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TIMING OF CAPACITY CHANGE: MODELS FOR CAPITAL INTENSIVE INDUSTRY

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ABSTRACT

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The suitable timing of capacity investments is a remarkable issue especially in capital intensive industries. Despite its importance, fairly few studies have been published on the topic. In the present study models for the timing of capacity change in capital intensive industry are developed. The study considers mainly the optimal timing of single capacity changes. The review of earlier research describes connections between cost, capacity and timing literature, and empirical examples are used to describe the starting point of the study and to test the developed models.

The study includes four models, which describe the timing question from different perspectives. The first model, which minimizes unit costs, has been built for capacity expansion and replacement situations. It is shown that the optimal timing of an investment can be presented with the capacity and cost advantage ratios. After the unit cost minimization model the view is extended to the direction of profit maximization. The second model states that early investments are preferable if the change of fixed costs is small compared to the change of the contribution margin. The third model is a numerical discounted cash flow model, which emphasizes the roles of start-up time, capacity utilization rate and value of waiting as drivers of the profitable timing of a project. The last model expands the view from project level to company level and connects the flexibility of assets and cost structures to the timing problem.

The main results of the research are the solutions of the models and analysis or simulations done with the models. The relevance and applicability of the results are verified by evaluating the logic of the models and by numerical cases.

Keywords : timing, model, capacity, capital investment
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My parents, my sister and favourable circumstances had been an essential role as well. I also appreciate my ancestry and my sports friends. Without cross-country skiing and canoeing this work would never have been realized. At the end, it is easy to say that in real life bad timing is common, good timing is often possible, but perfect timing is always a crazy dream.

Lappeenranta, December 2007

Timo Kärri

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SYMBOLS

A	sales
B	average depreciation time of fixed assets
C	total costs
C_E	total costs of expansion
C_L	linear total cost function
C_R	total costs of replacement
C_0	total costs of old machine
C_1	total costs of new machine
D	depreciation
E	equity
F	net present value of investment opportunity
G	value of real option
H	capital invested
I	investment costs of machine, plant or project
J	present value of investment costs
K	net present value of sequential projects
L	capital turnover
M	contribution margin percentage
N	lifetime of machine
$N(\cdot)$	cumulative normal distribution
O	operating margin percentage
P	profit
P_E	profit in the expansion case
P_{Er}	profit in the expansion case, includes discount rate
P_{ErNI}	profit in the expansion case, includes discount rate, lifetime and initial investment
P_R	profit in the replacement case
Q	total production quantity
Q_c	total capacity
R	return on investment
S	expanded net present value of project
T	planning period, time window for capacity change
U	net present value of single project
V	present value of project inflows
W	fixed assets ratio
X	fixed assets
Y	long term loans
Z	net working capital

a	variable unit costs of old machine
b	fixed costs of old machine
c	variable unit costs of new machine
$d_{1,2}$	parameters of cumulative normal distribution
f	inflation
i	nominal interest rate
k	arithmetical growth rate of demand
l	net working capital rate
m	contribution margin
o	operating income
p	product price
p_0	product price for old machine
p_1	product price for new machine
q	production quantity
q^*	minimum point of marginal costs
q_0	capacity of old machine
q_1	capacity of new machine
r	annual continuously compounded discount rate
s	fixed asset rate
r_f	annual continuously compounded risk free rate
t	time
t_{opt}	optimal capacity expansion time
t^*	optimal investment time or cycle
u_{opt}	optimal capacity cutting time
v	fixed costs of new machine
w	fixed costs ratio
x	breakeven point
y	variable costs ratio
z	cost advantage parameter

Π	operating income percentage
α	cost advantage ratio
β	capacity ratio
γ_i	coefficients of cost functions
δ	scale-factor
$\mathrm{d}\zeta$	increment of Wiener process
λ	constant
μ	capacity utilization rate
σ	standard deviation
τ	timing ratio
ω	drift parameter

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1 INTRODUCTION

1.1 Background

The optimal capacity expansion time is an essential problem especially in capital intensive industries, and capacity expansion decisions have a great influence on a firm's operations and profitability. It can be said that the timing question is quite complex, and in practice the experience and intuition of the decision-makers have a central role. However, theoretical models can be used to explain many essential relations and deepen our understanding of the nature of capacity changes.

Traditional capital investment literature describes how to calculate the profitability of individual projects and how to allocate capital to accepted projects at a certain point of time. Comments on the suitable timing of projects or the effects caused the project by accelerating or delaying are seldom presented (cf. Lee 1988, p. 165). This is quite surprising because in practice businessmen can often be heard to say how a certain project has been executed at a good or a bad time. It is also commonly known that the discount rate is an essential factor in capital investment calculations, and in fact the interest rate is a function of time. Another interesting issue which has been reviewed in capital investment literature only in passing is how technological development and economies of scale impact the optimal timing of projects.

Concrete empirical observations of capacity changes have offered some starting points to the present research, but they have also been important motivators for the theoretical study as well. During the past years in teaching work, I have also become familiar with the themes of corporate growth, success and decline, and it is easy to say that those themes have left some footprints on the research. Studying the timing of capacity changes has inspired me to do some work in the areas of economies of scale, the value of growth opportunities and the nature of capital investment projects.

1.2 Scope and Objectives

This study considers the area of capital investment management. When a single capital investment is planned, there are three basic problems: the financing, sizing and timing of the project. In the changing world, timing can be a remarkable issue when the outcomes of projects are considered. Correct timing can be assumed to be of some meaning for successful operations, and often a certain action is possible only during a given period. The research area of this study is to consider the timing of capital investment projects. The actual research problem is how to find the optimal timing for a capacity expansion project.

Demand has to be in balance with supply in the long run, and this will cause requirements for changing the capacity. This means that the production capacity will be either expanded, unloaded, or unchanged. The objective of this study is to develop models for the timing of capacity change in capital intensive industry (Figure 1). The research view is to prepare a model-based theoretical study with illustrative empirical examples.

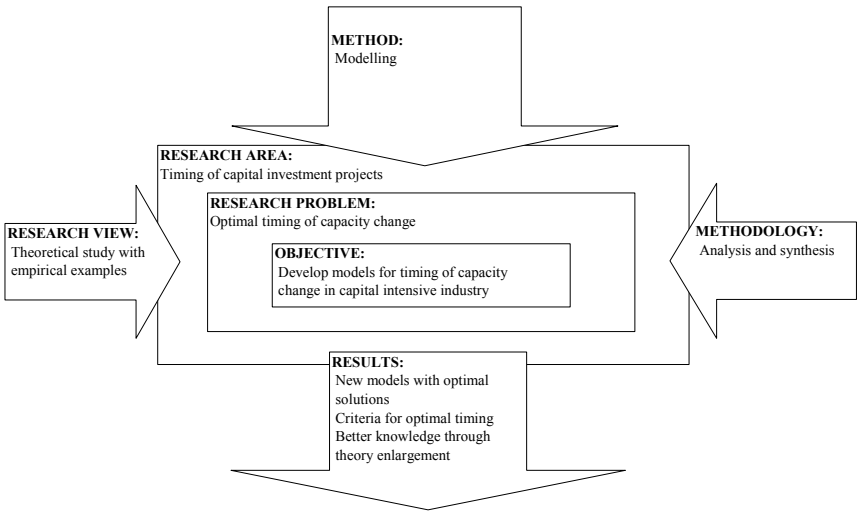

Figure 1. Objective of the study.

The starting point of the study is the view that going-concern and entity-improvement assumptions, not short-sighted exploitation, prevail in the business. Capacity adjustment to a new equilibrium is seen as a claim to the firm's existence in the long run. The kind of timing is sought where the transition from one state to the next one is appropriate and as easy as possible for the firm.

The success of firms or their parts is often described with various advantages. In different kinds of situations comparative or competitive advantage, synergy effects and economies of scale or scope are mentioned. Companies try to gain some kind of advantage over their competitors or the firm’s previous position with varying operations. Achieving an advantage partly means that the certainty of existence for the firm increases. This study emphasizes the significance of cost advantages in the conditions of price rivalry.

1.3 Definitions and Limitations

In the present study, capacity is defined as theoretical production ability at a certain period of time when the resources are given. In capital intensive companies, the capacity of machines is an essential factor, and in workforce or knowledge intensive companies the capacity of man is the dominating element. Since the measurement of exact capacity is difficult, it is often useful to consider the capital investments of companies. The retaining of capacity requires replacement investments and its growing demand capacity expansions.

This study focuses on capacity leaps, and the other alternative of increasing capacity step by step has a minor role. Technological aging, wearing, selling, or capacity cutting decrease the capacity level of the firm. The starting point of the study is capacity expansion -type investments, but after that the view is broadened to other types of capacity changes, such as replacement investments and cutting situations.

The study looks at the question of timing from the perspective of capital investments, not the viewpoint of financial investments, and therefore the timing of capacity changes is emphasized. Here timing means finding the best possible moment to fulfill certain

target criteria. It must be noted that the best timing of a project is not necessarily its earliest possible completion time. From the point of view of an actor or an observer, a difference can also be made between an active and passive attitude to timing.

From the viewpoint of accounting, the timing question has an effect also on the matching problem of costs and revenues. The acquisition costs of capacity can often be stated accurately, and typically they are allocated to a couple of years, but revenues earned in the future are highly uncertain. It is known that when the revenues are large enough and as accelerated as possible, then the profitability of the project is highest. In the case of a single project, the main interest is on how speeding up or deferring affect the profitability.

The focus of the study is to consider the timing questions of capital intensive industry. The production processes of this kind of industry are capital demanding, i.e. massive investments are needed for factories, production lines and equipment. Enlargements of capacity are often big. The most remarkable capital intensive industries in Finland are the forest industry, chemical industry and base-metal industry (Kärri 2000b, pp. 3-10). On the other hand, when a certain industry becomes more mature, the share of capital in the cost structures of firms increase and the industry typically becomes more capital intensive. No exact and widely accepted limits for when a firm or industry is capital intensive, raw-material, labor or knowledge intensive have been defined. In most cases the share of fixed assets in the total assets is 60 - 75% in capital intensive firms. Despite the fact that most of the empirical examples of the study are related to the forest industry, it is emphasized that the models built are general, and that is why the term capital intensive industry is used in the title of the dissertation.

1.4 Research Method

Capital investment studies can be divided into normative, investment process, and empirical studies (Honko et al. 1982, pp. 15-20). This study is mainly normative (Kasanen et al. 1991, pp. 315-317) and it considers the optimal timing question of a single project. Empirical examples are used for building and testing the models (cf. Varian 1994). The whole investment process is discussed only briefly, and with this review the timing decision can be connected to a broader context.

The objects of the study and the background of the researcher naturally affect the choice of research methods and approaches (Haaparanta & Niiniluoto 1986, pp. 11-17, Kauranen et al. 1992, pp. 29-31). An individual researcher has to make his choice between different possible alternatives. It is the present author's personal view that the most essential characteristics in scientific reasoning are contribution, invariance and objectivity.

It can be asked why to study well-known things. Clearly every era has its own open questions. Sometimes things can be forgotten, and they will return to discussion in a slightly different form years later. It is useful to evaluate basic relationships periodically, and this is a gate to permanent progress. Contribution or newness are partly subjective and fuzzy concepts. From the scientific viewpoint, newness has certain value because of it challenges the traditional way of looking at things.

Science tends to look for some reason, mechanism or law affecting the matter being studied. Theoretical models are developed on the basis of single observations, and existing models are used to explain the behaviour of individual phenomena (Figure 2). Mainly, science builds different models, which are expected to describe reality and help to control things (Harrison 2000, pp. 1011-1017). The formality of the models naturally varies, and conceptual frameworks and mathematical models are contrary in this sense. However, understanding the research environment is always essential to successful model building. Models are often used in situations which are outside their applicability, and this is a continuous reason for misunderstandings. It must always

be kept in mind that the conclusions based on the models are correct only in cases where the premises are valid.

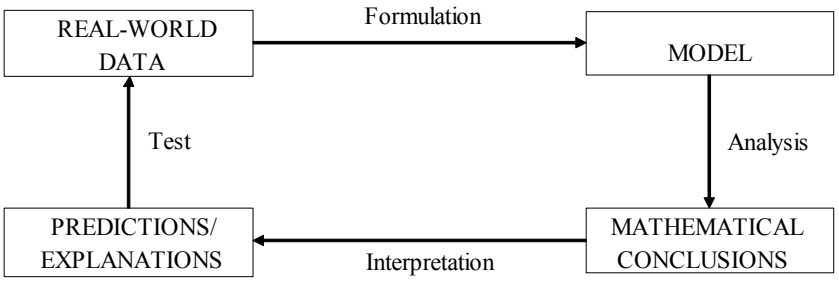

Figure 2. Models tell about real world (Giordano et al. 1997, pp. 32-33).

Objectivity is a guiding principle, despite the fact that nobody can ever achieve it. Because the scientific method is self-corrective, it is the honesty of the researcher that has the greatest value at the end. A lot of criticism is always needed considering the research results and the used methods. Achieving objectivity is often difficult in areas which are near economic utility. In the field of industrial engineering and management this problem is continuously present, and the researchers have to live with it. Emphasizing objectivity means that the research area is often narrower, but on the other hand it forces to seek depth and invariance (cf. Lukka & Kasanen 1993, pp.373-376).

It can be concluded on the above that the method of this study is not based on the interpretation of texts (Kasanen et al. 1991, pp. 313-314), but rather on problem solving and model building (cf. Alvarez 1993, Kanniainen 2005). In this context, rational reasoning and analytical methods have certain creative worth as compared to plain interpretation of matters. Models can be used for three purposes, which are analysis of problem structure, forecasting of future behaviour and development of decision alternatives (cf. Ghauri & Grønhaug 2002, pp. 42-44). Models give us tools for learning, understanding and controlling things. In the real world conclusions are often reached with trials, and modelling is an alternative and often a cost effective way for that.

The modelling process of the study is described in Figure 3. The research area, former studies and essential relationships are described in chapters 1-4. In chapter 5 the view focuses on existing timing models. Before model building, also the target criteria for optimization and the parameters included in the model must be determined. The first model is described in chapter 6. After the solution, the results are analysed and the model is tested with case data. After that the model is extended and new insights are explored. In chapters 7-9 three more models are developed, and thus different modelling processes are repeated four times in the study.

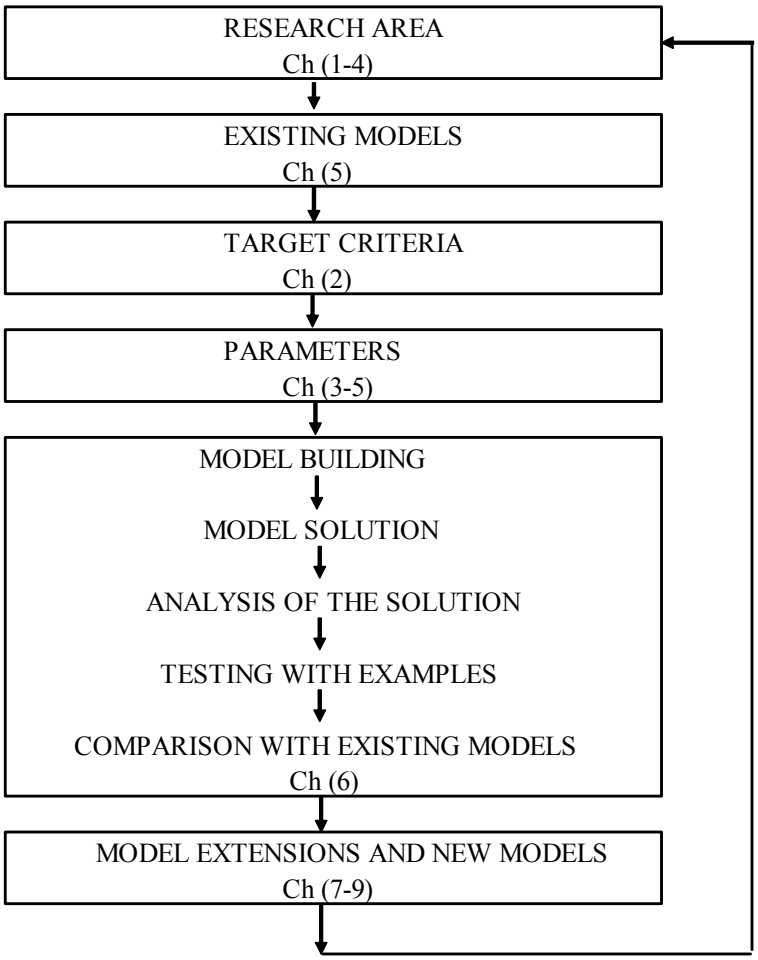

Figure 3. Modelling process.

1.5 Structure of the Study

The study begins with an introduction ,which includes the background and scope of the study (Table 1). In the first chapter the goals, restrictictions and methodological choices are described. Empirical observations and former theoretical knowledge offer a view on the essential factors that affect capacity changes and their timing. The chracteristics of timing decisions and strategies are described in chapter 2. The role of demand, capacity and production is presented in chapter 3. In the following chapter, the relation of costs and capacity is described, and in chapter 5 the role of timing in former models is analysed. Chapters 2 to 5 describe existing knowledge, and they form the background for the models. These chapters also begin with old citations, which show how timing and capacity problems are not new and industrialists have discussed them for decades.

The unit cost model for the timing of capacity change is built in chapter 6. Especially the way how cost advantage influences optimal timing is studied, and the premises of the model are restricted so that an analytical solution of the model can be done. The main points of the model have been published earlier in the journal The Engineering Economist (Kärri 2000a). In chapter 7, the views are broadened and deepened by extending the model to the direction of open questions. The applicability of the developed models is evaluated by way of single examples and by analysing their logic.

Numerical models can often be much more realistic and useful than analytical models. In chapter 8, a numerical cash flow model for capacity expansion is presented. It is especially considered with sensitivity analysis how large the effects of start-up time, capacity utilization rate and other key-parameters can be to the net present value of a capital intensive project. After that the value of waiting under certainty or uncertainty is discussed.

In chapter 9 the fourth model is built. The model describes how the timing of capacity change and flexibility of fixed assets can be combined. The fourth model also binds the above presented models to the larger context of the whole firm.

Table 1. Structure of the study.

INPUT	PROCESS	OUTPUT
EXISTING KNOWLEDGE FORMS THE BACKGOUND FOR THE MODELS (THEORY)		
Background Research problem Methodology	**1 INTRODUCTION** Formulation	Objectives Definitions Research method Type of results
Cycles Strategies Horizon Opportunities Investment process	**2 CHARACTERISTICS OF TIMING** Theory presentation, classification	Features for optimal timing Different approaches Timing criteria
Empirical examples Demand and supply Capacity levels Increasing machine size	**3 NATURE OF CAPACITY CHANGES** Theory presentation, analysis and synthesis	Growth rate of demand Expansion/machine size
Capital investments Cost categories Cost functions Scale economies Cost-volume-profit	**4 SCALE ECONOMIES WITH FIXED COSTS** Theory presentation, analysis and synthesis	Relation of costs to capacity Cost parameters
Capacity expansion models Replacement models Cash flow models Real option models	**5 TIMING IN CURRENT MODELS** Theory presentation, analysis and synthesis	Optimization criteria
NEW KNOWLEDGE THROUGH MODEL BUILDING (THEORY ENLARGEMENT)		
Parameters; based on chapters 2-5	**6 UNIT COST MODEL FOR OPTIMAL TIMING** Model building, analysis and evaluation	Model Optimal solution
Open questions; based on chapter 6	**7 PROFIT AND TIMING DECISION** Model building, analysis and evaluation	Model Optimal solution
Open questions; based on chapters 6-7 Affecting factors	**8 CASH FLOW MODEL AND TIMING IMPACT** Model building, analysis and evaluation	Model Solutions Sensitivity analysis
Open questions; based on chapters 6-8	**9 TIMING AND FLEXIBLE ASSET STRUCTURE** Model building, analysis and evaluation	Model Relations
Solutions (chapters 6-9) Earlier models (chapter 5)	**10 RESULTS** Presentation Comparison, analysis and synthesis Discussion	Main results Managerial implications Relevance Further Study
Objectives Models Solutions	**11 CONCLUSIONS** Discussion	General overview Contribution

The relevance of the models, the differences and similarities between current and earlier research results, and also some directions for future research are finally presented in chapter 10. It can be summed up that in the present study, empirical observations and theoretical knowledge are combined, and the specific models have been built on the basis of these two. Differences between the models and the reality are discussed, and thus understanding of the research topic is hopefully slightly better than before. Chapter 11 broadens the discussion to a more general level.

2 CHARACTERISTICS OF TIMING

Rudolf Wallden said about the modernization plans of Myllykoski plant in 1925:

> *"We ... have to have waited for the moment when the financial position of the firm would make it possible to put the plans into practice. However, the state of being absolutely free from debt is maybe not needed for this."* (Nordberg 1980, p. 119)

2.1 Timing with Business Cycles

In industries where expansions take place with big incremental units, it is said to be critical in which phase of the business cycle the startup happens. During a downward trend, overcapacity and hard price rivalry dominate the markets. The selling of new production is naturally easier if the demand and prices are increasing. Hayes and Wheelwright (1984, pp. 69-70) have noticed that firms apply four different types of capacity expansion approaches:

- Building capacity when the need for it develops often means additions at the peak of a business cycle.
- Following a countercyclical strategy means that the capacity is added at the lower point of the cycle.
- Buying capacity for the long-term goals indicates that the firm has noticed an impossibility to outguess the behaviour of markets continuously.
- Expanding when the leaders build tend to sustain the competitive position of the firm.

In practice there seems to be two timing schools among forest industry managers. Some managers emphasize that timing with business cycles is essential and others say that timing is impossible and capacity has to be built according to long-term goals:

"Timing is extremely important. The first 2.5-3 years after the start-up the factory are decisive, because, depending on business cycle, there can be variance of over one billion FIM in the cash flow of the factory." (Board member Heikki Sara about building a Metsä-Rauma pulp mill, Tekniikka & Talous 6.10.1994)

"When technical lifetime of the pulp mill is 25-30 years, the timing of the capital investment is not important, but the initial investment, production efficiency and product quality." (Mill manager Risto Joronen, after the investment of Joutseno pulp mill of Metsä-Botnia, Etelä-Saimaa 10.9.2001)

The building of a new plant is a long-term project, and the best timing of it is always a complex question. Instead of building new capacity, it is sometimes sensible to buy excess capacity in the downturn and modernize the existing capacity in the upturn (Achi et al. 1996). Capacity buying as a form of acquisition is risky and can contain unpredictable management difficulties. Also, the balancing of financial and competitive risks is most difficult at the bottom of the business cycle (Ghemawat 1993).

The financing of investments is not a problem to most producers in good years. During an upturn, the companies make profits, and the terms of finance are convenient. The firms can get low loan rates and they have possibilities to raise their equity. The selling of extraordinary assets is also a realistic possibility. In traditional branches, most investments are timed to the good years, when the financing of projects is easy to arrange. A pitfall is that the simultaneous expansions of competitors rather increase than decrease business fluctuation. The problem is how to arrange the finance of projects during a downturn, when the financing possibilities reduce the timing opportunities of firms. In these situations, some international firms have used convertible bonds, sale and lease-back arrangements, capital loans, or project finance as substitutes for bank loans (van Dijk & Dekker 1995).

