HELSINGIN KAUPPAKORKEAKOULU

Rahoituksen suuntautumisvaihtoehto

Real option valuation of technological competencies: Research and development and company acquisitions

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Tomi Laamanen
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KTT Matti Keloharju KTT Vesa Puttonen

Abstract

The main focus of this thesis is on the valuation of technological competencies using the real option valuation. The research problem can be expressed in terms of the question: How could the real option valuation be applied for the valuation of technological competencies in general and for the valuation of new, technology-based companies in acquisition situations. The thesis has four major objectives. The objectives are

1 to create an overview of the real option valuation literature and the methodological state of development of the real option valuation

2 to assess the applicability of the option valuation methods for valuing technological competencies in general and new, technology-based companies in acquisition situations

3 to assess the applicability of the compound option valuation for valuing investments into the development of absorptive capacity

4 to identify value drivers affecting the valuation of new technology-based companies in acquisition situations and, in general, to develop the existing knowledge concerning the use of option valuation in the valuation of technological competencies

The research work itself is divided into four separate papers. The first paper reviews the existing literature on real option valuation. Methodological development in the area of financial option valuation seems to have gradually facilitated the emergence of methods to value also other contingent claims than claims on financial assets. Competence valuation would seem to offer a new interesting expansion of the real option methodology. Competence absorption, competence building, and competence leverage represent opportunities to use the real option valuation. Real option valuation of competencies requires a sufficient understanding of the interactions between the different competencies. Attention should also be directed more towards understanding the underlying uncertainty. Modelling the uncertainty in the value of the underlying competence would seem to present one of the most potential routes for the development of the real option valuation.

The second paper reviews briefly the methodological state of development of the real option valuation. So far, the development of the real option valuation has mainly been methodological. It has been constrained to some extent by the lack of published empirical research that would apply and test the developed methodology in real life situations. The paper addresses the need for the development of the real option valuation methodology to adapt it to competence building and capability acquisition situations. Valuation of a generic competence investment is presented as an example on the use of real option valuation.

The third paper addresses the concept of absorptive capacity. The concept of absorptive capacity has originally been used in the literature to describe the ability of a company to absorb new technologies from the environment. The third paper expands the concept of absorptive capacity to include also time dimension. Due to the apparent path dependency of technological development, the absorptive capacity is seen to provide an important building block that allows companies not only to absorb other existing knowledge, but it provides the option for developing, understanding, and absorbing future technological competencies. Absorptive capacity is modeled as a compound option. The role of absorptive capacity is analyzed with the aid of a numerical algorithm.

The fourth paper discusses the option nature of collaborative arrangements and acquisitions motivated by the acquisition of competencies. An analysis of the possibility to apply the real option valuation in the valuation of 111 new, technology-based companies in company acquisition situations is presented. In the studied sample, the collaborative arrangements were not extensively used as options to acquire the collaborative partner. The company acquisitions themselves were used more as options to enter a new technology or business area. The maturity of the acquired competencies, the patentability of the acquired competencies, and the research and development intensity of the acquiring company were found to correlate with the option nature of the acquisition. In the studied sample, the growth option upside realization was found connected to the relatedness of the acquiring and the acquired company, proactive sales motive of the seller, and a favorable industry trend. The findings concerning the performance of the acquisition of related technological competencies seem to be connected to the imperfect markets of new technological competencies.

Real option valuation of technological competencies: Research and development and company acquisitions

1 Introduction

1.1 Motivation for the study

Today's business environment is characterized by complexity, uncertainty, and rapid change. The emergence of new technologies is instrumental in this process. The existing technologies seem to become obsolete at an ever increasing pace.

The highly dynamic nature of the business environment drives the large corporations both to turn their attention to the innovative activities as well as to monitor their business environments. In the strategic management literature, the attention on innovation has resulted in a large body of literature on innovation management. In this literature, the process of technological innovation, the prerequisites for innovation, and the management of innovation have received a lot of attention. Less emphasis has been placed on the financial valuation of the consequences of the innovative activities.

The selection of research and development projects in a corporation is often a very complex, far-reaching investment decision. It is a decision that is closely linked both with the innovative capabilities within the company as well as with the rapidly changing environment. Both aspects have to be addressed in the project evaluation and selection process. In addition to these, several other important considerations have to be taken into account. Even the organizational decision making process, for example the extent of the evaluation, can have an impact on the success of the project.

If a company is in a position where it cannot develop the needed competencies by itself, it may become necessary to outsource them. There are several alternative ways to outsource new technologies. The company can simply buy the technology from the source. It may buy a patent or get a licence. It may construct a cooperative arrangement with the source of the technology or it can, in some cases, acquire the whole source of the technology. The acquisition of small, technology-based companies can for many purposes be observed in a similar fashion as the selection of research and development projects. Both are usually rather long term in nature and both must be closely tied to the overall corporate strategy. In both cases, the results are usually very uncertain, difficult to quantify, prone to high risks, and may have several long-reaching consequences.

Even though both the selection and evaluation of research and development projects as well as the acquisition and valuation of companies have been the topic of a large body of academic literature, it seems that there are potential possibilities to improve the methodologies for the valuation of small, technology-based companies in acquisition situations by the application of modern financial theory. One of the tools that has been put forward both in the financial literature as well as in the technology management literature is the valuation of new technologies using the option valuation.

1.2 Research problem and objectives of the study

The research problem of the thesis can be expressed in terms of the question: How could the real option valuation be applied for the valuation of technological competencies in general and for the valuation of new, technology-based companies in acquisition situations. The study has four major objectives. The objectives of the study are

1. to create an overview of the real option valuation literature and the methodological state of development of the real option valuation

2. to assess the applicability of the option valuation methods for valuing technological competencies in general and new, technology-based companies in acquisition situations

3. to assess the applicability of the compound option valuation for valuing investments into the development of absorptive capacity

4. to identify value drivers affecting the valuation of new technology-based companies in acquisition situations and, in general, to develop the existing knowledge concerning the use of option valuation in the valuation of technological competencies

The objectives aim at solving the research problem. The research work itself is divided into four distinctive papers. The first paper reviews the existing literature on real option valuation. The second paper discusses the methodological state of development of the real option valuation and the application of the real option valuation to real life situations. The third paper discusses the valuation of absorptive capacity as a compound option. The fourth paper analyzes empirically the option nature of new, technology-based company acquisitions in a sample of 111 acquisition cases.

1.3 Definitions

Technology

Due to the central role of technology for this study, a rather detailed discussion on the concept is necessary. The word technology has originally been derived from classical Greek, where "techne" could be interpreted as the skill of hand or technique and "logos" as knowledge or science. Using these interpretations, technology could be defined as a knowledge of kills or techniques or a science of skills or techniques. A detailed discussion on the definition of technology is provided by Autio (Autio, 1993, 1995).

In the broadest sense, the concept of technology includes the physical manifestations of technology, named here as "technoware", the articulated knowledge concerning the physical manifestations, named here as "infoware", the individual technological skills, named here as "humanware", and the organizational technological components, named here as "orgaware". In addition, the technology can be considered to contain a tacit part which is impossible to articulate and which can, for example, be transferred to another organization only by transferring the whole source of technology.

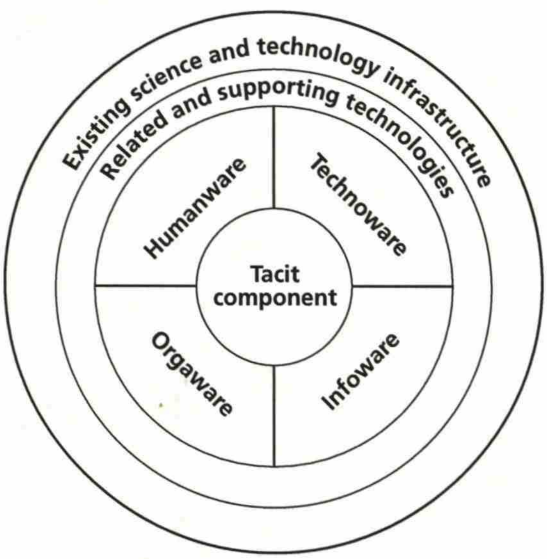

Figure 1.1 Component model of technology (Autio, 1995)

Several studies have tried to find characteristics or dimensions of technology that would capture central nature of the technology. According to these studies, technologies could be characterized according to their articulability, complexity, degree of formalization, fusibility, generity, modularity, observability, systemic character, and teachability.

Table 1.1 Dimensions of technology (Autio, 1995)

Dimension	End of continuum	End of continuum
Articulability	Tacit	Articulable
Complexity	Complex	Simple
Formalization	Unformalized	Formalized
Fusibility	Fusible	Not fusible
Generity	Specific	Generic
Modularity	Modular	Monolithic
Observability	Observable in use	Not observable in use
Systemic character	Element of a system	Independent
Teachability	Not teachable	Teachable

Small, technology-based companies

Small, technology-based companies are small, companies, under 50 employees, which are established to develop, transfer, or commercialize new technology or which base their strategy essentially on developing, transferring, or commercializing new technology. The word technology is used here in its broadest meaning applying the component model discussed on the previous page.

Acquisition situation

Acquisition situation is defined here to be a situation where a company, a target company, is considered for acquisition. A distinction is made between the acquisition of the company and the acquisition of the stock. The company is here considered to be acquired if the acquirer gets a ruling position in the acquired company as a consequence of the acquisition. In principle, the ownership change can range from nearly 0 percent to 100 percent and still lead to a ruling position for the acquirer. Here it is, however, assumed that an acquisition is in question only if the acquirer is considering to buy a majority position of over 50 percent in the target company.

Option

An option is a security giving the right to buy or sell an asset, subject to certain conditions, within a specified period of time (Black and Scholes, 1973). The options can be divided into two main types of options according to the exercise time. An American option can be exercised at any time up to the date the option expires. The European options can be exercised only at a specified exercise date.

2 REAL OPTION VALUATION OF RESEARCH AND DEVELOPMENT A REVIEW OF THE LITERATURE AND SYNTHESIS

Tomi Laamanen

ABSTRACT

This paper reviews the existing literature on real option valuation. Methodological development in the area of financial option valuation has gradually facilitated the emergence methods to value also other contingent claims than claims on financial assets. The real option valuation seems to be particularly applicable in natural resource valuation. Competence valuation would seem to offer a new interesting expansion of the real option methodology. Competence absorption, competence building, and competence leverage represent opportunities to use the real option valuation. The competence leverage would seem to correspond to the option upside realization. Due to the often reduced uncertainty at this stage, the competence leverage would seem to allow also for the use of net present valuation. At the competence absorption and competence building stages, the real option valuation should be the preferred method. Real option valuation of competencies requires a sufficient understanding of the interactions between the different competencies. Attention should also be directed more towards understanding the underlying uncertainty. The drift process of the value of the underlying competence has often been modeled using the constant volatility assumption. Modelling the uncertainty in the value of the underlying competence would seem to present one of the most potential routes for the further development of the real option valuation.

1 Introduction

In the academic literature, the traditional discounted cash flow methodologies and the net present value rule have been found deficient in research and development valuation (Trigeorgis, 1993b). The net present value rule makes implicit assumptions concerning the expected cash flows and presumes management's passive commitment to a certain fixed strategy or a certain "expected scenario". It does not take into account the managerial flexibility and the inherent growth options in the investments. During the past several years, a number different approaches has been suggested to solve the problem of how to better value strategic investments. One suggested approach is that the strategic investments should be separated from the operative investments and justified using qualitative subjective criteria, managerial judgement. One approach is the expanded financial analysis framework developed by Kaplan (1986). Kaplan proposed that the strategic investments should be justified with a lower discount rate and with a better assessment of the intangible benefits. In recent years, the approach developed in the field of finance, the use of options to value strategic investments, has received a lot of attention. After the first few articles in the latter part of the 1970s there is now a large body articles and related writings on real option valuation.

This paper contributes to the existing literature by reviewing the real option literature and by analyzing it from the research and development valuation perspective. The principal difference between the financial and the real options is that the financial options give the right to purchase shares at the exercise price before the expiration date whereas the real options give the right to invest by paying the investment cost before the opportunity disappears (Trigeorgis, 1993b). It is useful to divide real options further into operating or *flexibility* options and growth options (Trigeorgis, 1986). Operating options represent the management's flexibility to change the direction of its future actions when new information arrives. Typical operating options are the option to defer investment, the option to carry out a staged investment, the option to alter operating scale, the option to abandon, and the option to switch (See, for example, Kulatilaka, 1993). Each of these operating options can have a significant value-added in an investment. The option to defer investment is typically a major consideration in the natural resource extraction industries, mainly in the oil industry. Staged investment is an option of major importance typically in research and development intensive industries, for example in pharmaceutical industry. The option to alter operating scale is valuable typically in cyclical industries, such as the fashion apparel or consumer goods. The option to abandon is valuable typically in capital intensive industries, such as airlines or railroads, or in new product introductions. The option to switch is commonly encountered in industries where the goods are subject to volatile demand (Trigeorgis, 1993b).

Growth options are options where an early investment is a prerequisite that opens up possible future growth opportunities. Growth options could be hypothesized to be most important in all infrastructural industries and research and development based industries where there are multiple product generations (Trigeorgis, 1993b). Similarly growth options could be considered to be applied to company acquisitions and the capability development in general in a corporation. A difference should be made between the *spawning of investments* and the *option to invest.* Kasanen (1986) developed in his dissertation a model on the spawning of new investment opportunities in connection with strategic investments. He presents a matrix that he calls the spawning matrix. The elements of the matrix are multipliers that determine how many investment opportunities are created by a unit investment in one category. The spawning matrix describes the synergy of the investments across time in contrast to the synergy across the investments. It is important to note that the spawning of investments is not the same as an option provided by an investment. Spawning itself is deterministic. If the spawning effect is uncertain there is an option element. There is the option that the investment will spawn new investment opportunities (Kasanen, 1993).

Different models have been developed for the valuation of options. For simple real option valuation situations, there are both binomial models and continuous models. For more complex situations, there are numeric algorithms for the valuation. The valuation of operating and growth options can be carried out according to the same main principles as with the financial options. The binomial model of Cox, Ross, and Rubinstein applies to the valuation of operating options directly. The Black and Scholes (1973) model is not as well suited because of its rather restrictive assumptions concerning the stability of the interest rate, the distribution of the underlying asset values, dividends, transaction costs, divisibility of the underlying asset, and the assumptions concerning short selling.

There are often multiple options embedded in each investment project. The fact that the values of the different options are not additive makes the calculations difficult. The option interactions need to be taken into account in the option valuation. Fortunately, the added value from increasing the number of options that are taken into account is marginally decreasing. In most cases, it suffices to take into account only the most important options. Closed form analytical solutions exist for the simplest compound options. The combination of the different options similarly as in the compound call option valuation facilitates the modelling of the different complex real option situations. The inclusion of the dividends can be used to model the possible competitive actions taken by the competitors. Expanding the Black and Scholes model, Trigeorgis (1986) uses a different diffusion process, jump-diffusion, to model the influence of the entry of new competitors to an industry. Trigeorgis divides the different competitive situations into four categories according to the proprietary versus shared and expiring versus deferrable nature of the options. In addition, he includes also the simple versus compound nature of the options in the valuation process.

Trigeorgis distinguishes the main dimension in real option valuation situations as follows:

- *Competitive interaction, exclusiveness of the option*
    - proprietary option
    - shared option
- *Interaction between the projects, inter versus intra project interaction*
    - simple options when no interactions
    - compound options when inter or intra project interactions
- *Urgency of the decision making situation*
    - expiring options
    - deferrable options

According to Trigeorgis, the valuation can proceed as a process where the competitive interaction is assessed first. Then the interaction between the projects needs to be taken into account. Finally, the four different types of options classified this way can be either expiring or deferrable. The dimensions of the decision making process are not entirely orthogonal. The competitive interaction and the urgency of the decision making situation may be connected to each other. The exclusive options may be more often deferrable than the non-exclusive options. There may be, however, also other factors affecting the deferability of an option than the competitive interaction.

2 Research on real option valuation

The valuation of real options has emerged as an application area of the financial option valuation. Most of the methodological development has taken place in connection with the financial option valuation where the applicability of the models has been immediate in the expanding options markets. The first actual option valuation models that were taken extensively to use can be attributed to Black and Scholes (1973) and Merton (1973). Black and Scholes were the first to present a closed form formulation of the continuous time analytic option valuation formula. Since the pioneering articles of Black and Scholes and Merton, different analytical, numerical, and analytical approximation models have been developed for option valuation. From the perspective of real option valuation, some of the milestones of option valuation literature are shown in figure 1.

