B. (1978): *Average Produktionsfunktionen und Effizienzmessung über Frontier Production Functions,* Bonn: Bonner Betriebswirtschaftliche Schriften, Band 3.

Pohl, H., R. Schramm, and F. Schönert-Röhlk (1983): Die Chemische Industrie in den Rheinlanden während der industriellen Revolution, Band 1: Die Farbenindustrie, *Zeitschrift für Unternehmensgeschichte,* Beiheft 18.

Wenz, C. (1976): *Vergleichende Wachstumsanalyse von Unternehmen,* University of Bonn: Master-Thesis.

Wessel, H. (1983): Die Entwicklung des elektrischen Nachrichtenwesens in Deutschland und die rheinische Industrie, *Zeitschrift für Unternehmensgeschichte,* Beiheft 25.