2.2 Time Horizons

The financing possibilities of a firm largely determine which projects are realized. It can be said that the unregulation and globalization of financial markets have made it easier to transfer capital over national and corporate borders. The American practice is thought to prefer projects which produce high net present value during a relatively short period (Porter 1992). In Europe and Japan, the benefits of long-run development projects have traditionally been emphasized more. Naturally, the general values of the society, like willingness for savings, attitudes planning and growth, have central impacts on the goal-settings of return on investments in the long-run.

After World War II, the capacity expansion of Finnish forest firms has largely been based on national interests. The most remarkable trends have been a continuous increase of value added, optimization of raw material usage, integration of multiple products, and vertical integration of companies (Ryti 1988, p. 94). Depreciation and tax regulations have offered incentives to firms for a rapid pace of investments and massive use of debt. Under inflationary conditions it has been sensible from the companies' point of view to utilize depreciation allowances and tax shiels as soon as possible (Aho & Virtanen 1981, p. 351). In circumstances where overinvestments have been profitable, there has been only little need to deliberate over the exact sizing and timing of investments. However, during the depression years in the 1990's many firms recognized how essential the realistic sizing of investment projects and adequate solvency in the global environment are.

In capital investment calculations, there are different alternatives to determine the time horizons. Infinite planning horizons or the average lifetimes of machines can be used, i.e. calculations can be made for a certain planning period. Often the going-concern principle offers a central argument for infinite horizons. Typically the life-cycles of e.g. electronic equipment have shortened and the technology of machines becomes obsolete quicker than before, and these factors give us reasons to use shorter, i.e. finite planning horizons. However, this is not the whole truth (Suomala 2004, p.131), because there are also very long life cycles, e.g. in plants of basic industries. It can also be said that when the development of markets is predictable, it is sensible to use long planning

horizons, but when the movements of markets are highly uncertain and difficult to forecast, shorter horizons offer more flexibility for the future operations of firms.

2.3 Timing Strategies

Successful timing has effects on the profitability of projects and thus also on the competitiveness of a company. It is said that the natural tendency of managers is to wait too long, move too slowly and so lose the best momentum (Eisenhardt & Brown 1998). In principle, a firm can follow either a proactive or a reactive strategy, i.e. with a time pacing strategy the company creates a predictable rhythm for expansions, or with an event pacing strategy it reacts to the movements of competitors. Lieberman (1987) has presented four possible strategies for capacity expansions (Figure 4):

- Preemption is used to restrain the possible expansion of competitors.
- Coordination means agreement from expansion turns.
- Insulation about market fluctuations happens as a form of vertical integration or with protected markets.
- Timing of expansion means that the opportunities of markets are fully utilized.

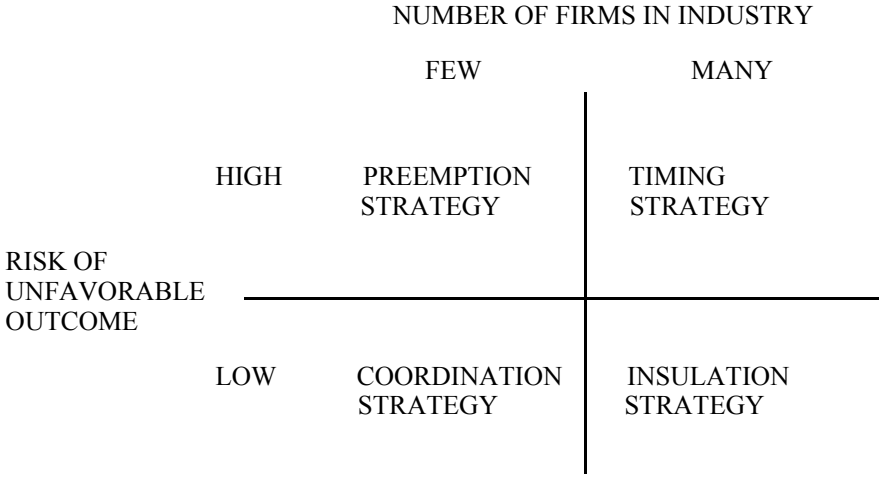

Figure 4. Capacity expansion strategies (Lieberman 1987, p. 25).

Preemption and coordination strategies try to affect the investment decisions of competitors. Insulation and timing choices take the behaviour of other parties as given and try to minimize or exploit the fluctuation of the markets. Preemption or coordination are possible when there are only a few companies in the industry or the company has a dominating market position. When there are many rivals without market domination, a single firm's action has only marginal effects to the others' investment decisions, and the two last-mentioned strategies are the more realistic alternatives.

It is known that the building of new capacity first is an efficient way to obstacle the plans of competitors. Often only a building announcement is enough to do this. The game theory analyses different alternatives in situations like this (Myerson 1991, pp. 97-98 and Bierman & Smidt 1990, pp. 289-291). It is also commonly known that even if two companies operate in a favourable way from their own viewpoint, i.e. expand their capacity simultaneously, their profit is smaller than in the situation where only one of the parties does the expansion. Thus, it is quite understandable why it is profitable for companies in many branches to agree on enlargements together.

2.4 Timing of Sequential Projects

Previous investment decisions give frames to the following operations of a firm. The research trend which emphasizes the dynamic connections of projects claims that also future actions must be taken into account in planning. Different connections between single projects direct the attention towards the planning of sequential projects, i.e. capital investment programs (Reponen 1977 and Booth et al. 1991).

If equal projects are repeated to the infinity, and a continuously compounded discount rate is used for simplicity, the optimal time interval between projects can be determined (Bierman & Smidt 1990, pp. 281-286). The optimal cycle is the time interval which maximizes the net present value of all projects.

$$K = U + Ue^{-rt} + Ue^{-r2t} + Ue^{-r3t} + \ldots = \frac{U}{1 - e^{-rt}} \quad (1)$$

where

K = the net present value of sequential projects
U = the net present value of a single project
r = annual continuously compounded discount rate.

If the model is used to calculate e.g. the best harvesting time of a forest, it contains the assumption that the best use of land is the growing of trees. The model does not take into account other usage possibilities or the changing nature of project alternatives.

2.5 Timing Opportunities

The evaluation of investment projects is often based on the net present value, internal rate of return or payback rules, and different appraisal techniques can lead to different kinds of recommendations. It can be said that the choice of the best project in a certain point of time is a well-formulated question in the capital investment literature. On the other hand, it is rarely discussed how the profitability of a project changes if it is carried out earlier or later than originally planned. Traditionally, investment calculations are based on the assumption of certainty, and risk-adjustments, sensitivity analysis, decision trees or simulations are used to deal with the effects of uncertainty. If a project is so big that its failure can destroy the whole company, it is essential to look at the sources of uncertainty. In expansion projects, the main risk factor is often that the product or raw material markets do not behave as forecasted.

Fixed assets are often planned for a certain use and are not easy to sell. If a machine is very specific and its lifetime is long, we can talk about irreversible investment. If this kind of project fails, it binds the corporate resources for a long time, and it is difficult to get rid of it at moderate costs. Economists often emphasize the importance of irreversibility, adjustment costs, and expectations with investment projects (Nickell

1978). From the viewpoint of the risk management of a company, it is sensible that all resources are not bound. This gives reserves for uncertainty and possibilities for future opportunities. But it is also true that the best results in a motivational sense are sometimes achieved in desperate situations, where a firm has only one way to escape alive (Tirole 1990, p. 316).

The traditional net present value rule has been criticized for not taking future opportunities into account. It has been claimed that the net present value of expected cash flows must be added by the value of real options. Typically the management can defer, stage or abandon the project, alter the scale of the project or switch it to an alternative use (Trigeorgis 1993). The question is how these actions affect the costs and revenues of the project, and thus the firms' profitability. Future growth options are often a central argument for undertaking unprofitable investments or speeding up projects. If the demand is extremely difficult to forecast, it is better to undertake a small project first and carry out a larger project later if the markets seem to be favourable. The real option literature considers these kinds of questions (Dixit & Pindyck 1994 and Trigeorgis 1997). In these studies uncertain cash flows are modelled with stochastic processes. Some contributors of real options (McDonald & Siegel 1986 and Dixit 1992) have highlighted the value of waiting in investment projects. In circumstances of low uncertainty there is only minor value in waiting, but when the uncertainty is high, then the right timing can save from some bad outcomes.

2.6 Timing in Capital Investment Process

Despite the fact the focus of the study is not in behavioural aspects of decision makers, it is worthwhile to discuss briefly the position of the timing decision in the capital budgeting process of firms. Pike and Neale (2003, p. 229-239) divide the process to five main stages:

1) Determination of the budget

2) Search and development
- search
- screening
- definition

3) Evaluation
- purpose of the project
- project classification
- finance request (timing mentioned)
- operating cash flows (timing mentioned)
- sensitivity of the assumptions
- review of alternatives
- implications of not accepting the proposal
- non-financial considerations

4) Authorization
- quality control function
- motivational function

5) Monitoring and control
- during implementation and ongoing
- post auditing.

Levy and Sarnat (1994, pp. 28-29) use the traditional three main management phases and several stages below them:

1) Planning
- search & identification
- formulation
- preliminary estimates
- revision of estimates
- economic evaluation
- appropriation request
- approval
- capital budget

2) Implementation	- investment outlays
	- operations: production, sales, costs, financing
3) Control	- feedback check against budget estimates
	- post-completion audit
	- review of planning procedures.

There are also other classifications (e.g. Mott 1997, p.3, Horngren et al. 2003, p. 719), but the general finding is that the timing decision is seldom mentioned as the context of investment processes. This raises several questions and is a potential area for further research. Does the timing decision have no practical meaning, is it avoided as a speculative element, or is it in the decision area of top management and so not described as a part of formal administrative processes? It can be assumed that in practice timing has a role as a part of evaluation or approval procedures. Larger investment programs are also divided to parts and implemented during several years, and thus timing has a direct connection to capital budgets. Different timing alternatives can be planned before the investment decision phase. It can be forecasted how different timing alternatives affect the profitability of a project, or it can be asked what impacts there are on the company's financial and funding position. The final timing decision is done when a certain project is accepted, rejected or delayed.

2.7 Concluding Remarks

The capacity of the whole industry, the competitive position of a firm, and the risk factors of current projects set the general framework for timing possibilities. Timing strategies have the greatest meaning in conditions of uncertainty (Figure 4). If there are only a few remarkable producers, it is sensible to be the first mover and so restrain the competitors' plans. If there are several producers, flexibility gives the best possibilities to utilize the market movements. Successful timing can mean that the firm invests before its competitors or at a suitable moment for itself.

The timing of investments in its broadest sense is possible only for the best companies. The financial position affects the size and timing of capital investments most, together

with competitive factors. Even if the competitive environment requires expanding the capacity, this is not always possible because of financial restrictions. In a fluctuating environment, it is difficult to determine a certain fixed cycle to sequential investments. The fixed cycle is quite rare also in practice, when large renewal programs of plants have to be carried out in several stages during a long period.

The possibilities of unfavourable outcomes and the existence of competitors wake it sensible to think carefully about the best timing of capital investment projects. This is emphasized when the bounded resources are remarkable compared to the risk-bearing capacity of the firm. When investments require a supply of specific assets, it is often difficult to release those assets in the case of failure. The choice of best timing of a project is typically a problem whose solution varies in different cases. It is often useful to consider the critical factors and alternative project scenarios. In timing questions, the detailed judgement of managers often leads to slightly surprising decisions (cf. Uusi-Rauva 1980, pp. 110-112).

The timing question in six different contexts was described above. In capital investment and accounting calculations there is typically a certain time horizon, which can be finite or infinite. The strategy literature looks at different timing strategies, and in practice businessmen associate the question of favourable timing strategy to the business cycles of their industry. Traditionally, operation researchers have discussed an optimal time cycle between sequential investments. Recently there has also been discussion among economists about the option nature of timing. It can also be asked what the role of timing is in the context of capital budgeting process. As seen above, timing is not a well-defined concept in industrial engineering, and suitable timing is discussed at least in three different meanings: when two actions or operations happen exactly at the same time, when the action happens just before a favourable or an unfavourable outcome, or when the timing of an operation is optimized regarding some target criteria.

3 NATURE OF CAPACITY CHANGES

In 1932, Rudolf Wallden argued for building a new paper machine in Valkeakoski as follows:

> *"It is true that the markets are weak, but just because of that the new paper machine must be acquired if we want to continue papermaking, as only with first-class products can we hope to survive in the future severe competition."* (Nordberg 1980, p. 164)

3.1 Capacity Measures

In most references (McNair & Vangermeersch 1998, pp. 27-29, Horngren et al. 2003, pp. 300- 301, DeBruine & Sopariwala 1994, pp. 25-26), the capacity baseline measures or definitions are:

- theoretical
- practical
- normal
- budgeted and
- actual capacity.

Theoretical capacity is described as the maximum output a plant can produce in a determined period, e.g. per one year. The traditional view is that when the maximum capacity is reached, existing plant must be enlarged. Theoretical capacity does not allow for any factory maintenance, repairs, production interruptions, nonworking days or holidays, i.e. it is unattainable in the real world. Practical capacity is the theoretical capacity adjusted for the downtime and waste mentioned above, and when most managers talk about full capacity they mean just the practical capacity of the mill. Normal capacity is the level that satisfies the average demand over a longer period, i.e. 2 to 3 years, and it takes also seasonal and cyclical factors into account. Budgeted capacity is the planned use of the resourches and the actual capacity output really achieved within any period.

It is an interesting question when capacity addition is necessary and what the reasons behind this kind of decision are. The capacity expansion decison must always be carefully considered, because it creates new fixed costs and may cause a ratchet effect, i.e. the growing amount of waste is embedded in the total costs (McNair & Vangermeersh 1998, pp. 102-104).

The motives for capacity addition come mainly from growing demand or fluctuations in it. Market increase, higher market share or business cycles cause temporary or permanent lack of capacity and need for new investments. Sometimes also technologial change, increasing quality needs or environmental demands can be behind the capacity investments decisions.

3.2 Role of Technology Change

When only single investment decisions of companies are looked at, it is sometimes difficult to notice the whole logic of them. But if it is considered how the capacity of a certain company has developed in the long run, many interesting observations about the life-cycles of technology and the mechanisms of capacity changes can be made. The history of technology tells us interesting stories about capacity changes, and one of them is described below. Figure 5 presents the evolution of Gustaf Erikson's shipping capacity in 1913-1961. In his time, this Ålandian sea captain owned the world's biggest private shipping company. As the curve shows, the trend of capacity increase turned after 20 years to zero-growth and after that an opposite development began. The majority of the ships were 2 000-5 000 tonne sailing vessels. The average unit size of the ships increased 46 percent within the same period. The greatest expansion happened after the First World War, and after the Second World War more economical steam and motorships replaced sailing vessels at most freightlines. The industry had faced an enormous technical revolution, as the modern ships carried freight to the destination faster, more safely and at lower costs.

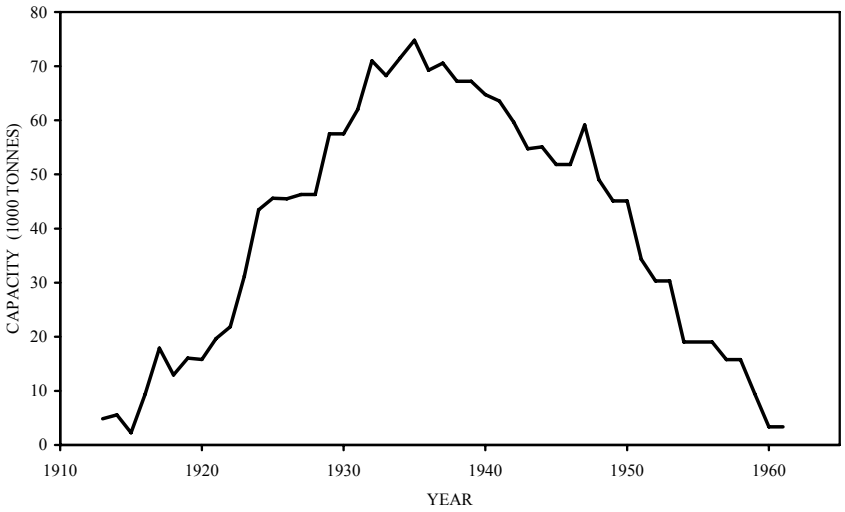

Figure 5. Life-cycle of total capacity (based on Koivistoinen 1983).

A remarkable issue is the question of what kind of vessels the company used and how they were driven in different lines. The age of all big ships was 20-40 years, i.e. they were not new when acquired. The age of small ships was either below 20 years or more than 40 years. It can be said that the middle-aged and cost-effective vessels drove basic lines, and the small ships were mainly used for special purposes or they were used for demand peaks. Because of the efficient markets, ship capacity is easy to sell and buy, but in all industries this is not the state of affairs.

This particular case also shows how an enterprise evolves from a one-ship firm to a thirty-ship one and how dramatically technology change can affect the course of a firm. In Figure 5 three expansion periods where the capacity was increased remarkably can be discerned. After the expansion periods there were quite stable capacity levels, the duration of which was about five years. The capacity decrease was much more straightforward, and there were no clear breaking levels. In shipping industry, as in many others, capacity selling or buying happens only as a form of certain sized lumps, and behind these kind of capacity changes there are often long lifetimes of used machines.

3.3 Growth of New Technology

The success story of information technology and telecommunication industry has largely based on the progress in microprocessor technology. The number of transistors in one microprocessor has increased at logarithmic speed (Figure 6). This phenomenon is known as Moore's law, which says that the number of transistors will double every two years.

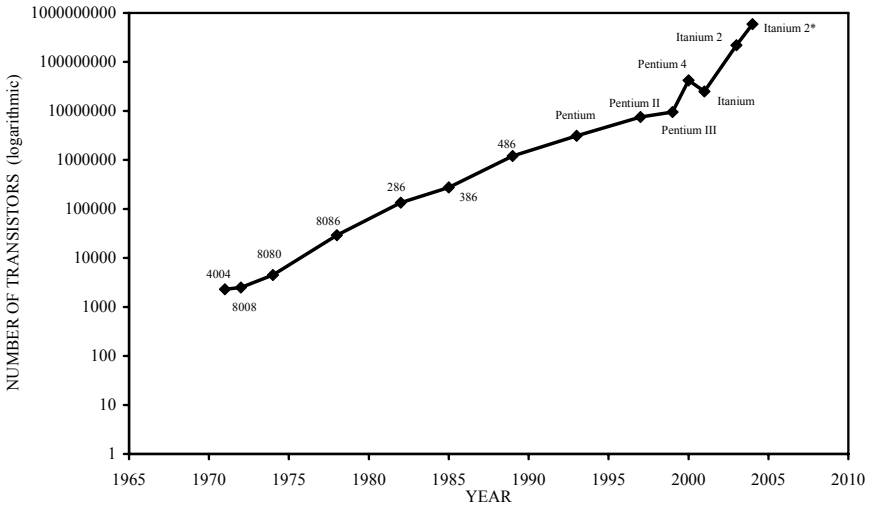

Figure 6. Number of transistors in one microprocessor (based on Intel 2006).

In microcomputers and in mobile phones, as in many other machines, the unit price is decreasing. When a new model comes to the market, the prices of old machines typically fall. In practice the price of the modern model is almost fixed, because it must suit the purchase power of the customers. A continuous capacity increase of microprocessors and a capability to find new markets are essential conditions for the profitability of the industry. However, the outlook is that also the information and telecommunication industry will mature inevitably, when it faces decreasing returns of scale as many other industries before it. When that time comes, there will probably be new exciting industries to work for.

The question is, how long can developers find new solutions to increasing technical problems? Simultaneously the production of microprocessors is changing from work

intensive to a more capital demanding direction. With the raised complexity of processors, the price of plants has been observed to increase almost in an exponential rhythm. In 1970 processors were made in factories that cost about 500 million dollars, but the costs of factories producing Pentium prosessors were more than five billion dollars in 2000 (Meieran 1998).

In rapidly growing branches, the nature of timing decisions differs from the same problems in mature industries. A quickly increasing demand needs all the free capacity fairly soon, and mistakes in capacity planning do not have so catastrophic long-term consequences. In these industries it is much more critical to be the first mover in new technology than to select the optimal capacity expansion size and time.

3.4 Dualism of Capacity Change

Essential findings about technology and capacity changes come out when the observation periods are long enough. In the case of paper industry, the trend is that the size and the speed of machines have increased with the technological progress.

Figure 7 shows how an individual company has expanded its paper production. The capacity of the first paper machine was only 24 000 tonnes per year in the 1950's, but when the fourth machine started in 1982 its capacity was already 170 000 tonnes per year. Nowadays companies build paper machines that produce more than 400 000 tonnes of paper per year and the total costs of this kind of investment are typically 500 million euros. The ability to construct bigger and faster machines and to accomplish building projects in a shorter time than before have been dominating forces behind the capacity expansion development of paper industry.

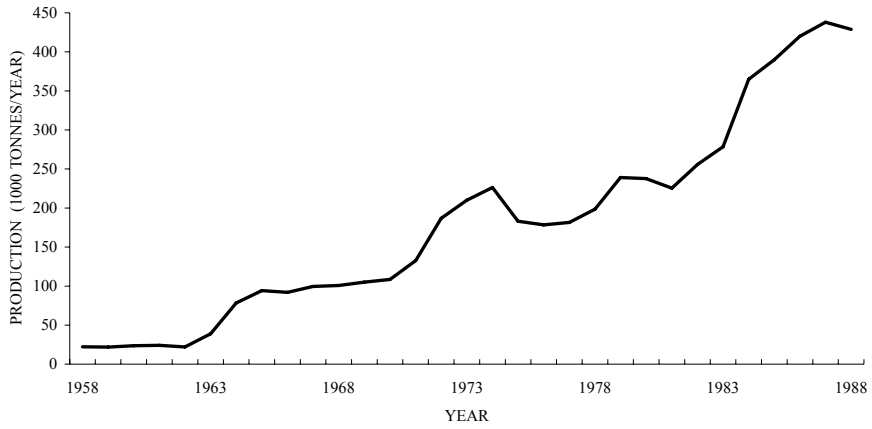

Figure 7. Paper production of the Kajaani company in 1950-1988 (based on Virtanen 1985 and Kajaani Oy 1988).

Sometimes general economic recession or a more firm specific reason can drop the production level far below the planned. In the example of Figure 7 this happened soon after the firm's third machine started in the 1970's. The oil crisis following a depression was deepest in 1975-1977, and then the capacity utilization rate of the firm's paper production dropped near to 70%.

A different view on capacity changes is received if a group of companies instead of an individual company are looked at. For example, the individual history of the Kajaani company ended when it merged with United Paper Mills in 1989. In the case of Kajaani clear quantum leaps to the next level can be seen, but despite this fact the total growth of paper and board production capacity has been almost linear in Finland during the past 25 years (Figure 8). The explanation for this is that the additions of capacity and the marketing of paper have in the past been coordinated by the main producers. This era ended when Finland joined the European Union, after which firms' individual capacity adding and marketing strategies have been emphasized. Coordination is not a phenomenon found in Finnish forest industry only; studies have reported some forms of coordination in pricing and capacity expansion situations also in the paper industry of North America (Booth et al. 1991).