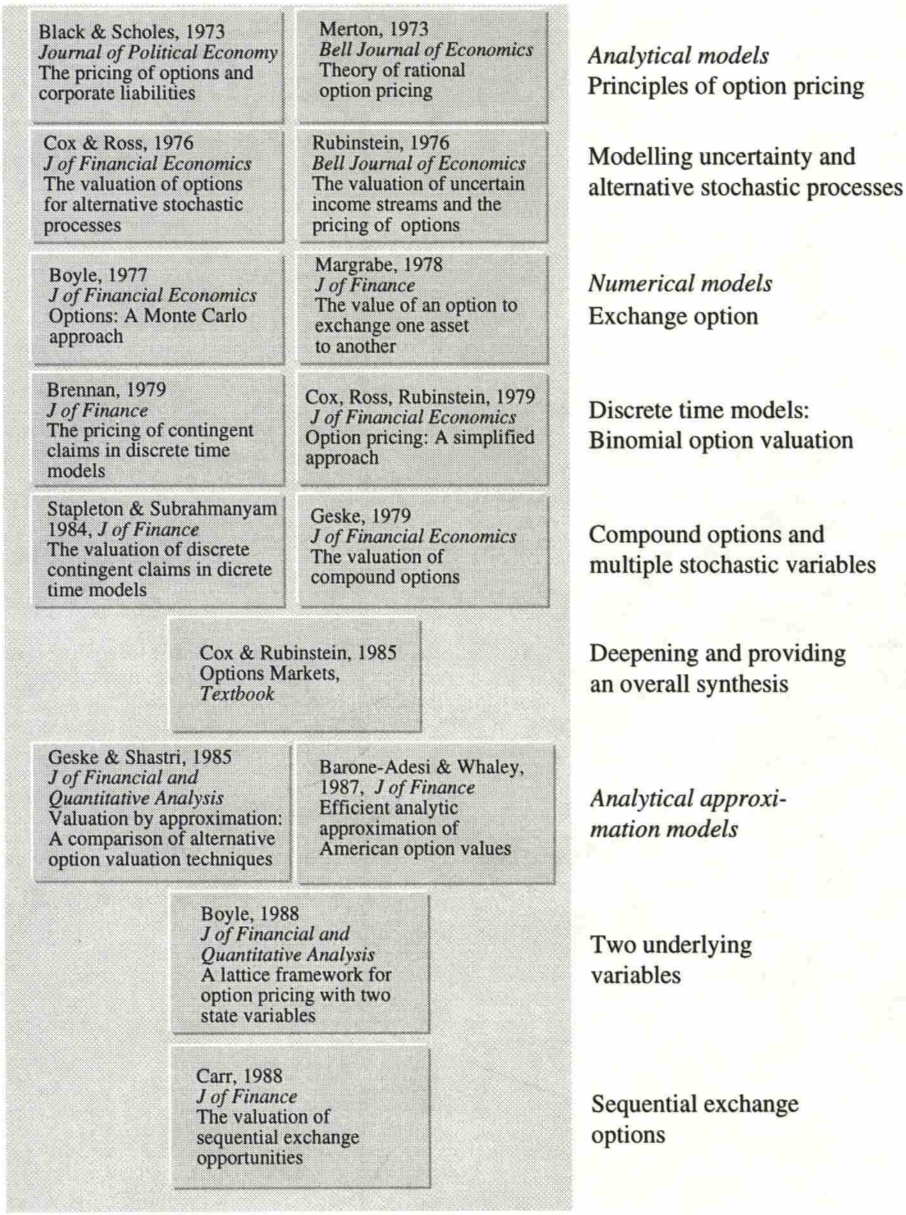

Figure 1 Methodological development of the option valuation

One of the earliest expansions of the pioneering analytical option valuation models was the incorporation of different uncertainties into the option valuation. Rubinstein (1976) showed that the existence of continuous trading opportunities enabling a riskless hedge is not necessary. Different diffusion processes were modeled and the corresponding option valuation models were derived (Cox and Ross, 1976). Creating a basis for numerical models, Monte Carlo simulation was applied to simulate the uncertainty in the option valuation (Boyle, 1977). Gradually, the focus can be seen to have shifted to more complex exchange option valuation (Margrabe, 1978). To complement the analytical models, Cox et alii (1979) published the principles of binomial option valuation in 1979.

Further methodological rigor was added to the option valuation when Geske (1979) showed how to value compound options. Stapleton and Subrahmanyam (1984) expanded the work of Brennan to contingent claims that involve two or more stochastic variables. Cox and Rubinstein (1985) published their book on option valuation methods deepening the understanding of the option valuation. Analytical approximation methods for option valuation were developed, for example, by Barone-Adesi and Whaley (1987) and Geske and Shastri (1985). Boyle (1988) developed a lattice framework for option valuation expanding the valuation to include two state variables and Carr (1988) showed how to value sequential exchange opportunities.

Stewart C Myers (1977) was the first to discuss the similarities between the financial options and options on other assets. One of the first applications of the real option valuation were the natural resource investments (Tourinho, 1979). The natural resource investments provided an excellent opportunity to apply the financial option valuation. There was information readily available on the prices of the different natural resources. The volatility and the drift process of the underlying asset could be evaluated in a similar manner as in connection with the financial options. There have been several studies on the valuation of oil reserves (McDonald and Siegel, 1984, 1985, 1986). The valuation can be applied to also other kinds of natural reserves. For example, Brennan and Schwartz (1985a, 1985b) analyzed the valuation of gold mine reserves.

Kester (1983, 1984) was one of the first to discuss the use of option valuation in connection with strategic capital budgeting. Kester points out in his pioneering article that *any investment project whose implementation can be deferred, that can be modified by the company, or that creates new investment opportunities can be analyzed using the option framework.* The approach of Kester was new in that respect that he diverted from the valuation of natural resource investment and pointed out that the expected future cash flows from an investment can be seen as an underlying asset. Kester also suggested that the difference between the total market value of a company's equity and the capitalized value of the current equity stream represents the growth option values of the company. For the analysis of the different growth options, Kester recommended a two-dimensional framework shown in figure 2. According to Kester, the investments should be classified in the first place according to their growth option characteristics into projects involving simple or compound growth options. Then the investments should be classified according to their shared versus proprietary nature and according to the intensity of the competitive rivalry. The intensity of the competitive rivalry determines the timing when the growth options should be exercised. Under intense rivalry and in case of shared options, the growth options should be exercised immediately. Under minimal rivalry and in case of proprietary options, the options should be held until expiration. According to Kester, the other quadrants represent intermediate cases. The framework has been further mathematically modeled and expanded by Trigeorgis (1986).

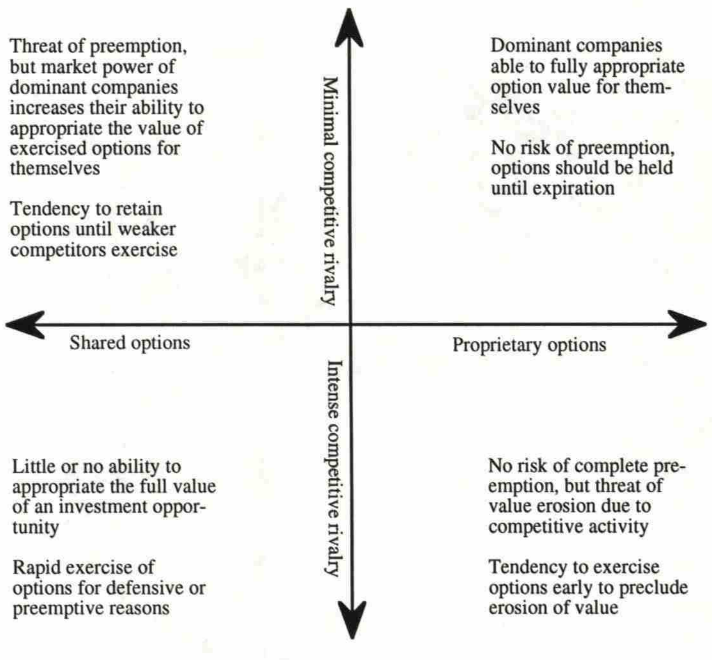

Figure 2 Timing the commitment of capital (Kester, 1984)

As the real option valuation research expanded from the valuation of natural resource investments, also models for the valuation of *different types* of options were presented. Myers and Majd (1983) were among the first to analyze the valuation of the abandonment options. McDonald and Siegel (1985, 1986) focused in their research both on the abandonment options and the deferability options. They studied how option valuation can be applied in the investment problem of a company that has the option to shut down production if variable production costs exceed revenues. They also studied the optimal timing of investment in an irreversible project. They found out that the reversibility of a project reduces the value of waiting to invest. Miles focused on the growth options. He analyzed the relationship between the growth options and the beta of a firm. According to Miles, the beta of a firm is a weighted average of the asset beta and the beta of the growth options. The firm beta is a function of the quantity of future investment opportunities of a firm. As a result, the firm beta should not be used in capital budgeting. According to Miles (1986), the companies should use instead the asset beta which corresponds to the assets in place. Since the middle of 1980s, the research on different types of real options has increased significantly. Trigeorgis (1993b) summarizes the research on different types of real options as "A tablet for each case". He discusses the multiplicity of models for valuing different types of real options. The summary table of Trigeorgis is shown in table 1. It summarizes, in addition to the first generation research on real option valuation shown in figure 1, the subsequent research with the focus on different types of options. The early research on real option valuation is named here as the first generation research due to the relatively restricted initial focus on natural resource investment and the pioneering nature of the research.

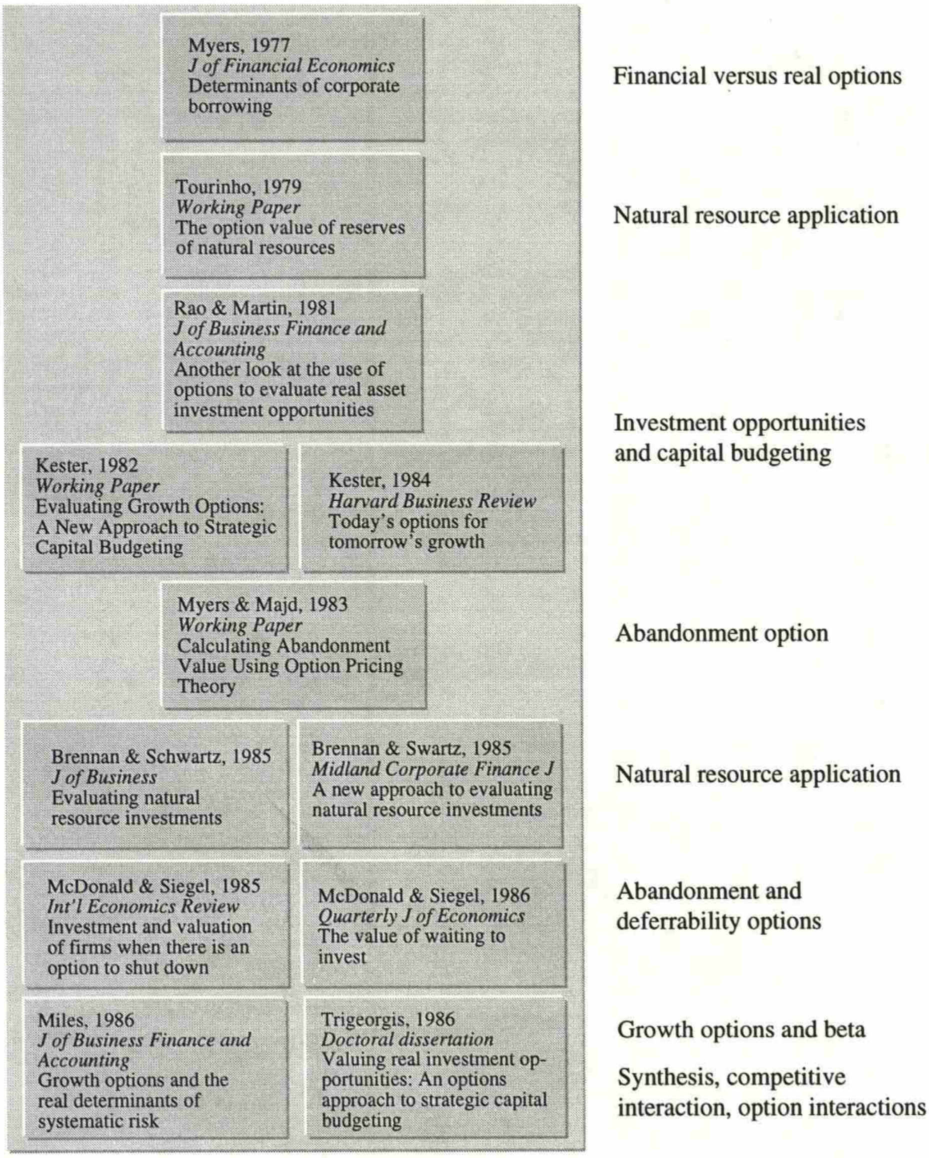

Figure 3 First generation research on real options

The different types of real options are illustrated in table 1 according to Trigeorgis.

Table 1 Common real options (Trigeorgis, 1993b)

Category	Description	Important in
Option to defer	Management holds a lease on valuable land or resources. It can wait to see if output prices justify constructing a building or plant, or developing a field	All natural resource extraction industries; real estate development; farming; paper products
Time to build option (staged investment)	Staging investment as a series of outlays creates the option to abandon the enterprise in midstream if new information is unfavorable. Each stage can be viewed as an option on the value of subsequent stages, and valued as a compound option	All research and development intensive industries, especially pharmaceuticals; long development capital-intensive projects, e.g., large-scale construction or energy-generating plants; start-up ventures
Option to alter operating scale	If market conditions are more favorable than expected, the firm can expand the scale of production or accelerate resource utilization. Conversely, if conditions are less favorable than expected, it can reduce the scale of operations. In extreme cases, production may temporarily halt and start up again	Natural resource industries such as mine operations; facilities planning and construction in cyclical industries; fashion apparel; consumer goods; commercial real estate
Option to abandon	If market conditions decline, management can abandon current operations permanently and realize the resale value of capital equipment and other assets in second-hand markets	Capital intensive industries, such as airlines and railroads; financial services; new product introductions in uncertain markets
Option to switch	If prices or demand change, management can change the output mix of the facility. Alternatively, the same outputs can be produced using different types of inputs.	*Output shifts:* Any good sought in small batches or subject to volatile demand, e.g., consumer electronics; toys; specialty paper; machine parts; autos. *Input shifts:* All feedstock-dependent facilities, e.g., out; electric power; chemicals; crop switching; sourcing.
Growth options	An early investment is a prerequisite or link in a chain of interrelated projects, opening up future growth opportunities. Like inter-project compound options	All infrastructure-based or strategic industries, especially high-tech, research and development, or industries with multiple product generations or applications; multinational operations; strategic acquisitions
Multiple interacting options	Real-life projects often involve a "collection" of various options, both upward-potential enhancing calls and downward-protection put options present in combination. Their combined option value may differ from the sum of separate option values, i.e., they interact.	Real-life projects in most industries discussed above.

The dissertation of Trigeorgis (1986) would seem to conclude the first generation real options research. The dissertation synthesizes the existing research on real option valuation. It presents a model where competitive interaction is mathematically incorporated into the real option valuation. Trigeorgis brings up the issue of valuation of option interactions within and between projects. He also presents a numerical analysis approach to extend the valuation ability to complex projects with multiple real options that may interact. Trigeorgis points out that the combined value can be as important as that of the cash flows. All the options cannot be ignored. On the other hand, Trigeorgis points out that due to the negative interactions between the options, the incremental value of an additional option may be small. For this reason, no serious valuation errors are made if all the options are not taken into account in the valuation. The first generation research on real option valuation outlines a vision of a potentially new improved method for valuation.

The second generation research on real options, from 1987 to 1993, would seem to have emerged from the optimistic platform provided by the first generation research. The growth in the number of articles would seem to have been nearly exponential. Even within the period, the number of articles seems to be nearly the same during the four year period of 1987 to 1990, during the two-year period of 1991-1992, and during the year 1993. Taking into account that the articles represent only the most significant findings in the field, the expansion of the research area is considerable. On the whole, the second generation research on real option valuation would seem to be characterized by the development of new models for the valuation of different types of real options and the application of the real option valuation methods to new kinds of underlying assets and valuation situations. The articles representing the second generation are shown in figure 4.

Despite the expansion of the research area, the valuation of natural resource investments seems to have remained as one the major areas of research in real option valuation. Particularly, the valuation of petroleum reserves has been studied extensively (Siegel et alii, 1987; Dentskevich and Salkin, 1991). The valuation of flexibility in general seems to have emerged as a new stream of research (Trigeorgis and Mason, 1987). In contrast to the atomistic options, the managerial flexibility is recognized as a palette of flexibility options. Another potential new stream would seem to be the numerical analysis of complex real options (Trigeorgis, 1991a). The valuation of research and development using the real option methodology was brought up explicitly by Mitchell and Hamilton (1988). Sharp (1991) discusses the importance of option valuation in high risk research and development investments. Ott (1992) discusses the opportunities of option valuation in research and development. Despite its importance, specific research on the combination of option valuation to research and development remains on a relatively superficial level.

In the second generation research on real options, the options approach is increasingly seen in line with Kester's pioneering work as an approach to strategic management. The option valuation is applied for the valuation of joint ventures, equity collaboration, and company acquisition decisions. For example, Kogut (1991) studied joint ventures as an option to acquire the joint activity established in the form of a joint venture. He found that the joint ventures that were successful were commonly acquired. The joint ventures that were not successful, were not divested. In addition to the acquisition and collaboration decisions, the options approach is discussed in the second generation research in connection with the capabilities development. Sanchez discusses the strategic flexibility from the strategic options perspective in competence development (1993). Baldwin and Clark discuss the option nature of the capabilities investments (1992). Baldwin and Clark (1993) also discuss the importance of the modularity from the option perspective. Baldwin and Trigeorgis (1993) discuss the option nature of the investments into TQM capabilities.

