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The use of sensitivity and risk analysis also enables some quantification of the effects of intangible benefits. We have shown earlier that the tangible effects of, say, quality on scrap, rework, warranty, etc. can be analysed, using the calculator with probability distributions. The effects of market share would be assessed by a possible increase in contribution, arising from an estimated increase in sales. In this case a fairly pessimistic view of the possible increase in market share would be taken and if desirable the reaction of competition in the marketplace could be modelled as well.

We believe that the ease of use of the PC to enable risk analysis to be undertaken is such that is should be more widespread as an additional support to management decision making.

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15 Analysis and Evaluation of Flexible Capital Investment

Carl-Henric Nilsson, Håkan Nordahl and Ingvar Persson

15.1 Introduction

Modern production systems are technologically advanced. The change in technology has made it increasingly possible to modify the flow of products and to handle different product variants. The ability to offer customized products has become an important competitive factor. The companies at the cutting edge of the advanced technology are forced to adjust to these changes and, hence, operate under a higher degree of uncertainty. Flexibility in manufacturing is, therefore, of substantial significance to all companies in the manufacturing industry.

In the industry, managers are expected to do economic analysis with respect to capital budgeting. The production system should be viewed as a tool for business development (Hill, 1989). It is thus important that the evaluation of an investment be in harmony with what the business development demands. It is also important that the tools used for economic analysis deepen the insight and understanding of the strengths and weaknesses of the installation (Persson, 1990).

Certain types of machinery are better suited than others to meet the demands for flexibility such as, for example, FMS (flexible manufacturing system) and industrial robots. Flexibility is a broad concept and is dependent upon the circumstances under which it is used. Different perspectives will generate different conceptualizations of flexibility. In this article, flexibility related to the product scope and flexibility related to the components of an investment are discussed.

The advantages of flexibility must be taken into account in the capital budgeting process. Until now, there has been a lack of CBTs (capital budgeting techniques) that evaluate flexibility. One such CBT (Nilsson and Nordahl, 1988; Nordahl *et al.*, 1988; Persson, 1988; Persson *et al.*, 1989) called capital-back method is presented in this article. The capital-back method takes into account the flexibility of the components that constitute an installation.

The capital-back method is then compared with the pay-back method. A deeper study of the capital-back method is carried out with respect to:

1. The share of flexible parts in the installation;
2. Sensitivity to the discount rate level;
3. The profitability of the total investment; and
4. The lifespan of the components.

Finally, conclusions are drawn concerning capital-back method and its implications for the management and the decision makers of companies.

15.2 Economic evaluation of capital investments – an overview

The theoretical foundations of capital budgeting techniques are: modern microeconomic theory, statistical theory for decisions under uncertainty and operations research. The discounted cash flow techniques are fundamental (Fisher 1930). With the passage of time, these techniques have become very sophisticated. The use of advanced statistical methods (Hertz, 1964; Wagle, 1968), decision-tree techniques (Magee, 1964a; Magee, 1964b), linear programming (Weingartner, 1962; Näslund, 1966) and option theory (Brealey and Myers, 1988; Cox and Rubinstein, 1985) are now possible in capital budgeting practice.

Surveys have shown that there is an increasing adoption of discounted cash-flow techniques in firms (Gitman and Forrester, 1977; Kim and Farragher, 1981; Hendricks, 1983), and the most advanced methods are still seldom used. The surveys indicate that managers still trust highly the results obtained by using capital budgeting techniques.

In a Swedish study (Yard, 1987), it was found that 40% of the companies in Sweden used the pay-back method as the primary method. Since the educational level in Swedish industry was high, the simplicity of the pay-back method cannot by itself explain the frequent use of this method. This raises an interesting question as to what important piece of information the pay-back period gives.

Weingartner (1969) argues that pay-back method is not an appropriate method for profitability evaluation according to economic theory. Yard's (1987) interpretation is that the pay-back method is to be considered as a measure of flexibility.

In order to explore the information offered by the capital budgeting process, a large capacity-expansion project was analysed in a case study (Persson, 1989b). No traditional calculations of profitability were made, even though the company regulations insisted on using traditional calculations. Instead, the investment evaluation was based on the cost-

accounting analysis for the product, initial outlay, existing demand for the product and a forecast for future demand. The justification that can be given for using cost-accounting analysis is that it gives the management better perspective of the initial strength of the investment.

