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## Value generation by industrial research

Manuskripte aus den Instituten für Betriebswirtschaftslehre der Universität Kiel, No. 366

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*Suggested Citation:* Brockhoff, Klaus (1995) : Value generation by industrial research, Manuskripte aus den Instituten für Betriebswirtschaftslehre der Universität Kiel, No. 366, Universität Kiel, Institut für Betriebswirtschaftslehre, Kiel

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Nr. 366

**Value Generation by Industrial Research**

Klaus Brockhoff

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# VALUE GENERATION BY INDUSTRIAL RESEARCH

KLAUS BROCKHOFF

## Abstract

Industrial research may have many different functions. In this paper we develop the economic consequences that can be derived from the function of increasing the productivity of development work within a long-term equilibrium model of a profit-maximizing firm. Two models are presented and analyzed: one of mandatory research, the other of supplementary research.

30.1.1995

The ideas were developed as part of the Company of the Future project with support from the European Union. Prof. Dr. Klaus Brockhoff is Director of the Institute of Research in Innovation Management, University of Kiel, 24098 Kiel, Germany. The author would like to thank Dipl.-Kfm. H.C. Reinhardt for valuable suggestions and the numerical calculations.

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## I. Introduction

Research results have very peculiar economic characteristics. Once available, they can be used by an unlimited number of interested persons at no additional cost. Furthermore, it is difficult to exclude rivaling use, except by keeping the results secret. Patenting is very often not available to protect the new knowledge, and keeping it secret may severely constrain the derivation of an economic benefit from the new knowledge even to its originator. Thus, there exist little incentives for companies to engage in research, particularly if these companies mobilize all of their resources to fight their competitors.

Contrary to the plausible argument just mentioned we can observe that some private business set aside a certain share of their expenditures for research. As early as 1926 the director of the chemical department of Du Pont argues before the Executive Committee of his company for increased support of research. He develops four reasons: "First was the scientific prestige or advertising value to be gained through the presentation and publishing of papers. Second, interesting scientific research would improve morale and make the recruiting of PhD chemists easier. Third, the results of Du Pont's pure science work could be used to barter for information about research in other institutions. Fourth, pure science work might give rise to practical applications. Although Stine personally believed that these would inevitably result, he felt that this proposal was totally justified by the first three reasons" <sup>1</sup>. Also, it is remarkable that econometric research could demonstrate the fact that company internal research supports productivity growth, and it does so to a

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<sup>1</sup> Hounshell, D.A., Smith, J.K., jr., Science and Corporate Strategy. Research and Development at Du Pont 1908 to 1980. Cambridge 1989, p. 223.

stronger degree in relative terms than development work <sup>2</sup>. Even if the last-mentioned result would be undisputed, the question remains at what level research should be supported within a profit-seeking private firm. The history of Du Pont proves very nicely how the top management of this company was constantly searching for this level, mostly guided by the analysis of past experiences<sup>3</sup>.

Certainly, a great number of criteria can be used in order to come up with such a managerial decision. It is shown in Table 1 that decision makers in German industry give very different weights to these reasons<sup>4</sup>. However, the large number of reasons collapses to only three mutually independent factors. The third factor loads on the two variables that describe research as a support function for the improvement of existing processes and products. The second factor describes the function of research as a source for innovations and not merely a side-product of applied research or development. The first factor loads on all remaining variables. These describe research as a set of activities to identify, acquire and transfer new external knowledge into the company. If the factor values are clustered, we identify three clusters. These clusters are composed of firms from different industries, and firms of one industry are distributed over different clusters. Of the six firms in the electrical and electronics industry, one is in cluster 1, three in cluster 2, and two in cluster 3. Thus it appears that the functions of research are not primarily

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<sup>2</sup> Griliches, Z., Productivity, R&D, and Basic Research at the Firm Level in the 1970's, American Economic Review, Vol. 76, 1986, pp. 141-154, with further references.

<sup>3</sup> Hounshell, D.A., Smith, J.K., jr., Science and Corporate Strategy, op. cit., passim.