Bowman and Hurry (1993) discuss the applicability of the option perspective for the strategic management in general. They point out that strategic management involves decisions which in the long term form a pattern of resource deployment that can be termed strategy. According to Bowman and Hurry, strategy is seen through the option lens as a process of organizational resource-investment choices. Organization's resources are seen as a bundle of options for future strategic choice. Opportunities for strategic choice emerge only when they are recognized. The bundle of options created through the organizational resources contains a number of options that are not recognized. Bowman and Hurry term these options as shadow options. They are existing options that are not recognized. Bowman and Hurry model the activation of options with an option chain. Recognition of a shadow option transforms the option into a real option. Exercise of options facilitates growth or expansion, abandonment, or other strategic flexibility. Exercise of options creates further shadow options and recognized real options. According to Bowman and Hurry, the option lens can be used to integrate many of the themes discussed in strategic management research.

1987-1990

Majd & Pindyck, 1987
Time to build, option value and investment decisions
J of Financial Economics

Siegel, Smith & Paddock, 1987
Valuing offshore oil properties with option pricing models
Midland Corporate Finance J

Trigeorgis, Mason, 1987
Valuing managerial flexility
Midland Corporate Finance J

Ekern, 1988
An option pricing approach to evaluating petroleum projects
Energy Economics

Trigeorgis, 1988
A conceptual options framework for capital budgeting
Adv. in Futures and Options Research

Pindyck, 1988
Irreversible commitment, capacity choice, and the value of the firm
American Economic Review

Brealey & Myers, 1988
Principles of corporate finance

Paddock, Siegel & Smith, 1988
Option valuation of claims on real assets: the case of offshore petroleum leases
Quarterly Journal of Economics

Mitchell & Hamilton, 1988
Managing R&D as a strategic option
Research Technology Mgmnt

Kulatilaka & Marcus, 1988
A general formulation of corporate operating options
Research in Finance, JAI

Lee, 1988
Capital budgeting under uncertainty
J of Business Finance and Accounting

Teisberg, 1988
Capital investment strategies under regulation: A binomial option pricing approach
Doctoral dissertation

Sick, 1989
Capital budgeting with real options
Working paper

Myers & Majd, 1990
Abandonment value and project life
Adv. in Futures and Options Research

Triantis & Hodder, 1990
Valuing flexibility as a complex option
Journal of Finance

Trigeorgis, 1990
A real options application in natural resource investments
Adv. in Futures and Options Research

Trigeorgis, 1990
Valuing the impact of uncertain competitive arrivals on deferrable real investment opportunities
Working Paper

1991-1992

Chung & Charoenwong, 1991
Investment options, assets in place, and the risk of stocks
Financial Managment

Dentskevich & Salkin, 1991
Valuation of real projects using option pricing techniques
Int'l Journal of Management Science

Williams, 1991
Real estate development as an option
Journal of Real Estate Economics

Trigeorgis, 1991
Anticipated competitive entry and early preemptive investment in deferrable projects
Journal of Economics and Business

Trigeorgis, 1991
A Log-Transformed Binomial Numerical Analysis Method for Valuing Complex Multi-Option Investments
J of Financial and Quantitative Analysis

Trigeorgis & Kasanen, 1991
An integrated options-based strategic planning and control model
Managerial Finance

Kogut, 1991
Joint ventures and the option to expand and acquire
Management Science

Sharp, 1991
Uncovering the hidden value in high-risk investments
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Figure 4 Second generation research on real options

The third generation research on real options would seem to emerge from 1994 onwards. Surprisingly, the number of articles published on the topic seems to go down. This may be explained partly by the fact that the special issue in Financial Management collected most of the recent writings in 1993. It can also be explained partly by the fact that Trigeorgis published an edited book in 1995 with articles from seventeen authors. Together with the six articles found to be published in 1994 this would be more than the 16 articles that were published in 1993. The third generation research on real options would seem to be more coordinated, more consolidated. Large part of the contribution in the field in 1994, 1995, and 1996 would seem to originate from the two books of Trigeorgis (1995, 1996), the dissertations of Folta (1994) and Childs (1995), and some few articles. Kogut and Kulatilaka published three articles (Kogut and Kulatilaka, 1994a, 1994b, Kulatilaka and Trigeorgis, 1994). Newton and Pearson (1994) restate the importance of the options perspective in research and development. Sercu and Uppal (1994) discuss the option pricing theory in international capital budgeting. Nichols (1994) reports experiences on the use of option valuation in pharmaceutical research an development. Dixit and Pindyck (1995) review the use of option valuation in capital investment.

In his books Trigeorgis first provides an overview of the research on real options (Trigeorgis, 1995) and then melts the different views together into a concise textbook (Trigeorgis, 1996). In the first book edited by Trigeorgis, three writers address the relation of real options with different valuation paradigms. Teisberg discusses the alternative valuation methods for evaluating capital investment decisions. She compares the dynamic discounted cash flow analysis, decision analysis, and option valuation. As a conclusion she discusses how the type of analysis is chosen. According to Teisberg (1995), some methods are more appropriate in some situations than other. She concludes that decision analysis is a good choice if estimating the market value of the project is not the main aim. Dynamic discounted cash flow analysis is appropriate if the risk remains relatively constant, forgone earnings cannot be estimated, and market valuation is the goal of the valuation. Option valuation is appropriate if the analysis is intended to estimate the market value of the project and the underlying asset value and forgone earnings can be estimated. Kasanen and Trigeorgis (1995) discuss the differences between finance and decision theory when valuing investments. Son Lai and Trigeorgis (1995) discuss the strategic capital budgeting process. They link capital budgeting to strategic planning noting that strategic capital budgeting must combine the top-down and bottom-up processes of strategic planning and capital budgeting in a complementary and interactive way. The edited book of Trigeorgis covers also a number of other issues related to modelling option interdependencies, conceptualizing strategic and infrastructure investment options, examining alternative valuation formulations, and extending real option valuation to new application areas.

With reference to the valuation of research and development and the valuation of competencies, the articles of Smith and Triantis (1995) and the article of Willner (1995) seem to be the most relevant. Smith and Triantis discuss the value of options in strategic acquisitions. According to them, the traditional valuation of target companies may be too conservative. Smith and Triantis point out that option valuation can play an important role in strategic company acquisitions. Firstly, acquisition programs can enhance the competitive position of the acquiring company through the creation of growth options. Secondly, companies with flexible resources in organization, marketing, manufacturing, and finance can benefit from utilizing these resources in the future for the benefit of the acquisition targets. A strategic diversification program can increase a company's flexibility to redirect its strategy. Thirdly, the traditional acquisition valuation does not take into account the option to divest all or parts of the acquired companies. Smith and Triantis mention a number of examples of options created by strategic acquisitions. As an example of a growth option, a computer company can acquire a software start-up company rather than developing its own software.

Willner (1995) discusses the valuation of start-up venture growth options. According to Willner, many new businesses have the characteristics of growth options. Willner sees, however, a difficulty when attempting to apply the assumption of a continuous cash flow generation process for the valuation of start-up ventures. According to Willner, the discovery nature of start-up ventures is better described with a jump formulation of the option valuation equations. In contrast to seeing an investment into a start-up company as a simple growth option, Willner models the investment into a start-up company as a compound option on an option. The jump formulation of the option valuation requires the estimation of the expected frequency of discovery, the expected percentage of value increase per discovery, and the expected value of the company at the time it expects to undertake full-scale operations. These may be sometimes difficult to estimate practice. On the other hand, Willner points out that it is easier to estimate parameters that characterize the cash flow generation rather than the cash flows themselves.

The dissertations of Folta and Childs deepen the understanding of real option valuation in two respects. Childs (1995) discusses the capital budgeting in interrelated projects. He applies the real options framework in an attempt to model the learning-by-doing nature of research and development projects. Childs compares situations where a company carries out two projects sequentially and where a company carries out two projects in parallel. Under sequential development, the carrying out of the second project provides the company an option to replace a potentially low value project with a potentially high value project. Under parallel development the company always gets the option to switch. It can always implement the best of the alternative projects and accelerate the receipt of the option that the sequential development would provide. According to Childs, the parallel development becomes more likely when uncertainty increases, development time increases, development cost decreases, or correlation between the project benefits decreases.

Folta (1994) discusses the use of the option theory in governance decisions in the biotechnology industry. He analyzed the motives for using partial equity investments versus outright acquisition of another company. According to Folta, the equity-based collaborations can be seen as call options on the acquisition of the collaborative partner. He hypothesizes that the choice between partial equity investments and outright acquisition is a function of transaction costs and option value. The empirical analysis of Folta focuses on testing the combined transaction cost-option theory model in a sample of 451 minority investments, joint ventures, and acquisitions in the biotechnology industry in the United States. According to Folta, the results support the combined transaction cost-option theory model. Variables that theoretically increase the option value were related to the preference for initiating minority investments and joint ventures over acquisitions. Furthermore, Folta points out that option theory can be applied to provide insights to the use of unrelated diversification.

Even though the number of articles published on real options would be regarded to have remained on the same level in 1994 than in 1993, there is a clear drop in the number of articles published on the topic in 1995 and in 1996. It would seem that the research area is maturing. This would seem to be evident based on the fact that the focus seems to be shifting to extensive synthesis books instead of articles reporting new findings and methods. The third generation research on real options would seem to represent a some kind of consolidation of the research area. The research on real options does not seem to be progressing at least in a way observable in terms of published articles. It may be that the main weight in the development of the methodology and applications is now in the companies. This would seem to be the situation in some of the more advanced companies.

Another explanation for the decreasing number of published articles may be that no real new methodological or application development has taken place that would add to the earlier research. The research area may be saturated with applications with the present level of knowledge. It may be that the researchers do not perceive after all that the option valuation would be among the most potential ways to solve the research and development valuation problem. It may also be that the slow pace of option valuation methodology adoption by companies has decreased the interest of researchers to focus on the option valuation models. There are also relatively high barriers of entry to the field of real option valuation by new researchers due to the mathematical complexity and the existence of the plentiful second generation research on real option valuation.

It would seem that to make the research on real option valuation to proceed, a new perspective or a new methodological invention would be needed. Myers, who can be considered as one of the pioneers of the real option research (Myers, 1977) seems to have gradually shifted his focus from the real option research more towards modelling the influence of different evolutionary risk processes in the valuation of research and development. It would seem that understanding and modelling the uncertainty is one of the keys to improving the existing methods used for the real option valuation. Myers and Howe (1996) model uncertainty as a decreasing risk-return staircase.

The real option methods typically assume constant volatility of the underlying asset. In research and development, the volatility of the underlying asset is not constant, however. It typically decreases as the uncertainty decreases when the research and development project proceeds. Based on the real option literature this would seem to be one the most potential routes for methodological development. The focus on the evolution of uncertainty involves, however, the problem of industry, company, and competence specificity. To be able to model the possible underlying uncertainty structure, more information on the specific uncertainty structure would seem to be needed. The uncertainty involved in the different processes of competence evolution would need to be understood to be able to take it into account in the competence valuation.

In addition to the need to understand the competence-specific uncertainty of the research and development, a number of other factors seem have inhibited the adoption of option valuation in research and development valuation. One of the problems would seem to be the complexity of the methods. The complexity of the real option valuation methods may make it in some valuation situations impossible to apply real option valuation. More importantly, however, the complexity may be one of the major obstacles for the everyday management use. The complexity of the real option valuation methods restricts the ability of the management to easily cross-check the results of the valuation. The value-added provided by the option valuation may be difficult to perceive. In an analogous pioneering study, Maher and Rubenstein (1974) studied the adoption of a quantitative method for project selection. They found that the assessment of the value of data generated by a method is an important factor in determining an individual's willingness to adopt a method.

To help the implementation of the options-based valuation methods, a number of normative rules for the management have been developed by different researchers. For example, Kemna (1993) presents a seven-step decision making process that were considered important in the introduction of the option valuation methods at Shell. The steps proposed by Kemna include

1. Convince management that some proposals contain flexibility that cannot be valued by using discounted cash flow analysis and must be valued using option valuation methods.
2. Make a clear distinction between investment alternatives and options embedded in these alternatives, because management often considers options as alternatives, which leads to misinterpretations.
3. Restrict the number of options to the most important ones; more options increase complexity without necessarily adding much value.
4. Restate the investment problem in the following sense: Can the costs of the additional flexibility be justified by the benefits when the flexible alternative is compared to the alternative without flexibility?
5. Define properly the uncertainties that management faces and, given these uncertainties, determine the most valuable option(s).
6. Whenever possible, incorporate the influence of competitors and other costs that may affect the value of the option(s) for free. It may be possible that due to the specific situation of the firm, the option is cheaper to the firm than to other firms. But options are usually not free. It is also important to incorporate the effects of competition not only on the cash flow estimates, but also on the value of the option.
7. Focus on the value of the project including the option(s) and present sensitivity analysis, especially for volatility.

Similar kinds of steps and prescriptive rules have been presented also by a number of other researchers. For example, Mitchell and Hamilton (1988) discuss three steps that should be considered when applying the options perspective for strategic positioning. These three steps include

1. The identification of strategic objectives. According to Mitchell and Hamilton, it is necessary to review and categorize the research and development project portfolio to reflect the nature and purpose of research and development activities. It is necessary to distinguish between the projects that produce options and that do not.
2. The review of the impact of strategic options. According to Mitchell and Hamilton, it is necessary to analyze the potential impact of the research and development programs from the options perspective.
3. The identification of strategic positioning targets. According to Mitchell and Hamilton, the most fundamental step is to address explicitly the long term strategic positioning targets as a basis for the research and development.

To sum up, the normative lists address a number of key issues in the use of the option valuation in real life situations. Four important points would seem to emerge from the normative list of Kemna: the large number of options existing in all the decision making situations, the interactions between the options, the modelling of the uncertainty, and the competitive interaction. The steps proposed by Mitchell and Hamilton focus on the project portfolio creation, selection of the most important options, and the identification of the longer term vision to form a basis for the platform creation.

3 Research and development valuation

Traditionally, the research and development valuation has been carried out from the research and development project evaluation and selection perspective. The traditional research and development valuation has been based on criteria lists, optimization models, and eventually net present value methods to provide a numeric value judgement for a project under review. The actual numeric value has often been regarded only as one criterion among a number of other criteria. The value of a project has often been determined on a binary scale: whether to accept the project if in conforms to the predetermined criteria or whether to reject the project. The actual quantification of how much could be spent on the project was left for subjective consideration. The amount of spending would seem to depend on the management belief in the project. This subjective judgement is not as bad criterion as it might appear. The more committed the management is to the project, the more the management is willing to invest in it. It can be further assumed that the more committed the management is, the more the project also receives management attention. The commitment can be assumed to be one of the critical success factors in a research and development project success.

The analytical hierarchy process represents one of the more structured criteria-based approaches to prioritize, select, and eventually to value research and development. The analytical hierarchy process is typically applied in four steps: construction of a hierarchy, determination of the between-level priorities, calculation of overall priorities, and the sensitivity and uncertainty analyses. In the analytical hierarchy process, there are several criteria that are arranged in hierarchical levels. The most general criterion is at the top level. The next levels reflect the partitioning into more specific criteria. Having created a hierarchy, the priorities between the criteria are decided and the research and development ventures are prioritized according to the priorities of the criteria. The role of the sensitivity and uncertainty analyses is in determining the sensitivity of the overall priorities to the existence and priorities of the individual criteria (Manahan, 1989). In addition to the analytical hierarchy process, there is a number of other methods for the evaluation, selection, and valuation of research and development projects. One of the methods is the constraint analysis. In constraint analysis, the attractiveness of the new business and the capabilities of the company are matched together as opportunities and constraints. Projects where a good match is achieved are selected for further development (Merrifield, 1981, 1988). In both of these methods, the value of a project is itself implicitly derived directly from the business drivers, criteria, that are expected to drive the value creation in the project. With these methods, the project itself is typically not valued explicitly.

The criteria-based approaches for the research and development evaluation and selection date back to the beginning of the 1960s (Baker and Bound, 1964). Similarly to the real option valuation literature at the beginning of the 1990s, the literature on research and development project evaluation and selection expanded rapidly in the first part of the 1970s. New methods were developed and a number of review articles emerged where the developed methods were compared (Augood, 1973). After the first part of the 1970s, new methods have been developed in a gradually decreasing manner. In a summarizing article, Danila (1989) distinguishes altogether thirteen families of research and development evaluation an selection methods developed by the end of 1980s. According to Danila the thirteen categories include the ratio family, the score index family, the programming family, the portfolio family, the matrices family, the systemic family, the checklist family, the relevance trees, the table family, the multicriteria family, the consensus family, the graphic family, and the integrative family. Danila points out that the evaluation and selection of research and development projects is often integrated into strategic planning. In line with the dominant focus of the research and development project evaluation and selection literature, Danila does not address explicitly the valuation aspect.