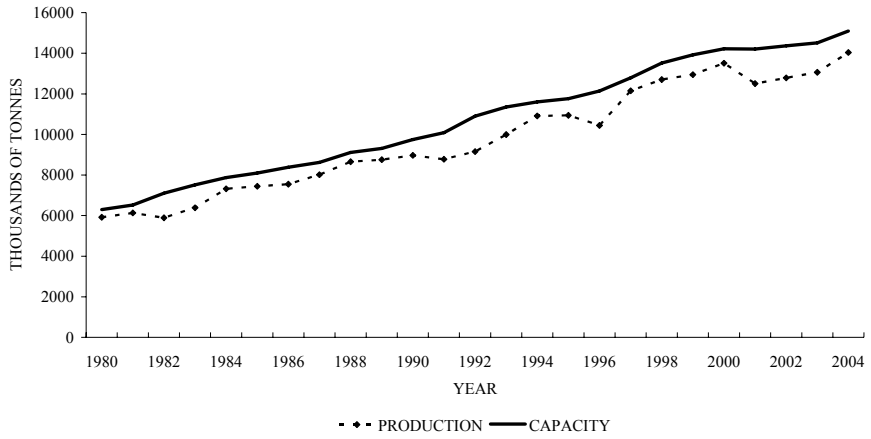

Figure 8. Production and theoretical capacity of paper and paperboard in 1980-2004 (Finnish Forest Research Institute 2005).

In a cyclical and capital intensive industry, all producers suffer from the consequences of mistaken capacity expansion decisions, and quantity is a more essential decision variable than the price (Booth & Vertinsky 1993). As Figure 8 shows, variation in production quantity is remarkable in a cyclical industry. How can this gap between actual capacity and production be narrowed? Clearly, a full capacity utilization rate is a technical impossibility, but how can firms get nearer to 95 percent? Proper production management answers these questions partly. It is essential to know which are the most economic driving priorities, production programs and optimal run lengths of machines. However, a part of the problems of low profitability is apparently always solved with mergers, acquisitions and restructuring. In recent years e.g. paper companies have announced cost saving programs and closed down their unprofitable machines.

3.5 Flexibility of Capacity

When the demand variation is wide, capacity management is difficult, and flexibility is needed. Galbraith (1977, pp. 224-242) has mentioned ways that a firm can use to smooth its production. An individual company can affect inventories, work force utilization and size, product mix and subcontracting. A firm can influence the demand through promotion, price and rationing. Cooperative strategies are implicit cooperation, contracting and coalition. The last possibility is strategic manoeuvering, when the organization changes strategy, technology or location.

Steps for increasing flexibility are well-functioning real estate and machine markets, possibilities for leasing and sale- and lease-back arrangements, effective capital markets, flexible working hours and flexible manufacturing systems. It is natural that the capacities of men and machines are different, but it is also inevitable that the production process connects these two together. When the capacity is general enough, the flexibility offered by the markets can be used. If capacity is planned, designed or built for specific purposes, it is difficult to achieve flexibility with markets. Different ownership arrangements and the use of external services can be seen as a way of sharing the risk of ownership of production facilities as well. It can be said that mere the existence of competitive companies means emphasizing a mechanism that reacts to environmental changes.

3.6 Sustainable Growth and Size

When the cost structure of a firm is given, the development of net sales mainly says how much cash flow financing can be used to capital investments per year. Despite the fact that the releasing of working capital, selling of assets or raising of share capital are sometimes essential financing sources, cash flow financing and loans are the most remarkable sources for big projects. Common sense says that the investment projects must be realistic enough compared to the firm's size and solvency. Essential changes in the business environment emphasize the meaning of solvency as a guarantor of the firm's existence. Typically when a big project fails, the corporate governance shifts

from the owners to banks or other financiers. A pitfall is that the financiers only seldom have adequate competence in the business areas of the firms.

The profitability of the firm and its solvency affect the financial risk of a company. The above mentioned risk aspects influence the availability of equity and debt and also the costs of these. It is a principal rule that only positive earnings guarantee continued growth of equity, and this gives possibilities to raise the share capital and take more debt. From the corporate's viewpoint it is essential to synchronize its capital investments and finance possibilities more efficiently than its rivals. Many self-sustaining growth models (Talonen 1973 and Aho 1993) are based on the connection of growth, profitability and capital structure. The models tell how much a firm can invest when the goals of profitability and debt-equity are fixed, but they do not say anything about how and when a single big capacity change must happen.

It is obvious that big and small are relative matters, but it is only seldom mentioned that the question of optimal size has a near connection to how the wholeness is divided into pieces. If the firm operates only in domestic markets with a certain number of competitors and the markets do not have remarkable growth opportunities, the limits of the firm’s production capacity are given. Global markets often offer new opportunities for growth and specialization, which also means that the size of production units can be increased. The balance-sheet limits of firms are connected to this question of size relativity. Typically, in the long run the balance-sheet limits are based on the profitability and the solvency of the firm, and reflecting factors are the utility and ownership structure of the company.

Miller & Friesen (1984) and Mintzberg (1989) have explained changes in corporate structures with the quantum theory and the life-cycle theory. They argue that each phase of a life cycle has its own typical organizational form. These types are entrepreneurial, machine, diversified, professional, innovative, missionary and political organizations. The organizations spend most of their lives in steady states, but periodically they undergo brief periods of transitions.

The technology-based tradition looks at firms from the viewpoint of production and cost functions. Minimization of costs or maximization of profit are common goals. Concentration development is explained with economies of scale, and the minimum of unit costs determines the optimal size of the firm. This technology-based view takes into account most affairs in industrial production. Cost advantages in the area of marketing and management have led to a view which sees the company as a network of short and long term contracts. Those contracts can be either complete or incomplete (Holmström & Tirole 1989, pp. 63-78 and Tirole 1990, pp. 21-34). This expands the traditional cost view to the direction of transaction costs. Some tasks are profitable to arrange with markets and others with hierarchies, and this determines the borders of the firm (Williamson 1983). The transaction cost approach explains the characteristics of service companies, but also the integration and networking trends of manufacturing companies.

3.7 Concluding Remarks

Due to the different definitions of capacity and their usability in different industries and situations, also the capacity utilization rate can be calculated in various ways. Of course the numerator is the actual output, but the denominator can be any of the above mentioned capacity measures. In this study capacity is determined to be the theoretical capacity level of the output, and the capacity utilization rate is the actual production divided by the theoretical capacity measured during a certain calculation period.

As presented above, the role of technology change is essential when a firms' capacity changes in the long run are considered. Some kind of dualism is also observed between big capacity leaps of companies and smooth capacity increase in capital intensive industry. Largely, it seems that gradual evolutionary and dramatic revolutionary changes alternate with each other in the corporate world. When natural development is restrained for long periods, this is an imperative and sufficient condition to a strong change. In such cases, the revolution can be characterized as dammed evolution, or vice versa, it can be said that evolution is a series of tiny revolutions.

The large number and different sizes of companies means resistance to market changes and uncertainties. Big size and speed are often opposite properties. Where a big company utilizes the economies of scale, a small company must use its operational flexibility. The big size of the company and scale economies are competitive imperatives, which ensure minimization of costs. On the other hand, small companies represent innovativeness, flexibility and creative abilities in markets. In a rapidly changing environment big size can be a disastrous force, and also giants can collapse. Sensible diversification is an effective way of dealing with risks in a changing environment. Traditionally, companies have diversified their action to different business areas. Nowadays, in efficient financial markets, a growing part of diversification is done by shareowners in their portfolios.

This study is not concerned with whether there are technological, contractual or some other reasons behind the costs. The problem setting is near the traditional view, which asks how to do work with minimum costs. There are often several ways of accomplishing a task, but it is not known with certainty which one is the best. When an expansion decision of production capacity is done, both the timing and the size of the unit must be chosen. Often in practice there are only a few sensible alternatives. Economies of scale are tried to be achieved with massive investments, but also the risks are remarkable. Emphasizing flexibility means that capacity additions happen as a form of smaller units. In this study, the choice of different sizes of units is not considered, i.e. expansion size and the corresponding costs are assumed to be known, and this makes it possible to consider the best timing of a single capacity expansion.

4 SCALE ECONOMIES WITH FIXED COSTS

In 1934, Rudolf Wallden talked about building a second paper machine to Myllykoski:

> *"Every mill had to be of a certain size, before it would be profitable and yield its best outcome."* (Nordberg 1980, p. 213).

4.1 Economies and Diseconomies of Scale

The principle of comparative advantage is a classical argument for free trade. The traditional theory has been criticized, however, because it cannot explain many inconsistencies, such as the behaviour of multinational companies and the possibilities of monopoly profits. Today researchers emphasize the roles of imperfect competition, economies of scale and product differentiation. Specialization has often been mentioned as being in the background of these scale economies, and for specialized products, firms need bigger markets. These tendencies are central points when firms' attitudes to economic integration are discussed (cf. Kärri 1999).

What are the main sources of these scale economies? Empirical studies have shown the existence of scale effects on the levels of production equipment, plants and whole firms (Scherer 1980, pp. 81-84 and Hay & Morris 1991, pp. 31-34). At the firm level economies of scale are typically achieved in the areas of production, marketing, distribution, administration, or research and development. In the context of organization control economists often speak about lower information or transaction costs. The necessity of smaller reserves can also bring significant cost savings. The big firms' ability to operate in different markets stabilizes the profit fluctuation and can mean a lower cost of capital. When capital investments are considered, the financing and risk management of investment projects are also possible sources of certain economies of scale.

The capacities of the plant equipment are not necessarily in balance with each other, e.g.there can be bottlenecks when the main equipment operates almost at full capacity but the auxiliary devices have remarkable capacity left. When the plant operates on

low capacity utilization rates, the incompatibility costs increase. Often the main equipment of the plant is the determining factor as regards the amount of economies of scale. In some situations, the structural geometry of the equipment determines the sensible size and thus also the costs. Cost engineers know this phenomenon as the 0.6-rule which says that doubling the size increases the equipment costs by half (Tribe & Albine 1986).

The unit costs of products typically decrease if the run-length of production increases. The specializing of labour uses the learning curve effect to its whole extent. Greater production quantity often gives possibilities to more economical use of materials and energy or better purchase and inventory management. Economies of scale are usually mentioned in connection with mass production, and some writers see them as a means to competitive advantage (Porter 1990). The economical effects of joint production have their own economies of scope idea (Tirole 1990, pp. 18-20). Capacity and production quantities can be found quite easily in mass production processes, but even these things are difficult to measure when unique products are concerned. Nowadays many firms use flexible manufacturing systems to produce a wide variety of products with the same equipment. Their competitive advantage is based on economies of scope. This is opposite to the tendency of mass production to achieve competitive advantage with economies of scale (Johnson & Kaplan 1991, pp. 216-217). Especially in small countries and in small enterprises, flexibility and adaptability have been seen as a strategic choice (Honko 1984, p. 243).

The average unit costs can decrease in a growing company if there are no restrictive factors. However, changes in the competitive environment, unmanageable rapid growth or organizational problems can eventually lead to increasing costs. High distribution costs, problems of bureaucratization, complexity confusion and vulnerability to risks also explain diseconomies of scale (Hayes & Wheelwright 1984, pp.61-64). When the economies of scale are estimated, it must be noticed that the cost advantages often diminish because of competition and technological progress. Sometimes economies of scale are still increasing, but the larger plants seem to grow slower than the smaller plants (Brush & Karnai 1996).

In some industries firms have to take advantage of economies of scale by expanding overseas. Their home markets can be too small if for example the research and development costs of their products are huge. Competing in the world scale is the direction not only for knowledge based, but also for capital intensive industries. Many traditional industries need greater volumes to spread their high overhead costs (Shapiro 1993).

4.2 Short and Long Term Cost Functions

Hayes and Wheelwright (1984, pp. 55-61) divide economies of scale to short-term, intermediate term and long-term economies. In the present study, the focus is on cost advantages in the short and long run. In the short term the interesting topic is how to reduce the unit costs of production. Total costs (C) are often described with the three-degree function (γ_i are positive coefficients of cost functions and q is production quantity):

$$C = \gamma_3 q^3 - \gamma_2 q^2 + \gamma_1 q + \gamma_0 \tag{2}$$

In the beginning, the total costs increase slower than the production quantity, but near he maximum capacity the rise is sharp. Figure 9 shows, with case numbers (γ_1, γ_0) used later (Appendix 1), how total, average and marginal cost functions behave. The average cost reaches the minimum when $\mathrm{d}(C/q)/\mathrm{d}q = 0$, or graphically it can be found with the tangent to the total cost function. Marginal costs are naturally the changes of the total costs, but they are also changes of variable costs, because the derivative of fixed costs is zero. The minimum point of marginal costs $\mathrm{d}C/\mathrm{d}q$ is

$$q^* = \frac{\gamma_2 \pm \sqrt{\gamma_2^2 - 3\gamma_3\gamma_1}}{3\gamma_3} \tag{3}$$

which is determined when

$$\gamma_2 \geq \sqrt{3\gamma_3\gamma_1} \tag{4}$$

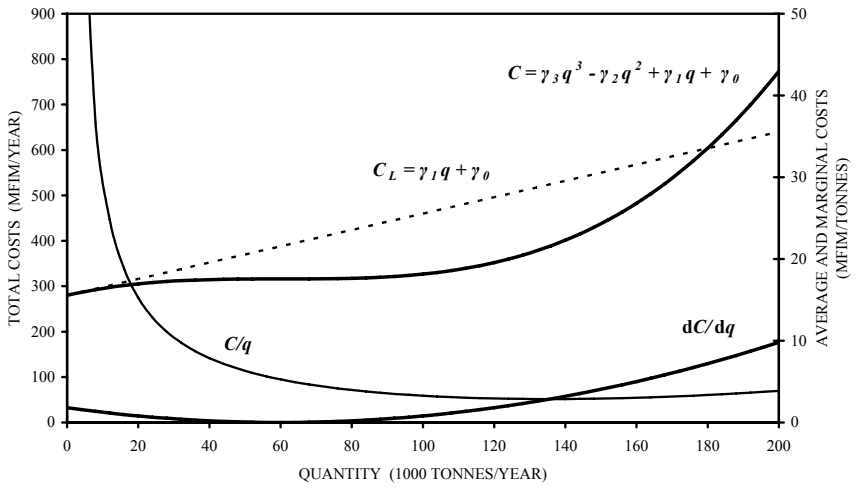

Figure 9. Total, average and marginal costs (γ_3=1/6000, γ_2=3/100, γ_1=1.8, γ_0=280).

It is also interesting to note that the average costs are equal to the marginal costs when the average costs are at a minimum (Figure 9 and Naylor & Vernon 1969, pp. 100):

$$\frac{\mathrm{d}(C/q)}{\mathrm{d}q} = \frac{q(\mathrm{d}C/\mathrm{d}q) - C}{q^2} = 0 \tag{5}$$

and by rewriting

$$\frac{\mathrm{d}C}{\mathrm{d}q} = \frac{C}{q} \tag{6}$$

Cost functions can be estimated for an individual machine, plant or firm. From a firm's viewpoint, explaining the change of production output only with the quantity of

production inputs is not a satisfactory solution when proper production management is considered. The driving time or efficiency of a single machine and the number of used machines impact the costs of production in the short term (Gutenberg 1969). Even though many product and production process-dependent factors influence the shape of real cost function, a simplification is often made and the function is presented in the following linear form (Figure 9):

$$C = \gamma_1 q + \gamma_0 \tag{7}$$

In this type of function, the fixed costs per unit are minimized when the production is as high as possible, i.e. the average costs reach the minimum at full capacity. The marginal costs are constant and equal to γ_1. In practice linear function is much more operational, because parameters γ_2 and γ_3 are difficult to estimate.

In the long term, the company can change the number of its machines and their size. As commonly known, all costs are variable in the long run, and the long term cost function is shaped as an envelope curve of the short term cost functions (e.g. Naylor & Vernon 1969, pp. 100-104). The long term costs can be described with the scale-factor δ (Figure 10):

$$C = \gamma q^{\delta} \tag{8}$$

When $\delta = 1$, there are constant returns of scale. If $\delta < 1$, there are economies of scale, and production growth leads to decreasing unit costs. If $\delta > 1$, it is a question of diseconomies of scale. In empirical studies, researchers have noticed the existence of economies of scale in the case of operating and investment costs (e.g. Hay & Morris 1991, pp. 31-32). At plant level 84% of the observations showed that the scale factor was lower than 0.9 and the median was 0.73. In Ryti's (1988, p. 84) presentation based on technology and costs in 1979, the scale-factors of paper and pulp mills were about 0.7-0.8.

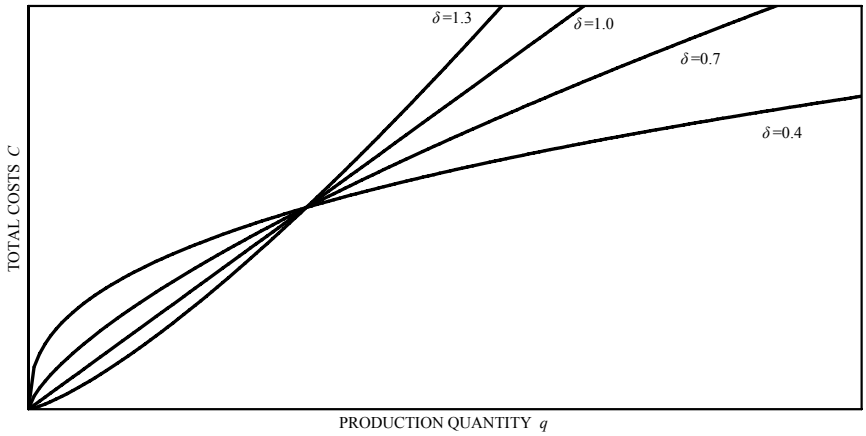

Figure 10. Long term cost functions on different scale factors, when γ=1.

4.3 Cost-Volume-Profit Analysis

In the previous chapter it was described how scale factors can be used to decribe the relation of capacities and initial investment costs. Estimations of product price, production capacity and quantities and operational costs are also needed as basic data for investment calculations. Typically cost-volume-profit analysis connects these things together.

In practice total costs are divided to various categories in different types of firms and industries. Combinations are numerous, and only general classification is useful in this context. The most common and traditional cost categoriazations are variable and fixed costs or direct and indirect costs (e.g. Horngren et al. 2003, pp. 30-33, Uusi-Rauva 1989, pp. 20-25). Variable costs change when the level of activity or volume vary, but fixed costs are unchanged. Fixed costs vary when the capacity behind these costs changes. Direct costs can be traced to the cost object in an economically feasible way, contrary to indirect costs, which are allocated to a particular cost object. Products, services, customers, brands, activities, departments or projects are typical cost objects. Variable and fixed costs can be divided to direct and indirect, when cost assigments are done. It is important to notice that costs can be direct and variable, direct and fixed, indirect and variable or indirect and fixed at the same time. Kaplan and Atkinson (1998,

pp. 13-14) have also made a cost classification to flexible and committed costs. This kind of itemisation emphasizes the role of production capacity level even more than the traditional categorizations.

As its name says, cost-volume-profit analysis describes the relationship between three things. In standard cost-volume-profit analysis (Horngren et al. 2003, pp. 61-67) the profit (P) is

$$P = pq - \gamma_1 q - \gamma_0 \tag{9}$$

where

p = price of the product
q = production quantity
γ_1 = variable unit costs
γ_0 = fixed costs.

The equation can also be written as follows:

$$P = (p - \gamma_1)q - \gamma_0 \tag{10}$$

It is determined that in breakeven point the profit or operating income is zero, and thus

$$q = \frac{\gamma_0}{p - \gamma_1} \tag{11}$$

There are several assumptions behind the standard cost-volume-profit model (Upchurch 2002, pp. 369-372, Horngren et al. 2003, pp.62-63). First of all the analysis uses linear sales and cost functions, which is not the case in the reality. The linear cost function

of sales ignores the price elasticity of demand and the linear cost function overtakes the possibilities of economies or diseconomies of scale and step costs. Of course more complex function forms can be used, but they are seldom presented in theoretical reviews. The model is a single period model and so it presumes that production is equal to sales, i.e. there are no significant changes in stocks during the planning period. The analysis demands that a single product or service is sold, or in the multi-product situation the sales mix is constant at all volumes. A static and deterministic environment is also assumed, e.g. the model works with conditions of constant technology and no uncertainty. Changes of environment can be incorporated to the model with sensitivity analysis.

4.4 Capacity Utilization and Scale Economies

Firms try to take advantage of new products, technologies and business structures when they make capacity adding decisions. A remarkable overcapacity of the industry clearly restricts the firms' willingness to build new capacity. Capacity addition is mostly a wrong decision if the utilization rate is low. In such a situation it is much more useful to consider whether other kinds of solutions, such as additional shifts, process redesign or outside vendors can achieve the short or long term capacity targets.

The costs of unused capacity are remarkable and it has been noticed that most companies use actually less than 25% of their effective capacity (McNair & Vangermeersch 1998, p. 103). Low capacity utilization naturally means foregone profits and unnecessarily high fixed costs. In capital intensive industries a high capacity utilization rate is a critical success factor, and in good years it can be near 95% (see Figure 8). However, in cyclical branches it is inevitable that in bad years, when prices are low, some firms have difficulties to allocate all capacity costs to products.

When large capacity addition investments are planned, the production capacity will be doubled or even more. Then economies of scale are the central motive behind this kind of industrial investments. When capital investment calculations for this kind of projects are done, there must be a well-grounded view of the factors of economies of scale, and this view will affect the cash flow of the project.

The most commonly used evaluation methods in industrial projects are net present value, internal rate of return, and payback time, which can all be calculated from the cash flow of the project. In recent years more attention in literature and also in practice has been directed to the determination of the correct discount rate (Mott 1997, pp. 133-156). In big firms the most common way is to use the weighted average cost of capital, which includes the targeted cost of debt, cost of equity and debt-equity ratio. Determination of the cost of equity can be done with market-based data. It is quite clear that when the optimal timing of an industrial project is considered, the first years after building are most critical and their impact on profitability is strongest. This is why the right determination of the discount rate is a remarkable issue. Of course an even more important issue is how fast the full production capacity can be reached, i.e. that the capacity utilization rate is as high as possible.

4.5 Concluding Remarks

In previous chapters it is presented how short and long term cost functions, economies of scale and capacity utilization are linked together. These definitions are needed and used in the modelling part of the study. It is also considered that cost-volume-profit analysis gives a basic view of the profitability of a project and it can be used as a tool of cash flow estimations. Typically the development of new technology and automation means bigger and faster machines and gives possibilities to economies of scale, but the price is higher fixed costs.

The competition environment, the availability of resources, and financing possibilities set restrictions to capacity expansion decisions. A planned expansion is often based on one or a few long term advantages. If long term cost advantage is sought, then the economies of scale cannot be omitted. Long-term advantages often require the use of new technology, but permanent benefits can also be achieved as a form of successful product or process development.

When the costs are divided to variable and fixed parts, then profitable capacity expansion means that either the variable or fixed unit costs decrease proportionally, as compared to the former situation. In other words all costs can be altered in the long

run. The flexibility of capacity increases when fixed costs are substituted for variable costs and vice versa. This can be done e.g. with sale- and lease-back arrangements, network partners-transferred capital investments or flexible subcontracting contracts. On the other hand, if the capacity is too flexible, then the advantage of right investments might disappear. It can be said that scale economies also describe successful investment decisions and return on right risk taking. The idea of constant returns on scale is often used in scientific studies, but in this work the existence of scale economies belongs to the basic assumptions.