<sup>4</sup> See Eggers, O., Funktionen und Management der Forschung in Unternehmen, (Manuscript Kiel) 1995. It should be noted that the present results represent only a subsample of the total sample. Almost half of the responses had to be excluded as they exhibited almost random responses that could not be used for further analysis. This indicates that up til now few companies seem to have established a systematic research management.

defined by the industry context, but rather by the individual strategic considerations in those companies where these issues are taken up more systematically.

In view of these divergent results, we are interested in developing models that explain the level at which research is supported in a profit-maximizing company. Such models do not

Table 1: Functions of Research in German Companies (n = 26); scale 0 (does not at all apply) to 6 (completely correct)

Our own research ...	Mean	Std.dev.
... is a source for innovations	4.62	1.60
... helps us to understand the technology of our existing products or processes better	4.27	1.40
... helps us to improve existing products or processes	4.15	1.46
... improves relationships to universities and other research institutions	3.85	1.67
... increases our alertness vis-a-vis new developments in science	3.85	1.71
... simplifies the application of research results from universities or other research institutions	3.73	1.61
... simplifies the evaluation of research results from universities or other research institutions	3.62	1.98
... simplifies the acquisition of scientific know how and methods	3.23	1.70
... increases our image	2.96	1.87
... supports the hiring of new research personnel	2.38	1.81
... is a side-product of our applied research or development	1.96	1.97
... is pursued because it gets public funding	1.00	1.33

Source: Eggers, O., Funktionen und Management der Forschung in Unternehmen, (Manuscript Kiel) 1995.

seem to be available. We think that - although abstract - they help to clarify issues and relationships, even for the practi-

sing research manager. They even guide us to the relevant questions to be asked in empirical research. Still, this paper is primarily intended to start further discussion.

## II. A Model of Mandatory Research

### 1. The Basic Model

Consider a risk-neutral, profit-maximizing firm with a planning horizon of  $T$  periods. The firm employs an interest rate  $i$  to discount future profits or losses to the planning period 0. Its output is derived from a Cobb-Douglas-type production function with two input factors, namely knowledge  $K$  and all other factors  $C$ . The aggregation of all other factors into one factor of production does not constrain our arguments. Knowledge  $K$  in the firm is derived from two sources, namely development  $D$  and research  $R$ . For simplicity we assume that the results of development become available instantaneously, while the results from research need  $k$  periods to bear fruit. Eventually these results will enhance the results of pure development work. From this we can formulate

$$(1) \quad K_t = \varphi D_t^g R_{t-k}^j$$

with  $\varphi, g, j$  as non-negative parameters. The parameter  $\varphi$  defines the numeraire, and it absorbs the degree of uncertainty that is inherent in the research and development process. This implies that the generation of knowledge without any research is impossible. In this sense, research is mandatory. However, the level of the research expenditure still has to be determined. Furthermore, we assume at the transfer of research results into development is possible without any transfer cost. We shall abolish this assumption in a later model. The production function for the output  $X$  is assumed to be

$$(2) \quad X_t = x C_t^b K_t^c.$$



with the non-negative parameters  $x$ ,  $b$  and  $c$ . After inserting (1) into (2) and redefining parameters we can derive the present value of the company's future profits as

$$(3) \quad G_0 = \sum_{t=0}^T (a c_t^b D_t^h R_{t-k}^l - C_t - D_t - R_t) (1 + i)^{-t}.$$

where  $a = x\phi^c$ ,  $h = cg$  and  $l = cj$  are non-negative parameters.  $b$ ,  $h$  and  $l$  are known as elasticities, that is relative change in output  $X$  over relative change in the respective input. We assume that the company modeled in (3) is a going concern and not a new venture. Thus, for  $t - k < 0$  we could have data. As will become clear shortly, this assumption is of no particular relevance.

The firm seeks to maximize (3) with respect to the different types of research and development expenditure, while treating the other inputs as given. The necessary conditions for this optimization are

$$(4) \quad \partial G_0 / \partial D_t = 0 \Rightarrow (h / D_t) X_t - 1 = 0,$$

$$(5) \quad \partial G_0 / \partial R_t = 0 \Rightarrow (l / R_t) X_{t+k} (1 + i)^{-k} - 1 = 0,$$

$$(6) \quad \partial G_0 / \partial C_t = 0 \Rightarrow (b / C_t) X_t - 1 = 0.$$

Under long-term optimal equilibrium conditions, firms would not want to change the values of the variables. Therefore, we can let  $X_t = X$ ,  $D_t = D$  and  $R_t = R$ . From these assumptions it follows that the optimum levels  $R^*$  and  $D^*$  (where the asteriks are not shown in the following formulae) are determined by:

$$(7) \quad \frac{R}{D} = \frac{l}{h} \cdot \frac{1}{(1 + i)^k}.$$

Thus, the relative shares of research and development expenditures are determined.