In the manufacturing industry, the pay-back periods considered are often short. Hayes and Garvin (1982) point out that in the early 1970s, 20% of the US companies that were studied had adopted a pay-back periods of not more than three years. A decade later, the percentage increased to 25%. Other studies confirm that pay-back periods considered by US companies are still short. The pay-back periods are especially low for rationalization investments such as, for example, robots. Our research has indicated that the pay-back periods used in the industry are as low as two years most of the times.

15.3 Flexibility

Flexibility has several dimensions. Let us elaborate on the term flexibility. Flexibility related to the design of products and the flow of goods is well analysed. Also, several authors (Browne *et al.*, 1984; Gerwin, 1983) have discussed and defined flexibility in the manufacturing process. These definitions have one major shortcoming: they are concerned with only two dimensions, the product dimension and the material flow dimension. The analyses do not consider the possibilities of reusing the equipment in different manufacturing processes. A method which takes this aspect into account at the acquisition stage ensures that the flexibility is not only evaluated but also analysed.

In the investment analysis of the manufacturing process, flexibility is given three dimensions: material flow, products and components.

To be able to analyse the flexibility part of an investment, we need to decide on the flexibility perspective to be considered. In this article, the analysis of flexibility is limited to the following perspectives:

1. Product scope (Nilsson and Nordahl, 1988; Molin and Söderlind, 1989), i.e. the width of the variety of products that can be produced in the installation; and
2. Component flexibility, i.e. the parts of the investment that can be reused in another installation.

15.3.1 Product scope

Gerwin (1983) has defined two flexibilities related to products:

1. *Mix flexibility*. The capability to handle a mixture of details that are only faintly related to each other; and

2. *Detail flexibility*. The capability to add or reduce a detail from the mix over time.

Similar thoughts have been presented by Browne *et al.* (1984) who define production flexibility as the capability to produce a wide variety of products.

The normal problem facing an installation is uncertainty about the future demands of the market. Under such condition, product scope can be defined as:

> The boundaries within which the critical parameters of the product can be varied.

One way to operationalize the product scope is to define it as the product mix or the predicted products, that can be produced without rebuilding the production system at any given time.

An interesting aspect of the product scope is the possibility to adjust it over time. Ahlmann (1987) points out the possibility to choose an installation that can handle the present situation and to add supplementary equipment when the need arises. The capability to change the product scope is achieved through an installation that is suited to be supplemented with different building blocks whenever a specific ability is needed.

15.3.2 Component flexibility

An installation can be regarded as a system composed of different sub-systems or components as described in Fig. 15.1.

A component can be a standard equipment or a specially designed tool. Examples of investment components are a bed plate for a machine, a computer program and the cost of project management.

The flexibility of a component refers to the usability of the component for purposes other than those originally intended, either within or outside the manufacturing process of a company. Examples of this type of flexible equipment are robots, CNC machines and parts of FMS.

The component flexibility gets important when the demand for the installation ceases. For instance, this situation happens when the product that is being produced becomes obsolete.

Martins (1986), for example, argues that an important part of the flexibility of an industrial robot is its capability to be used as a standard component over a wide range of tasks, not related to the original task.

If we aggregate the investment costs of the flexible components, we get the total flexible part of the investment G_f.

If the same aggregation is done with the inflexible components, we get the risky part of the investment G_r. The components belonging to the