5 TIMING IN CURRENT MODELS

5.1 Capacity Expansion Problem

Different models have been built for capacity expansion situations. If the demand is expected to be known with certainty, it is a question of a deterministic capacity expansion problem. In his classical model, Manne (1967) considers capacity expansion on a single market area, and assumes arithmetic growth of demand *k*. The demand is continuously satisfied and the firm builds plants between certain time intervals *t* over an infinite horizon. The plant size is *kt*, and the present value of investment costs can be presented as follows (cf. equation 1):

$$J = \frac{\lambda(kt)^{\delta}}{1 - e^{-rt}} \tag{12}$$

where

J = present value of investment costs
t = time interval between expansions
k = annual increase in demand
kt = plant size
δ = scale-factor
λ = constant
r = annual continuously compounded discount rate.

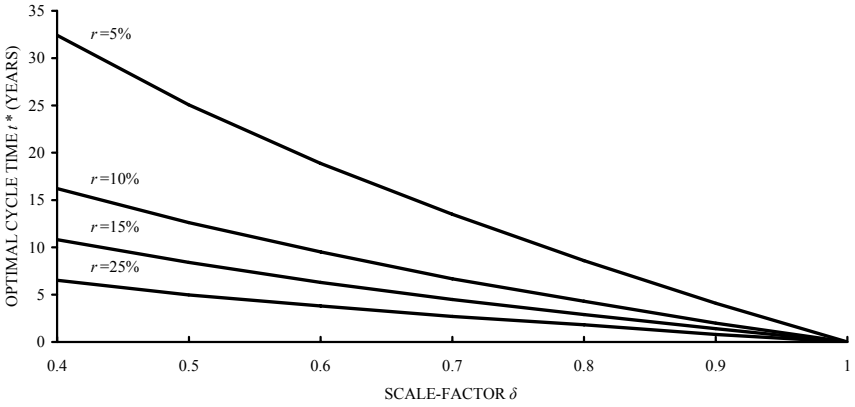

Figure 11. Optimal investment cycle, discount rate and scale-factor in Manne's (1967) model.

When cost equation 12 is minimized with respect to the cycle time, it is seen that the optimal investment cycle t^* depends only on the scale-factor and discount rate (Manne 1967, pp. 37-38):

$$t^* = \frac{\delta(e^{rt^*} - 1)}{r} \tag{13}$$

In the model, a high rate of return always leads to short investment cycles (Figure 11), and a low discount rate and remarkable economies of scale cause long investment intervals. Investments accelerate, when economies of scale tend to decrease, i.e. the scale factor is near one.

5.2 Capacity Expansion Models

The size, timing and location of expansion are planned in capacity models. Typical goals are the minimization of costs or profit maximization. The growth of demand is assumed to be arithmetic, geometric or stochastic. Part of the models include the economies of scale -effect.

The capacity expansion models developed on the basis of Manne's seminal work assume the growth of demand to be geometric or stochastic (cf. Manne 1967 and Freidenfelds 1981). In extended cases, the selection of plant location is connected to the models. Naturally, the import and export possibility and transportation costs make the solutions more complicated. Also Laitinen (1984) has built a model for the timing and sizing of investments. In his model, maximization of the net present value criteria and limited planning horizon are used.

Whitt (1981) and Luss (1982) have developed a model which describes the changes of utilization rate in capacity expansion situations. The growth of demand is assumed to be stochastic, and capacity addition happens when the demand exceeds the capacity. The size of expansion depends on the current demand. In this type of models, the expansion takes place at some stochastic time in the future.

The above-mentioned models presuppose that capacity is expanded with big units. If capacity additions can be done with small cost effective increments, the Newsboy model can be used instead (Hayes & Wheelwright 1984, pp.52-54 and Lieberman 1989). In the Newsboy model the firm chooses the capacity level which maximizes the expected profits at some known probability distribution of demand. The optimal decision rule for the firm is to set the capacity at such a level that it is expected to operate at full capacity with certain probability, which is determined with the marginal costs and contribution margin per unit sold. If the actual demand is less than the chosen capacity level, the firm suffers excess capacity costs, and if the demand is more than the capacity, the firm loses profits. This model does not contain the economies of scale possibility. Clearly, in capital intensive industries the costs of unused capacity are remarkable, and high utilization rates are natural goals.

Lieberman (1989) has tested with multiple regression analysis how the Manne model, the Whitt-Luss model and the Newsboy model explain the capacity utilization rates of chemical industry products. The results show that the Whitt-Luss and Newsboy models describe the expansion decisions better than the Manne model. Capital intensity, the rate of demand growth, demand variability, the size of capacity increments and

the plant size were the most important capacity utilization explaining factors. Scale economies and multi-plant operation had only little effect on capacity utilization.

Different capacity expansion models have been developed by operation researchers. These have been applied to the capacity planning of electrical power supply, water resources, process industry, communication networks and public services. Despite this it can be said that the theory and the models are more advanced than real life applications (Luss 1982, pp. 936-939).

5.3 Replacement Models

There exists a great variety of replacement models, which can be divided to two main types (Canada et al. 1996, pp. 216-237). The first category includes models that compare the old machine (defender) with the new one (challenger), and typically the replacement decision is based on the net present value of minimum costs. In replacement models the planning horizon, technology, cost behaviour and availability of capital alter case by case, and this generates a rich variety of models (Park & Sharp-Bette 1990, pp. 654-669). Costs are often described with increasing or decreasing functions of time, and with this logic, changing operation and maintenance costs, i.e. the so called bathtub phenomenom (Suomala 2004, p.129), can be taken into account.

The second type involves models which determine a certain economic service life of a single machine (Levy & Sarnat 1994, pp. 124-126). Typically the operation and maintenance costs of a machine increase, and the capital costs and salvage value decrease as time passes. The replacement chain of identical machines is found out with the help of optimization. A higher discount rate or lower growth of operation and maintenance costs lead to longer service lifes of machines. Aho and Virtanen (1984, pp. 60-80) have shown that inflation and tax rate have a lenghtening effect on the optimal service life. Also the option nature of replacement investments is considered and it is noticed that uncertainty tends to extend the average economic life of plant (Dobbs 2004, p. 731).

5.4 Timing in Cash Flow Models

The profitability of capital investments is evaluated with discounted cash flow models. Normally net present value, internal rate of return and payback time is calculated and the profitability of the project is based on these. Of course, the same technique can be used when the optimal timing question is considered. Sometimes a delaying project can cause a higher net present value than implementing it immediately (Arnold 1998, p. 119). Typically the timing problem is only briefly presented in the literature. Park & Sharp-Bette (1990, pp. 273-275) have said that rapidly changing technology or fluctuation in inflation and financing costs give reasons for making this kind of evaluations.

5.5 Real Options and Value of Waiting

In most cases conventional cash flows and net present value analysis give a systematic and adequate view on the profitability of projects. In situations when the role of uncertainty is dominating, the strategic value of the project can be calculated with the real options:

$$S = U + G \tag{14}$$

where

S = expanded net present value of project
U = conventional net present value of project
G = value of real option.

Park and Herath (2000, p. 7) have noted that the real options framework suits well for equipment replacement and expansion decisions under high uncertainty, evaluation of mergers, aquisitions and divestments, research and development projects, and projects that can be deferred. In these cases the value of waiting can be considered,

and it is explained that waiting typically gives new and valuable information about the project before the firm commits its resourches.

McDonald and Siegel (1986) have developed a model, which considers the point at which it is optimal to invest amount I for a project whose value is V:

$$dV = \omega V dt + \sigma V d\zeta \tag{15}$$

where

V = present value of project inflows
dV = change of present value of project
ω = drift parameter
dt = time interval
σ = standard deviation
$d\zeta$ = increment of Wiener process.

A stochastic process combines dynamics with uncertainty, i.e it is a variable that evolves over time, at least partly randomly. The Wiener process (Brownian motion) is a continuous-time stochastic process, which has three important properties: the future values of the process depend on its current value, not past values, the process has independent increments, and changes in the process are normally distributed (Dixit & Pindyck 1994, p. 60-63). Naturally the value of the timing option crucially depends on the nature of the stochastic process (Lee 1988, p. 155).

In the deterministic case ($\sigma = 0$) the value of investment opportunity

$$F = (Ve^{\omega t} - I)e^{-rt} \tag{16}$$

where

t = future investment time and

r = discount rate.

If $\omega \leq 0$ and $V > I$ it is optimal to invest immediately. If $0 < \omega < r$ it is better wait than invest at once. Optimal timing t^* is solved with equation

$$dF/dt = -(r - \omega)Ve^{-(r-\omega)t}e^{-rt} + rIe^{-rt} \tag{17}$$

and it is

$$t^* = \max\left[\left(\frac{1}{\omega}\right)\ln\left(\frac{rI}{(r-\omega)V}\right),\ 0\right] \tag{18}$$

In the deterministic case $\sigma = 0$ and in the stochastic case $\sigma > 0$. It must also be noted that both growth ($\omega > 0$) and uncertainty ($\sigma > 0$) affect investment timing (Dixit & Pindyck 1994, p. 140). In the stochastic case the value of investment opportunity under uncertainty can be calculated with the equation of American call option (Trigeorgis 1997, p. 117):

$$F = VN(d_1) - Ie^{-r_f t}N(d_2) \tag{19}$$

where $N(\cdot)$ is cumulative normal distribution and r_f is risk free rate

$$d_1 = \frac{\ln(V/I) + (r_f + \tfrac{1}{2}\sigma^2)t}{\sigma\sqrt{t}} \tag{20}$$

$$d_2 = d_1 - \sigma\sqrt{t} \tag{21}$$

It is well known that the value of the call option rises when the value of the underlaying asset, standard deviation of asset returns, or riskless interest rate increase, the exercise price decreases or the time to expiration becomes longer (Brealey & Myers 1991, p. 52).

5.6 Concluding Remarks

It can be summed up that the timing issue is handled in the current theoretical models in various ways and it is partly fuzzy concept. Noticed shortcomings of the current timing approaches are (cf. Chapter 2):

- There are different kinds of models, but the general view is fragmented and timing is in a secondary role in most models.
- The timing logic of the expansion and the replacement decisions are not harmonized.
- The fixed investment cycle assumption used in the early capacity expansion and economic service life models, is not necessarily realistic when the business environment is rapidly changing and flexibility is needed.
- Stochastic models explain timing behaviour quite well, but are not operational decision tools for managers.
- The value of waiting types of models are not typically integrated to traditional discounted cash flow calculations at the level of capital intensive industrial projects.
- The models' connections to the corporate strategy vary.
- The timing impacts on the income statement, balance sheet or key ratios of companies are not well defined.
- The importance of the timing decision is not determined in the context of capital budgeting process of a firm.

In this study the aim is to find a much more general and analytical view to the complex timing question. In practice industrialists have two opposite views to timing, as some say that it is a vitally important issue in the world of business cycles and others argue that timing has no remarkable role, because of the long lifetimes of machines.

Traditionally the optimal capacity-adding interval is determined as a function of the scale factor and discount rate. This approach is based on an infinite planning horizon and certain size of projects. In stochastic capacity models, expansions happen at a some unforecasted point of time in the future. This viewpoint is not, however, applicable when the aim is to find an analytical solution to the problem. In the present study, the object is not to search a certain investment cycle or program, but rather to find optimal timing for a single project. This choice means the use of a limited horizon, and it can be also argued that a planned project often has to be implemented during a certain time window.

In the present work, the purpose is to build first an analytical model which is based on the linear relationship between costs and production quantities. This means that the operationalization of the model and finding of essential relationships are more important goals than the exactness of the model. The object of the first model is to minimize the unit costs of production. The sense in this kind of a target is twofold: in practice a new advanced technology often means decreasing unit costs, and increasing rivalry decreases the prices in the course of time. After the first model the study continues to the direction of open questions and towards a richer view. Because of this the timing issue is also discussed in the context of the replacement, cash flow and real option models.

6 UNIT COST MODEL FOR OPTIMAL TIMING

6.1 Practical Origin

The timing of capital investments often has a great influence on the firm's profitability. This problem is common in capital intensive industries with massive capacity additions. Several things, such as the firm's competitive position, possibilities to finance projects, and costs of projects all have effects on the optimal solution. Despite the complexity, the situation can be simplified, and closer analysis can be made about the parameters that really matter. Below, a model focusing on production quantities and costs is developed. It is also shown how this unit cost model can be applied to one numerical case (Appendix 1 and 2). It must be emphasized that the focus is on a single capacity expansion only, not the firm's whole investment program.

Technological change and life cycles have their own roles in medium and long run decisions. Large investments are naturally extremely risky, and economies of scale often have a central impact on these decisions. For example in metal, forest and shipping industry capacity changes happen from a lower to an upper level with a single big capital investment. Figure 12 shows how one company has expanded its paper production capacity with a big investment. Typically the size of machines increases year after year. When the capital investment is significant as compared to the firm's size, knowing the best timing for the expansion is valuable.

Different models have been developed for capacity expansion purposes, but only a few deal with timing questions. Some strategic timing frameworks were presented in chapter 2, but they outline a general expansion strategy rather than an exact solution to the problem. The literature on operations research includes several capacity expansion models based on the work by Manne. In the basic models, capacity additions typically happen within a fixed time cycle. Some attention has recently been directed to the irreversibility, delaying and option nature of investment projects (Dixit & Pindyck 1994 and Trigeorgis 1997). This real option view takes also timing questions into account (McDonald & Siegel 1986 and Dixit 1992). Typically researchers discuss the value of waiting, i.e. is it profitable to invest now or later? Although all these

studies have influenced the present work, the real starting point is in empirical observations as presented in Figure 12. In the following model the strategic view of the production levels is connected to the real production costs.

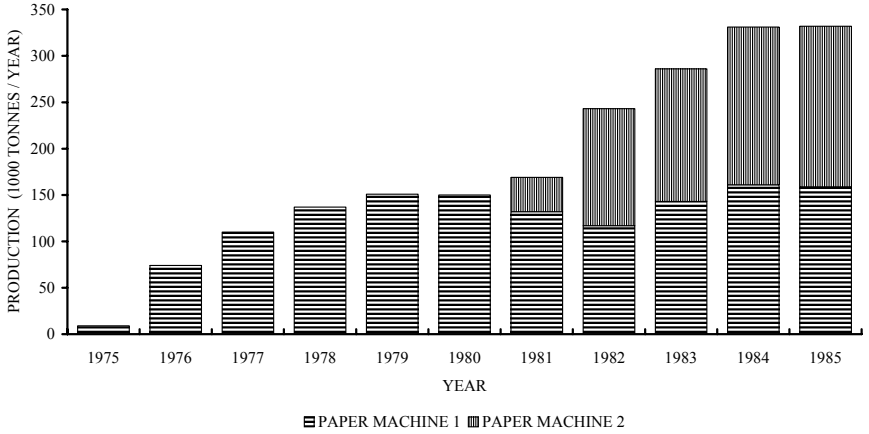

Figure 12. The production of two paper machines (based on Kaukas Oy 1975-1985).

In the case presented in Figure 12, a new paper machine was built close to the old machine. The construction began in autumn 1979 and the machine was started up two years later. After the building of the new machine the factory had two lines. The capacity adding option was maybe already outlined when the first machine was planned. Factory building in two stages is a remarkable response to the uncertainty of demand, and sometimes also the availability of financing can require advancement with several stages. Significant capacity increase clearly affects the price level of the markets. In this case the price decreased after the building decision and the former price level was achieved when the new capacity was at full use (Figure 13). This indicates that the timing and sizing of the project was suitable in the prevailing market conditions. In the years 1977-1978 there were totally 19% and in 1982 totally 11% devaluations of FIM, and this subvention helped the export industry to attain high capacity utilization rates and good profitability after expansion investments (cf. Statistics Finland 2007 and Hänninen 1999, pp. 280-281).

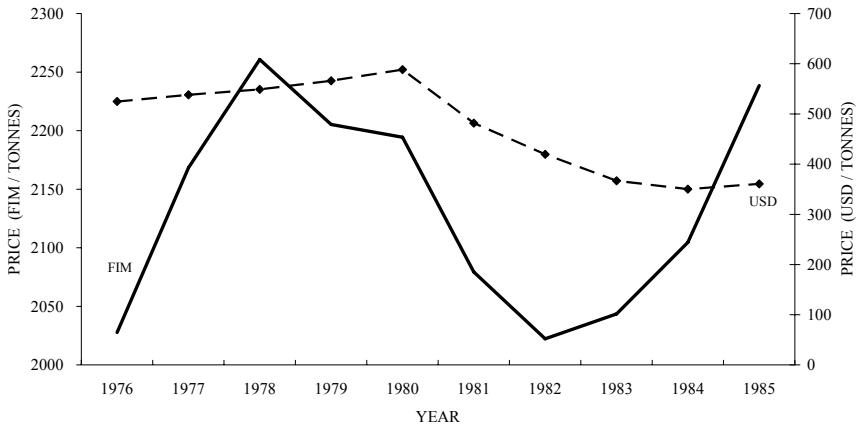

Figure 13. Behaviour of paper price before and after expansion (based on net sales of two machines and presented as the export prices of 1979).

6.2 Building a New Machine

Next the situation presented above where the capacity of the old machine is in full use and the company plans to build a new machine is modelled. The purpose is not to slightly improve the production capacity of the old machine, but to build a totally new machine, and thus increase the capacity substantially. The existing demand is managed with the old machine and the expansion investment is directed to growing markets. It is a question of an irreversible investment, which will bind corporate resources for decades.

The following assumptions lie behind the model:

- technological progress and economies of scale mean increasing machine size and decreasing production costs
- the variable and fixed costs of the machines and their capacity can be determined accurately enough
- certain machine sizes determine the firm's capacity options and give the possibility to find the exact solution for the suitable expansion time

- a limited planning horizon is used due to demand and technology unpredictability in the long run.

In the model, cost minimization is the essential target, but later profit maximization is also discussed. The notation is the following (Figure 14):

t_{opt} = optimal expansion time [years]
q_0 = capacity of the old machine [unit/year]
a = variable unit costs of the old machine [currency unit/unit]
b = fixed costs of the old machine [currency unit/year]
q_1 = capacity of the new machine [unit/year]
c = variable unit costs of the new machine [currency unit/unit]
v = fixed costs of the new machine [currency unit/year]
k = arithmetical growth rate of demand [unit/year/year].

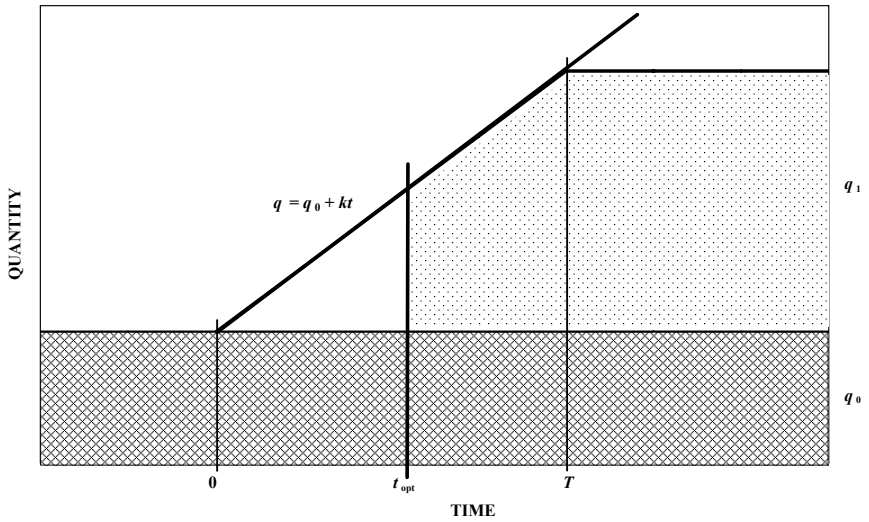

Figure 14. Notation of the expansion investment.

The length of the planning period is $T = q_1/k$ [years], and all calculations are made at period $[0,T]$. This means that capacity is added during the time window, i.e. after the demand exceeds the capacity of the old machine but before the capacity of the new machine is reached. The capacity is not necessarily the maximum production quantity,

i.e. it can also be seen as the planned production level in the long term. There is no inventory possibility, and so the whole production is also sold. The old machine is in full use all the time, and the new machine makes all adjustments. The costs are modelled here with simple linear functions and all costs are real costs without inflation.

The total production of the two machines is

$$Q = \int_0^{t_{opt}} q_0 \mathrm{d}t + \int_{t_{opt}}^{T} (q_0 + kt)\mathrm{d}t \tag{22}$$

$$Q = q_0 t_{opt} + q_0(T - t_{opt}) + \tfrac{1}{2}k(T^2 - t_{opt}^2) \tag{23}$$

$$Q = -\tfrac{1}{2}kt_{opt}^2 + T(q_0 + \tfrac{1}{2}kT) \tag{24}$$

When $T = q_1/k$,

$$Q = -\tfrac{1}{2}kt_{opt}^2 + (q_1/k)(q_0 + \tfrac{1}{2}q_1) \tag{25}$$

The total costs of the two machines are

$$C_E = \int_0^{t_{opt}} (aq_0 + b)\mathrm{d}t + \int_{t_{opt}}^{T} (aq_0 + b + ckt + v)\mathrm{d}t \tag{26}$$

$$C_E = (aq_0 + b)t_{opt} + (aq_0 + b + v)(T - t_{opt}) + \tfrac{1}{2}ck(T^2 - t_{opt}^2) \tag{27}$$

$$C_E = -\tfrac{1}{2}ckt_{opt}^2 - vt_{opt} + T(aq_0 + b + \tfrac{1}{2}ckT + v) \tag{28}$$

Using other parameters

$$C_E = -\tfrac{1}{2}ckt_{opt}^2 - vt_{opt} + (q_1/k)(aq_0 + b + \tfrac{1}{2}cq_1 + v) \tag{29}$$

Now the unit cost function

$$\frac{C_E}{Q}(t_{opt}) = \frac{-\tfrac{1}{2}ckt_{opt}^2 - vt_{opt} + (q_1/k)(aq_0 + b + \tfrac{1}{2}cq_1 + v)}{-\tfrac{1}{2}kt_{opt}^2 + (q_1/k)(q_0 + \tfrac{1}{2}q_1)} \tag{30}$$

is optimized. The function is determined, when

$$t_{opt} \neq \pm\left(\frac{q_1}{k}\right)\sqrt{\frac{2q_0}{q_1} + 1} \tag{31}$$

This is true when $t_{opt} \in [0,T]$, because $q_1/k = T$ and the square root is greater than one. $C_E' = -ckt_{opt} - v$, $Q' = -kt_{opt}$ and $\mathrm{d}(C_E/Q) / \mathrm{d}(t_{opt}) = (C_E'Q - Q'C_E)/Q^2 = 0$. Because the denominator is always positive, only the numerator's zero-points are looked at

$$\begin{aligned}&(-ckt_{opt} - v)[-\tfrac{1}{2}kt_{opt}^2 + (q_1/k)(q_0 + \tfrac{1}{2}q_1)] + \\ &kt_{opt}[-\tfrac{1}{2}ckt_{opt}^2 - vt_{opt} + (q_1/k)(aq_0 + b + \tfrac{1}{2}cq_1 + v)] = 0\end{aligned} \tag{32}$$

$$vkt_{opt}^2 - 2q_1[(a-c)q_0 + b + v]t_{opt} + (vq_1/k)(2q_0 + q_1) = 0 \tag{33}$$

When the sum of the fixed costs of machines after expansion, plus the change in variable costs (i.e. change of marginal costs) is marked with

$$z = (a-c)q_0 + b + v \tag{34}$$

the equation can be presented as follows

$$vkt_{opt}^2 - 2q_1 z t_{opt} + (vq_1/k)(2q_0 + q_1) = 0 \tag{35}$$

and the optimal expansion time is

$$t_{opt} = \frac{2q_1 z \pm \sqrt{(2q_1 z)^2 - 4vk(vq_1/k)(2q_0 + q_1)}}{2vk} \tag{36}$$

$$t_{opt} = \frac{q_1}{k}\left[\frac{z}{v} \pm \sqrt{\left(\frac{z}{v}\right)^2 - \left(\frac{2q_0}{q_1} + 1\right)}\right] \tag{37}$$

Because the upper limit is $T = q_1/k$ and the ratio z/v is normally ($a > c$) greater than one and the square root must be positive, the only acceptable solution is

$$t_{opt} = \frac{q_1}{k}\left[\frac{z}{v} - \sqrt{\left(\frac{z}{v}\right)^2 - \left(\frac{2q_0}{q_1} + 1\right)}\right] \tag{38}$$

This is the optimal solution, because with normal parameters (a, b, c, v, q_0, q_1, $k > 0$) the function values in points 0 and T are greater than in this optimal point. The model has a solution, when

$$\frac{z}{v} \geq \sqrt{\frac{2q_0}{q_1} + 1} \tag{39}$$

6.3 Analysis of the Model

Three ratios appear in the solution of the model. As mentioned above, the capacity of the new machine q_1 is related to the growth of demand k, and the ratio is the same as time window T. If the demand grows faster than planned, the capacity of the new machine is put to full use faster than forecasted. Exactly, this means a shorter planning horizon and faster investments. On the other hand, the meaning of correct timing is most essential when the building of a big machine is planned to slowly growing markets.