In connection with the explicit research and development valuation, Tipping et al (1995) discuss the role of research and development. According to them, the role of research and development can be meaningfully represented by a hierarchy of managerial factors that provide the foundations, links to strategy, and eventual value creation. The view of Tipping et al is illustrated in figure 5. Tipping et al emphasize that in order to result into value creation integration with business on the strategic level is required. The connection to businesses can mean many things. Here it is assumed that it means that the value created through competence building needs competence leveraging to result into value creation. In fact, it is assumed in this paper that the highest stepwise value realization comes from the competence leverage. This can take place, for example, in the integration of the developed technological competencies into the existing market-related competencies. This takes place, for example, when the developed competencies or even completed products are adjusted so that they fit to the existing distribution system of a company.

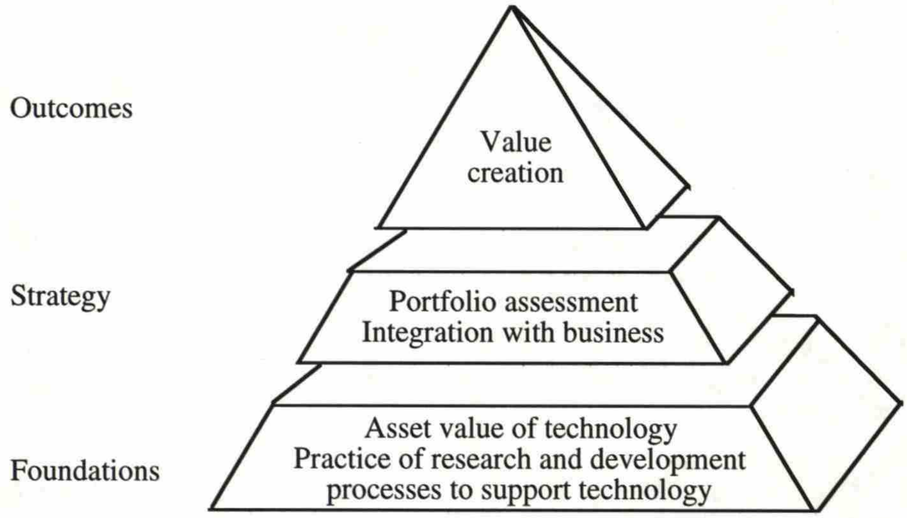

Figure 5 Five managerial factors forming the technology value pyramid (Tipping et al, 1995)

Tipping et al (1995) aim at creating a holistic perspective for assessing the value of technology. To aid in the valuation, they present 33 metrics for assessing the different subareas. The metrics include metrics for the financial return of the research and development, gross profit margin, market share, quality of personnel in research and development, customer rating of technical capability et cetera. Interestingly, Tipping et al do not mention option valuation when discussing technology valuation. Despite their holistic perspective, Tipping et al do not demonstrate how the large number of metrics could be used jointly to get an estimate of the value of a technology.

Many of the metrics proposed by Tipping et al are accounting-based. The valuation that they imply is similar to the traditional discounted cash flow or multiplier-based valuation used for the valuation of companies. The valuation of small, technology-based companies can be seen to be analogous to the valuation of technology and the valuation of research and development projects. The value of small, technology-based companies can be seen to be dominated by the growth expectations that are expected to be realized through the technological competencies possessed by the new, technology-based company. There are a number of methods that could be applied for the valuation of small, technology-based companies. The scarcity of the previous data commonly seems to restrict the extensive use of accounting-based measures. Venture capital companies are often reported to apply sales and earnings multipliers in determining the value of the ventures. The sales or the earnings of the companies are typically multiplied with some fixed number to get an estimate of the value of a company (Ballas, 1992). The literature seems to prefer the use of the discounted cash flow methods. Other methods used for the valuation of companies include substance value analysis, comparable companies analysis, and the valuation by components. Sometimes also comparable transactions analysis is recommended for the valuation in connection with acquisition target valuation.

The substance value analysis is not particularly suitable for the valuation of research and development. Since the substance value is calculated by subtracting the corporate liabilities from the corporate assets, the substance value analysis does not address the problem of how to actually value the corporate research and development assets. There are also problems in applying the comparable companies analysis for the valuation of research and development since the developed technological competencies are typically so unique that there are no comparative competencies, projects, or companies. Furthermore, if some comparative project or company would be found, nothing indicates that the research and development project under valuation would proceed in a similar manner. Different technologies exhibit different characteristics in their evolution. The valuation of components would seem to be an applicable way to value technological competencies. The valuation by components means originally that the total stream of cash flows from a company are broken into substreams and each of the streams are valued separately. Similarly, in connection with technological competencies, the different possible scenarios provided by the different competencies could be estimated and valued. Problems may sometimes be caused by the fact that the success of a research and development project may require the combination of different kinds of competencies. A sufficient understanding of the success drivers would seem to be required in any case.

Factors involved in research and development valuation are typically subject to uncertainty. An analysis of the uncertainty can be considered to be one of the fundamental core analyses in valuing technological competencies and research and development. One of the earliest definitions of uncertainty is attributed to Knight. Knight pointed out that uncertainty exists if the probability distribution of outcomes is unknown (Knight, 1922). Risk can be seen to differ from uncertainty because it involves accurate knowledge of the probability distribution of outcomes (Folta, 1994). According to Conrath, fundamental uncertainty means further that neither the expected states of the world nor the probability distribution are known (Conrath, 1967). The use of the terms risk and uncertainty is often inconsistent. Folta makes the distinction that he defines risk as the unpredictability of firm outcome variables. According to his definition, the definition of risk is consistent with the variance of outcomes. Further, Folta defines uncertainty as the unpredictability of organizational or environmental variables that have an impact on firm outcomes. Folta points out that uncertainty increases risk. His definition divides the uncertainty into internal company level uncertainty and external environmental uncertainty. The internal company level uncertainty deals with issues such as the uncertainty in completion of the project, in the introduction of the appropriate production processes, and in the acquisition and development of the needed competencies. The environmental uncertainty can further be divided into infrastructural uncertainty, market uncertainty, uncertainty concerning the distribution channels, technological uncertainty, competitive uncertainty, and uncertainty concerning the government actions (Folta, 1994).

One view is to associate uncertainty to a lack of precision. The cost of a research and development project may vary between certain values to some level of certainty. On the other hand, a decision to abandon a project could imply a totally different course of action. These are different sources of uncertainties. Uncertainties concerning the exact cash flows can be regarded as continuous uncertainties. Uncertainties concerning the continuation of a project can be considered discrete uncertainties. Due to the difficulties to take the discrete uncertainties into account in the determination of the confidence intervals for the cash flows, several reports on research and development evaluation have ended up in focusing on the *continuous* uncertainties. The uncertainty has often thus been defined as *the lack of precision believed to be associated with the rating assigned to a factor under the assumption that the project plan occurs essentially as forecast without major modification* (EIRMA, 1970). It is interesting to note that Myers and Howe (1996) focus in their recent paper written twenty-six years later solely on the discrete uncertainties in the different phases of pharmaceutical research and development projects. Myers and Howe model the uncertainty using Monte Carlo simulation. Using the definitions of Folta, continuous uncertainty can be seen to overlap the definition of risk. Discrete uncertainty can be seen to be closer to Folta's definition of uncertainty.

A third major way to view uncertainty is to divide it into substantative and procedural uncertainty. According to Dosi and Egidi (1991), uncertainty has fundamentally two origins. First, it can originate from the lack of information necessary to make decisions with certain outcomes. Second, it can originate from the limitations on the computational and cognitive capabilities of the to pursue objectives, given the available information. According to Dosi and Egidi, the first source of uncertainty is the incompleteness of information. The second source is the incompleteness of knowledge. According to the substantative and procedural rationality defined by Simon, Dosi and Egidi name the first source of uncertainty as the substantative uncertainty. They name the second source of uncertainty as the procedural uncertainty. Compared to the other discussed definitions of uncertainty, the definition of uncertainty by Dosi and Egidi brings up a new dimension: the distinction between information and knowledge. Dosi and Egidi make a further distinction between weak and strong substantative uncertainty. Weak substantative uncertainty is present when the events and the probability distribution of outcomes are known. Strong substantative uncertainty is present when there are unknown events or it is impossible to determine the probability distribution of the events. Weak substantative uncertainty corresponds the definition of risk defined earlier. Strong substantative uncertainty corresponds to the definition of uncertainty by Folta.

It is commonly stated that the uncertainty in research and development in most of the cases reduces over time. The overall uncertainty concerning the value of research and development is assumed to decrease over time. There are different views of how the uncertainty decreases over time. Sometimes, it has been hypothesized that the uncertainty would decrease exponentially so that the lower levels of uncertainty would be achieved relatively soon after the initial investments. Myers and Howe discuss a more discrete risk-return staircase. According to their model the decrease in the risk is mostly linear. They hypothesize that the decreases in uncertainty take place in the pharmaceutical industry in discrete time intervals in line with different approval processes.

Some research has already been carried out in order to combine the real option valuation to research and development valuation. Many of the real option articles mention the real options in connection with research and development. In addition, there are at least two articles focusing explicitly the use of the option valuation in research and development: Mitchell and Hamilton (1988) and Newton and Pearson (1994). The existing work has not gone, however, beyond the mere application of the existing option valuation models. New methods have not been developed in connection with research and development valuation. Concerning the role of uncertainty in the option valuation, Newton and Pearson point out that it should be possible for large research and development based companies to classify projects into sets of similar risk and return profiles and to derive from these volatilities usable in the assessment of the worth of future projects.

Mitchell and Hamilton (1988) establish a parallel between the stock option and the research and development option. According to them, the price of a call option is analogous to the cost of the research and development program. The cost of the research and development program can be calculated as the present value of the costs for creating the option. The exercise price corresponds to the cost of the future investment needed by the company to capitalize on the research and development program when the investment is made. The exercise price can be calculated as the present value of the of expected future costs of at time T. The time T is the time of the exercise. It means the time when the future investment is made. The value of the underlying asset in the call option is analogous in research and development to the returns the company will receive from the future investment. This can be calculated as the present value of the expected returns at time T. Mitchell and Hamilton note that the value of the option varies in the opposite direction as one would expect. A higher volatility corresponds to a higher option value. This is in contrast to the net present value methods where the higher volatility corresponds to the lower net present value.

Mitchell and Hamilton (1988) also discuss the role of the downside risk, uncertainty increases, and time increases in connection with the option valuation of research and development. They point out that the downside risk is limited to the initial investment. As a company does not make a significant investment in the beginning, it has time to wait and see how the technology evolves. During the initial stage, it may gain valuable insights into the future opportunities. This is illustrated in figure 6 drawn according to Folta (1994). According to Mitchell and Hamilton, the uncertainty increases increase the upside potential without increasing the downside risk represented by the initial investment cost. Long time to expiration of the research and development option make investments more attractive increasing the value of the research and development option. In connection with net present valuation, a longer time would lead into a lower net present value of an investment.

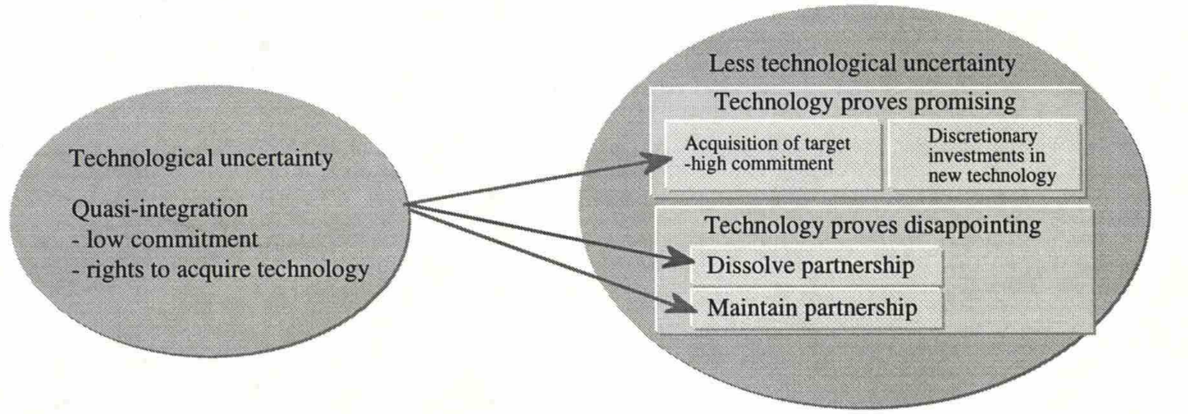

Figure 6 Decrease in the technological uncertainty in connection with technological collaboration (Folta 1994)

Folta discusses how the choice of governance could be seen as an option to create a new technological area as the uncertainty concerning the technology decreases. Folta discusses particularly the option nature of collaboration. An acquisition or a further investment is seen as the option exercise. Similar kind of gradually increasing integration in the different modes of collaboration has been evidenced by Kogut. In a study of 148 joint ventures, Kogut found that the industries that were the most active acquirers of joint ventures are chemicals, primary metal industries, communications, machinery, and other manufacturing industries. Altogether 68 joint ventures had been either dissolved or acquired (Kogut 1988). Few years later, in a follow-up study of a subsample of 92 manufacturing joint ventures, Kogut found that 27 joint ventures had been terminated by dissolution, 37 by acquisition, and 28 were still operational (Kogut 1991) . Hypothesizing that joint ventures are options to buy technology, Kogut studied factors increasing the likelihood of acquisition. In line with the option hypothesis, the main correlations were found between the unexpected increases in the value of the venture, the degree of concentration of the industry, and the propensity to acquire the joint venture. Similarly in line with the option hypothesis, Kogut found that a market decline did not correlate statistically significantly with the dissolution of a joint venture.

Hagedoorn and Sadowski (1996) have studied the potential transition from collaborative arrangements to acquisitions on the basis of their databases of collaborative arrangements and acquisitions. More specifically, Hagedoorn and Sadowski studied the transition from contractual research and development agreements, joint development agreements, technology-motivated joint ventures, and technology-motivated minority holdings to acquisitions. In addition, Hagedoorn and Sadowski studied whether contractual technology alliances are transformed into joint ventures. All the results were contrary to the expectations. Out of the total of 6060 alliances only 143 or 2.4 % were found to be transformed into acquisitions. Out of all the contractual alliances only 84 were found to be transformed into joint ventures. Out of the transformed alliances 33 % represented companies of similar size and 68 % represented companies of dissimilar sizes. A total of 64 % of the companies in the transformed alliances were from identical sectors and 36 % were from different sectors. Over 70 % of the companies in the transformed alliances had over 5000 employees.

The findings of Laamanen (1997) corroborate the findings of Hagedoorn and Sadowski. Both studies would seem to contradict the findings of Folta and Kogut. Despite the attractiveness of the idea that collaborative arrangements would be used as an option for further investments or subsequent acquisition, the predicted kind of subsequent acquisition activity is not observable in the behavior of companies. In connection with small, technology-based companies, the acquisition takes place typically as a sequence of events where the acquiring company has the possibility to acquire a company or not to acquire a company. If only some part of a company is acquired at first, it typically means the existence of an earn-out formula rather than a conscious option strategy. Companies seem to end up carrying out acquisitions due to a number of varying reasons. The use of an option strategy requires an intentional acquisition strategy. Another reason why the option theory would not seem to work in connection with small, technology-based company acquisitions is the need for investments in the small company. In order to activate the beneficial dynamic complementarities between the small and large companies, it is necessary that investments to combine the complementary competencies are made. Due to possible agency problems, the large companies do not want to invest in small companies if they cannot be sure that they possess the rights to the results. They rather acquire the small companies and invest when the small companies are in their possession. Investments by a large company may also easily lead into a situation where the large company has already invested more than the entrepreneurs that established the company. Despite the fact all the studies have not observed option-like behavior in the company acquisition behavior, it does not mean that option-based methods would be inapplicable for the valuation of collaborative arrangements as options. Collaborative arrangements can be used as options to acquire the collaborative partner and valued as such. That holds even if all many of the companies would not have recognized the attractiveness of such option building and eventual option exercise.

Mitchell and Hamilton (1988) divide the different valuation situations according to strategic objectives into knowledge building, strategic positioning, and business investment. The knowledge building includes fundamental, basic, and exploratory research. The strategic positioning includes focused applied research and exploratory development. The business investment includes development and engineering. According to Mitchell and Hamilton, the best suited financial approaches for the business investments would be the discounted cash flow and the return on investment approaches. The best suited approach for the strategic positioning would be the option valuation. The best suited approach for the knowledge building would be the cost allocation. Mitchell and Hamilton determine the suitability of the financial approach according to the possibilities to identify the potential market. According to Mitchell and Hamilton, the potential market is not possible to identify in connection with knowledge building. Due to the impossibility to identify the potential market Mitchell and Hamilton end up concluding that cost allocation is superior to option valuation in connection with knowledge building. In connection with strategic positioning, the potential market that is used as a basis for valuation is broad, but possible to identify. In connection with business investment, the potential market can be determined more specifically.

Mitchell and Hamilton (1988) differentiate between knowledge building and strategic positioning. The more recent literature in the field of strategic management would seem to bring the knowledge building into the center of strategic management. The companies position themselves in terms of their core competencies. The different capability platforms form options for business positioning and growth. The strategic management literature discusses the bifocal companies that focus on the long term visions and short term platform creation. The capability platforms are each growth option platforms. Together they can be seen to form a staircase to growth (Baghai et alii, 1996). The recent literature in the field of strategic management would seem to include knowledge building as one of the core elements into the strategic positioning. If the knowledge building would be seen as a basis for strategic positioning, it could be valued as an option or as a compound option. Despite the difficulty to determine the potential market and the value drivers, different scenarios can be used as a basis even for the valuation of knowledge building. Using the compound option valuation, the value of knowledge building could be derived from the different strategic positioning alternatives.