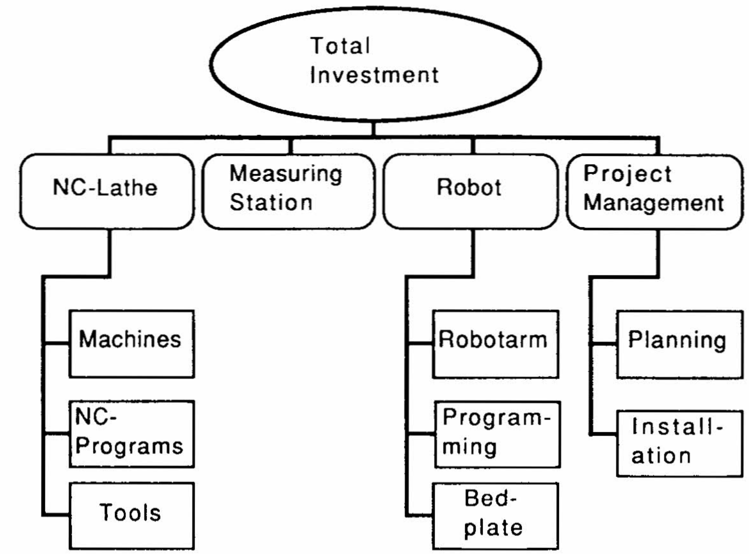

Fig. 15.1 *The sub-systems or components of an installation.*

risky investment cannot be used to produce other products in other manufacturing processes. The residual value is zero irrespective of how long the component has been used. Examples of this type of components are the fixtures and gripping appliances that are intended for a specific product. Included as part of the capital investment are also the expenditures for projection and design as well as the physical installation of these components. It is not usually possible to recover these expenditures if the project fails, and hence they form part of the risky investment.

A component can either be flexible or inflexible. If it is not possible to decide whether a component is flexible or not, the installation structure has to be further disintegrated.

The total investment G is the sum of the flexible part and the risky part of the investment.

$$G = G_f + G_r \tag{15.1}$$

This segregation of the capital investment into flexible and risky parts is by itself an important step. Component flexibility f is defined as the flexible share of an investment, as given below:

$$f = \frac{G_f}{G} \tag{15.2}$$

Once the categorization of the components that constitute an investment is done, the investment can be analysed with the capital-back method. This analysis is explained below.

15.4 Capital-back method

15.4.1 Capital-back method *v.* pay-back method

The objective of the capital-back (CB) method is to release flexible investments from the unreasonably high demands of a short pay-back (PB) period, which arises out of a high degree of uncertainty and short-term planning. The CB period should not be used as the sole determining factor of an investment as is done with other CBTs. It should be used as a complement to other CBTs such as NPV (net present value), IRR (internal rate of return) and PB. It will be seen later that the combination of CB and PB will generate interesting information that is related to NPV and IRR. The advantage of the CB method is that it takes into consideration the uncertainty of the custom-made part and the requirement for profitability for the flexible part.

The capital-back method applies the pay-back period for the risky investment, while the flexible part of the investment generates a yield that is as high as the discount rate. A low degree of uncertainty resulting from the flexibility makes a low interest rate acceptable for the capital invested in flexible equipment. This reasoning is consistent with the capital asset pricing model (CAPM) (Brealey and Myers, 1988).

When the capital-back method is used, calculation of the cost for the flexible part of the investment includes both depreciation and cost of capital. This calculation can be done in different ways, and the choice of calculation method will obviously affect the result. The most natural method used in capital budgeting is the annuity method. This provides a constant annual cost during the lifespan of the installation. According to the annuity method, if the discount rate is $i\%$ and the expected lifespan is n years, then the annual cost for the flexible part of the investment is G_f * ann (n years, $i\%$). When this amount is deducted from the annual net receipt, it gives the annual net receipt of the risky investment and it can be accumulated in the same way as in the pay-back method.

In analytical terms, the calculation of CB period is analogous to that of PB period, i.e. the investment divided with the annual net receipt, as given below:

$$CB = \frac{G_r}{a - G_f * \text{ann } (n \text{ years}, i\%)} \qquad (15.3)$$

From equation (15.3), it may be concluded that the gradient of the lower dotted line in Fig. 15.2 decreases as the interest rate increases. The interest rate which generates a capital-back period equal to the pay-back period is of special significance. At this rate of interest, the rate of return on the risky investment is as high as the rate of return on the flexible part