From (4) to (6) we may derive some funding principles for

research or for development. Thus, the intensity of research or development is

$$(8a) \quad \frac{R}{X} = \frac{l}{(1+i)^k},$$

$$(8b) \quad \frac{D}{X} = h,$$

and the intensity of the other factors is

$$(8c) \quad \frac{C}{X} = b.$$

If empirical observations reflect optimal behavior and if the present model represents the process of value generation in principle, we may assume that  $h = 0.1$  (the development intensity, which equals the elasticity, is about 10%) and  $l = 0.01$  (the research elasticity is about 1%, which arises from the assumptions of a 10% interest rate, a time lag of 8 years between research and sales, and research expenditures of 5% of the development budget).

If the total research and development budget would be given, the following expenditures should be set aside for research and for development, respectively:

$$(9a) \quad R = \frac{l}{l + h(1+i)^k} (R+D),$$

$$(9b) \quad D = \frac{h}{l(1+i)^{-k} + h} (R+D).$$

The shares in the total expenditures are

$$(10a) \quad R = \frac{l}{l + (h + b)(1+i)^k} (R+D+C),$$

$$(10b) \quad D = \frac{h}{h + b + l(1+i)^{-k}} (R+D+C),$$

$$(10c) \quad C = \frac{b}{h + b + l(1+i)^{-k}} (R+D+C).$$

Here, optimum R and D expenditures depend not only on their own elasticities, but also on the elasticity b. This influence is stronger on R than on D, as it is enhanced in the former case by the interest-lag-effect  $(1+i)^k$ . Thus, a reduced elasticity of the other factors should call for a relatively stronger increase in R than in D.

## 2. Interpretation

For starting, let us shortly look at some numerical results that are derived for the above-mentioned parameters of the research and development processes. We assume that the parameter a is simply a scaling constant that can be set to  $a = 100$ . Furthermore, we assume  $b = (0.5; 0.6)$ , alternatively. The following results can be derived (Table 2). It is apparent that an increasing elasticity of the "other" factors of production not only increases their usage, but also the absolute levels of research and development. The effect is very strong. As indicated by (7), the R/D share is not affected.

Table 2: Sample results for Optimum Factor Usage in Model (3), with  $h=0.1$ ,  $l=0.01$ ,  $a=100$ ,  $i=0.1$ ,  $k=8$ , and T approaching infinity.

b	C	D	R	$G_0$
0.5	13,336.9	2,667.4	124.4	105,451
0.6	617,296.0	102,833.0	4,799.6	3,038,487

The results in (7), (8a) and (8b) may be interpreted as follows. The discounting factor causes a relative increase in research activities if k can be shortened, and a relative reduction if k grows larger. Thus, the faster research results can be made to bear upon the development activities, the more it pays to invest in research activities. Similarly, higher interest rates reduce the share of research as opposed to

development. In fact, they increase the intensity of development and they lower the intensity of research. This is of particular interest if the real price of capital is different in different countries and if the term structure of interest rates is not constant. Both assumptions can be substantiated easily in reality. If the interest rate increases from 10% p.a. to 12.5%, and if the time-lag for research is 10 years, this would decrease the share of R/D by 20.1%. This effect grows as  $k$  increases. It is augmented by the effects of a normal term structure of interest rates, where short term interests are lower than long term interests.

The effect of higher cost of capital may be counterbalanced by a shortening of the time-lag  $k$ . Assuming that interest rates are increased from 10% p.a. to 12.5% or to 15%, these developments could be compensated if research time-lags would be reduced from 10 time periods to 8.092 or to 6.819 time periods, respectively.

It may be more than a coincidence that the pressure on many research directors to reduce research expenditures and to shorten the time period from research to product introduction arose in a period of comparatively high interest rates.