The capacities of the old and the new machine are described with q_0/q_1. Technology development says that usually a new machine has bigger capacity than the old one, e.g. in the paper industry the driving speed is higher or the width of the machine has increased. On the other hand, different sizes of machines are commonly compared in plans. Remarkable economies of scale normally require that the new machine is many times bigger than the old one.

The ratio $z/v = (a\text{-}c)q_0/v + b/v + 1$ describes how the expansion influences the variable and fixed costs and compounds this effect to the capacity of the old machine. The question is about the relation of costs and quantities, i.e. how the changing scale creates advantage or disadvantage. The variable and fixed costs of the new machine and its capacity are changeable things at the planning stage, but the corresponding parameters of the old machine are permanent. It is also said that in capacity investments the variable unit costs are fixed and the fixed unit costs are variable. If the variable unit

costs of the old and the new machine are equal ($a=c$), then $z/v = b/v + 1$. Then there are lower fixed unit costs behind the cost advantage, not decreasing variable unit costs. An essential capacity expansion has an effect on the availability and price of raw materials. If the main resources are under the company's control, the variable unit cost can be constant, but this is not usually the situation.

Because the size of machines and the growth rates of demand vary in different situations, it is sensible to present equation 38 in the form

$$\frac{t_{opt}}{T} = \frac{z}{v} - \sqrt{\left(\frac{z}{v}\right)^2 - \left(\frac{2q_0}{q_1} + 1\right)} \tag{40}$$

Thus, the optimal timing moment is related to the length of planning period T.
When $\tau = t_{opt}/T$, $\alpha = z/v$ and $\beta = q_1/q_0$, the relative timing can be presented in the form

$$\tau = \alpha - \sqrt{\alpha^2 - \left(\frac{2}{\beta} + 1\right)} \tag{41}$$

Figure 15 presents in general form how the timing of expansion depends on the size of machines and the achieved cost advantage. If the timing ratio τ is lower than half, making an early investment is sensible in the unit cost minimization sense, but if it is near one it is better to defer the capacity addition to the end of the planning period.

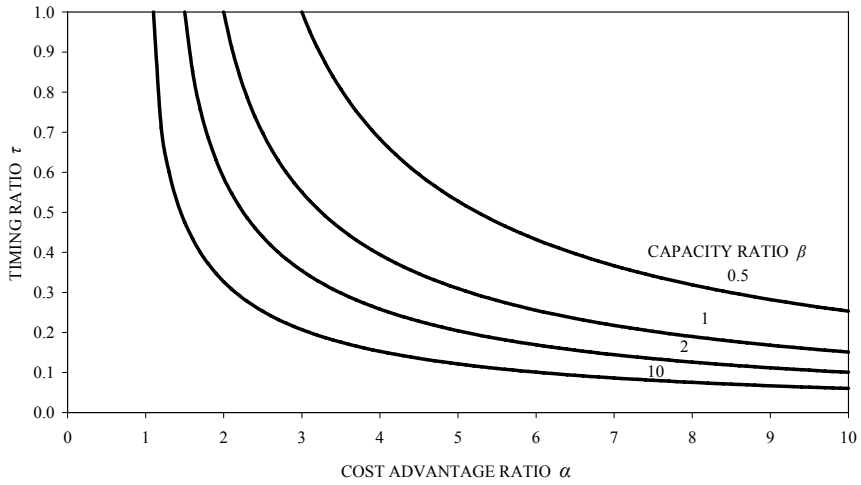

Figure 15. Timing ratio as a function of cost advantage and capacity ratios.

The term $\alpha = z/v$ is the cost advantage measure, which describes how large the cost advantage of the expansion is, and the ratio $\beta = q_1/q_0$ compares the expansion capacity with the existing capacity. The cost advantage ratio of the model is greater than one, and this means that the cost benefit can be achieved by lower fixed and/or variable costs. If the expansion is planned with a machine of double size, i.e. $\beta = 2$, the sensible timing solution requires that $\alpha \geq 1.5$, and similar limit values can be read from the top of Figure 15 for other expansion sizes as well. The significant cost advantage, which is often characteristic of new technology, means an early expansion possibility. On the other hand, in traditional branches cost advantages are often small and early investments demand big expansion units.

6.4 Case Solution

The developed model can be tested with illustrative numbers (Appendix 1). It is assumed that the production capacity of the old machine is 100 and the capacity of the new machine is 200 thousand tonnes per year, and the income statements are the following (MFIM/year):

	Old machine		New machine	
Net sales	400	100%	800	100%
Variable costs	200	50%	360	45%
Fixed costs	160	40%	280	35%
Profit	40	10%	160	20%

The growth of demand is expected to be 40 thousand tonnes/year/year, which means that the time window T = 200 000 tonnes/year / 40 000 tonnes/year/year = 5 years. In this case, the cost advantage comes mainly from the lower fixed unit costs. When α = 1.64 and β = 2, then τ = 0.81. This means that the optimal investment time is 4.0 years from the current time and the average unit costs of the planning period are 3 535 FIM per tonne (Figure 18).

6.5 Measuring Cost Advantage

When the relationship between the production capacities of machines and the total production costs are considered, equation 8 is a natural starting point. If the production costs of the old machine at full capacity are $C_0 = \gamma q_0^{\delta}$, and γ and δ are constants of a certain long-term cost curve, then the total costs of the new machine at full capacity are $C_1 = \gamma q_1^{\delta}$. The total costs of the machines relate to each other as follows (q_0, q_1 > 0):

$$\frac{C_1}{C_0} = \left(\frac{q_1}{q_0} \right)^{\delta} \tag{42}$$

In process industry the capital need of a new plant is frequently estimated with the above equation, and the scale factor δ is often near the value 0.6 (Humphreys 1991, p. 382). The equation says that when the production is doubled then the costs will increase only by about 50 percent. Naturally the content of the costs affects the value of the scale factor. Different outcomes are received if operating costs, total costs, or investment costs are used in the calculations. The economies of scale -effect can be measured by solving the scale factor

$$\delta = \frac{\ln(C_1/C_0)}{\ln(q_1/q_0)} \tag{43}$$

If the cost advantage of the new machine is evaluated in the case example with equation 43, the measure for economies of scale is δ = ln(640 MFIM/year / 360 MFIM/year) / ln(200 000 tonnes/year / 100 000 tonnes/year) ≈ 0.83 (γ=7.9). This says that a remarkable cost advantage is attained with the new machine, i.e. when the production capacity is doubled, the total costs of the new machine are only 1.8 times as high as those of the old machine (Figure 16).

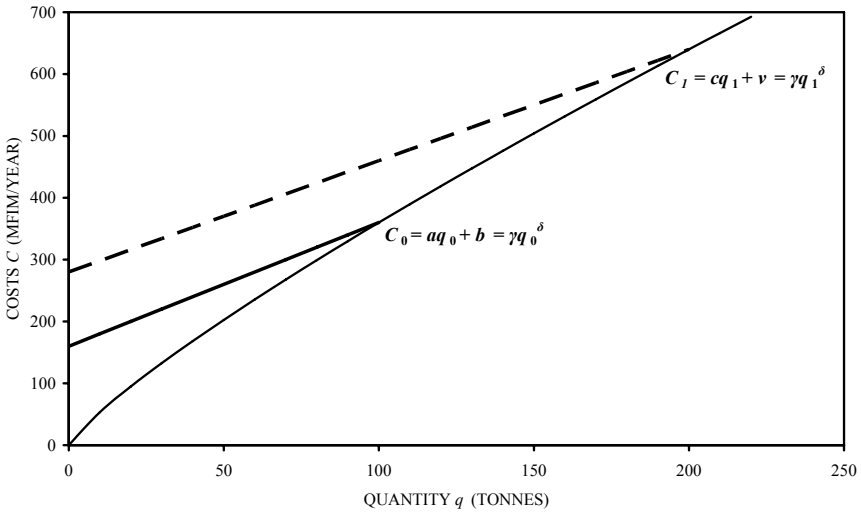

Figure 16. Cost functions of the machines.

6.6 Affecting Factors

Some factors which influence the solution of the model are discussed below. It is assumed that the capacity of the new machine is wholly available directly after the expansion. In the real world this is possible only if the capacity can be added through buying. The building of a modern paper machine takes about 18 months, and the building of a nuclear power plant can take over five years, which are remarkable delays

if optimal timing and fitting of projects to the business cycle is planned. On the other hand, cargo ships or other transport equipment can be accquired from international second-hand markets in a short time. If capacity is built, the model proposes it to be ready by the expansion moment. Because the building and start-up of the new machine takes time, assuming that the old machine is in full production is convenient and all production adjustments are done with the new machine.

The sensible and possible driving order of the machines affects the optimal solution as well. The unit costs of the new machine at full capacity are commonly lower than those of the old one. The lowest unit cost during the period can be achieved if the utilization rate of the new machine is as high as possible and adjustment is done with the old machine. The best timing to capacity expansion is in these circumstances earlier than the model shows and it can be calculated with a numerical model (Kärri 1994, p. 52). An opposite impact on timing arises when the production capacity of the old machine can be expanded with low investment costs or without them. Deferring the building time of the new machine is then possible, and in practice this means removing production bottlenecks (Kärri 1994, pp. 54-55).

In the model presented above the unit costs are minimized. This target leads also to a high capacity utilization rate during the planning period. As equation 24 says, the production quantity $Q = -½kt_{opt}^2 + T(q_0+½kT)$. When the capacity of the machines during the same period is

$$Q_c = \int_0^{t_{opt}} q_0 \mathrm{d}t + \int_{t_{opt}}^{T} (q_0 + q_1)\mathrm{d}t = q_0 T + q_1 (T - t_{opt}) \qquad (44)$$

the average utilization rate can be determined as Q/Q_c. If the capacity expansion happens in the case example (Figure 18) at the moment t_{opt} = 4.0 years, then the capacity utilization rate is 97%. In capital intensive industries, the importance of high capacity utilization, speed in start-up and dominance of first year cash flows are commonly known, and the present analysis gives support to this view.

6.7 Replacement of the Old Machine

The model presented above was used in a situation where a new machine was acquired to expand production capacity. The same kind of a model can also be made to the case where the old machine is replaced with a new machine. The purpose is to use the old machine as far as the replacement moment and then discard it. In this case the decision is timed near the end of the service life of the old machine.

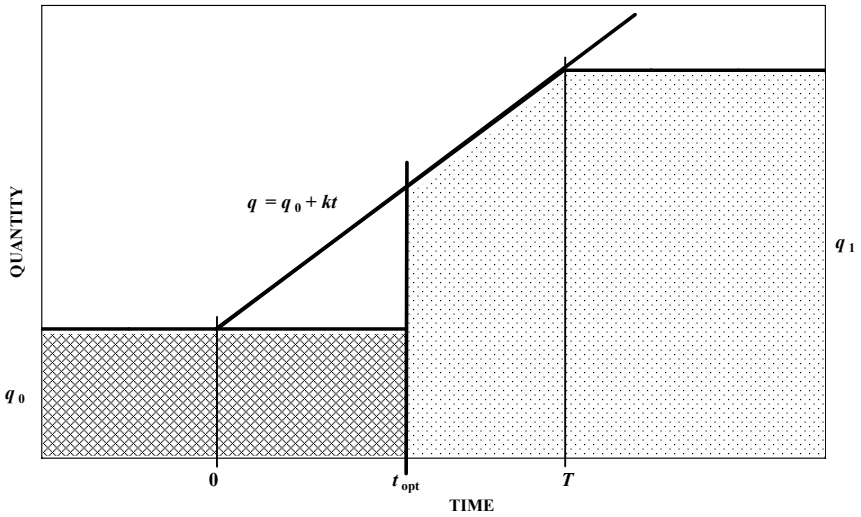

Figure 17. Notation for the replacement investment.

The total production is the same as in equation 24. Now the planning horizon $T=(q_1-q_0)/k$, which means that capacity is added during the time window, i.e. after the demand exceeds the practical capacity of the old machine but before the capacity of the new machine is reached. Because the old machine is retired, its demand is transferred to the new machine. During the period the total costs are

$$C_R = \int_0^{t_{opt}} (aq_0 + b)\mathrm{d}t + \int_{t_{opt}}^{T} (cq_0 + ckt + v)\mathrm{d}t \tag{45}$$

$$C_R = -\tfrac{1}{2}ckt_{opt}^2 + (aq_0 + b - cq_0 - v)t_{opt} + T(cq_0 + v + \tfrac{1}{2}ckT) \tag{46}$$

Now the function

$$\frac{C_R}{Q}(t_{opt}) = \frac{-½ckt_{opt}^2 + (aq_0 + b - cq_0 - v)t_{opt} + T(cq_0 + v + ½ckT)}{-½kt_{opt}^2 + T(q_0 + ½kT)} \quad (47)$$

is optimized. The denominator is the same as in the expansion case and so the function is determined as presented in equation 31. $C_R' = -ckt_{opt} + aq_0 + b - cq_0 - v$, $Q' = -kt_{opt}$ and $\mathrm{d}(C_R/Q) / \mathrm{d}(t_{opt}) = (C_R'Q - Q'C_R)/Q^2 = 0$.

Because the denominator is positive, we see only the numerator's zero-points

$$\begin{aligned}&(-ckt_{opt} + aq_0 + b - cq_0 - v)[-½kt_{opt}^2 + T(q_0 + ½kT)] + \\ &kt_{opt}[-½ckt_{opt}^2 + (aq_0 + b - cq_0 - v)t_{opt} + T(cq_0 + v + ½ckT)] = 0\end{aligned} \quad (48)$$

$$k(aq_0 + b - cq_0 - v)t_{opt}^2 + 2vkTt_{opt} + (aq_0 + b - cq_0 - v)(2q_0 + kT)T = 0 \quad (49)$$

When $kT=q_1-q_0$ and now $z=(a-c)q_0+b-v$, the equation is

$$kzt_{opt}^2 + 2v(q_1 - q_0)t_{opt} + z[2q_0 + (q_1 - q_0)][(q_1 - q_0)/k] = 0 \quad (50)$$

$$k^2zt_{opt}^2 + 2vk(q_1 - q_0)t_{opt} + 2zq_0(q_1 - q_0) + z(q_1 - q_0)^2 = 0 \quad (51)$$

The optimal replacement time is

$$t_{opt} = \frac{-2vk(q_1-q_0) \pm \sqrt{[2vk(q_1-q_0)]^2 - 4k^2z[2zq_0(q_1-q_0) + z(q_1-q_0)^2]}}{2k^2z} \quad (52)$$

$$t_{opt} = \frac{(q_1 - q_0)}{k}\left[-\frac{v}{z} \pm \sqrt{\left(-\frac{v}{z}\right)^2 - \left(\frac{2q_0}{q_1 - q_0} + 1\right)}\right] \tag{53}$$

Because the ratio $-v/z$ is normally greater than one and the square root must be positive, the only acceptable solution is

$$t_{opt} = \frac{(q_1 - q_0)}{k}\left[-\frac{v}{z} - \sqrt{\left(-\frac{v}{z}\right)^2 - \left(\frac{2q_0}{q_1 - q_0} + 1\right)}\right] \tag{54}$$

So when the unit costs are minimized and $z = (a\text{-}c)q_0 + b - v$, the solution of the model is analogical with the expansion case. Using another notation

$$\frac{t_{opt}}{T} = -\frac{v}{z} - \sqrt{\left(-\frac{v}{z}\right)^2 - \left(\frac{2q_0}{q_1 - q_0} + 1\right)} \tag{55}$$

It must be noted that $T = (q_1\text{-}q_0)/k$ and z are determined differently than for the expansion investment. Now z describes cost advantage after replacement, i.e. there are not fixed costs and higher marginal costs of the old machine after the replacement. The same curves as in Figure 15 can be used, but now $\alpha = -v/z$ and $\beta = (q_1\text{-}q_0)/q_0$.

It is assumed that the production capacity of the old machine is 100, and the capacity of the new machine is 300 thousand tonnes per year, and the income statements are the following (MFIM/year):

	Old machine		New machine	
Net sales	400	100%	1200	100%
Variable costs	200	50%	480	40%
Fixed costs	160	40%	360	30%
Profit	40	10%	160	30%

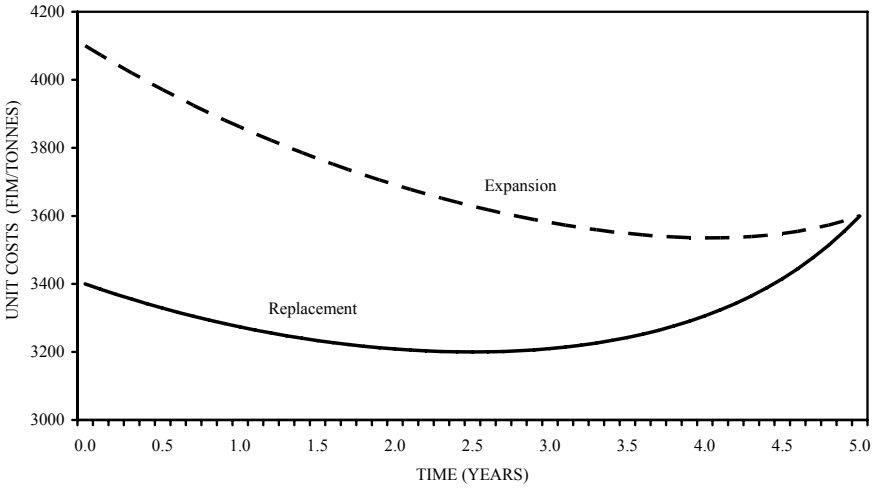

Figure 18. Case solutions of the expansion and the replacement in the unit cost model.

The time window T = (300 000 tonnes/year - 100 000 tonnes/year) / 40 000 tonnes/year/year = 5 years is the same as in the expansion case. When $\alpha = 2.25$ and $\beta = 2$, then $\tau = 0.50$. Clearly, the necessity to replace the old machine is a strong motivator for the investment. Because the demand of the old machine can be shifted to the new machine, the replacement investment can be made typically earlier than in pure expansions (Appendix 1). Of course in this example there is also a remarkable cost difference between the new and the old machine (Figure 18).

6.8 Capacity Cutting

The way to find the optimal changing moment when capacity is added with expansion or replacement investments was discussed above. If capacity must be cut off instead (cf. Figure 18), the situation becomes the reverse, and the question is when moving from a higher long term capacity level to a lower one is optimal. Some short-term or seasonal variations exist in product markets, but also long-term development trends in demand can often be found. The equations presented above assume that the decision makers have a reasonable view of the trend during the planning period.

Equations 38 and 54 can be used also for capacity cutting purposes. The optimal capacity cutting time is then

$$u_{opt} = T - t_{opt} \tag{56}$$

and the relative timing

$$\frac{u_{opt}}{T} = 1 - \frac{t_{opt}}{T} \tag{57}$$

It can be considered for example that both the machines presented in the expansion case are in use and the demand falls to a level before the expansion, and it is necessary to adapt the capacity to the new situation. The machine owner probably wants to know when to sell the new machine and keep only the old one. Because t_{opt}/T was 0.81, thus $u_{opt}/T = 0.19$, the optimal solution is to sell the machine about one year after the turning point, if the demand level is evaluated to prevail. These kinds of calculations give us reason to suspect that in cost minimizing sense, capacity changes often happen too early for the higher and too late for the lower level.

6.9 Concluding Remarks

A solution for the optimal timing of capacity change, when unit costs are minimized in a planning period, was presented above. Naturally there are some simplifications that reduce the suitability of the model to practice and give reason to criticism. The model does not include the inventory possibility, but on the other hand it can be said that an inventory gives only short-term flexibility to the firm, and does not solve long-term capacity problems. There are also many situations where a firm has no inventory at all in practice.

It is also true that the optimal expansion time can be earlier than the model shows if the new machine can be put to full production in a shorter time, i.e. part or all of the

adjustment is done with the uneconomical old machine. This is because in modern technology low unit costs usually require high capacity utilization rates. These kinds of models are numerical rather than analytical. Of course more complicated solutions give possibilities for further research. It is also clear that more calculations in different situations of capacity changes are needed to verify the applicability of the model in practice. Capacity cutting was only briefly considered and it offers possibilities for further analysis.

The model can be applied in situations where low unit costs and a high capacity utilization rate are central points. Behind the model there is the view about adequate demand and cost advantage in the long run. The main point is how to find suitable capacity adaption time when all production can be sold. When the capacity of the new machine and the growth rate of demand are given, then in fact the planning period, i.e. the period when the new machine is in full use, is fixed. The model cannot be used in cases where the capacity must be all the time bigger than or equal to demand. Also seeking rapid growth often requires earlier timing than the model suggests.

Because the solution is based on minimizing the unit costs of production, other possible decision criteria, such as profit maximization or best possible rate of return are not considered. Some of these points are discussed in the next chapters.

7 PROFIT AND TIMING DECISION

7.1 Profit and New Machine

It is often thought that in a competitive environment the lowest average costs mean also the biggest possible profit in the long run (Honko 1955, p.104). In the short term this is not true because of allocation problems of costs and revenues, and due to the effect which increasing production causes to the price of products (cf. Figure 13).

However, it can be asked what the optimal timing is when a firm tries to maximize its profit. If the product price of the old machine is p_0 [currency unit/unit] and the unit price for the new machine is p_1 [currency unit/unit], the total profit of the two machines in the expansion case is

$$P_E = \int_0^{t_{opt}} (p_0 q_0 - a q_0 - b)\mathrm{d}t + \int_{t_{opt}}^{T} (p_0 q_0 - a q_0 - b + p_1 k t - c k t - v)\mathrm{d}t \tag{58}$$

$$P_E = \tfrac{1}{2} k (c - p_1) t_{opt}^2 + v t_{opt} + T[p_0 q_0 - a q_0 - b - v + \tfrac{1}{2} k T (p_1 - c)] \tag{59}$$

Profit maximization gives the equation

$$k(c - p_1) t_{opt} + v = 0 \tag{60}$$

and so the best timing is

$$t_{opt} = \frac{v}{k(p_1 - c)} \tag{61}$$

or the relative timing

$$\frac{t_{opt}}{T} = \frac{v}{q_1(p_1 - c)} \tag{62}$$

This maximum profit solution depends only on the size and fixed costs of the new machine and the difference of the price and variable costs per unit. If the capacity of the new machine is 200 thousand tonnes per year, and the cost parameters are the same as above, i.e. c = 1.8 thousand FIM/tonne, v = 280 MFIM/year and the price p_1 = 4.0 thousand FIM/tonne, the optimal expansion time t_{opt} / T = 0.64, i.e. 3.2 years (Figure 20, Appendix 2).