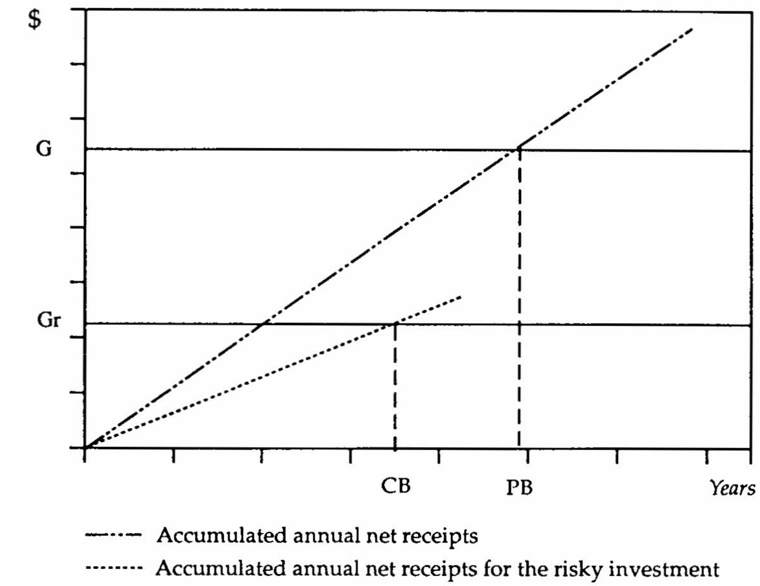

Fig. 15.2 *The relationship between capital-back method and pay-back method.*

of the investment. This calculation assumes that the lifespan of the risky investment is equal to the lifespan of the flexible part of the investments.

The capital-back method is described in Fig. 15.2. The horizontal lines show the capital investments. The lower line is the risky investment G_r and the upper line is the total investment G, which is equal to the total of G_f and G_r (equation (15.1)). The difference between the lines is the flexible part of the investment G_f.

The two lines extending from the origin show how the accumulated annual net receipts for PB and CB grow as a function of time. The lines are straight due to the fact that the annual net receipts are constants with respect to time. The steeper line is the accumulated annual net receipts a for the total investment. The interception of this line with the upper line for G gives the pay-back period.

The less inclined line shows the accumulated annual net receipts a minus the annual cost of the flexible part of the investment ($a - G_f$ * ann (n years, $i\%$)). The interception of this line with the risky investment G_r line gives the capital-back period.

The above described calculation of the CB period is valid only if the annual net receipts are equal every year. If the annual net receipts vary, they have to be added together until the sum equals the amount invested in the risky part. This is analogous to the PB method.

The capital-back condition for the investment is then:

$$G_r = \sum_{x=1}^{CB} [a_x - G_f * \text{ann } (n \text{ years}, i\%)] \qquad (15.4)$$

a_x is the annual net receipts in year x($); n is the lifespan of the flexible part (years), and i is the discount rate of the company (%).

The PB method emphasizes on the short-term planning, uncertainty and the initial strength of the investment. But, for flexible investments, this method can lead to wrong investment decision, as the uncertainty is focused on the total investment. The advantage of the CB method is that it takes into consideration the uncertainty of the risky part and the requirement for profitability for the flexible part.

15.4.2 CB and PB *v.* IRR and NPV

The NPV rule states that an investment is justifiable if the NPV > 0. The IRR rule states that an investment is acceptable if IRR > i. Actually when the NPV = 0, the IRR will be equal to i. This means that the NPV and IRR rules will always give the same results. However, when the choice among different acceptable investments is considered, these rules can generate different results.

In order to compare the CB method with other methods, we need to rewrite the CB equation (equation 15.3) as given below:

$$CB = \frac{G_r}{a - G_f * \text{ann } (n \text{ years}, i\%)} \qquad (15.3)$$

Since the component flexibility f is equal to G_f/G (equation (15.2)), the CB equation can alternatively be written as:

$$CB = \frac{(1-f) * G}{a - f * G * ann \ (n \text{ years}, i\%)} \qquad (15.5)$$

If we assume that the lifespan of the flexible part equals the lifespan of the risky part, then:

1. When NPV > 0 and IRR > i, it can be shown that $\partial CB/\partial f < 0$. This means the investment is acceptable and thus the CB period $\leq$ PB period for all values of f.
2. When NPV = 0 and IRR = i, it can be shown that $\partial CB/\partial f = 0$. This means that the CB period, as a function of the flexible share of the investment f is constant. It turns out that this constant is the PB period.
3. Lastly, when NPV < 0 and IRR < i, then $\partial CB/\partial f > 0$. This means that CB as a function of f is increasing and the investment is not justifiable.

At the breaking point, when the denominator of equation (15.5) becomes zero, i.e. when:

$$f = \frac{a}{G * \text{ann } (n \text{ years}, i\%)} \qquad (15.6)$$

the CB function is discontinuous. For higher f, the CB period is less than zero. This, of course, does not have any practical meaning. For higher discount rates, the breaking point will have lower values.