Given the effect of the discounting, the relative share of research activities over development activities is determined by the quotient of the parameters  $l$  and  $h$ . It is well-known that these parameters are output-elasticities of the respective input factors. They answer to the question: What is the expected percentage change of output given a one percent change in input? It is plausible to assume that this value is smaller for research than for development, given the substantial uncertainty that is involved in research as opposed to development. If management decisions of setting research budgets to 5% of the total R&D budgets could be considered as rational, we should expect that the estimated development elasticities should be about six to seven times higher than the research elasticities (for time-lags of ten years and interest rates in the neighborhood of those discussed above). As indicated above, the elasticities may be estimated either

in a one-step procedure or in a two-step-procedure. In this case, R&D managers would have to answer two questions: What is the percentage change of development activities, given a one percent change in research activities, and what is the percentage change of output, given a one percent change in development activities. The product of both figures would lead to the required result. At present, technology managers may not be accustomed to answer such questions. In other functional areas, such as marketing, managers are already quite used to working with elasticities for determining optimal levels of prices, advertising expenditures or sales force compensation.

### 3. Mandatory Research and Transfer Expenditures

#### 3.1 Internal Transfer

In addition to the expenditures already covered in (3), above, we may have to consider transfer expenditures. These arise from the integration of research work into development work. This can be accomplished by joint working groups, transfers of personnel, internal seminars or workshops etc. It is plausible to assume that the expenditure grows with a growing level of knowledge from research to be transferred into development. Using the concept of absorptive capacity as developed by Cohen/Levinthal<sup>5</sup>, we may assume that an increasing level of knowledge from development per period may facilitate the transfer, which lowers the expenditure for transferring research results. Alternative assumptions may be that research itself develops the basis for a transfer of its results into development, or any combination of this and the aforementioned procedure. We do not intend to develop models for all these situations, particularly as the first situation is supported by yet another plausible assumption: The higher the development expenditure, the broader may be the possible applications of some knowledge developed by a research process. However,

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<sup>5</sup> Cohen, W.M., Levinthal, D.A., Absorptive Capacity: A New Perspective on Learning and Innovation, Administrative Science Quarterly, Vol. 35, 1990, pp. 128-152.

the capacity of development to integrate research results may be less than proportional to  $D$ , but occur at a rate  $D^f$ . The transfer expenditures can then be written as  $vR_{t-k}/D_t^f$ , where  $v$  is a constant.

These expenditures are incorporated into (3). With respect to  $D$  and  $R$  this leads to the following optimization conditions:

$$(11) \quad \partial G_0 / \partial D_t = 0 \rightarrow (h/D_t) X_t - 1 + f v R_{t-k} / D_t^{f+1} = 0,$$

$$(12) \quad \partial G_0 / \partial R_t = 0 \rightarrow (1 / R_t) X_{t+k} (1 + i)^{-k} - 1 - v / D_t^f = 0,$$

and (6). From these conditions we derive

$$(13) \quad \frac{R}{D} = \frac{1}{h} \cdot \frac{1}{(1 + i)^k} \cdot \frac{1}{1 + (v/D^f) (1 + 1f/h \cdot (1 + i)^k)}.$$

The first two quotients on the right-hand side are identical with the right-hand side of (7). The third quotient is always smaller than 1, as the terms in the brackets are positive for positive  $v$ . Thus, the existence of transfer expenditures reduces the share of research expenditures. It should be kept in mind that this does not necessarily imply that the level of both types of expenditures is reduced as well.

It follows from (11) and (6) that  $R$  is non-negative if and only if  $D > hX$ . Comparing with (4) we can conclude that the existence of transfer expenditure necessitates a higher development expenditure. This additional expenditure is needed to integrate research results into development. Research is reduced if  $v$ ,  $h$  and  $C$  are increased or  $b$  is decreased. It is reduced also if  $\ln D < 1/f^2$ , and it is increased otherwise.