Mathematically, there would seem to be one problem in the reasoning of Mitchell and Hamilton (1988). Following the logic of Mitchell and Hamilton, the value of the research and development would continue to increase continuously as the underlying uncertainty increases. The volatility increases the option value. The option value increases the value of the research and development investment. The value increases as long as the volatility increases. This result is due to the fact that Mitchell and Hamilton assume that a same discount rate is used despite volatility changes. For example, weighted average cost of capital WACC, is used to calculate the initial values for the option valuation: the investment cost, the exercise price as a net present value of the future investments at the exercise time T, and the value of the underlying asset as the net present value of the future revenues at the exercise time T. The calculation of these initial variables would require, however, the determination of an appropriate discount rate for each uncertainty. The determination of an appropriate discount rate is dependent on the underlying uncertainty of an investment. An increase in the uncertainty or risk of a research and development project implies a higher option value. If the same increase in risk is taken into account in calculating the initial variables, the increase in uncertainty also implies lower net revenues at the exercise time T. This is the case even if one would use different discount rates for the revenues and costs. The eventual change in the value due to a change in the uncertainty depends on the relative magnitude of the opposite changes. In practice this would mean that the increases in uncertainty have at least the following implications:

=> The present value of the investments constituting the exercise price at time T decreases due to a larger discount rate to take into account the increased uncertainty. The present value needs to be calculated since the exercise price is typically not a one-time investment, but a series of investments after the exercise decision has been made.

=> The present value of future sales revenues at time T decreases due to a larger discount rate to take into account the increased uncertainty. The present value of the future sales revenues after the exercise time T is the underlying asset in the real option valuation. The present value needs to be calculated since the underlying asset consists of the cash flows created in different times.

=> The increase in the uncertainty itself is seen as an increase in the volatility parameter. If only the volatility parameter would be changed ceteris paribus then the option valuation equation would give a higher value when there is higher volatility.

Consequently, the option value either increases or decreases depending on the relative magnitude of changes. This is formalized in equation 1. A decrease of the underlying asset value decreases the option value. A decrease in the exercise price increases the option value. An increase in the volatility increases the option value ceteris paribus.

(1) $$\frac{dC}{d\sigma} = \frac{\partial C}{\partial \sigma} + \frac{\partial C}{\partial X(\sigma)} + \frac{\partial C}{\partial S(\sigma)}$$

where C is the growth option value, s is the volatility of the underlying asset S, and X is the exercise price as the present value of the investments exercising the option. A decrease in the uncertainty shown as a decrease in the volatility would have opposite changes in the option valuation.

4 Synthesis and potential areas for further research

The recent developments in the field of strategic management have made the competence development into the center of focus. From a more static core competence analysis there has been a shift to more dynamic competence development. This has increased the focus on issues such as competence building and competence leverage. In addition to the question of how to develop and leverage competencies, the question of how to select and value competencies has increased in importance. It has been found that these questions are to some extent related. For example, the absorptive capacity of a corporation can be seen to affect both the identification of relevant competencies and the absorption of competencies.

The competence building and competence leverage can be seen to correspond to the research and development and commercialization respectively. The competence building focuses on the identification of the relevant competencies and the acquisition and development of these competencies. The competencies can be acquired from external sources or developed internally. The external acquisition of competencies can take place in several ways. It can be carried out by acquiring other companies, by creating collaborative arrangements with companies possessing the competencies, or through licensing, patenting, et cetera. The competence development typically involves cash outflows while the competence leveraging typically involves cash inflows. Taking the options perspective, the competence development can be seen as the option building stage and the competence leveraging can be seen as the option exercise stage. This analogy is illustrated in figure 7. For example, in connection with company acquisitions, the company acquisition could be seen as an option. The realization of a new business area could be seen as option exercise. Taking the perspective of Folta, a minority equity investment into the company with the purpose to get an option to acquire the company could be considered as an option on an option.

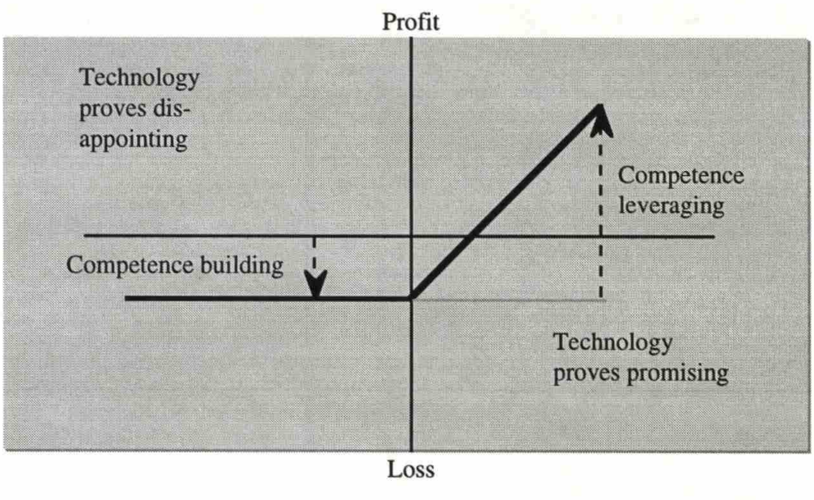

Figure 7 An illustration of competence building and competence leveraging in a call option framework

The analogy between the different types of competence building and option development partly contradicts the article of Mitchell and Hamilton where the authors recommend that knowledge building should be valued using cost allocation. It is seen that together the different types of competencies, created through knowledge building, form competence platforms which provide growth opportunities. The competence platforms are seen as strategic positioning. Depending on the type of competence building, the distinction between the strategic positioning and the knowledge building can disappear. It is acknowledged that the option platforms are sometimes relatively generic and the markets very difficult even to identify and predict. In this kind of situations, the competence building is closer to compound option analogy than simple option analogy. The strategic positioning is typically closer to a simple option. The normal short-term business investments can easily be justified using the discounted cash flow methods. It would seem that the option nature of the investment increases, the higher the uncertainty and the further the investment is from the actual option exercise. An investment that allows direct competence leveraging, can be valued as a normal business investment. The investments in competence building would seem to require option valuation methods. This is illustrated in figure 8.

	Competence building	Competence leverage
High uncertainty concerning the future development	Option valuation	
Low uncertainty concerning the future development		Net present valuation

Figure 8 Competence transactions and the type of valuation

In order to better value technological competencies or research and development, it would seem necessary to go deeper in modelling the different uncertainties inherent in the specific industry, business, and technological area. Traditionally, these uncertainties have been checked and modeled using criteria lists and scoring cards. The criteria in criteria lists correspond to different elements of uncertainty. Good evaluation results in terms of some specific criterion typically means lower uncertainty in that respect. Research and development projects passing such a criteria list or getting a high score have a higher probability of success, because so many of the dimensions of uncertainty can be considered to have favorable initial conditions. Modelling the uncertainty structure of the valuation problem into a quantifiable value judgement is a more difficult task requiring advanced valuation techniques. The traditional net present valuation methods can be regarded deficient in that respect. The uncertainty in the net present valuation methods is represented only through the discount factor that should correspond the risk of the project. Weighted average cost of capital or adjusted weighted average cost of capital are typically used. With these measures, there is typically the problem that companies do not really take the risk or the uncertainty of the project in question into account. They often use uniform hurdle rates for justifying projects with different risks. A further problem is that even if companies would like to take into account the risk of the project in question, the transformation of the underlying uncertainties into a single figure represents a difficult task. An even further problem is that even this uncertainty can be expected to be different for costs and revenues as demonstrated by Myers and Howe (1996). In line with Myers and Howe, Ott and Thompson analyze a situation where the uncertainty in cash inflows and cash outflows are not correlated. They show that the higher the uncertainty concerning the cash outflows, the higher the project value due to higher discount rate used to discount cash outflows (Ott and Thompson, 1996).

The uncertainty can also be expected to differ in the different years during the research and development project. There is the discrete uncertainty whether the project succeeds or not. There is the volatility of the expected cash outflows and there is the volatility of the expected cash inflows. In addition, there is the specific uncertainty concerning the external environment, the interest rate uncertainty. The interest rate uncertainty affects the opportunity costs of the investment. As a result, it affects the volatility of the both the expected cash inflows and cash outflows. For example, Ingersoll and Ross discuss the interest rate uncertainty level pointing out that all the projects have an option nature if there is interest rate uncertainty. The projects have an option nature even if there would not be any uncertainty in the underlying asset. According to Ingersoll and Ross, each project can be seen to compete against itself in a deferred form.

The differing uncertainties in cash inflows and cash outflows could be taken into account in the discounted cash flow methods using different discount rates for the costs and revenues. The discrete success-failure uncertainty could be taken into account by assigning success probabilities for each stage of the investment project. The external interest rate uncertainty could be taken into account by using option valuation to determine whether to continue or to abandon the project at each stage. The decreasing uncertainty over time causes problems for both methods. The option valuation methods are typically based on the assumption that the volatility of the underlying asset, modeled here as the present value of project revenues, remains constant. A decreasing uncertainty would require changes in the analytical solution of the option valuation equations. In binomial option valuation, it would lead into a situation where the binomial tree grows exponentially.

It is generally agreed that option valuation applies in principle for the valuation of different kinds of competence options. It is also a fact that the option valuation of research and development has been taken to use in companies only gradually. One reason for this may be the perceived complexity of the methods. One reason may be the restrictive assumptions made in the option valuation. It would seem that even though the option valuation in principle would be the ideal method for competence valuation, the existing valuation methodology is not sufficient to take into account the dynamism in the different uncertainties. More methodological development would be needed to integrate the value drivers in a specific valuation situation and the modelling of the uncertainty. The value of the option valuation methods should not be underestimated, however. The option valuation can provide significant value-added when compared to the traditional research and development valuation based only on cost allocation or different types of criteria lists.

The third generation real option literature would seem to present a saturated picture of the research on real options. The initial enthusiasm related to the use of real option valuation seems to have gradually decreased. According to the literature study presented in this article, one of the most potential routes for further development of the research on real option valuation would seem to be the more holistic modelling of uncertainties in competence building. More specifically, the valuation should be developed to take into account the differing uncertainty structures in cash inflows and outflows, the dynamism in the uncertainties, the question of discrete versus continuous uncertainties, and the link between the real process value drivers and the uncertainties. A holistic valuation of these uncertainties could possibly help the companies to improve the valuation of their research and development and other competence development initiatives.

An important area of its own that could provide one possible route for the further development of the real option valuation methods is the combination of the game theoretical analysis for the analysis of the competitive uncertainty. The existence and nature of competition can be seen as one of the value drivers in competence development. Pre-emptive moves from competitors may reduce the value of an option to defer. Combining the game theoretical considerations to the option analysis represents a time frame of 3 to 6 years. The analysis of competence platform building represents an analysis time frame of 10 to 15 years. In less strategic investments, where the analysis time frame is less than three years, the discounted cash flow methods would seem to be the most appropriate.

5 Summary

To summarize, the main issues pointed out in this article are

- in contrast to Mitchell and Hamilton (1988), the valuation of knowledge building is proposed to be carried out using the option valuation methods. With the present competence focus in the strategic management literature, the competence building is seen to be part of strategic positioning. Competence building could be seen to correspond to compound option valuation. More market-oriented strategic positioning is seen to correspond to simple option valuation
- the increases in uncertainty in the cash inflows and cash outflows both increase and decrease the resulting option values depending on the relative magnitudes of the opposite changes
- understanding the uncertainty structure is crucial for the use of real option valuation in the valuation of research and development. For this reason, it is necessary to understand the drivers of the underlying asset uncertainty
- option valuation can be applied for the valuation of absorptive capacity, competence building, and competence leverage. Absorptive capacity and competence building could best be valued as compound options, competence leverage typically involves less uncertainty and could be valued directly using the discounted cash flow methods
- the different uncertainties in the costs and the revenues could be taken into account with the use of different discount rates. This is necessary also in connection with the real option valuation of research and development since the determination of the initial values for the option valuation requires discounting cash inflows and cash outflows
- the option valuation equations implicitly assume constant volatility in the value of the underlying asset. This is not a valid assumption in research and development valuation. The decrease in the uncertainty over time should be taken into account in the option valuation

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3 REAL OPTION VALUATION OF TECHNOLOGICAL COMPETENCIES COMPANY ACQUISITIONS AND OTHER STRATEGIC INVESTMENTS

Tomi Laamanen

ABSTRACT

This paper reviews briefly the methodological state of development of the real option valuation. The use of real option valuation for the valuation of competencies is identified as one of the emerging fields of research in the field of finance. It is an interdisciplinary field of research that has potential to contribute both to the field of finance and to the field of strategic management. So far, the development of the real option valuation has mainly been methodological. It has been constrained to some extent by the lack of published empirical research that would apply and test the developed methodology in tangible real life situations. The recent developments in the field of strategic management have made the use of the real option valuation more applicable. This paper addresses the need for the development of the real option valuation methodology to adapt it to competence building and capability acquisition situations. The valuation of a tangible competence investment is presented as an example on the practical use of real option valuation.

1 Introduction

The dynamics of capabilities development in a corporation has started to receive more attention in the field of finance. In the research on capital budgeting practices, there has been a gradual shift from the traditional research and development project selection and cost allocation emphasis to strategic capital budgeting. At the same time, the need to measure and to value technological competencies has received increasing attention in the field of strategic management (Collis, 1991).

This paper aims at bridging these two separate streams of research. Applying the real option valuation methods for the valuation of strategic investments would seem to provide for an interface between the strategic management research and the research in the field of finance. There exists already some attempts to bridge these two streams of research. The empirical applications have remained, however, relatively few in number. There are no real guidelines for the management on how to apply the real option valuation in practice. The purpose of this paper is to contribute to the practical application of the real option valuation. This is done by first analyzing the methodological state of development of the real option valuation. Based on the existing methods, a tangible valuation example is provided. The example contributes to the development of practical guidelines for the use of the real option valuation in competence valuation. The example presents four expansions of the real option valuation methodology. The expansions emerge from the empirical application of real options in competence valuation. The four expansions represent four uncertainty-related issues that a person carrying out competence valuation with real options should be aware of.

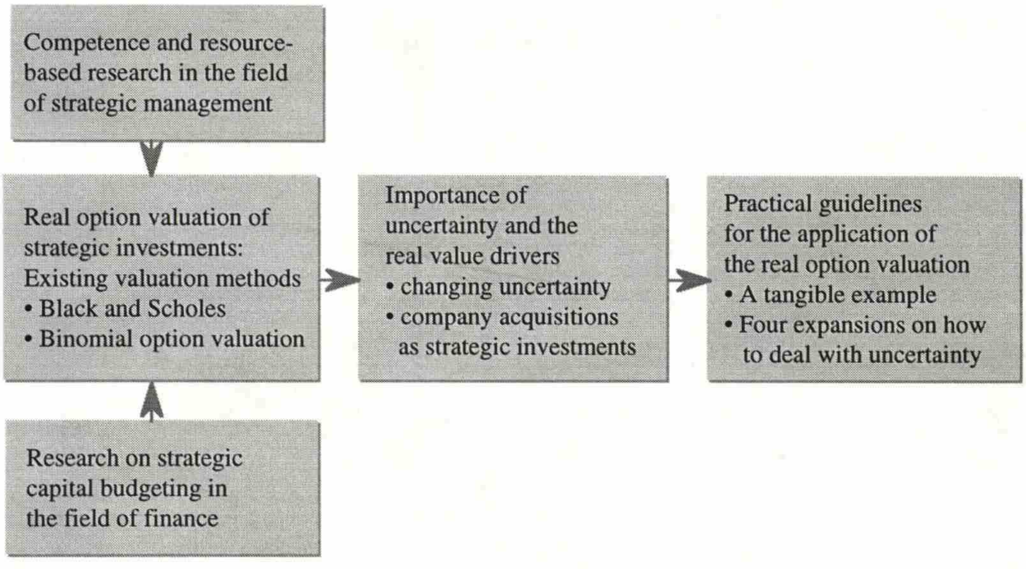

Figure 1 The logic of reasoning in the present paper

In investment appraisal and capital budgeting, the field of strategic management is close to the field of finance. Recently, the growth options can be seen to have received special attention in the of field of strategic management. From a static competitive analysis approach, the field of strategic management has moved through a resource-based view of strategy to a dynamic capabilities view of strategy. The field of strategic management is largely driven by the question of how companies achieve and sustain distinctive competitive advantage (Teece et alii, 1992). One of the approaches to answer this question is the competitive forces approach (Porter, 1980), rooted in the structure-conduct-performance paradigm of industrial organization (See, for example, Rasche, 1994; Porter, 1981; Caves, 1980). Another approach is the entry deterrence approach rooted in the game theoretical methodology of the industrial organization theory. These two approaches attempt to explain the sources of competitive advantage through variables related to industry structure.