From the above discussion, we may conclude that:

1. The CB period, together with the PB period, indicates whether or not an investment is acceptable or in agreement with the NPV and IRR rules.
2. The results we get from the CB and PB calculations are meaningful only for acceptable investments, and not for unacceptable investments.
3. When the choice among different acceptable investments is considered, the three rules, NPV, IRR, and CB and PB, can give different answers as to which investment is to be chosen.

15.5 Analysis of the parameters that affect the capital-back period

The CB period is influenced by four parameters:

1. The flexible share of the investment;
2. The level of the discount rate;
3. The profitability of the total investment (measured with NPV or IRR); and
4. The lifespan of the flexible part of the investment.

As there is no room to carry out a total analysis here, only an illustration of how the different parameters influence the outcome is given. The flexible part of the investment is chosen as the main parameter. The effect on the CB period is then analyzed for different levels of the discount rate, profitability and lifespan.

15.5.1 The discount rate level

Earlier research conducted is used here to select the discount rates. Research carried out on Swedish companies showed that the average discount rate used by these companies was 20%, without considering taxation. The variation of the discount rates used, however, was high. Yard (1987) found that the minimum discount rates ranged between 10% and 30% and the maximum rates were around 50%. Tell (1978) also found that the discount rates averaged slightly below 20%. But, none of them could establish if the discount rates were real or nominal. According to Gitman and Forrester (1977), the discount rates used by US companies were lower; in several cases the discount rates were between 10% and

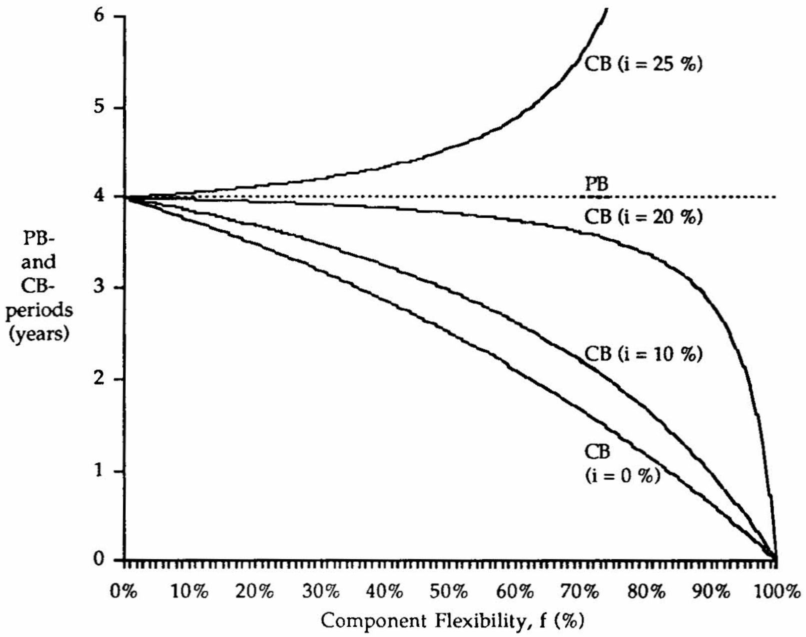

Fig. 15.3 *PB period and CB period as functions of the share of flexible part and the discount rate level.*

15%. Hayes and Garvin (1982) felt that these estimates of discount rates were considerably lower than the actual rates.

With these findings in mind, the influence of the discount rate on the CB period is analysed for discount rates between 10% and 25%. In order to save space, the total analysis is carried out for a pay-back period of only four years. This analysis is supplemented with a schematic description of what happens when the PB period is shortened to two years. The extreme value of 0% discount rate is also displayed for comparison. The analysis assumes that the annual net receipts are same every year.

Figure 15.3 describes an investment by showing the PB period and the CB period as functions of the share of the flexible part in the total investment, under following conditions:

1. G, the initial outlay, was $1 000 000;
2. a, the annual net receipts, were $250 000 per year;
3. n is the lifespan of 10 years;
4. i, the discount rate, ranged between 0% and 25%; and
5. f, the share ($f = G_f/G$), ranged between 0% and 100%

On the x-axis is the share of the flexible part and on the y-axis are the PB period and CB period in years.

PB is defined as G/a and is thus a constant over four years, irrespective of the variation in n, i or f.

The figure reveals that:

1. The CB curves are decreasing, which means that the CB period decreases when the share of flexibility increases. This is valid only when the internal rate of return is higher than the discount rate. When the share of flexibility approaches 100%, the CB period approaches zero.
2. The CB period increases as the discount rate increases. This has been mentioned earlier.