The mutual relationship between the parameters of the transfer cost function and development expenditure is rather complicated. Therefore, we present again some numerical insights (Table 3, see also Figure 1). If  $f$  is small, which indicates a

weak ability to integrate research results into development, then  $d$  decreases as  $v$  increases. This is the most plausible situation. If the ability to integrate research results into development is strong (high values of  $f$ ), then the development expenditure increases up to a certain level with increasing  $v$ . Here, additional development expenditure more than compensates the effect of the rising unit transfer cost, as it helps to make available more results from research for the generation of additional value. Holding  $v$  constant, we may observe an optimum value of  $f$  with respect to development expenditure  $D$ . Here, a similar argument can be used as above. In Figure 1 give a unified impression of these results.

Certainly, high development expenditures do not necessarily guarantee high net present values of the company. In Figure 2 we show that the optimum net present value decreases for any given level of  $f$  (the capacity of development to integrate research) with increasing  $v$ , while for any given  $v$  the optimum

Table 3: Parameters of the Transfer Cost Function and Optimum Development Expenditure from (11), (12) and (6), with  $h=0.1$ ,  $l=0.01$ ,  $b=0.5$ ,  $a=100$ ,  $i=0.1$ ,  $k=8$ .

	$f=0.5$	$f=0.6$	$f=0.7$	$f=0.8$
$v= 5$	$D=2,667.96$	$D=2,668.39$	$D=2,668.18$	$D=2,667.89$
$v=15$	$D=2,667.50$	$D=2,669.83$	$D=2,669.59$	$D=2,668.86$
$v=25$	$D=2,665.79$	$D=2,670.66$	$D=2,670.80$	$D=2,669.78$
$v=35$	$D=2,663.42$	$D=2,671.04$	$D=2,671.84$	$D=2,670.64$
$v=45$	$D=2,660.72$	$D=2,671.08$	$D=2,672.72$	$D=2,671.45$
$v=55$	$D=2,657.86$	$D=2,670.85$	$D=2,673.46$	$D=2,672.21$
$v=65$	$D=2,654.93$	$D=2,670.41$	$D=2,674.09$	$D=2,672.93$
$v=75$	$D=2,652.00$	$D=2,669.82$	$D=2,674.60$	$D=2,673.61$
$v=85$	$D=2,649.10$	$D=2,669.10$	$D=2,675.03$	$D=2,674.25$

net present value increases as  $f$  increases. These observations are immediately plausible.

-- Figures 1 and 2 about here --

### 3.2 External Transfer

In a very recent comment on "Science and Technology Policy in the U.S. it is said: "As a result of the restructuring of many companies, the levels of their efforts in basic research have been attenuated. Their dependence on university research has increased. Industry has expanded its support of university research and entered into many hundreds of collaborative arrangements. About 35% of all U.S. patents issued to industry have arisen from collaborations between basic scientists working in universities and industrial scientists working in their laboratories"<sup>6</sup>. While the last sentence may entail some biased measurements, the tendencies described here are basically undisputed. They can also be observed in Europe, where for instance companies like Schering Corp. have developed the same approach very systematically. The approach makes sense, if the cost of acquiring new knowledge can thus be reduced as compared with exclusive internal knowledge generation.

We may now consider an extreme case, where all research results are available from outside the company and alternatively from internal research efforts. If research results are available from the outside, the company would not have to shoulder the respective expenditure  $R$  ( $>0$ ). However, it is plausible to assume that the transfer expenditure for research results from outside the company ( $wR/D^f$ ) is higher than the expenditure for internal transfer. The optimum relationship between  $R$  and  $D$ , where  $R$  is an input factor that has only an indirectly associated expenditure (namely the transfer expenditure), can now be written as

$$(14) \quad \frac{R}{D} = \frac{1}{h} \cdot \frac{1}{(1+i)^k} \cdot \frac{1}{(w/D^f)(1+lf/h \cdot (1+i)^k)}.$$

Again, the quotient in (14) is smaller than the one in (7). We

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<sup>6</sup> Abelson, P.H., Science and Technology Policy, Science, Vol. 267, 27 January 1995, p. 435.



may also explore under which conditions (14) is smaller than (13). This is true if

$$(15) \quad w - v \geq \frac{D^f}{1 + lf/h \cdot (1 + i)^k}.$$

The larger  $l$  and the smaller  $i$ ,  $k$  and  $h$ , the more likely it is that the share of research over development will be more reduced with the incorporation of outside research as compared with the integration of inside research into development. A different interpretation is that external research is favored over internal research as interest rates ( $i$ ) or research time lags ( $k$ ) increase or as the elasticity of research ( $l$ ) decreases.