Early investments are thus preferable when the fixed costs are small as compared with the planned contribution margin of the product. This is also what common sense says about sensible expansion possibilities, and in this respect the solution is consistent with general cost-volume-profit analysis (chapter 4.3, Kaplan & Atkinson 1989, pp. 30-31). Because the breakeven point x is just the fixed cost per contribution margin per unit, then the relative timing in the expansion case can be presented with the breakeven point and the capacity of the new machine

$$\frac{t_{opt}}{T} = \frac{x}{q_1} \tag{63}$$

When the net sales of the new machine are p_1q_1, the variable costs are cq_1 and the fixed costs are v, then

$$\frac{t_{opt}}{T} = \frac{v/p_1q_1}{1 - cq_1/p_1q_1} \tag{64}$$

If w is the fixed cost per net sales and y is variable costs per net sales then the equation can be presented in the form

$$\frac{t_{opt}}{T} = \frac{w}{1-y} \tag{65}$$

This is presented in Figure 19, which says that if the shares of fixed and variable costs are small, i.e. the profits are remarkable, then early investments can be suggested. If the amount of fixed costs is small and the share of variable costs is moderate, then the timing possibilities of the project are generally large.

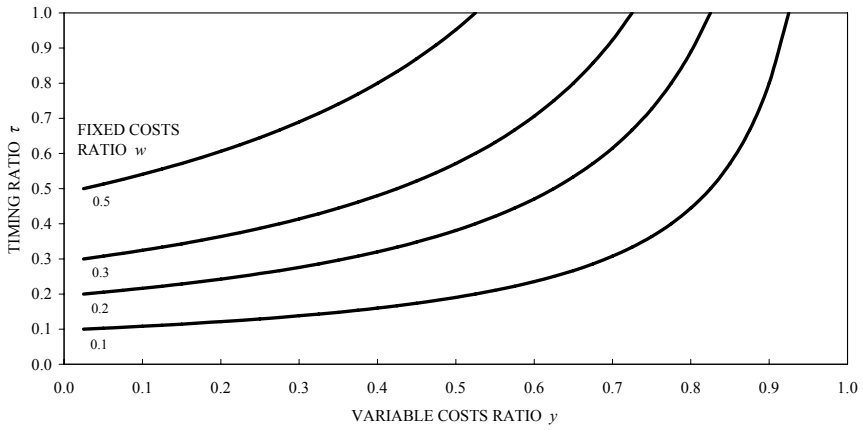

Figure 19. Timing ratio as a function of variable and fixed cost ratios.

It can be asked further, what new unit price p_1 will fulfill both equations 40 and 62? In other words, the timing that minimizes the unit costs and maximizes the total profit of the period is tried to be found. Thus, the setting

$$\frac{v}{q_1(p_1-c)} = \frac{z}{v} - \sqrt{\left(\frac{z}{v}\right)^2 - \left(\frac{2q_0}{q_1}+1\right)} \tag{66}$$

gives the price

$$p_1 = c + \frac{v}{q_1}\left[\frac{z}{v} - \sqrt{\left(\frac{z}{v}\right)^2 - \left(\frac{2q_0}{q_1} + 1\right)}\right] \tag{67}$$

In the expansion case the price p_1 = 3.5 thousand FIM/tonne minimizes the unit costs and maximizes the profit. This is naturally lower than the unit costs of the old machine (3.6 thousand FIM/tonne), but higher than the costs of the new machine (3.2 thousand FIM/tonne) at full capacity. If it is wished to invest earlier then the price must be higher. Naturally the price level of the new product is a remarkable issue, if the plan is to speed up or delay capacity expansions.

7.2 Profit and Machine Replacement

The extension above looked at the expansion case, but a same kind of solution can be derived also for the replacement alternative, where the profit P_R of the period is

$$P_R = \int_0^{t_{opt}} (p_0 q_0 - a q_0 - b)\,\mathrm{d}t + \int_{t_{opt}}^{T} (p_1 q_0 - c q_0 + p_1 k t - c k t - v)\,\mathrm{d}t \tag{68}$$

$$P_R = \tfrac{1}{2}k(c - p_1)t_{opt}^2 + (p_0 q_0 - a q_0 - b - p_1 q_0 + c q_0 + v)t_{opt} + T[p_1 q_0 - c q_0 - v + \tfrac{1}{2}kT(p_1 - c)] \tag{69}$$

profit maximization gives the equation

$$k(c - p_1)t_{opt} + (p_0 q_0 - a q_0 - b - p_1 q_0 + c q_0 + v) = 0 \tag{70}$$

and so the best timing is

$$t_{opt} = \frac{v - b - (a - c)q_0 - (p_1 - p_0)q_0}{k(p_1 - c)} \tag{71}$$

or using another notation

$$\frac{t_{opt}}{T} = \frac{v - b - (a - c)q_0 - (p_1 - p_0)q_0}{(q_1 - q_0)(p_1 - c)} \tag{72}$$

Equation 72 says quite the same as equation 62 in the expansion case, i.e. early investments are preferable if the change in fixed costs is small compared to the change in the contribution margin.

If the capacity of the old machine is 100 and the capacity of the new machine 300 thousand tonnes per year, the cost parameters are the same as above, a = 2 thousand FIM/tonne, b = 160 MFIM/year, c = 1.6 thousand FIM/tonne, v = 360 MFIM/year, and the price $p_0 = p_1$= 4.0 thousand FIM/tonne, then the optimal expansion time t_{opt}/T = 0.33, i.e. t_{opt}=1.7 years. This is the timing which maximizes the profit of the replacement alternative (Figure 20, Appendix 2).

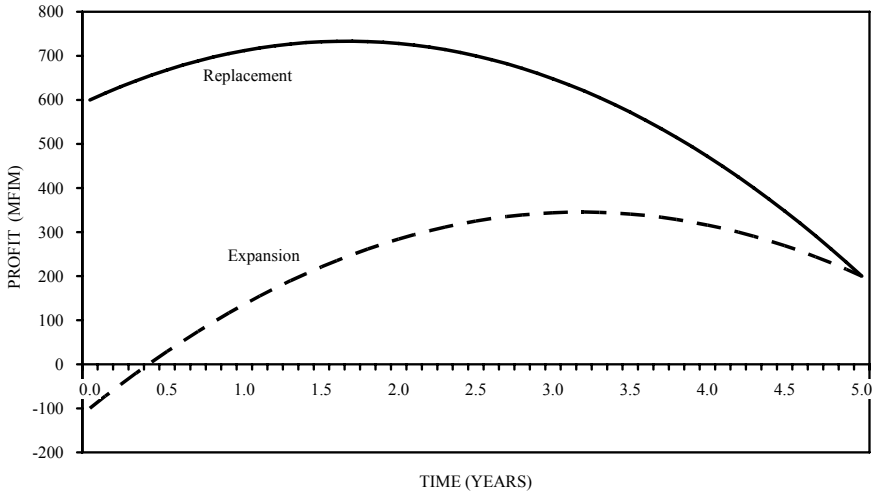

Figure 20. Case solutions of the expansion and the replacement in the profit maximization model.

7.3 Present Value of Profits

The models above have been built without interest rate and inflation, i.e. using real terms. Now the present value of profits can be calculated using the real interest rate r and continuous discounting. When $\int e^{-rt}\,dt = e^{-rt}/r$ and $\int te^{-rt}\,dt = -e^{-rt}(rt+1)/r^2$, the present value of profits is

$$P_{Er} = \int_0^{t_{opt}} (p_0q_0 - aq_0 - b)e^{-rt}dt + \int_{t_{opt}}^{T} (p_0q_0 - aq_0 - b + p_1kt - ckt - v)e^{-rt}dt \qquad (73)$$

$$P_{Er} = (p_0q_0 - aq_0 - b)\left(\frac{1-e^{-rT}}{r}\right) - k(p_1 - c)\left(\frac{e^{-rT}}{r^2}\right)(rT+1) + \frac{ve^{-rT}}{r} + k(p_1 - c)\left(\frac{e^{-rt_{opt}}}{r^2}\right)(rt_{opt}+1) - \frac{ve^{-rt_{opt}}}{r} \qquad (74)$$

So the profit maximization gives the same solution as above,

$$[k(p_1 - c)t_{opt} + v]e^{-rt_{opt}} = 0 \tag{75}$$

and the best timing is

$$\frac{t_{opt}}{T} = \frac{v}{q_1(p_1 - c)} \tag{76}$$

This means that the interest rate does not change the solution of the profit maximization model. The real interest rate can be determined with nominal rate i and inflation f, i.e. $e^r = e^i / e^f = e^{i-f}$, so $r = i - f$. The analysis also says that general inflation does not affect the optimal solution either. It must be noted that the interest rate and inflation naturally lead to different present values of projects, but not to a different optimal solution of timing in this type of a model (Figure 21).

7.4 Net Present Value of Expansion

Next a model extension where the net present value of a single expansion is maximized will be considered. In the models above only period $[0,T]$ is used, but now it is assumed that the lifetime of a machine is N ($\geq T$) and the capital needed for the new machine is I. The net present value of the project at optimal investment time is

$$P_{ErNI} = \int_0^{t_{opt}} (p_0q_0 - aq_0 - b)e^{-rt}dt + \int_{t_{opt}}^{T} (p_0q_0 - aq_0 - b + p_1kt - ckt - v)e^{-rt}dt + \int_T^N (p_0q_0 - aq_0 - b + p_1q_1 - cq_1 - v)e^{-rt}dt - Ie^{-rt_{opt}} \tag{77}$$

Because

$$P'_{ErNI} = k(c - p_1)t_{opt} + v + rI \tag{78}$$

the optimal solution is

$$t_{opt} = \frac{v + rI}{k(p_1 - c)} \tag{79}$$

or

$$\frac{t_{opt}}{T} = \frac{v + rI}{q_1(p_1 - c)} \tag{80}$$

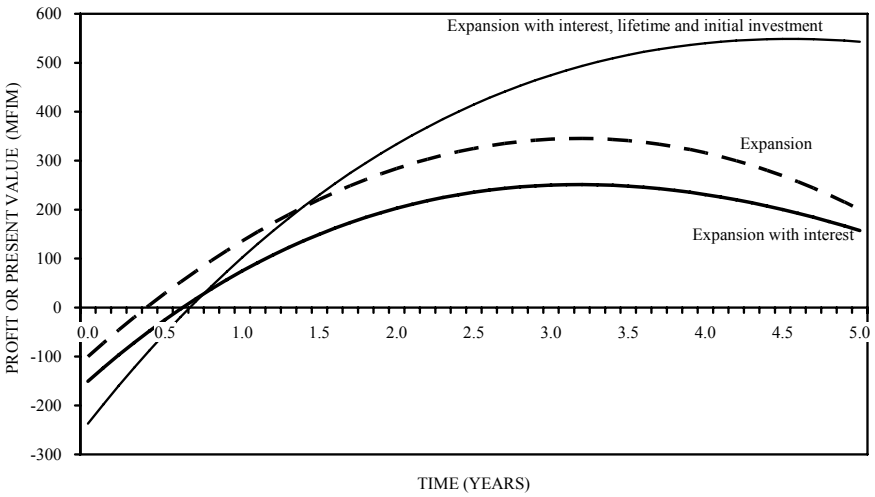

Figure 21. Case solutions of the expansion in the profit maximization model (interests, lifetime and initial investment included).

In this type of a model both the interest rate r and the initial investment defer the optimal timing ($t_{opt}/T = 0.91$, i.e. t_{opt}=4.6 years) as compared to earlier solutions (Figure 21). Lifetime N does not affect the optimal timing, only the level of the net present value of the project (Appendix 2).

7.5 Price and Demand Elasticity of Timing

When higher costs, the discount rate or initial investment delay investments, it can be also asked how large impacts the lower product price or growth of demand have on the optimal timing solutions. When equation 61 is derived for elasticity determination, it gives for price

$$t'_{opt}(p_1) = -\frac{v}{k(p_1 - c)^2} \tag{81}$$

and for demand

$$t'_{opt}(k) = -\frac{v}{(p_1 - c)k^2} \tag{82}$$

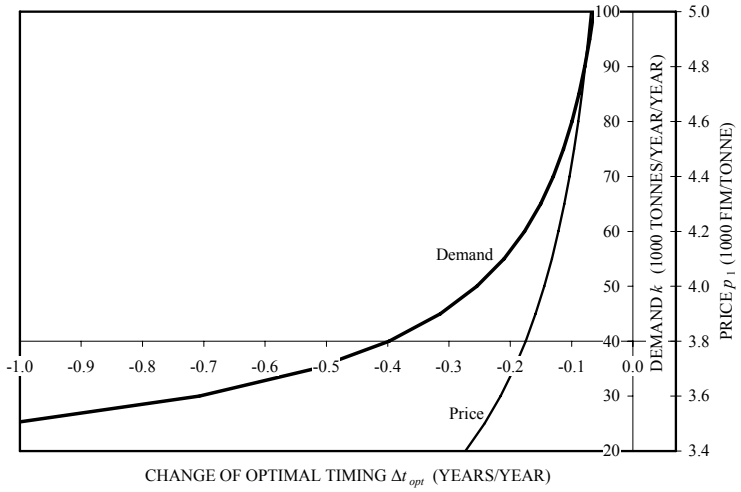

Figure 22. Price and demand elasticity of timing (Δk=5,Δp_1=0.1).

Figure 22 shows, using the above mentioned functions, how the optimal timing changes when the demand or price change. In the relevant case numbers (Appendix 2), demand causes a bigger effect to timing. Alternatively, it is also possible to make numerical sensitivity analysis with different parameters with the built models (Figure 23).

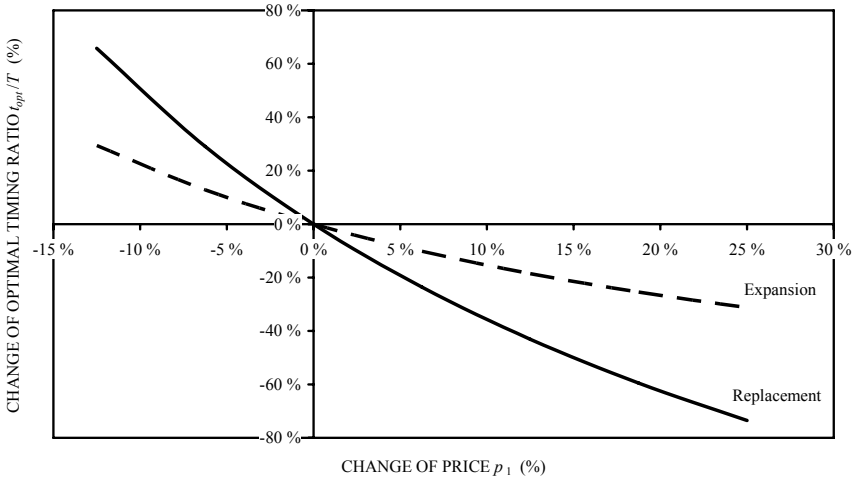

Figure 23. Changes of product price and optimal timing ratio.

If the product price increases in the expansion case by e.g. 25%, then the optimal timing ratio becomes 31% lower. An equal price change in the replacement case means an even 74% lower timing ratio. It must also be noted that the expansion curve is general to all variants of the profit maximization model discussed above. Figure 23 shows that the effect of the price elasticity of timing is much more dramatic to replacement than expansion investments. Typically the acceleration of expansion investments requires bigger changes in price level than replacement decisions.

In Figure 24 it is considered how changes in arithmetical demand growth rate affect the optimal timing. The curve is common to all unit cost minimization and profit maximization models, as well as expansion and replacement situations, e.g. a 25% higher demand growth means 20% earlier investment timing possibilities. It must also be noticed that because the time window (T) is determined with capacity growth (q) and demand growth rate (k), then the timing ratio (t_{opt}/T) is a model-based constant

when the demand growth rate varies. Higher demand growth means also a shorter time window for the decisions.

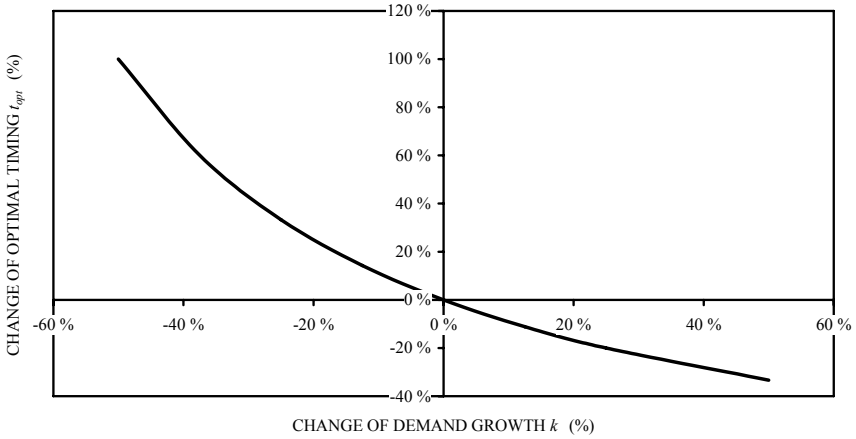

Figure 24. Changes of demand growth and optimal timing.

With the models it can also be analysed how much the optimal timing changes when both the demand growth and product price change at the same time. If for example both increase by 25%, then optimal timing shortens from 3.2 to 1.8 years (-45%) in the expansion case and from 1.7 to 0.4 years (-79%) in the replacement case.

7.6 Capacity Utilization Rate

It is commonly known that low capacity utilization rates mean deficient profitability of projects. If the capacity utilization rate μ is connected to the net present value model discussed above, only the production quantity is lower than the capacity, and so the solution is

$$\frac{t_{opt}}{T} = \frac{v + rI}{\mu q_1 (p_1 - c)} \tag{83}$$

This kind of equation shows that the accepted rate of return and capacity utilization rate both affect the optimal solution. A bigger capacity utilization rate and lower cost of capital make early investments possible. Typically in good years the utilization rates are high and the cost of capital is low, but in bad years they are the opposite in capital intensive industries (Kärri 1998, pp. 7-8).

7.7 Operationalization of Timing Ratio

If the timing ratio model presented in equation 62 is operationalized and the following cost structures are used, only the contribution and operating income margins determine the timing advantage (Kärri 2005). For the operationalization of the model it is marked

Net sales = p_1q_1
- Variable costs = cq_1

Contribution margin = m
- Fixed costs = v

Operating income = o.

If the contribution margin and operating income percentages are $M = m / p_1q_1$ and $\Pi = o / p_1q_1$, then

$$\frac{t_{opt}}{T} = \frac{v/p_1q_1}{1 - cq_1/p_1q_1} \tag{84}$$

$$\frac{t_{opt}}{T} = \frac{(m - o)/p_1q_1}{1 - (p_1q_1 - m)/p_1q_1} \tag{85}$$

$$\frac{t_{opt}}{T} = 1 - \frac{\Pi}{M} \tag{86}$$

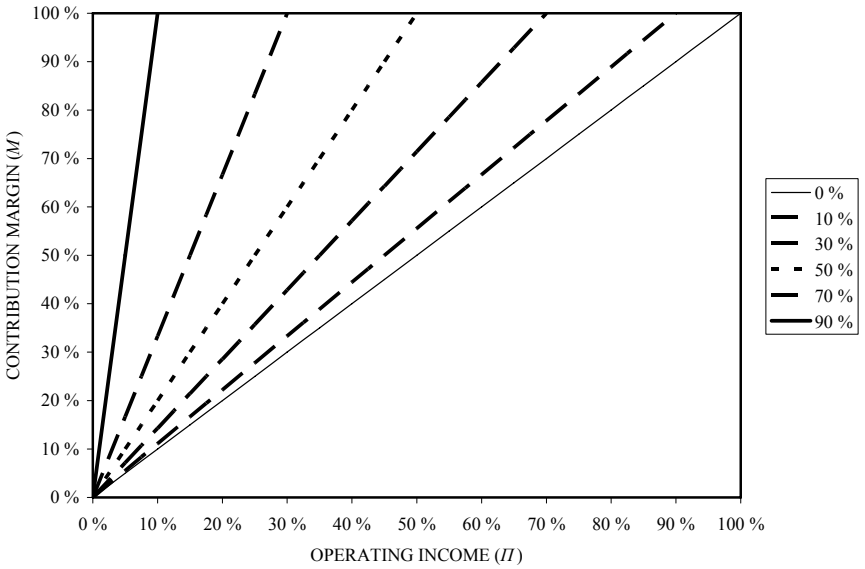

Figure 25. Timing ratio as a function of the contribution margin and the operating income.

As known, equation 86 presents exactly the best timing of the new machine investment. If it is assumed that the cost structure of a company describes also its typical expansion project, then the timing possibilities of firms can be compared with each other. Figure 25 shows that when the difference between the contribution margin and the operating income is low, i.e. the amount of fixed costs is small, then early investments are possible. If both margins are positive and equal, i.e. there are no fixed costs, then a firm can invest immediately. A high contribution margin and low fixed costs naturally give broad possibilities for investment timing. In general when a firm has a low timing ratio its possibilities are strong in the timing sense, and if the ratio is near 100 % or more, the timing possibilities are weak. In certain industries the timing ratios of competitors are natural reference points for the position of an individual firm.

Income statement-based data of the year 2003 of nine global companies were used to test the model (Table 2). It must noticed that in their public income statements most firms give only the cost of products sold and the gross margin, and so the contribution margin cannot be calculated. For testing the model the contribution margin was estimated only for three Finnish forest companies and for the other six companies only

the gross margin, i.e. net sales minus the cost of goods sold, could be calculated. The operating income is in that case gross margin subtracted by nonmanufacturing costs.

Table 2. Timing ratios of selected companies in 2003.

	Net sales millions	Contribution margin %	Gross margin %	Operating income %	Timing ratio %
Stora Enso	12 172 €	38.5		3.3	91.3
UPM-Kymmene	9 948 €	45.5		5.4	88.0
Metsä-Serla	6 044 €	40.9		0.1	99.8
International Paper	25 179 $		25.3	4.4	82.6
Georgia-Pacific	20 255 $		21.8	5.8	73.5
Weyerhauser	19 873 $		29.2	5.9	79.8
Motorola	27 058 $		33.1	4.0	87.9
Nokia	29 455 €		41.5	17.0	59.0
Ericsson	12 973 €		33.0	-9.5	128.9

Table 2 shows that among the Finnish forest industry companies UPM-Kymmene has best investment chances, i.e. it has possibilities to invest earlier than the other companies. Among the U.S. forest companies Georgia-Pacific has a better position than the other two. When forest industry firms implement large capital investment programs, the amount of capital employed and the fixed costs will rise faster than the net sales, which means that the timing ratio is high. In practice, past investments of firms limit their future expansion possibilities. Three knowledge intensive companies, i.e. mobile phone firms offer a comparison point to capital intensive firms. It can be seen that Nokia has the best position, and because of negative operating income, Ericsson has the weakest investment timing possibilities.