A closer study of the curves reveals that for a discount rate of 20%, the CB period is close to the PB period, which is four years. This is because the internal rate of return (21.4%) is very close to the discount rate used (20%) there. The share of the flexible part has to be 70% or more in order to have a significant difference between periods for PB and CB.

When the discount rate is 10%, the capital-back period decreases at almost a constant rate and the difference between PB and CB periods is more significant, even when the share of the flexible part is low. This situation is representative of the capital-back method. A low discount rate generates a low annual cost for the flexible part of the investment. Thus, the share of the annual net receipts for the risky investment increases. At higher f, the CB period becomes shorter.

15.5.2 Profitability of the total investment

In Fig. 15.3, the PB period is four years. If the PB period becomes shorter, then the CB period becomes less dependent on the level of the discount rate. This is due to the facts that a high IRR has been used and the annuity method has been chosen to calculate the annual cost.

If the IRR is high, then the annual net receipts are high and so is the share of the annual net receipts for the risky investment. For instance, an investment with a PB period of two years has a very high profitability. If the lifespan of the total investment is 10 years, IRR is close to 50%. If the demand for profitability of the flexible part of the investment is 20%, then the remaining part of the surplus that will be added to the risky investment is large. This means that if the IRR is very high, the level of the discount rate become insignificant.

The result is also influenced by the depreciation method used. When the annuity method is used, the total cost for the flexible investment is distributed as a constant annual cost for the lifespan of the flexible investment. This implies that the depreciation is lower during the earlier years. For instance, if the lifespan of the investment is 10 years, the first-year depreciation is 3.9% with a discount rate of 20%. The capital back is also compatible with other depreciation and cost of capital models. Those alternatives are, however, not discussed here.

15.5.3 The lifespan of the flexible components

The lifespan of the risky components and the flexible components need not be equal. It is, for instance, possible that the lifespan of a robot is longer than that of the gripping appliances (Björkman and Ekdahl-Svensson, 1986). This factor will influence the IRR. If the flexible components of an installation have different expected lifespans, then the CB calculations will also be affected.

The CB equation for an installation with flexible components having different lifespans is:

$$CB = \frac{G_r}{a - \sum_{j=1}^{m}[G_{fj} * \text{ann}\ (n_j \text{ years}, i\%)]} \qquad (15.7)$$

G_{fj} is the cost of the flexible component j; m is the number of flexible components; and n_j is the lifespan of flexible component j.

In order to use this equation, an installation has to be described in terms of its components (Fig. 15.1) and these components are to be classified as flexible or risky. If it is not possible to classify a component, it has to be divided further until the classification can be made. For each component, the investment cost is specified, and for each flexible component, lifespan is also specified.

If the lifespan of a flexible component is shorter than the CB period, the component has to be replaced before the CB period is reached. Since the flexible part is treated as an annual cost according to the annuity method, the CB calculations are not affected by the replacement. Therefore, the CB equation is valid for replacement component, too.

In Fig. 15.4, the CB period is shown as a function of f, the share of the flexible part (of investment) and the lifespan n, of the flexible components.

For Fig. 15.4, the PB period is taken as four years and the discount rate as 15%. The upper curve shows the CB period when the lifespan is seven years for all components. This curve is closer to the PB line, which would mean that the investment is profitable, but the profitability itself is rather low. In this case, NPV and IRR are $40 000 and 16.3%, respectively.

If some of the flexible components have longer lifespans, the CB period will decrease and the NPV and IRR will increase. The lower line shows the CB period when the lifespan is 12 years for all components. In this case, NPV = $355 000 and IRR = 22.9%. The PB line and the CB curve are further apart and the gap widens as the component flexibility increases.