The resource-based approach and the dynamic capabilities approach focus on variables related to the company resources and capabilities (Teece et alii, 1992). Company-specific resources and capabilities are seen as sources of competitive advantage (Penrose, 1959; Rumelt, 1984; Wernerfelt, 1984). The philosophical difference compared to the industrial organization approach is the order of analysis. In the traditional industrial organization approach, the industry is selected as a basis for analysis. The resources needed to compete in that industry are then developed. In contrast, according to the resource-based approach to strategy, the resources are seen to be unique and difficult to develop. A company should first try to identify and develop own resources and after that identify the most attractive industries (Teece et alii, 1992). The resource-based approach to strategy can be seen as complementary to the industrial organization approach (Amit and Schoemaker, 1993; Porter, 1991; Collis, 1991). The definition and identification of resources and the linking of resources to different distinctive competencies are among the main issues in the resource-based approach. Several classes of resources can be identified. Similarly, also several different links between the resources and the distinctive competitive advantage can be identified. Amit et al identify several characteristics of resources contributing to distinctive competencies. Among the others, they mention, scarcity, complementarity, low tradability, inimitability, limited substitutability, appropriability, and durability of resources as well as the overlap of company resources with the strategic industry factors (Amit and Schoemaker, 1993). According to the resource-based approach, the growth is constrained by the availability of resources, mainly shortage of labor or physical inputs, shortage of finance, lack of suitable investment opportunities, and lack of sufficient managerial capacity (For a literature study, see Mahoney and Pandian, 1992).

The dynamic capabilities approach can be seen as an extension of the resource-based approach to strategy. It consists of the skill acquisition, learning, and capability accumulation dimensions of the resource-based approach. The dynamic capabilities approach focuses on how the resources are transformed into company-specific competencies and capabilities (Teece et alii, 1992). According to the dynamic capabilities approach, the competitive advantage is based on the ability to develop and nurture competencies. The central problem is what competencies to invest in. As the development of new competencies takes time, the strategic investment decision process is of great importance. In the selection of appropriate investment areas, the dynamic capabilities approach gets support from the evolutionary economics approach which focuses on the evolution of technologies, companies, industries, and nations on an overall level. At a given point in time, companies follow certain trajectory or a path of competence development. The chosen path or technological trajectory affects the number of choices available (Teece et alii, 1992). In addition to making some choices more attractive than others, it constrains the number of choices economically available due to idiosyncratic investments in company-specific assets, complementary assets (Teece, 1986) and dominant logic (Prahalad and Bettis, 1986). Together the discussion on core competencies and the dynamic capabilities approach have spawned extensive research on competence-based competition (Hamel and Heene, 1994; Sanchez et alii, 1996).

2 Real option valuation of strategic investments

During the past several years, a number different approaches has been suggested to solve the problem of how to better value strategic investments. One suggested approach has been that the strategic investments should be separated from the operative investments and justified using qualitative subjective criteria, managerial judgement. One approach has been the expanded financial analysis framework developed by Kaplan (1986). Kaplan proposed that the strategic investments should be justified with a lower discount rate and with a better assessment of the intangible benefits. In recent years, the approach developed in the field of finance, the use of options to value strategic investments, has received a lot of attention. After the first couple of articles in the end of 1970s and in the middle of 1980s, there have now been published nearly two hundred articles and related writings on real option valuation (Trigeorgis, 1993).

The difference between the financial and the real options is that the financial options give the right to purchase shares at the exercise price before the expiration date whereas the real options give the right to invest by paying the investment cost before the opportunity disappears (Trigeorgis, 1986). When discussing real options, it is useful to divide them further into operating or *flexibility* options and growth options. Operating options are in essence the management's flexibility to change the direction of its future actions when new information arrives. Typical operating options are the option to defer investment (Kemna, 1993), the option to carry out a staged investment, the option to alter operating scale, the option to abandon, and the option to switch, for example, from one input or output to another (Kulatilaka, 1993). Each of these operating options can have a significant value-added in an investment. The option to defer investment is typically a major consideration in the natural resource extraction industries, mainly in the oil industry. Staged investment is an option of major importance typically in research and development intensive industries, especially in pharmaceuticals. Option to alter operating scale is valuable typically in cyclical industries, such as the fashion apparel or consumer goods. The option to abandon is valuable typically in capital intensive industries or in new product introductions. The option to switch is most important typically in industries where the goods are subject to volatile demand (Trigeorgis, 1993).

Growth options are options where an early investment is a prerequisite opening up possible future growth opportunities. Growth options could be hypothesized to be most important in all infrastructural industries and research and development based industries where there are multiple product generations (Trigeorgis, 1993). Similarly growth options could be considered to be applied to company acquisitions and the capability development in general in a corporation. A difference should be made between the *spawning of investments* and the *option to invest*.. Kasanen (1986) developed in his doctoral dissertation a model on how the strategic investments create or "spawn" new investment opportunities. He presents a matrix that he calls the spawning matrix. The elements of the matrix are multipliers that determine how many investment opportunities are created by a unit investment in one category. The spawning matrix describes the synergy of the investments across time in contrast to the synergy across the investments (Kasanen, 1986). It is important to note that the spawning of investments is not the same as an option provided by an investment. Spawning itself is deterministic. If the spawning effect is uncertain there is an option element. There is the option that the investment will spawn new investment opportunities (Kasanen, 1993).

The growth options can be combined to the spawning matrix. A fundamental problem with the matrix would seem to be that it becomes cumulatively difficult to predict the deterministic spawning effects of the different projects in the subsequent time periods. The uncertainty of the spawning effects makes the spawning more option-like than deterministic. The complexity of the model could actually be reduced by incorporating the option nature of the strategic investments into the model. The combined model could then be further developed by combining also the interactions of other competitors in a market to the model. The complexity increases if multiple options and option interactions are added to the model. An interesting property of the real options is that an investment may facilitate an infinite number of different kinds of growth opportunities. As the real options are not standardized and as all the growth options are not known beforehand, it may be difficult to assess what are the most important growth options provided by an investment. As the options are not additive, a further assessment would require that the relationships of the most important options would need to be assessed.

Black and Scholes model and its expansions

Different models have been developed for the valuation of options. For simple real option valuation situations, there are both binomial models and continuous models. For more complex situations, there are numeric algorithms for the valuation. The valuation of operating and growth options can be carried out according to the same main principles as with the financial options. The binomial model of Cox, Ross, and Rubinstein (1979) applies to the valuation of operating options directly. The Black and Scholes model (1973) is not as well suited because of its assumptions concerning the stability of the interest rate, the distribution of the underlying asset values, dividends, transaction costs, divisibility of the underlying asset, and the assumptions concerning short selling. The basic Black and Scholes equations for the valuation of a simple European call option are

(1) $$w(x,t) = xN(d_1) - ce^{r(t^*-t)}N(d_2)$$

(2) $$d_1 = \frac{ln\,{}^{x}\!/_{c} + \left(r + \frac{1}{2}v^2\right)(t^* - t)}{v\sqrt{(t^* - t)}}$$

(3) $$d_2 = \frac{ln\,{}^{x}\!/_{c} + \left(r - \frac{1}{2}v^2\right)(t^* - t)}{v\sqrt{(t^* - t)}}$$

where w is the value function of the option, x is the stock price, N is the cumulative normal density function, c is the exercise price, r is the risk free interest rate, v is the standard deviation of the underlying stock returns, and t*-t is the time to expiration. The above Black and Scholes model is derived by integrating the partial differential equation

(4) $$\frac{1}{2}v^2x^2w_{xx} + rxw_x + w_t \text{ - } rw = 0$$

subject to the terminal conditions

(5) $$w(x,t;c) = \max(x - c, 0)$$

(6) $$w(0,t;c) = 0$$

(7) $$\frac{w(x,t;c)}{x} \to 1, \qquad x \to \infty$$

In using the partial differential equation, it is assumed that the stock prices are log-normally distributed. The distribution is not normal since in that case there would also need to be negative stock prices (Trigeorgis, 1996). It is more reasonable to assume that stock prices follow the generalized Wiener process. The generalized Wiener process drift equation is

(8) $$dx = \alpha(x,t)dt + v(x,t)dz$$

where x is the stock price, dz is the increment of a standard Wiener process with mean 0 and variance dt and where a(x,t) and v(x,t) are the drift and variance coefficients correspondingly expressed as functions of the current state and time. In the option valuation, a commonly used special case of the general Wiener process is the standard diffusion Wiener process. The expansion and application of the option valuation models should always start from the drift equations. The drift properties of the value of the underlying asset should be known before an application of the option valuation can be developed for different assets than stocks.

Several analytical expansions of the Black and Scholes model have been developed. The expansions are useful from the real options perspective due to the added capability to take other factors into account. For example, the inclusion of dividends into the model affects the underlying stochastic process. The diffusion process can be changed accordingly and solved (Merton, 1973). In addition to the dividends, the Black and Scholes model can also be generalized to include more than one underlying asset and several contingent claims. An expanded version of the Black and Scholes equations would assume each contingent claim dependent on values of N underlying assets. A detailed derivation of the N underlying assets solution is presented by Trigeorgis (1996).

One problem with the use of financial option valuation models in connection with real options is that, contrary to financial options, short selling of the underlying asset is not possible. The real options are often non-tradable. As a consequence, it is impossible to construct a riskless hedge. It would not be possible, in principle, to use the risk-free interest rate in the valuation. Assuming tradability in a situation where it does not exist may bias the calculations. The options may become valued more valuable than they really are. In real options, there are investment entry and exit barriers. Other differences between the financial and the real options include the nonexclusiveness of ownership in connection with real options and the real option interdependencies across time (Trigeorgis, 1996). Both differences may also bias the real option valuation.

Another problem is the long time periods typical for real options. The long time periods may bias the results. The discount rate starts to dominate the calculations. In the long time periods, the effect of uncertainty reduces to a nearly constant percentage of the total option value. The uncertainty would need to be taken into account by adjusting the discount rate making the whole option valuation process dependent on the guesses concerning the uncertainty structure. One attempt to reduce the dominant effect of time in the real option valuation could be the use of the Black's equations for the valuation of European call *futures* options (Black, 1976).

There are often multiple options embedded in an investment project. The fact that the values of the different are not always additive makes the calculations difficult. The option interactions need to be taken into account in the option valuation. Fortunately, the added value from increasing the number of options that are taken into account is marginally decreasing. In most cases, it suffices to take into account only the most important options. Closed form analytical solutions exist for the simplest compound options. A compound sequential exchange call option is valued analogously to the valuation of a compound call option (Carr, 1988).

The combination of different options similarly as in the compound call option valuation facilitates the modelling of different complex real option situations. The inclusion of dividends can be used to model the possible competitive actions taken by the competitors. Expanding the Black and Scholes model (1973), Trigeorgis uses a different diffusion process, jump-diffusion, to model the influence of the entry of new competitors to an industry (Trigeorgis, 1986). In line with Kester (1984), Trigeorgis divides the different competitive situations into four categories according to the proprietary versus shared and expiring versus deferrable nature of the options. In addition, he includes the simple versus compound nature of the options.

One of the weakest links of the Black and Scholes model and its closed form expansions when applied to real option valuation would seem to be the underlying drift process assumptions and the lack of a risk-neutral portfolio. The drift process assumed in the Black and Scholes equations is the geometrical Brownian motion. The drift process of the underlying asset is assumed to be constant until the option exercise. It means that the volatility of the underlying asset is assumed to be constant. This is typically not a valid assumption in research and development or competence building, in general. Typically, the uncertainty decreases over time making the underlying asset less volatile at a later time. As the option valuation equations assume constant volatility of the underlying asset, the use of the standard form equations would tend to overestimate the research and development option values. The option values are calculated typically with the highest initial volatility estimates. Another complication in the option valuation of research and development and competence building is that the costs and revenues may have different uncertainties and consequently different drift processes. The net present values of the costs and revenues are typically used as the underlying asset in research and development. It is implicitly assumed that the combined drift processes of costs and revenues sum up to the drift process of the underlying asset. The drift processes of costs and revenues do not need to be similar, however. For example, Ott and Thompson (1996) model the drift processes separately.

Binomial option valuation model and its expansion into a lattice

The binomial models may be better suited for the valuation of real options in some cases because of their flexibility due to their incremental discrete nature. In the binomial models (Cox and Rubinstein, 1985), it can be assumed that there is one major source of uncertainty, for example the price of some asset. A decision tree is constructed on the basis of the different values of this variable. The life of an option is split up into a number of equal time intervals, where only the underlying base variable can change up or down by some multiplicative factors. It can move up by a multiplicative of u and down by a multiplicative of d. The risk-free probability for the movement can be derived on the basis of the risk free interest rate and assuming an arbitrage free world

(9) $$p = \frac{r-d}{u-d}$$

where p is the risk-free probability, r-1 is the risk free interest rate, d is the multiplicative of downward movement, and u is the multiplicative of upward movement. Having constructed a binomial tree of the changes in the underlying base variable, the corresponding returns in each node of the tree can be calculated. The returns in each node are returns which would be realized if the base variable would move accordingly and if the option would be exercised. The option value in each node of the tree can be calculated starting from the last period by discounting the expected value of all the option values of the next periods and adding it to the returns of the node. The expected value is calculated using the risk-free probability p. The discounting is carried out using the risk free interest rate r. In the last period, the option values are the same as the realized returns in the corresponding nodes. The binomial option valuation method can be formalized using two-dimensional lattices (Dentskevich and Salkin, 1991). The uncertainty in the base variable, for example, the price of an asset, can be described with a lattice having a time and a state index

(10) $$S_{i,t} = S_{0,0} u^t d^{t-i}$$

The net returns of each node, calculated on the basis of the base uncertainty variable lattice $S_{i,t}$, can be described with a net return lattice $N_{i,t}$. If the value of this lattice would otherwise be negative, a zero value is used. Finally, the option value lattice of the tree can be calculated on the basis the future option values and the net return lattice

(11) $$\psi_{i,t} = \frac{1}{r}\left\{p\left(\psi_{i+1,t+1} + N_{i+1,t+1}\right) + (1-p)\left(\psi_{i,t+1} + N_{i,t+1}\right)\right\}$$

where y is the option value lattice, 1/r is the discount factor derived from the risk-free interest rate, p is the risk free probability, and N is the net return lattice. To form a more realistic binomial option valuation model, the assumption to have only one base variable can be relaxed. Using multi-dimensional lattices, the option values can be solved in principle similarly as with two-dimensional lattices. Also, the time unit can be changed to make the model better correspond to the reality. Other possible extensions are the inclusion of taxes, several options, option interactions, and dividends. For example, taxes can be taken account by redefining the net revenue lattice

(12) $$N_{i,t}{*} = \begin{cases} N_{i,t} \geq 0; N_{i,t}(1-X_t) \\ N_{i,t} < 0; N_{i,t} \end{cases}$$

where X_t is the tax rate for the period t. The interaction between the different options can complicate the valuation when there are several options on the same underlying asset. As was pointed out earlier, it can be shown that the incremental value of an additional option, in the presence of other options, is generally less than its value in isolation, and declines as more options are present (Trigeorgis, 1993a). In case there arises the need to take a large number of options and their interactions into account, it is possible to utilize also numerical analysis methods. For example, Trigeorgis has developed and tested a log-transformed binomial numerical analysis method that is able to take numerically some of the option interactions into account (Trigeorgis, 1991).

3 Real option valuation in connection with company acquisitions

The application and development of real option valuation methods is an emerging field that has potential for a significant contribution. Examples of real-life applications and testing of the real option valuation methods have remained relatively scarce, however. This paper attempts to contribute in this respect by exploring the practical use of the real option valuation in competence valuation. Despite the potential contribution, the option valuation of competencies has only been briefly mentioned in the literature. Competence-motivated company acquisitions would represent a suitable application area for the use of option valuation. Company acquisitions represent an important subcategory of strategic investments. There is an extensive literature dealing with the valuation of companies in acquisition situations. Even in connection with company acquisitions, however, the option valuation has not received much attention. There may be several reasons for this.

- The real option valuation has been developed methodologically only to a limited extent in connection with company acquisitions since the underlying processes of company acquisitions do not seem to be understood well enough. The real option valuation can only address the valuation of competencies from outside. Detailed real option valuation would seem to require a deeper understanding of the qualitative situational characteristics of each decision making situation or a deeper understanding of the phenomenon to be valued.

- In addition to the need to take into account more of the qualitative factors into the real option valuation, another reason for the lack of real-life applications of real option valuation may be the inherent complexity of the interrelationships. The competence interrelationships may be difficult to predict even to the extent needed for real option valuation. Similarly in company acquisitions, the relationships between the different factors influencing the outcome of a company acquisition are complex.

- The theoretical immaturity of the real options approach may also inhibit the use of the real option valuation in competence valuation. It may be that the real option frameworks are still too rigid and undeveloped to provide real value added in real-life situations. In many cases, the philosophy of seeing a strategic investment as an option may seem attractive for management in justifying research and development investments. Without a clear valuation of the upper limits of the option price, however, the options thinking may lead into justifying investments that should not have been made. In such a situation, the quantitative option valuation should be used to establish the upper boundaries of the option value taking into account the estimates of the future events and outcomes.