The theoretical implication is that the timing ratio can be calculated with the contribution margin and operating income ratios, i.e. standard cost-volume-profit

analysis gives useful information also for this purpose. The empirical implication is that comparable estimates for timing ratios are difficult to calculate with financial statement information for all firms. Most firms reveal only the costs of products sold and the gross margin, and so the contribution margin cannot be calculated. Further study of the applicability of the model is needed, and this can be done by analysing a larger group of firms.

7.8 Evidence of Original Case

To return back to the practical origin of the unit cost model presented in Figure 12, the timing estimates for that particular case are calculated below. The aim is to find some more evidence about the suitability of the model for reality. The costs of the machines are estimated according to public annual review information and the prices of 1979 are used. The building of the new machine was started in 1979, the machine was ready two years later, and full production was achieved in 1984.

The production capacity of the old machine is 150 and that of the new machine 180 thousand tonnes per year, and the income statements are the following (MFIM/year):

	Old machine		New machine	
Net sales	333	100%	364	100%
Variable costs	160	48%	166	46%
Fixed costs	82	25%	55	15%
Profit	91	27%	143	39%

When unit cost minimization criteria are used and $\alpha = 2.88$ and $\beta = 1.2$, then $\tau = 0.50$, i.e. the optimal investmebt time is 2.5 years. If the criterion is to maximize the profit then the estimate for suitable timing is 0.28, i.e. 1.4 years from the point when building starts. The new machine started production after a two-year building stage and it can be said that the investment was well timed in the light of both criteria. This case also indicates that the profit maximization target typically leads to earlier investments than cost minimization. Capital costs have not been included in the fixed costs in the above

calculations. If this is done, then the timing estimates are 0.67 in the unit cost model and 0.63 in the profit model. This says that the total cost principle requires later optimal investments than the operational cost basis.

When scale estimates are calculated by comparing the capacity and costs of the old and the new machine, the values are -0.49 without capital costs and -0.24 with capital costs. It seems that the economies of scale of expansion are exceptionally large. This is mainly because a large share of fixed costs is allocated to the old machine. A much more realistic view is attained if the advantage of a two-machine plant is compared to the single-machine plant situation. Then the equivalent scale factors are 0.82 and 0.85.

This kind of single cases give some evidence about the fact that unit cost minimization and profit maximization models describe the reality and can be used in situations where the limiting factors are valid.

7.9 Concluding Remarks

The solution of the profit maximizing model in the expansion case is simpler than the one where the target is to minimize unit costs, and it emphasizes the adequacy of the contribution margin to cover fixed costs. It can also be said that profit maximization is often a more realistic goal in practice. When the demand increases, profit opportunities make early investments possible, and during falling demand the capacity is cut too slowly.

Timing has only a minor role if cost and price adjustments can be made in a long period of time. If adjustments are not possible, timing is an essential factor which affects the profitability of projects. When a high net present value of a project is sought in the long run, also capacity utilization and the interest rate influence the suitable timing.

The timing ratio can be presented with the contribution margin and operating income ratios. It was also shown that the solution is compatible with cost-volume-profit analysis. In the empirical part of the research the timing ratios were calculated to capital

intensive and knowledge intensive companies. The primary contribution in this case is suggesting an evaluation method for the timing possibilities of firms and testing the model with financial statement-based examples.

8 CASH FLOW MODEL AND TIMING IMPACT

8.1 Structure of the Cash Flow Model

The third model is built for the situation where the old reference machine exists and the new machine is planned. The model is more complex than the previous ones and therefore it is numerical. It is especially considered how start-up time and the average capacity utilization rate affect the net present value of the project and what is the value of the defer option of real investment.

The model is built with a spreadsheet and it consists of the following parts:

- basic data for old and new machines (Appendix 3)
- capital costs and economies of scale factor of the machines
- cost-volume-profit analysis
- weighted average cost of capital
- cash flow of the project (Appendix 4)
- results, i.e. investment criteria
- risk analysis with sensitivity analysis
- value of waiting and real option pricing (Appendix 5 and 6).

The model also includes graphics from essential relationships. With the same logic of the model, the profitability of the old and new machine can be evaluated. The cash flow of the project is calculated the with logic presented in Appendix 4. The investment criteria are based on the cash flow of project, and in this study only the net present value of the project is used in further analysis.

The case figures (Appendix 3) describe the situation where the new paper machine is planned and the figures of the smaller old machine are known. The capacity of the new machine is 400 thousand tonnes per year and the capital investment for it is 504 M€. The sales price of the product is 500 €/tonne and the total production costs are 230 €/tonne. The cost structure is described with percentages and it is given with a certain capacity utilization rate.

The actual capacity utilization rate is the average planning estimate for the whole lifetime of the machine which is 30 years. The start-up time in years is the period, which is needed to attain full average production (Figure 26).

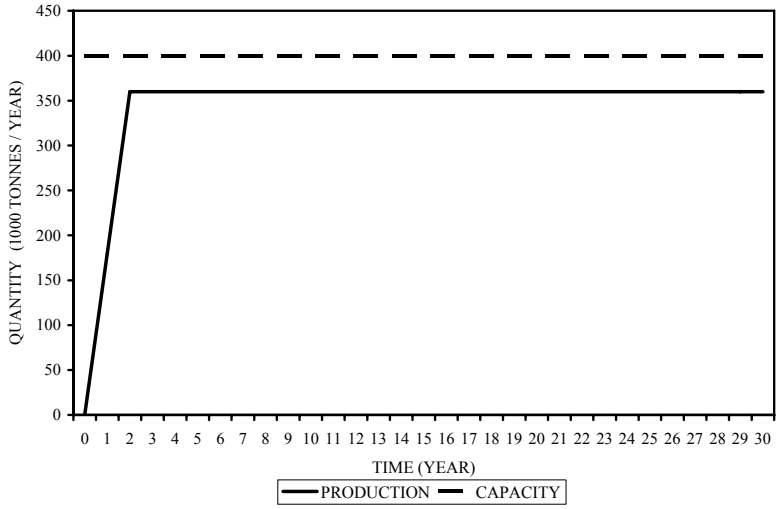

Figure 26. Production and capacity of the planned machine.

The weighted average cost of capital is used as the discount rate (13%) and it is determined with the debt/quity target, beta-factor, risk free rate, market return and average debt rate. The cash flow of the project and the annual net present values with the above mentioned discount rate are presented in Figure 27. It can be seen that for the first five years, the role of inflows is dominating if the project's total net present value is considered. It is also easy to understand that losses can be remarkable if the factory starts up in conditions of low demand and prices.

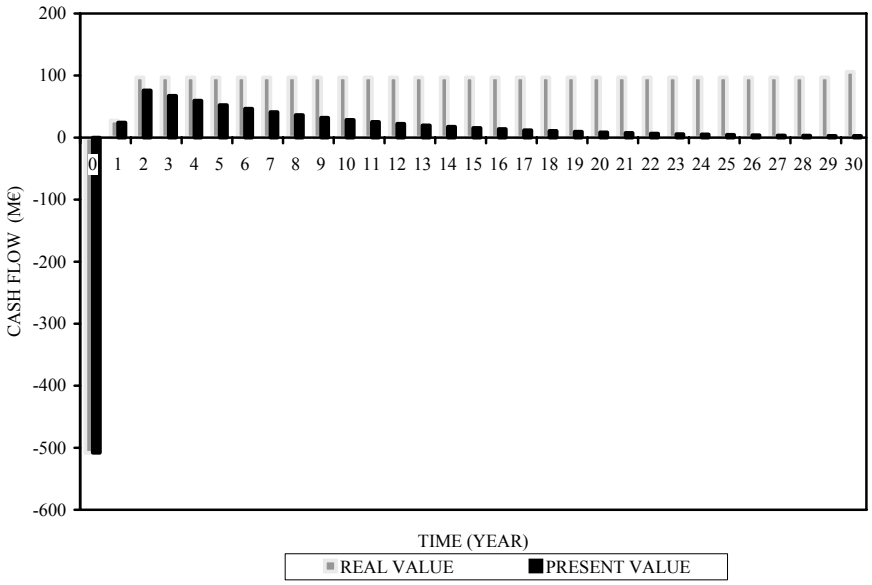

Figure 27. Cash flow of the project.

The net present value of the project is 157 M€ (>0), the internal rate of return is 17% (> 13%), and the payback time without interest is 5.9 year, i.e. the project is profitable with the basic parameters.

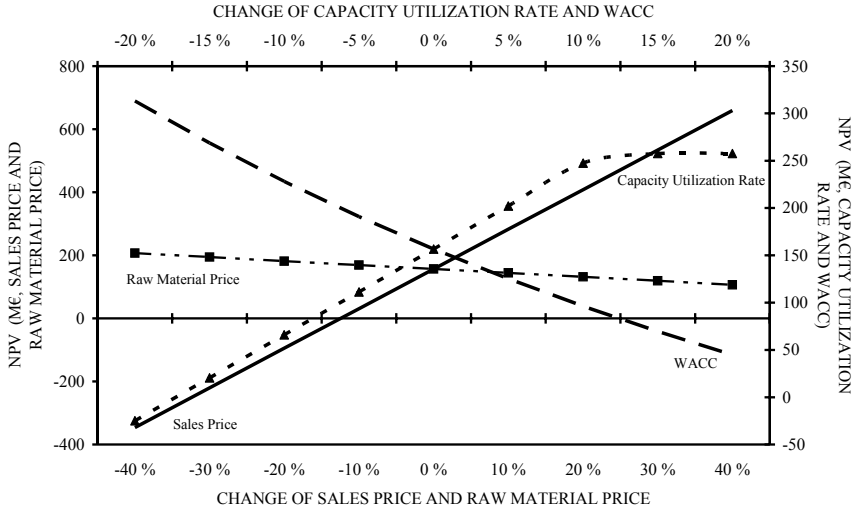

Figure 28. Sensitivity analysis of the project.

One-variable sensitivity analysis in Figure 28 shows that the project comes unprofitable if the sales price decreases over 12% or the capacity utilization rate over 17%, or the discount rate increases about 30%, i.e. from 13% to 17%. The share of raw material of the total costs is 21%, and so the price change does not have a notable role. Next, the timing effects of the project can be analysed.

8.2 Start-up Time and Capacity Utilization of the Project

It is quite common that remarkable industrial projects are not ready for start-up at a suitable time. Because the planning and building time is long, the business cycle can turn to an unfavourable direction. Other possible reasons are deferring factors during the building project or start-up, i.e. technical, quality, environmental, political or project management problems. In capital intensive plant investments the same kind of operational problems can also emerge during the long lifetime. In Figure 29 it is shown how combinations of the start-up time and capacity utilization rate in the long run affect the net present value of the project.

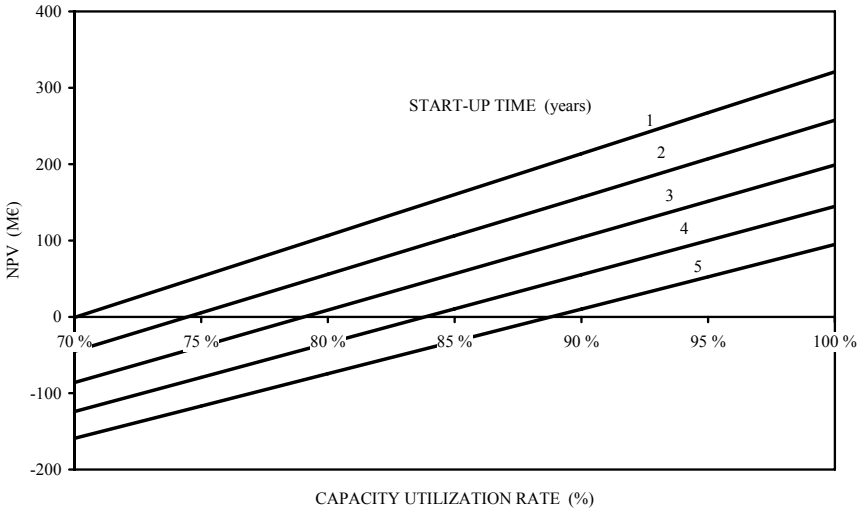

Figure 29. The NPV of the project as function of start-up time and capacity utilization rate.

A one-year delay in the building stage or a 5% lower utilization rate than planned have same kind of effects on the net present value of the project, i.e. about 50 M€, which is 10% of the initial investment or almost one third of the estimated net present value of the project. The consequences to the profitability of the project are catastrophic if the delay is remarkable or the utilization rate remains too low. It is easy to say that the timing of the project must be such that the start-up time is as short and the capacity utilization rate as high as possible.

8.3 Value of Waiting under Certainty

In the previous chapters it was described how traditional sensitivity analysis offers tools for the timing of projects as well. Also the real option approach can be used for modelling the effects of uncertainty to optimal timing. In the model, equations 16 and 18 are used for calculating how waiting can change the net present value of the project.

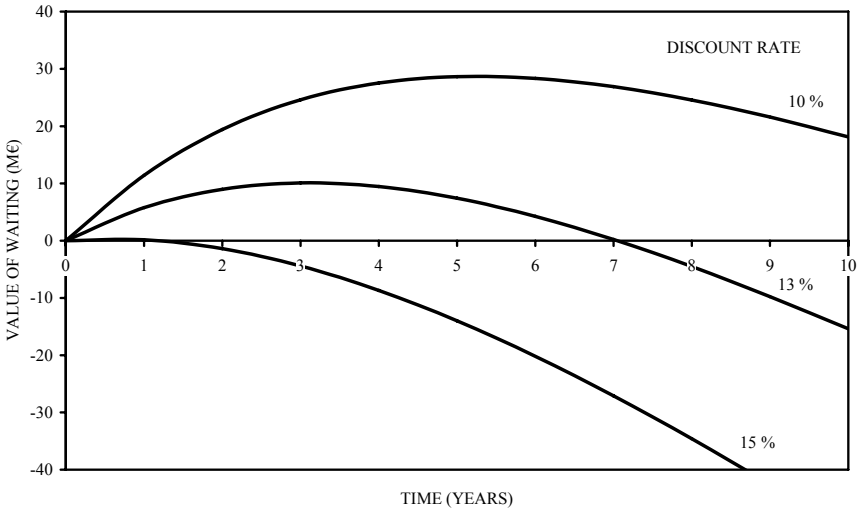

Figure 30. Value of waiting with certainty.

Now it is essential that the initial investment is I=504 M€ and the present value of inflows is V=660 M€, i.e. the net present value of the project is the above mentioned 157 M€. The discount rate of the company is 13%, and a certain value of waiting appears when the drift is e.g. 4 %. This means that the value of inflows is expected

to increase every year at this speed. The optimal waiting time is thus 3.1 years and the value of waiting 10 M€ (Figure 30, Appendix 5), i.e. the firm expects the value of the project to be 167 M€ if it is implemented three years later than originally planned. The same figure shows that the value of waiting can be bigger and the deferral time longer if a lower discount rate is used, and vice versa.

8.4 Value of Waiting under Uncertainty

In the previous chapter it was assumed that the present value of inflows can be forecasted in a deterministic way and so also the optimal delay time can be found. If uncertainty is modelled with normal distribution, option pricing formulas can be used also in real investment projects. Now equations 19-21 are used for this purpose. If the value of inflows 660 M€ is seen as the price of an underlying asset, the initial investment 504 M€ is the exercise price, and the 5% discrete risk free rate (comparable continuous rate 4.9%) is used, then the values for the waiting options can be calculated (Figure 31, Appendix 6).

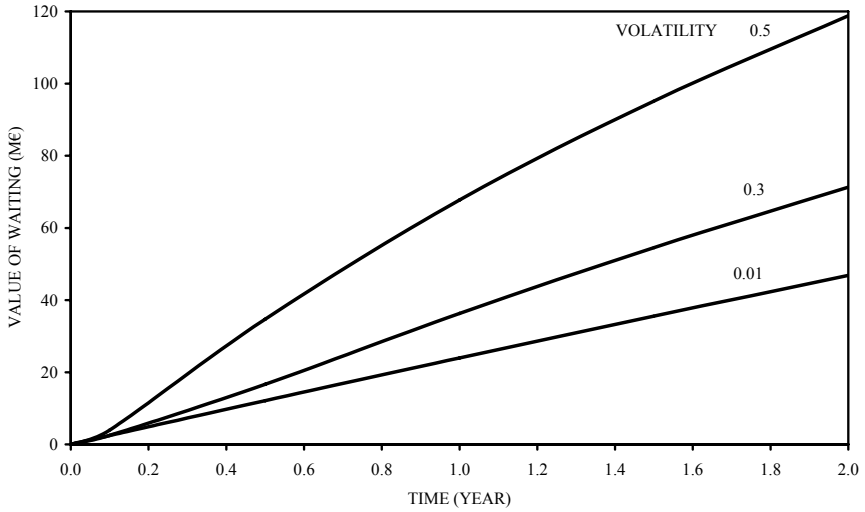

Figure 31. Value of waiting with uncertainty.

It is seen that if the volatility of inflow is high and the expiring time of the option is long enough , then also the value of the waiting option can be remarkable. Also a

higher risk-free rate means higher option values. However, in real projects the volatility estimation is difficult, and thus using option pricing can be a speculative and dangerous area.

8.5 Concluding Remarks

The cash flow model developed above is the most complex of the models of the study and it is also easy to expand. Because of its parameters, the model gives the best possibilities for sensitivity analysis and simulations. The analysis shows that the start-up time and average capacity utilization rate have a remarkable meaning for the profitability of the project, as well as the sensible timing of the project. Business cycles naturally affect both factors.

An interesting question is what is the need for real option analysis in profitability calculations of capital intensive projects. The view of the current study is quite similar to that of many other researchers (Block 2007), i.e. in some cases real option analysis can offer new insights to problems, but without general careful project planning and detailed estimation of basic data there is no solid ground for calculating the option values. With careful planning and implementation of these plans firms can avoid or diminish the risks of expansion projects.

9 TIMING AND FLEXIBLE ASSET STRUCTURE

9.1 Return on Investment and Fixed Assets

Current global problems of forest industry are overcapacity and low product prices. Companies' return on investment is low and far from the targets (cf. Kärri 2000b, p. 12). Old unprofitable factories are closed down and many companies have programs to decrease their operating costs and working capital. Firms' possibilities to big expansion investments in Finland are poor, and new plants are built in low cost countries or near to customers. In these circumstances new capacity investments, i.e. sizing and timing decisions must be based on detailed analysis.

In previous chapters, factors that affect to the timing of individual investment projects were considered. It was shown that flexibility of cost structure makes early investments possible. But how about the whole firm and its structure of fixed assets? The last model and the following equations connect the timing questions and effective capital asset management of a firm.

The following markings of income statement and balance sheet are needed for the developed model. Data of the year 2005 of two case companies are presented here, because the companies are analysed later with the developed model (Stora-Enso 2005, Nokia 2005).

M€/year	Stora-Enso	Nokia
Net sales (A)	13 188	34 191
- Costs	11 403	28 840
Operating margin	1 785	5 351
- Depreciation (D)	1 428	712
Operating income (o)	357	4 639

M€/year	Stora-Enso	Nokia		Stora-Enso	Nokia
Fixed assets (*X*)	13 018	3 347	Equity (*E*)	7 739	12 360
Current assets	5 077	18 951	Long term loans (*Y*)	6 271	268
			Current liabilities	4 085	9 670
Assets	18 095	22 298	Equity and liabilities	18 095	22 298

9.2 Flexible Structure of Fixed Assets

A firm's operating margin percentage

$$O = \frac{o + D}{A} \tag{87}$$

and capital invested

$$H = E + Y \tag{88}$$

When the return on investment is

$$R = \frac{o}{H} \tag{89}$$

then

$$O = \frac{RH + D}{A} \tag{90}$$

$$R = \left(O - \frac{D}{A} \right) \frac{A}{H} \tag{91}$$

Because capital turnover

$$L=\frac{A}{H} \tag{92}$$

then return on investment

$$R=LO-\frac{LD}{A} \tag{93}$$

$$R=LO-\frac{D}{H} \tag{94}$$

When average depreciation time of fixed assets

$$B=\frac{X+D}{D} \tag{95}$$

then

$$D=\frac{X}{B-1} \tag{96}$$

and

$$R=LO-\frac{X}{H(B-1)} \tag{97}$$

The fixed assets ratio is determined in this study as

$$W = \frac{X}{H} \tag{98}$$

and then return on investment can be presented with the help of four parameters

$$R = LO - \frac{W}{B - 1} \tag{99}$$

Equation 99 shows that capital turnover, average operating margin, fixed assets ratio, i.e. past investments and average depreciation time highly determine what a firm's return on investment can be. Better capital turnover, higher operating margin, longer depreciation time and lower fixed assets ratio mean higher return on investment.

9.3 Target for Return on Investment

In practice firms should have targets for return on investment, and the goals naturally affect the investment opportunities and also the timing of the investments of companies. The target for the operating margin ratio can be solved from equation 99 and it is

$$O = \frac{1}{L}\left(R + \frac{W}{B - 1} \right) \tag{100}$$

Next, the figures of the capital intensive Stora-Enso company are analysed and the figures of knowledge intensive Nokia are presented for comparison. The target for the return on investment of Stora-Enso is 13% over the business cycle. In 2005 the actual figure was 3% and the last five year average was 6%. Nokia's comparable numbers were 36% and 34% (Table 3). Why is the return of investment of Nokia over ten times better, even though the operating margin ratios of the companies are almost equal, i.e. 14 and 16%? Explanations can be seen in Figure 33, and they are the higher

capital turnover, lower fixed assets ratio and shorter average lifetime of fixed assets. The cost and asset structures of Nokia are more flexible than the corresponding structures of Stora-Enso.

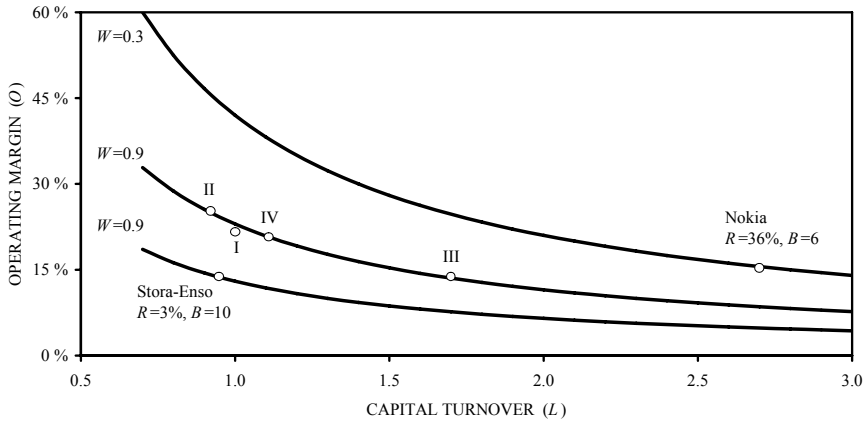

Figure 32. Operating margin target.

The model shows that if Stora-Enso wishes to attain its goal for the return on investment it has to increase ceteris paribus its net sales by 11%, decrease its total costs by 13%, or decrease its fixed assets by 47%. It is quite clear that in the current situation all the above mentioned actions are unrealistic alone, but they show how difficult the situation of the company is. A much more realistic scenario can be e.g. to sell or close down about 20% of the capacity. If this means approximately 15% less costs and 7% less sales, the target level of 13% of return on investment can be attained (Table 3).