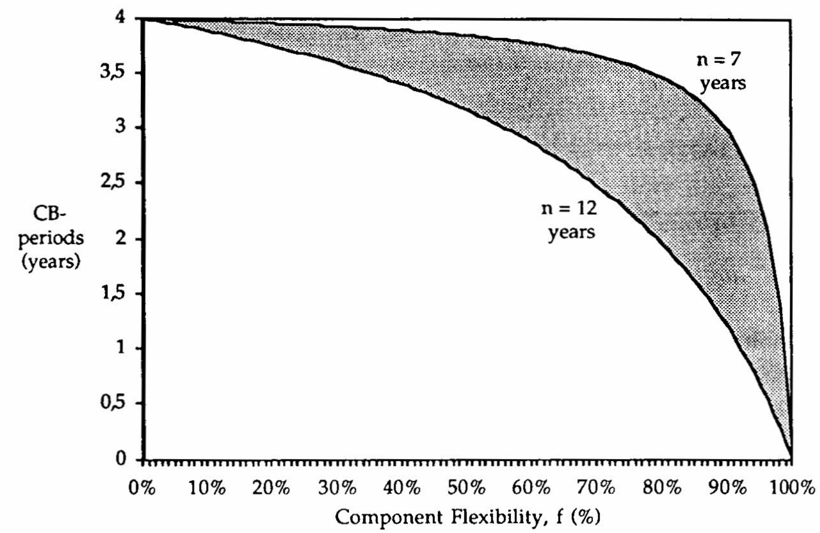

Fig. 15.4 *The influence of lifespan on CB period.*

15.5.4 Capital-back and priorities

An important characteristic of an evaluation method is its ability to prioritize different investment proposals. Below, the capital-back method is compared with the pay-back method on this aspect. Table 15.1 shows two investment proposals, A and B, which are to be compared. The profitability and the flexible share of the proposals were chosen such that the priority changes when the discount rate is reduced from 20% to 10%. The proposal A has a high flexible share but has a low IRR of 21%. This makes the alternative A sensitive to the discount rate. The alternative B, on the contrary, has a low flexible share but a high IRR. This means that alternative B is not so sensitive to changes in the discount rate.

For the competing investment proposals of Table 1, the capital back method recommendations are:

1. A company with a high requirement for profitability, i.e. willing to take risks, should prefer proposal B which has a high profitability, IRR 30%, and a high risk, 70% inflexible share.
2. A company with a low requirement for profitability, i.e. averse to risks, should prefer proposal A which has a low profitability, IRR 21%, and a low risk, 70% flexible share.

TABLE 15.1 *PB, CB and IRR: a comparison*

	Flexible share	Lifespan	IRR	PB(years)	CB(years)	
					(i = 20%)	(i = 10%)
A	70%	10 years	21%	4	3.61	(2.20)
B	30%	10 years	30%	3	2.67	(2.46)

15.6 Conclusion and recommendations

The manufacturing technology is advancing rapidly and new manufacturing processes and new products are replacing the older ones at a rapid rate. This situation necessitates that increasing the flexibility of the manufacturing process ought to be a strategic goal for companies in the manufacturing industry. The CB method highlights the importance of flexibility and recommends flexible investment alternatives. Traditional capital budgeting techniques do not take flexibility into consideration, but instead, consider the flexible and the risky parts of the capital investment as equally uncertain.

The use of the capital-back method will affect the investment process as well as the crucial decisions regarding alternate investments. The CB method assumes that the components that constitute the capital investment can be categorized into two groups, i.e. a flexible part and an inflexible part. The process of categorizing the components will force the decision makers to analyse as well as evaluate the flexibility of the different investment proposals. This process by itself is, therefore, important.

A careful study of the alternative uses of the components that constitute an investment may guide the investors to a more flexible installation. An increase in flexibility does not have to result in an increase in investment cost. When the CB criterion is used, a flexible investment is treated more favourably than a less flexible one. The shorter the CB period, the better. A project with a long PB period and high component flexibility gets a fair treatment when the CB method is used. The following illustrates this above concept.

In an FMS cell, the total investment G was $1 000 000, of which $600 000 was allocated to flexible industrial robots and $400 000 was meant for gripping appliances and other risky parts.

The investment led to an annual cost reduction of $300 000. The PB period was, therefore, 3.3 years, which was longer than the company requirement of 3.0 years. The discount rate used by the company was 20%. The lifespan of the flexible part of the investment was 10 years and, therefore, the CB period would be 2.5 years. This would imply that the risky investment could be approved against the PB period requirement of 3.0 years.

Neither capital-back nor any other capital budgeting technique gives any information about the degree of uncertainty that prevails, if the inflexible investment becomes obsolete. Neither says anything about when the investment will become obsolete. This judgment is still left to the management. But what the CB method can do is to help understand investments, especially flexible investments, and, therefore, the method is well suited for the future demands of the industry.

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