If industry has to share  $u\%$  of the external research expenditure that it wants to use, the nominator on the right hand side of (15) would be multiplied by  $(1 - u/100)$ , and a decreasing share of research would be even more likely. These considerations show why much importance is attributed to the question how industry could make better use of government supported research.

It is implicit in the models discussed above that research is not a substitute for development work. Rather, it is complementary to these activities. In order to check whether the model reflects reality, managers should answer affirmatively to the question: "In the long run, can sales be generated only with research?". If the answer should be no, the following model may be a better representation of reality.

### III. A Model of Supportive Research

#### 1. The Model

Let us again assume a profit-maximizing firm that employs the same interest rates and time lags for research as in the model above. However, its views of the function of research are different from the first firm. It should be noted that therefore the parameter values mentioned in the following may be different from those of the first model.

The total development expenditure (E) is to be split into two shares. With the share D sales are generated from an interaction of research and development, as before. These sales may be interpreted as the sales of radical innovations. With  $F = E - D$  the original sales can be increased by  $zB^g F^m$ . These sales may be interpreted as the sales of incremental innovations, where B is the input of other factors, g its respective elasticity, m the elasticity with respect to development expenditures for incremental innovation; z is a positive scaling constant. The resulting objective function is

$$(16) \quad G_0 = \sum_{t=0}^T (a C_t^b D_t^h R_{t-k}^l + z B_t^g F_t^m - C_t - B_t - E_t - R_t - v R_{t-k} / D^f) (1+i)^{-t}.$$

The optimization conditions are (6), (11), and (12) together with

$$(17) \quad \partial G_0 / \partial F_t = 0 \rightarrow (m/F_t) \cdot z B_t^g F_t^m - 1 = 0,$$

$$(18) \quad \partial G_0 / \partial B_t = 0 \rightarrow (g/B_t) \cdot z B_t^g F_t^m - 1 = 0.$$

From (17) and (18) we can derive a fully parametric solution for optimal levels of F and B, respectively:

$$(19) \quad F = \left[ \frac{(mZ)^{(g-1)/g}}{gZ} \right]^{g/(g+m-1)}.$$

$$(20) \quad B = \left[ \frac{(gZ)^{g(m-1)}}{(mZ)^m} \right]^{1/(g+m-1)}.$$

From (11) and (12) we can derive R/D as in (13). Let us call the right-hand side of this expression  $\xi$ . We can now derive  $R/E = R/(D + F)$ , where F can be taken from (19):

$$(21) \quad \frac{R}{D+F} = \xi \cdot \frac{D}{D+F}.$$

## 2. Interpretation

We observe that the share of research expenditures over the

total development expenditures is smaller than in (13), as the last quotient is less than 1 if  $F$  is positive. Thus, in the case of supportive research a company would spend relatively less on research as compared with the case of mandatory research. Furthermore, the share of research expenditures decreases as  $F$  increases: the higher the optimal expenditure for incremental innovations, the lower is the share of research expenditures. Successful incremental development may be interpreted as reducing the relative productivity of research to generate value. This effect is the stronger, the smaller the share of  $D/F$ . In reality, this share is rather small.

#### IV. Further Research

The results achieved so far from purely theoretical considerations appear to be of interest to practitioners as well. They allow us to phrase the most important questions on the determinants and consequences of research in the company much better than before. This leads to ideas on the kind of data to be collected for future substantiation in answering such questions. This would help in planning research activities in companies. The sensitivity of net present value with respect to all parameters of interest may be analyzed in order to get a better understanding of the relationships between research, development, and the future cash flows of a company.

The results achieved so far could be expanded in various directions: Similar results can be achieved for process innovations rather than product innovations, if cost savings are interpreted in the same way as sales in the foregoing models. Alternative ways to model absorptive capacity may be tested. If data from organizations became available, comparisons of the results from such alternative models could be used to find optimum ways to deal with the interface problem between research and development. Furthermore, growth models may be considered that describe an optimum growth path for a company. Competitive effects may be incorporated by embedding the above models into a game-theoretic framework.