- The transparency of the real options approach is not as good as the transparency of the net present value valuation. In net present value valuation the management can see directly the influence of a change in an initial parameter, for example, the discount rate, on the results. In the real option valuation, particularly in connection with the compound options and other interacting options, the relationships between the initial parameters and the results are more complex. The sensitivity analysis is more difficult to carry out and the results are more difficult to judge intuitively.

- In addition to all the above reasons, one additional reason for the lack of empirical evidence may be that there are separate people studying acquisitions, competencies, and real options. The real option valuation is a field that has spun off from the financial option valuation. It is still predominantly studied by finance researchers. The predominant focus of the strategic management and technology management researchers has been on the more qualitative characteristics of the phenomenon under study. In connection with valuation, the main valuation method used by the strategic and technology management researchers has been the net present value valuation.

This paper attempts overcome some of these problems by developing both the real option valuation methods and by developing a deeper understanding of the underlying phenomena in competence development and acquisition.

The performance of company acquisitions

One of the problems in the real option valuation is the interface to the performance factors of the strategic investments. The valuation of the growth options requires knowledge of the possible growth options inherent in the different kinds of strategic investments. This knowledge requires further knowledge of the uncertainty structure and the consequent performance and success factors inherent in the investments. There is a problem of generity of real options models and specificity of decision making situations. This can be seen to be one of the main factors inhibiting the development of a generic real options methodology that could be taken to use more broadly in the analysis of strategic investments.

The performance of company acquisitions has been the topic of a large number of both conceptual and empirical studies. It has attracted the interest of a large number of disciplines. The performance of acquisitions has been studied from the perspectives of financial economics, different schools of strategy, and organizational behavior. The studies in the field of financial economics have focused on the stock market responses to company acquisitions. The focus of the studies has been on relatively large acquiring and acquired companies. In these studies, the companies have been clustered according to several variables. The clustering has been done mainly into related and unrelated companies according to the similarity of the acquired company and the acquiring company. The studies have empirically attempted to find out whether the acquisitions lead into above average cumulative abnormal returns for the shareholders of the companies. A typical finding has been that the announcements of acquisitions have created positive or no changes in the combined wealth. The gains have occurred mainly for the shareholders of the acquired companies while the gains for the shareholders of the acquiring companies have commonly been insignificant, see, for example, Jensen and Ruback (1983). In parallel with the stock market studies, more conceptual work has been carried out in the strategy literature (Ansoff, 1965; Penrose, 1959; Kitching, 1967; Rumelt, 1974). The concept of relatedness between the acquired and the acquiring company has played a major role also in the strategy literature where the main focus has been on the relationships between the different acquisition strategies and company performance. The emergence of the resource-based approach to strategy and the dynamic capabilities view of strategy have further strengthened the theoretical basis of the strategy literature on acquisitions. As a result of the dissatisfaction in the dominating relatedness versus unrelatedness focus of both the strategy and the financial economics schools of acquisition research, there has been an increasing shift in the focus towards the integration issues. Combining the organizational behavior school approach to acquisition integration with the traditional strategy approach has resulted into a process perspective on the company acquisitions (Jemison and Sitkin, 1986a, 1986b).

The research on company acquisitions in the many different fields has resulted in a number of different measures for the acquisition performance. The dominant performance measure in the field of financial economics seems to have been the stock market performance of the acquiring and the acquired company. The strategy research has focused somewhat also on other quantitative measures such as net profit, sales and asset growth, earnings per share, and return on investment. The organizational behavior school has added some additional success measures such as measures on the successful completion of the post acquisition integration and the subjective perception of acquisition success in the different managerial levels (Vaara, 1995) A less often used measure of acquisition performance is the subsequent divestment of the acquired company (Ravenscraft and Scherer, 1987 and Porter, 1992). Softer, less frequently used process level performance measures include the employee reactions in the different levels of occurrence (Lohrum, 1996) and management turnover (Stewart, 1991). As the different disciplines seem to be converging in the most recent studies on company acquisitions, there is a multitude of measures for acquisition performance. A distinction can still be seen, however, between the 'traditional' strategy research on acquisitions and the research which combines the strategic and the organizational schools of research. There is still a tendency for the strategic school of research on acquisitions to rely more on the objective quantitative measures of success while the studies combining both schools seem to rely more on subjective measures of acquisition success (Nupponen, 1996). A business performance analysis framework has been proposed by Venkatman and Ramanujam (1986). The framework for analyzing the different acquisition performance measures consists of three dimensions. It distinguishes between objective and subjective measures of acquisition success, between financial and operational measures of acquisition success, and between measures that are based on primary and measures that are based on secondary data. The studies on company acquisitions have relied mainly on two types of financial measures, objective data from secondary sources and subjective data from primary sources (Nupponen, 1996).

In addition to the different measures of success, the multidisciplinary research on acquisitions has resulted in a large number of factors correlating with the performance of company acquisitions. The studies in the field of strategic management focusing on company acquisition performance include, for example, the studies of Ansoff et alii (1971), Borg et alii (1989), Cable et alii (1974), Chakrabarti (1990), Chakrabarti and Souder (1987), Chatterjee (1986), Chatterjee et alii (1992), Datta (1991), Datta and Grant (1990), Dewing (1922), Fowler and Schmidt (1989), Gimpel-Iske (1973), Hayes and Hoag (1974), Hogarty (1970), Hopkins (1987), Hunt (1990), Jemison and Sitkin (1986), Kelly (1967), Kilmer (1967), Kitching (1967, 1973), Kusewitt (1985), Larsson (1989), Lev and Mandelker (1972), Lindgren (1982), Livermore (1935), Lorie and Halpern (1970), Lubatkin (1987), Meeks (1977), Montgomery and Wilson (1986), Möller (1983), Nelson (1959), Newbould (1970), Porter (1987), Reid (1968, 1971), Rydén (1972), Segall (1968), Seth (1990), Shelton (1988), Singh (1971, 1984), Singh and Montgomery (1987), Souder and Chakrabarti (1984), Stich (1974), Vaara (1993), Weston and Mansinghka (1971). The studies in the field of financial economics include among the others the studies of Choi and Philippatos (1983), Elgers and Clark (1980), Ellert (1976), Franks et alii (1990), Halpern (1973), Healy et alii (1992), Higson and Elliot (1994), Jarrell and Poulsen (1994), Langetieg (1978), Mandelker (1974), Mason and Goudzwaart (1976), Melicher and Neilson (1978), Jensen and Ruback (1983), and Ravenscraft and Scherer (1987). Since the acquisition research streams of strategic management, financial economics, and organizational behavior are closer to each other today, strict borderlines are difficult to draw.

Due to the traditionally multi-disciplinary nature of the study on company acquisitions, the company acquisition phenomenon provides a particularly fruitful ground for trying to combine the research findings in fields of finance and strategic management. The emergence of a dynamic capabilities view of strategy would seem to provide the tools needed to apply the real options methodology into practice. A combination of the strengths of the both disciplines could be expected contribute to the both streams of research.

Smith et al discuss the potential benefits of the real option valuation in company acquisitions. According to them, the conventional cash flow analyses typically fail to take into account the flexibility and the growth options provided by the acquired companies. The valuation based on situational factors at the time of the acquisition places high requirements for the management to estimate the different alternative courses of action. According to Smith and Triantis, there are three main reasons why real option valuation could provide particular benefits in company acquisition valuation (Smith and Triantis, 1995)

- First, the conventional net present value valuation cannot take into account the growth options of the longer term acquisition programs. The acquisition programs may change the competitive position of the acquiring company and even the structure of the industry. Similarly to the collaborative arrangements (Doz, 1996), the acquisitions are typically driven by the acquisition process and the learning during the acquisition process. The initial conditions only set the stage for the subsequent actions.
- Second, the acquiring companies can utilize their flexible resources in organization, marketing, manufacturing, distribution, and financing to create new directions of diversification. They may create new strategic alternatives similar to growth options. An acquisition program focusing on strategic diversification in contrast to financial diversification may also increase the flexibility of the acquiring company. During a downturn, the new business areas can provide an option to switch production.
- Third, the net present value valuation does not take into account the divestiture option. The sale or the shutting down of the acquired company can be used to limit the downside of the company acquisition risk. The divestiture option is typically not accounted for since no need for that is typically perceived. Only the acquisitions that satisfy certain positive net present value projections are acquired. Due to the expectation of positive net present values there is no expectation of a divestiture.

4 Uncertainty as a core variable in the valuation

The development of the idea of competence valuation remains on a relatively theoretical level partly due to the abstract nature of the concepts and the mathematical complexity of the valuation. Another problem inhibiting the development of the option valuation methods in the valuation of technological competencies has been the assumption of constant volatility. The option valuation models presented earlier are based on an assumption of constant volatility. This is clearly not the case in technological competence development. It has been shown in several studies that both the technological and the market uncertainty decreases over time. The decrease is typically assumed to follow a decreasing exponential curve. The decrease in uncertainty is expected to be the steepest during the first years of competence development. After that the decrease is expected to take place more gradually. The exact shape of the curve depends on the type of competence development. For example, in the pharmaceutical industry, the uncertainty can be seen to decrease in steps as the research and development proceeds through the different approval phases. The decrease in uncertainty can be seen to take more the form of a staircase than a continuous exponential curve.

The decrease in uncertainty should be taken into account in the option valuation. In option valuation, the uncertainty plays a significant role in the role of the volatility of the underlying asset. The importance of the decrease in uncertainty is magnified by the long time perspectives typically present in valuing technological competencies using the option valuation. The changing uncertainty can be taken into account in the option valuation in several ways. One possibility is to analyze the underlying stochastic processes of underlying asset price change. For example, Cox and Ross (1976) discuss the valuation of options having different kinds of stochastic processes. They present a set of differential equations that can be derived under different kinds of drift process assumptions. The basic drift process that they start with is

$$dS = \mu(S,t)dt + \sigma(S,t)dz \tag{13}$$

where the first term describes the instantaneous mean of the diffusion process and the second term describes the instantaneous variance of the drift process. The variable S denotes the stock price and the variable t denotes time. In contrast to the basic drift process models, Cox and Ross model the instantaneous mean and variance as a function of the stock price and time. According to the Ito's lemma, Cox and Ross transform the drift process into an equation with which one can calculate a differential change in the option price as a function of the stock price, time, instantaneous mean, and instantaneous variance. Constructing a risk neutral portfolio with the option, a unit of stock, and lending or borrowing, the equation used for calculating a differential change in the option price can be transformed into a differential equation

$$\frac{1}{2}\sigma^2(S,t)P_{ss} + [rS - b(S,t)]P_s - rP = -P_t \tag{14}$$

where P describes the option price and the subscript characters denote the partial differentials of P according to the variable shown as a subscript. The variable r denotes the risk-free interest rate and b(S,t) denotes the dividend payments made to the stock as a function of stock price and time. This basic differential equation can be used for deriving the different analytical solutions under different kinds of assumptions concerning the volatility of the underlying asset. Cox and Ross examine, for example, the case where the variance is proportional to the stock price. Cox and Ross note that the diffusion processes are only one of two general classes of stochastic processes. The second stochastic process in continuous time is the jump process. The jump process is based on a continuous time Poisson process. Cox and Ross model the jump process as follows

$$\frac{dS}{S} = \mu dt + (k-1)d\pi \tag{15}$$

where S is the stock price, μ is the drift term, t is time, (k-1) is the jump amplitude, and π is a continuos time Poisson process with l as the intensity of the Poisson process.

There are also other ways to take into account the uncertainty evolution of the underlying asset in option valuation. For example, Merton (1973) shows that if volatility changes in a deterministic fashion, the Black and Scholes model for European options applies, with the average variance replacing the original constant variance. Merton's finding reduces the problem of analyzing the decreasing uncertainty over the lifetime of an option into the problem of deriving the average volatility of the underlying asset. The average volatility can be determined by integrating the volatility function over the time to option exercise and by dividing it with the time to exercise. For example, in connection with an exponentially decreasing volatility, $\sigma(t) = e^{-at}$, of the underlying asset, the average uncertainty could be derived as follows

(16) $$\overline{\sigma} = \frac{\int_{t_0}^{t_1} \sigma(t)dt}{t_1 - t_0} = \frac{\int_{t_0}^{t_1} e^{-at}dt}{t_1 - t_0} = \frac{-ae^{-at_1} + ae^{-at_0}}{t_1 - t_0}$$

where a is constant coefficient describing the steepness of the exponential volatility decrease. Using the average volatility is an applicable and easy way to adjust the Black and Scholes models to take into account the typically decreasing volatility in connection with research and development and competence platform valuation.

Taking the changing volatility into account in connection with binomial option valuation models is more difficult. One could implement exponentially decreasing multipliers, u and d, that would describe the decreasing volatility for the asset value development process. These changing multipliers in the tree would lead, however, into a situation where the three no longer is a binomial tree. Since the multipliers decrease over time, the later upward changes do not correspond to the earlier downward changes and the tree expands with a rate of 2 to the power of analysis time periods. The trees become non-recombining. In addition to making the option value calculations very laborious with already a small number of time periods, the binomial valuation models do not apply to this kind of exponentially expanding tree.

To facilitate the analysis of changing volatility also with the binomial trees, Rubinstein (1994) has developed the concept of implied binomial trees in the analysis of stock options. The analysis of Rubinstein emerged from the research pointing out that the underlying asset volatilities, implied by the observed option prices and the Black and Scholes option valuation formula, do not always exactly correspond to the underlying asset volatilities used in the option valuation. In the implied binomial tree methodology, the binomial trees are constructed according to a set of observed option prices. The risk neutral probabilities are estimated based on observed option data. When constructing the implied binomial trees, it is necessary to make certain assumptions concerning the underlying asset and the stochastic process. Rubinstein makes five assumptions. First, the underlying assets follow a binomial process. Second, the binomial tree is recombining meaning that the same number of up and down moves to lead to a same node in the tree. Third, the ending nodal values are ordered from lowest to highest. Fourth, all paths in the binomial tree that lead to the same ending node have the same risk-neutral probability. Fifth, all paths that lead to the same ending node have the same risk-neutral probability. Rubinstein, points out that the three first assumptions are necessary, but he also shows how the fourth and the fifth assumption can be relaxed. Having constructed an implied binomial tree, Rubinstein shows how to determine the local move volatility

(17) $$\mu[\bullet] \equiv \left((1 - p[\bullet]) \times \log d[\bullet]\right) + \left(p[\bullet] \times \log u[\bullet]\right)$$

(18) $$\sigma^2[\bullet] \equiv \left((1 - p[\bullet]) \times [\log d[\bullet] - \mu[\bullet]]^2\right) + \left(p[\bullet] \times [\log u[\bullet] - \mu[\bullet]]^2\right)$$

where • means the node in question, p means the risk-neutral probability, and u and d mean the up and down move multipliers. Rubinstein notes that as the number of moves increases and the move sizes decrease, the move volatility approaches the instantaneous diffusion volatility.

5 Valuation example

The use of option valuation in competence valuation is shown with an example. It is assumed that a company is considering competence development. The company sees an opportunity to invest into new competencies. The competence development would require 75 MFIM investment in the first year and 25 MFIM in subsequent years. It is expected that the competencies provide the investing company an option to invest further into a new business area through acquisition after four years. The business area is expected to be worth 500 MFIM if realized. The realization of the new business area would require additional investments worth 300 MFIM.

The traditional way of solving this kind of valuation problem would be to determine a suitable discount rate for the investment and to discount the net cash flows to the present time. The discount rate would be determined according to the riskiness of the investment. If the riskiness would be perceived to be high, the chosen discount rate should be high as well. The discount rate represents the cost of money for an investment. The cost is dependent on the riskiness of the investment. Often companies use company-wide weighted average cost of capital as a discount rate. The companies assume that the riskiness of an individual investment does not differ from the average riskiness of the company. The companies assume that they can get funding with the same average cost of capital for all their projects. The use of uniform company-wide discount rates leads the companies easily into a situation where they end up preferring higher risk projects over lower risk projects.

Assuming that a company would determine that the riskiness of the proposed investment corresponds to the discount rate of 15%, the example could be solved with simple net present value arithmetic. With the discount rate of 15% and with the above assumptions, the investment would show a negative net present value of -17.7 MFIM. According to the net present valuation, the competence investment would decrease the shareholder wealth and the competence investment should not be undertaken. Using a different discount rate would have yielded different results. This is illustrated below in figure 2 where the net present value of the competence investment is calculated as a function of the discount rate. The graph shows that the internal rate of return of the investment is 10%. If the riskiness of the investment would be considered to correspond to a discount rate of 10% or less, the investment would show positive net present value and should be undertaken. It has bee pointed out that different discount rates should be used for costs and for revenues because of the differing riskiness of these cash flows. In the present valuation example, the application of a discount rate of 6% for the cash outflows and a discount rate of 9% for cash inflows would result into a net present value of -25.2 MFIM. The investment appears less attractive when distinguishing between the discount rates. The cash outflows are typically less risky and they occur first. The cash inflows are more risky and they are further away from the present time.