Table 3. Actual and target return on investment and timing ratios.

	Nokia	Stora-Enso				
	Actual		Target scenarios			
Situation and actions	2005	2005	Sales +11% (I)	Costs -13% (II)	Fixed assets -47% (III)	Sales -7%, Costs -15%, Fixed assets -20% (IV)
Return on investment (%)	36	3	13	13	13	13
Operating margin (%)	16	14	22	25	14	21
Capital turnover	2.7	0.94	1.0	0.94	1.7	1.1
Fixed assets ratio	0.27	0.93	0.93	0.93	0.87	0.91
Lifetime (years)	5.7	10.1	10.1	10.1	10.1	10.1
t_{opt}/T (%)	61	93	72	70	79	73
u_{opt}/T (%)	39	7	28	30	21	27

The timing ratio for capacity expansion was in equation 86 determined as the function of operating income and contribution margin ratios, $t_{opt}/T = 1 - \Pi / M$, and the timing ratio for capacity cutting in equation 57, $u_{opt}/T = 1 - t_{opt}/T$. Table 3 shows that Nokia's timing possibilities are better in both capacity expansion and cutting situations. The timing ratios of Stora-Enso show that its possibilities to expansion investments are limited and capacity cutting is highly recommended. It is unlikely that the product

prices will rise sharply or the essential costs, i.e. wood, energy or personal costs, can be decreased dramatically. It seems that the only realistic way is to sell or close about 20% of the fixed assets of the company. If unprofitable units are sold or closed, it will reduce the costs proportionally more than decrease sales.

9.4 Disappearing Problem

If a firm has no fixed assets, i.e. W=0, then equation 99 says

$$R = LO \tag{101}$$

Of course in that case the firm has no capital investment or timing problems either. The problem is transfered wholly to network partners, subcontractors or suppliers. When the flexibility of assets and cost structure is increased, then typically also the timing possibilities become better. On the other hand, the economies of scale offered by own machines are lost. When the asset structure is flexible, efficient management of working capital also becomes an important question. The idea of larger flexibility of cost and asset structures is a quicker response to changes in the business environment.

9.5 Change of Capital Investments

The net working capital Z is current assets minus current liabilities and the capital employed is also the sum of the net working capital and fixed assets

$$H = E + Y = Z + X \tag{102}$$

Comparable net working capital and fixed asset rates are thus

$$l = \frac{Z}{A} \tag{103}$$

and

$$s = \frac{X}{A} \tag{104}$$

Now equation 99 can be written in the following form

$$R = \frac{1}{l+s} O - \frac{1}{1+(l/s)(B-1)} \tag{105}$$

The equation is useful, when a company has defined goals for return on investments and operating income ratios, and fixed and working capital need is forecasted on the basis of these (Kärri 2000b). This means that the change of investments is bound to the change of sales in the long run.

9.6 Concluding Remarks

The model presented above has same features as sustainable growth models (e.g. Talonen 1973, Aho 1993), which typically connect to growth, profitability and capital structure ratios of firms. However, these models do not highlight the fixed asset flexibility and timing questions of investments.

In the fourth model it was considered how a firm's asset structure affects the timing of investments. It was emphasized that firms with flexible asset and cost structures have also good timing possibilities for future investments. It can be said that network economy reduces and shares the risks of capital investment and also the risks of investment timing with the new way. It seems that firms which have low return on investment and poor flexibility of asset and cost structures are forced to restructurings in the modern global business environment.

10 RESULTS

10.1 Main Results

The main results of the study are the following four models and their implications:

Unit cost model - cost advantage with timing

- optimal timing solutions for expansion and replacement investments, when unit costs are minimized
- analogical capacity cutting equation

Profit maximization model - better profitability with timing

- optimal timing solutions for expansion and replacement investments, when profit is maximized
- compatibility of the solution with cost-volume-profit analysis
- operationalization of the developed timing ratio

Cash flow model - value with timing options

- effects of capacity utilization rate and start-up time to the net present value of a project
- analysis of the value of waiting options under certainty and uncertainty in capital intensive context

Flexible asset structure model - higher return on investments with timing

- flexible asset structure model
- connections of the flexibility of fixed asset and the timing ratios.

10.2 Evaluation of the Models

The relevance, reliability, validity and applicability of the models must always be evaluated. The present study is based on the analysis and modelling of factors that affect capacity changes. A general danger in this kind of models is that the results of the reasoning are self-evident, and they do not shed any new light on the issue

considered, i.e. the model has no relevance. If so, the matter involved is a group of useless calculations without any connections to the reality. On the other hand, it can be said that it is just the role of a continuous modelling process to reject unsuitable expressions and replace them with better solutions.

The simplifications and restrictions made naturally affect the reliability and validity of the developed models. Assumptions from linear cost functions, the aritmetical growth rate of demand, economies of scale and capacity levels have been made in the study. There is an assumption of a certain kind of stochastic process behind the values of waiting options as well. Despite the above mentioned limitations, basic timing principles have been presented and more realistic models can be developed as a part of further research.

Models applicability to practice obviously needs further research. The logic and applicability of the models has been verified with single cases, which is not a wholly satisfactory solution. Of course, testing the models with a large number of cases would be fruitful, but the main restriction for this is the availability of comparable and correct project data. It must also be noted that capital investment planning is outlining of the future and history does not tell all about future events. As mentioned above, some operational restrictions must be carefully considered when the models are applied to real cases. The measurement of capacity in multiproduct companies, uncertainty in demand forecasts, and the determination of categories and extent of costs are the main problem areas when the models are used.

Despite the restrictions mentioned above, it can be said that the models have also some clear benefits. The solutions are easy to understand and use for most managers, and the models offer tools with which to compare the timing effects of different expansion and replacement alternatives. The solution of the unit cost minimization model for expansion and the replacement situations can be presented with the same graphic curves (Figure 15), which emphasize how the relative timing ratio depends on the cost advantage and the capacity ratios. The curves show how early expansion investments require remarkable cost advantage or big capacity leaps, and if these are not obtainable, then the capacity replacement alternative is preferable.

When the purpose is to maximize the profit, the optimal timing solution in the expansion case is even more simple than the corresponding solution of the unit cost model. It was also shown that the fixed costs and the contribution margin largely determine the best timing in the profit maximization situations. From the theoretical point of view, the developed models can deepen the understanding of the nature of capacity changes.

In the third model it was considered how the waiting option can be connected to the traditional discounted cash flow of new machine investment. It was shown that despite the value of waiting can be remarkable, also the start-up time and the average capacity utilization rate highly determine the probitability of a project and thus affect also the timing of new machine investment. With the fourth model it was shown that the cost and asset structure of firms and the timing question of projects are not independent things. It was emphasized that a greater flexibility of these structures gives larger timing possibilities for firms.

10.3 Managerial Implications

In practice there seems to be two opposite schools of industrial managers:

1) the timing of projects and early cash flows have a dramatic impact on the profitability of the expansion project
2) the timing decision is a secondary problem because of the long lifetime of the plant.

This study gives support to the former argument and shows that timing can have an essential effect on the costs and profitability of a project in a global and competitive business environment. The developed models also offer some empirical suggestions to capital intensive industry and especially to forest industry managers:

- greater flexibility of fixed assets is needed in capital intensive industry in the future
- models give support to Finnish forest companies' recent capacity selling and cutting decisions

- the results show that losses can be massive if the start-up time is longer or the capacity utilization rate remains lower than planned
- replacement investments can be done earlier than pure capacity expansion projects.

10.4 Relation to Other Research Results

What is actually new in this particular study? The target of the first two models was to find the timing which minimize the unit costs of products or maximize the profit of the firm. In the earlier capacity expansion and location studies (Manne 1967, Whitt 1981, Luss 1982 and Lieberman 1989) timing has been in a secondary role, but in this work the main emphasis is just on the timing question. Four points of contribution can be mentioned. First, exact analytical solutions to the formulated problems of capacity expansion and replacement are shown. Secondly, capacity expansion and replacement decisions were described with the same type of logic for easy comparison. Thirdly, it was shown how the timing question can be associated with the standard cost-volume-profit analysis , and fourthly, the models provided clear suggestions for companies.

Timing is not presented in the current models as a fixed cycle as e.g. in Manne's model, and on the other hand it is not stochastic as e.g. in the Newsboy model or in the value of waiting -type models. The planning horizon of the models is also not so long as in the early capacity models. The presented timing estimates are relative, and they try to quantify the question of whether it is preferable to invest sooner or later. The models can be also related to different capacity strategies. The central point then is that the models can be applied in situations where there are many competitors in the market and the risk of an unfavourable outcome is high. The models suggest a timing in which capacity is in approximate equilibrium with demand, i.e. capacity does not lead the demand nor does it lag behind the demand. Even though the models are single period models, they do not exclude the role of technological progress and economies of scale, which lie behind the cost parameters.

In models three and four the view was extended by analyzing the effects of uncertainty and flexibility. The value of waiting -options (McDonald & Siegel, 1986, Dixit &

Pindyck 1994) can be connected to the traditional discounted cash flow model of a capital intensive project. However, it is difficult to find the exact timing solution, because of the great variation of calculated option values. The effects of the value of waiting can be described quite well in option models, but they are complicated management tools in projects where the bound capital is huge and the lifetime of equipment is long. The flexible asset structure -model has features of earlier sustainable growth models (e.g. Talonen 1973, Aho 1993), but the central difference is that it emphasizes the timing and need of fixed asset dynamics.

10.5 Further Study

The study offers five kinds of possibilities for further research. First, the existing models can be expanded by including additional parameters or other type of demand and cost functions. Of course this will lead to more complicated solutions, which are rather numerical than analytical in realistic situations. Secondly, the applicability of the models could be evaluated by a larger group of real project or company data. A preliminary view shows that the models can give sensible timing estimates when the possibilities of capital investments of firms or industries are considered. Thirdly, the applicability of the value of waiting -types options and stochastic processes need further considerations in the context of capital intensive projects. Fourth, the role of timing is an unclear issue in the context of capital investment and decision making processes. Fiftly, the timing of restructurings and the economies of scale achieved with them are also interesting areas for further research.

11 CONCLUSIONS

Capital investment decisions are often presented as a selection problem between different alternatives. At the end the choice is whether a certain project is executed or rejected. This particular question can also be seen in a different light. It can be asked, when is the optimal time to invest in a certain project. This work has considered the facts which determine the choice of optimal investment time.

Clearly, every significant investment decision is unique, and all features cannot be considered in general models. The timing of a project is seldom totally determined by a single factor, such as technology development, the competition environment, financial possibilities, quality requirements or economies of scale, but often one factor dominates the decision. The essential question is that the relevant factors and their relations are included in the models in each situation.

Decreasing product prices means in most industries that some kind of economies of scale must be achieved. Good timing of capacity additions offers one possible way to realize cost advantages in a competitive environment. Then the firm has a temporary possibility to better profitability than its competitors. Naturally, in a competitive environment remarkable profits are possible only at a certain period or in a particular geographic area.

Several matters influence how firms expand their capacity in practice, and typically capacity decisions have strategic and operational dimensions as well. When hard price competition, technological progress, capacity leaps and economies of scale are considered in capital intensive industries, unit cost minimization is an essential target. Despite the fact that unit cost minimization is in the background of good profitability, especially in traditional industries, the timing of capital investment is often unsuitable in the cost minimization sense.

In the current study, a unit cost minimization model for the optimal timing of capacity expansion and replacement was built. It was shown that the model has an analytical solution, and the relative timing of projects depends on the capacities of machines

and the achieved cost advantage. The central result is a curve that gives a possibility to compare different expansion or replacement alternatives with each other, and get a systematic view of their timing effects. It was shown that the optimal timing of expansion and replacement investments, i.e. timing ratios can be presented with capacity and cost advantage ratios. Behind these ratios is the economies of scale -effect. Cost advantage can be realized either as lower variable or fixed costs. Naturally the capacity addition can happen earlier, if the cost advantage is remarkable. A competitive environment often prefers early investments, but on the other hand it is not necessarily wise to invest too early due to the fact that cost minimizing requires high enough demand. Because of existing demand, replacement decisions are typically easier to make earlier than expansion decisions. The developed unit cost model can also be applied to capacity cutting situations.

The extensions of the model connect the price of the product and the profit goal to capacity changes. In the profit maximization case of expansion, only the breakeven point and the capacity of the new machine determine the optimal timing. It was shown that early investments are preferable if the fixed costs are small compared to the contribution margin.

Further analysis with the discounted cash flow model showed that the average capacity utilization rate and start-up time of a project also have a meaning in practice. The value of the waiting option can be connected to the traditional cash flow model. However, it is emphasized that in real projects the walue of waiting -type analysis with option pricing can be dangerous, because of estimation problems of volatility.

The last model shows that the flexibility of cost and asset structures gives the broadest timing possibilities to companies. It is also shown that at company level, sensible timing estimates can be calculated for capacity adding or cutting situations, and firms can be compared with these ratios.

It can be said that the presented models combine the strategic view from the production level to the operational production costs and the actual demand trend. The optimal timing of expansion is not necessarily a passive thing, i.e. fixed cycle time or stochastic

variable, as many early studies present. The suggested timing measures of the study are rather relative and continuous changing estimates, and they give the decision makers an active view of whether it is preferable to expand the capacity sooner or later in unit cost minimizing or profit maximization sense.

The central argument of the dissertation is that different timing alternatives and their effects on the profitability of capital investment projects are a poorly understood topic in theory and in practice. The models and approaches presented in the study may partly help to improve the state of affairs.

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APPENDIX 1: Calculations of the Case Solution, Unit Cost Minimization

	Expansion	Replacement
q_0 (1000 tonnes/year)	**100**	100
q_1 (1000 tonnes/year)	**200**	**300**
a (1000 FIM/tonne)	**2**	2
b (MFIM/year)	**160**	160
c (1000 FIM/tonne)	**1.8**	**1.6**
v (MFIM/year)	**280**	**360**
k (1000 tonnes/year/year)	**40**	40

		Expansion		Replacement
T (years)	q_1/k	5	$(q_1-q_0)/k$	5
z (MFIM)		460		-160
z/v		1.64	$-v/z$	2.25
q_0/q_1		0.5	$(q_1-q_0)/q_0$	2
α		1.64		2.25
β		2		2
τ		0.81		0.50
t_{opt} (years)		4.03		2.50
		MIN		MIN
Values of optimization criteria		3535		3200

t	C_E	Q	C_E/Q	C_R	C_R/Q
year	MFIM	1000 tonnes	FIM/tonne	1000 tonnes	FIM/tonne
0.0	4100	1000	4100	3400	3400
0.1	4072	1000	4072	3384	3384
0.2	4043	999	4046	3367	3369
2.1	3353	912	3678	2923	3206
2.2	3310	903	3664	2893	3203
2.3	3266	894	3652	2863	3201
2.4	3221	885	3640	2832	3200
2.5	3175	875	3629	2800	3200
2.6	3129	865	3618	2768	3200
2.7	3082	854	3608	2735	3201
2.8	3034	843	3598	2701	3203
3.9	2460	696	3536	2289	3290
4.0	2404	680	3535	2248	3306
4.1	2347	664	3535	2206	3323
4.2	2289	647	3537	2164	3343
4.3	2230	630	3539	2120	3365
4.9	1864	520	3585	1848	3555
5.0	1800	500	3600	1800	3600

APPENDIX 2: Calculations of the Case Solution, Profit Maximization

p_0 (1000 FIM/tonne)	**4**	
p_1(1000 FIM/tonne)	**4**	
r (%)	**10 %**	
I (MFIM)	**1200**	
N (year, $\geq T$)	**30**	
Other parameters same as in model MIN(C/Q)		

	Expansion	Replacement	Expansion			Expansion
T (years)	5	5	5			5
τ	0.64	0.33	0.64			0.91
t_{opt} (years)	3.18	1.67	3.18			4.55
	MAX	MAX	MAX			MAX
	345	733	251			549

t year	P_E MFIM	P_R MFIM	P_{Er} MFIM	P_{ErN} MFIM	I (NPV) MFIM	P_{ErNI} MFIM
0.0	-100	600	-151	963	1200	-237
0.1	-72	616	-123	990	1188	-198
0.2	-46	630	-97	1017	1176	-160
1.5	221	732	150	1263	1033	230
1.6	235	733	162	1276	1023	253
1.7	249	733	174	1287	1012	275
1.8	261	732	184	1298	1002	295
1.9	273	731	194	1307	992	315
2.8	339	672	246	1360	907	453
2.9	342	660	249	1362	898	464
3.0	344	648	250	1364	889	475
3.1	345	635	251	1364	880	484
3.2	345	620	251	1365	871	493
4.4	280	375	207	1321	773	548
4.5	269	348	200	1314	765	549
4.6	257	320	193	1306	758	549
4.7	244	292	184	1298	750	548
4.9	216	232	167	1280	735	545
5.0	200	200	157	1271	728	543

APPENDIX 3: Basic Data of the Cash Flow Model

PAPER MILL			
	Choice:	**N**	Have to be capital capital letter O or N
	New (N)	**Old (O)**	**New (N)**
Capacity (1000 tonnes/year)	400	**280**	**400**
Initial investment (M€)	504	390	504
Net working capital (%)	5 %	**5 %**	**5 %**
Sales price (€/tonne)	500	**500**	**500**
Cost structure (at a certain utilization rate)			
Capacity utilization rate	90 %	**90 %**	**90 %**
Total production costs (€/tonne)	230	**260**	**230**
Variable costs (%)			
Raw material	21	**23**	**21**
Chemicals	9	**9**	**9**
Energy	20	**20**	**20**
Other	10	**10**	**10**
Variable costs (%)	60	62	60
Fixed costs (%)			
Maintenance	6	**6**	**6**
Personnel and administration	22	**20**	**22**
Other	12	**12**	**12**
Fixed costs (%)	40	38	40
Total costs (%)	100	100	100
Actual capacity utilization rate	**90 %**		
WACC (%)	13.0 %		
Start-up time (years)	**2**		

APPENDIX 4: Logic of the Cash Flow Model

Time	Production	Revenues	Variable costs	Fixed costs	Operating margin	Initial investment	Net working capital	Cash flow	Discounting factor	Present value	Cumulative cash flow		Cumulative cf with interest	
	1000 t	M€	M€	M€	M€	M€	M€	M€		M€	M€		M€	
0	0	0	0	0	0	-504	-5	-508	1.000	-508	-508		-508	
1	180	90	25	33	32		-5	28	0.885	24	-481		-484	
2	360	180	50	33	97		0	97	0.783	76	-384		-408	
3	360	180	50	33	97		0	97	0.692	67	-286		-341	
4	360	180	50	33	97		0	97	0.612	60	-189		-281	
5	360	180	50	33	97		0	97	0.542	53	-92		-228	
6	360	180	50	33	97		0	97	0.479	47	5	5.9	-182	
7	360	180	50	33	97		0	97	0.424	41	102		-141	
8	360	180	50	33	97		0	97	0.375	36	200		-104	
9	360	180	50	33	97		0	97	0.332	32	297		-72	
10	360	180	50	33	97		0	97	0.293	29	394		-43	
11	360	180	50	33	97		0	97	0.260	25	491		-18	
12	360	180	50	33	97		0	97	0.230	22	588		4	11.8
13	360	180	50	33	97		0	97	0.203	20	686		24	
14	360	180	50	33	97		0	97	0.180	17	783		41	
15	360	180	50	33	97		0	97	0.159	15	880		57	
16	360	180	50	33	97		0	97	0.141	14	977		70	
17	360	180	50	33	97		0	97	0.124	12	1074		83	
18	360	180	50	33	97		0	97	0.110	11	1172		93	
19	360	180	50	33	97		0	97	0.097	9	1269		103	
20	360	180	50	33	97		0	97	0.086	8	1366		111	
21	360	180	50	33	97		0	97	0.076	7	1463		119	
22	360	180	50	33	97		0	97	0.067	7	1560		125	
23	360	180	50	33	97		0	97	0.060	6	1658		131	
24	360	180	50	33	97		0	97	0.053	5	1755		136	
25	360	180	50	33	97		0	97	0.047	5	1852		141	
26	360	180	50	33	97		0	97	0.041	4	1949		145	
27	360	180	50	33	97		0	97	0.036	4	2046		148	
28	360	180	50	33	97		0	97	0.032	3	2144		151	
29	360	180	50	33	97		0	97	0.029	3	2241		154	
30	360	180	50	33	97		9	106	0.025	3	2347		157	
				AVG	95		IRR	0.17	NPV	157	PB	5.9	PB(i)	11.8

APPENDIX 5: Value of Waiting, Deterministic Case

ω	**4.0 %**		
I (M€)	504		
V(M€)	660		
r (continuous)	12.3 %	13 %	(discrete rate)
t* (years)	3.10		

t year	$e^{\omega t}$	$Ve^{\omega t}$ M€	e^{-rt}	$(Ve^{\omega t})e^{-rt}$ M€	Ie^{-rt}	F M€	Value of waiting M€
0	1.0000	660	1.0000	660	504	157	0
1	1.0408	687	0.8846	608	446	162	6
2	1.0833	715	0.7825	560	394	166	9
3	1.1275	745	0.6922	515	349	167	10
4	1.1735	775	0.6124	475	308	166	9
5	1.2214	807	0.5417	437	273	164	7
6	1.2712	840	0.4792	402	241	161	4
7	1.3231	874	0.4239	370	214	157	0
8	1.3771	909	0.3750	341	189	152	-5
9	1.4333	947	0.3317	314	167	147	-10
10	1.4918	985	0.2934	289	148	141	-15
					MAX	167	10

ω = 4 %

r		9.5 %		12.3 %		14.0 %
t	F	10 %	F	13 %	F	15 %
year	M€	M€	M€	M€	M€	M€
0	342	0	157	0	68	0
1	342	0	162	6	79	11
2	340	-1	166	9	87	19
3	337	-4	167	10	92	25
4	333	-9	166	9	95	28
5	328	-14	164	7	96	29
6	322	-20	161	4	96	28
7	315	-27	157	0	95	27
8	307	-35	152	-5	92	25
9	299	-43	147	-10	89	22
10	291	-51	141	-15	86	18

APPENDIX 6: Value of Waiting, Stochastic Case

Real option:			
V = present value of project inflows (M€)		660	▲
I = initial investment (exercise price, M€)		504	▼
r_f = risk free rate (continuous, %)		4.88 %	▲
t = time to expiration (years)		**1**	▲
σ = standard deviation of returns (volatility)		**0.3**	▲
$N(.)$ = cumulative normal distribution			
	d_1	1.2152	
	d_2	0.9152	
	$N(d_1)$	0.8879	
	$N(d_2)$	0.8200	
	$VN(d_1)$	586	
	$IN(d_2)$	413	
	$e^{-r(f)t}$	0.9524	
F = call option (M€)		193	
NPV under uncertainty (M€)		193	
- NPV under certainty (M€)		157	
Value of waiting (M€)		36	

Value of waiting (M€)

	σ				
t	0.01	0.05	0.1	0.3	0.5
0.0001	0.0	0.0	0.0	0.0	0.0
0.1000	2.5	2.5	2.5	2.5	3.9
0.5000	12.1	12.1	12.1	16.6	34.7
1.0000	24.0	24.0	24.0	36.3	67.8
1.5000	35.6	35.6	35.6	54.5	95.2
2.0000	46.8	46.8	46.9	71.3	118.8

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