**Figure 1: Optimum development expenditure as a function of transfer cost parameters  $v$  and  $f$**

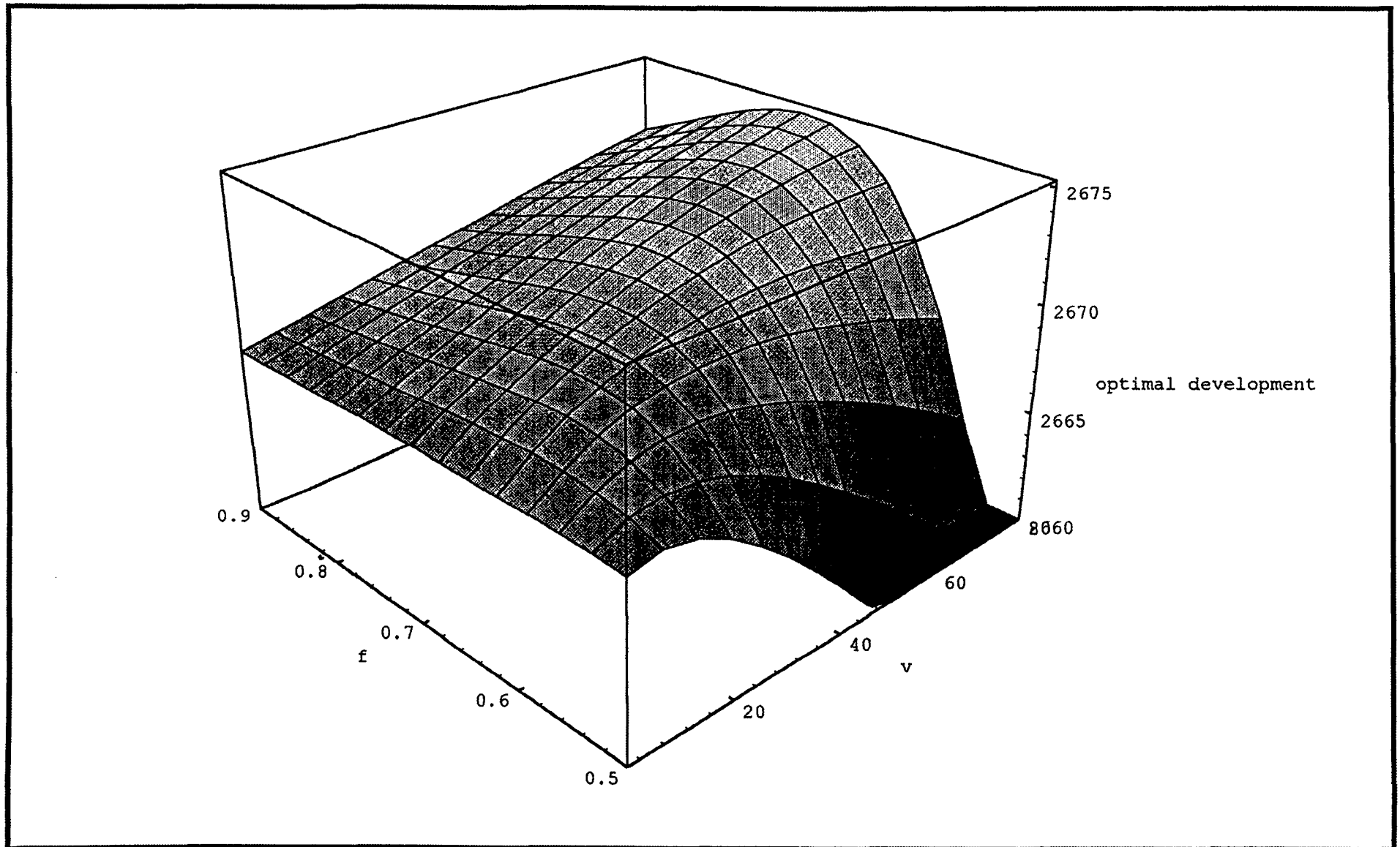


Figure 2: Optimum net present value as a function of transfer cost parameters  $v$  and  $f$