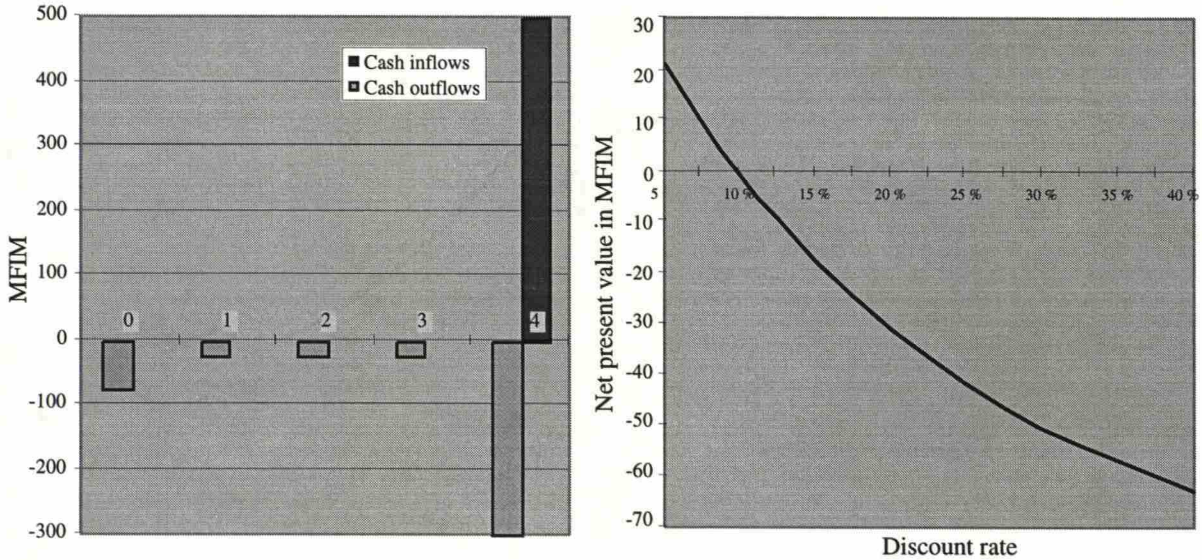

Figure 2 An illustration of the cash flows and net present values of the exemplary investment

The discrete uncertainties could be taken into account the in the net present valuation by using the expected cash flows. The expected cash flows could be determined on the basis of the discrete probabilities. The actual valuation could be carried out normally by discounting the expected cash flows to the present time. Implementing success probabilities into the above valuation example would make the project look even less profitable. Assuming, for example, that the success probability of the investment would be 0.8 each year would produce expected values that are weighed towards the costs occurring in the beginning of the investment. The probability of the realization of the initial investment of 75 MFIM would be 1. The probability of the first 25 MFIM investment would be 0.8, the second investment 0.64 and so on. As the positive cash flows occur at a later time point, the probability of realization of the positive cash flows after four years would be only 0.8 x 0.8 x 0.8 x 0.8 = 0.4096. Using both the differing discount rates of 6% for cash outflows and 9% for cash inflows and implementing the discrete uncertainties into the valuation would result into a net present value of -71.1 MFIM.

The valuation of the exemplary investment using the option valuation would follow a different logic. Despite its relatively restricted assumptions, the Black and Scholes model is used here to demonstrate the logic of option valuation in competence investments. In the above example, the underlying asset is the 500 MFIM present value of revenues in year four if the company acquisition option is exercised. The 300 MFIM investment in year four is the option exercise price. It could contain, for example, the company acquisition price, the costs of combining the acquiring and the acquired company, and the lost business during the acquisition process. The risk-free interest rate is assumed to be 5%. The time to expiration is assumed to be 4 years and the option to acquire the target company is assumed to be a European option. It cannot be exercised before four years. The volatility of the underlying asset is seen to be the volatility of the expected 500 MFIM present value of cash inflows after four years. The volatility is used as a variable in the calculations resulting into the curves shown in figure 3.

As the 500 MFIM underlying asset is the present value of the cash inflows in year four, the application of the Black and Scholes valuation model requires discounting the 500 MFIM to the present time. This discounting should be carried out using the discount factor appropriate for the investment. Again the discounting factor of 15 % is chosen and the present value of the underlying asset becomes 285.9 MFIM. The option is an out-of-the-money option. The application of the Black and Scholes equations for the valuation of the competence option produces option values ranging from below 50 MFIM to nearly 300 MFIM. Subtracting the present value of the initial competence investment, the net option value can be derived.

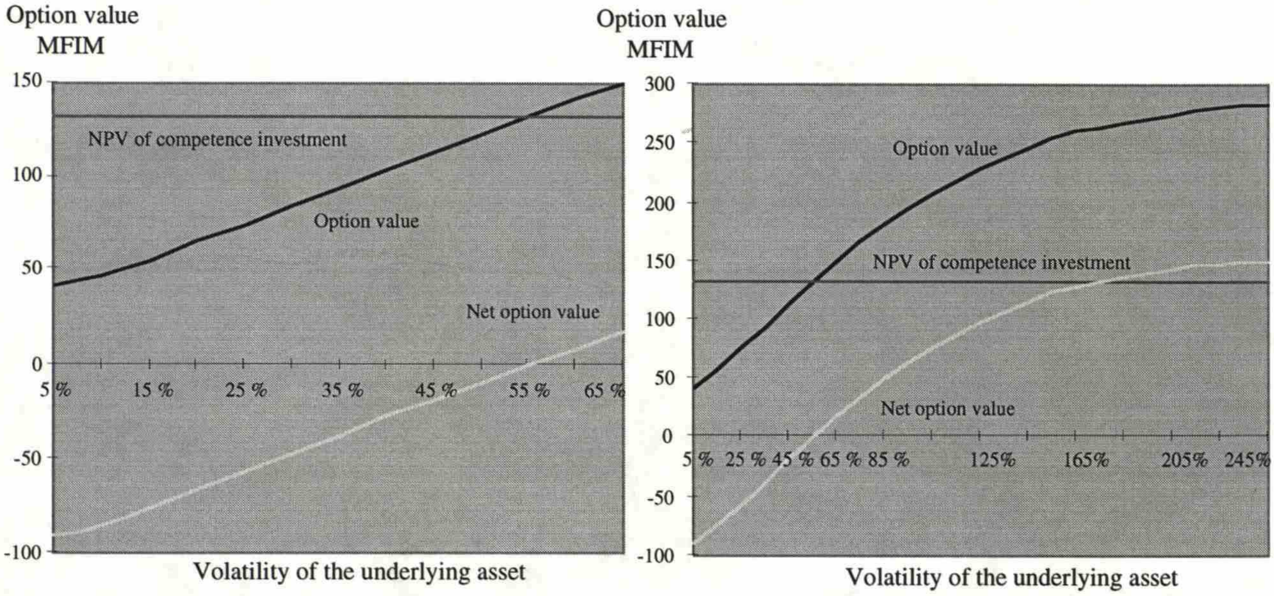

Figure 3 Option values of the exemplary investment as a function of the volatility of the underlying asset

In the example, the net option value is negative with asset volatilities that are below 55%. This is contrary to the net present valuation where the net present value was positive only in cases where the riskiness was considered low. Due to the missing downside, a more volatile option is more valuable. Figure 3 shows the option values in two volatility scales. In lower volatilities of the underlying asset, the option value can be seen to increase nearly linearly as a function of the volatility. In higher volatilities, the increases in option value are marginally decreasing. This means that the option value increases only to a certain point no matter how high the uncertainty is. When applicable, this property of the Black and Scholes equation can be used to determine the upper value for the option without the need to exactly determine the volatility of the underlying asset.

In the above option valuation example, there were a number of simplifying assumptions. The valuation did not take into account the differing discount rates for the costs and revenues and the discrete uncertainties discussed earlier. The discrete uncertainties can be taken into account in a similar way in option valuation as in connection with net present valuation. They can be taken into account by adjusting the cash inflows and cash outflows according to the discrete probabilities. The differing discount rates for cash inflows and cash outflows can be taken into account by assigning differing discount rates. The discount rates of 9% for cash inflows and 6% for cash outflows are used in here. Taking these into account, the Black and Scholes valuation of the competence investment produces the results presented in figure 4 on the left side. Now the range of different kinds of option values becomes much smaller. The option values vary between 60 MFIM and 150 MFIM. Subtracting the present value of the initial investments produces net option values which are negative until the underlying asset volatility of 115%.

The valuation example has not so far taken into account that also the 15% discount rate would need to be changed if the volatility of the underlying asset is changed. The 15% discount rate is also dependent on the riskiness of cash inflows which represent the underlying asset. The change in the discount rate could be taken into account, for example, by changing the revenue discount rate as a function of the underlying asset volatility. In here, the revenue discount rate is assumed to be a linear function of the underlying asset volatility by changing the revenue discount rate with the change in the volatility of the underlying asset divided by 20. This change has a dramatic effect on the results of the option valuation. The range of different kinds of option values becomes even narrower. The option value curve first increases and then starts to decrease as the discount rate starts to dominate. With the assumptions made concerning the competence investment and option valuation, it would seem that the investment is never profitable in terms of the net option value.

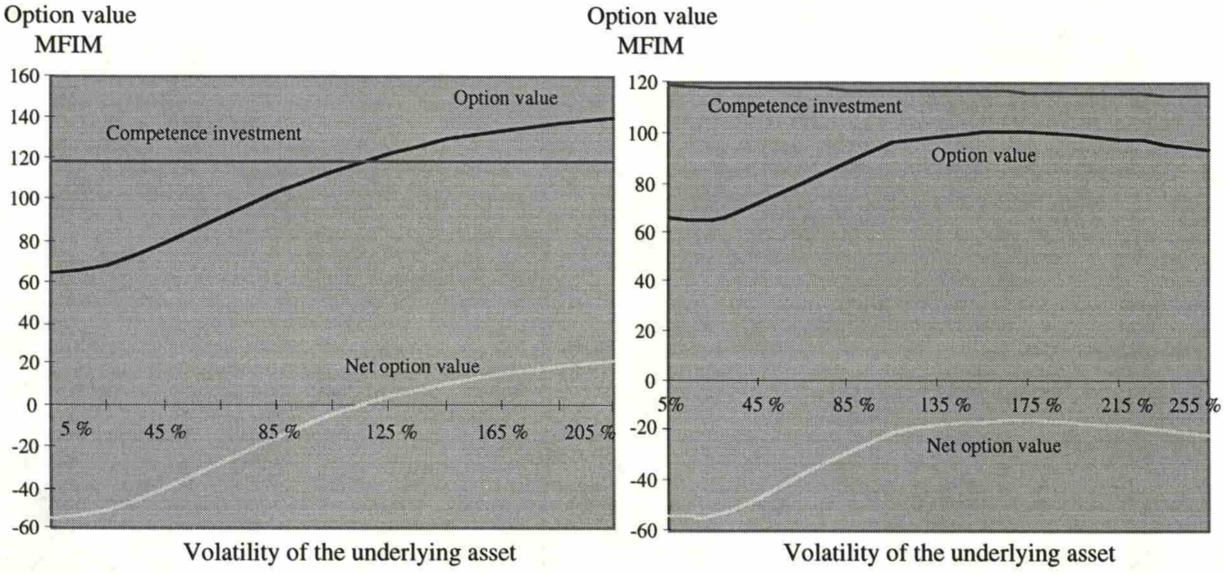

Figure 4 *Option values and net option values as a function of the underlying asset volatilities. The left figure represents a situation where the discrete success probabilities and the differing discount rates for cash inflows and cash outflows are taken into account. The right figure represents a situation where also the changing discount rate as a function of the volatility is taken into account*

Similarly to the above Black and Scholes model for option valuation, the binomial model can be tailored according to the real option valuation situation to take into account

- the changing uncertainty structure. First, the expected uncertainty structure of the competence is modeled. Second, the average uncertainty is calculated. Third, the average uncertainty is converted into up and down multipliers for the asset value development process of the binomial tree. Similarly to the Black and Scholes model, the use of the average uncertainty over the period produces the same result as the uncertainty as a function of time. The mathematical complexity is in the average case, however, significantly lower.
- the probability of continuing success of research and development. The success probabilities can be taken into account in the binomial model similarly than in the Black and Scholes model by using the expected cash flows. The estimated cash flows are replaced with the expected cash flows. The expected cash flows can be derived by weighing the estimated cash flows with the probability that the cash flows are realized.
- the differing discount rates for the costs and for the revenues. The differing discount rates can be taken into account when calculating the initial values for the initial investment and for the initial asset value. Using these initial values as input parameters allows to take into account the differing discount rates without changing the logic of the binomial valuation.

The binomial model allows for sensitivity analyses with the volatility of the underlying asset as the non-dependent variable. This requires somewhat more work, however. For each analyzed level of underlying asset volatility, the binomial tree has to be constructed separately. The binomial model facilitates also other analyses. It facilitates the combination of several different kinds of options into the binomial tree. The binomial option valuation model also provides the management a better view of the asset development process assumption. This is a particularly difficult assumption to make in connection with real options. The binomial valuation visually shows the management what they are assuming when they are assuming, for example, a volatility of 55 % for an underlying asset. The results become easier to understand. The valuation model becomes easier to adopt.

In connection with the binomial option valuation, the initial underlying asset value has to be calculated by first discounting the asset value estimate to present time. This should be carried out with a discount rate that takes into account the riskiness of the expected cash flows. An example of this is shown in figure 5. The 500 MFIM underlying asset is discounted into present time with a discount rate of 15 %. The discounting results into an initial underlying asset value of 286 MFIM. The binomial tree on the left of figure 5 shows the asset development process with an average volatility of 55% during the option life-time. This volatility estimate corresponds to an upward multiplier of 1.74 and a downward multiplier of 0.57. The right side of figure 5 represents the option value derivation. The binomial tree is solved starting from the leaves. A risk-free rate of interest of 5% is used. The risk-free probability can be derived from equation (9). In the example, the risk-free probability is 0.41. The resulting option value is 128 MFIM. The corresponding option value using the Black and Scholes option valuation is 132 MFIM, the difference being 4.5%. Having calculated the option value, the present value of the initial option investment should be deduced from the result. The net present value of the initial investment is 132 MFIM. The binomial option valuation confirms that the volatility of 55 % is close to the break-even volatility shown in figure 3.

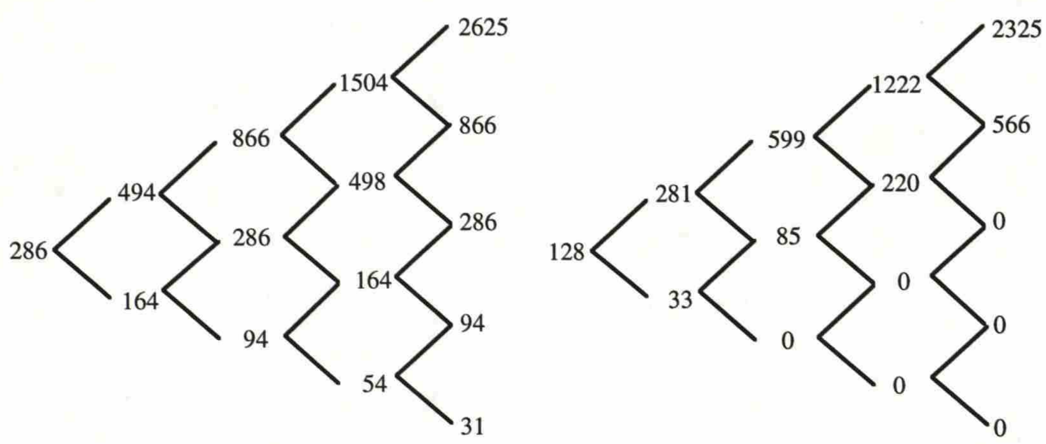

Figure 5 Binomial trees of an exemplary binomial option valuation procedure

6 Conclusion

This paper contributes to the development of real option valuation methodology and real option applications by pointing out four expansions. The expansions emerge from the empirical application of real options in concrete valuation situations. The four expansions represent four issues that a person carrying out valuation with real options should be aware of. The expansions are

- the introduction of different discount rates for the revenues and for the costs in situations where the riskiness of the revenues and the costs clearly differs. The different discount rates can be taken into account in the standard real option valuation methods by adjusting the input parameters.
- the introduction of changing uncertainty structure into the real option valuation. The real options can be used as an aid in valuations where the underlying asset is technological competence. The uncertainty concerning the future outcomes of a technological competence is typically not stable. It changes over time. As the underlying uncertainty is an important variable having a profound effect on the outcome of the valuation, it makes a great difference whether one uses the initial commonly high uncertainty or the resulting commonly low uncertainty. The correct way is to determine the average volatility of the underlying asset during the time to option expiration and use this estimate in the valuation.
- the introduction of discrete uncertainties in the competence investment into the real option valuation. In addition to the volatility of the underlying asset, there is a discrete success probability whether the development succeeds or not. This discrete uncertainty can be taken into account in the real option valuation by replacing the estimated cash flows with the expected cash flows. The expected cash flows are derived by weighing the estimated cash flows with the probability of occurrence.
- the necessity to analyze the relationship between the underlying asset volatility and the discount rate used for discounting the cash flows that form the underlying asset.

On the whole, it can be concluded that option valuation methods can be used to avoid some of the major pitfalls in the traditional valuation of competencies. For example, in the competence valuation case, the growth option value, the discrete uncertainties, the differing risks in cash inflows and cash outflows, and the changes in the discount rates according to the changes in the underlying asset volatilities were taken into account. The role of the decreasing uncertainty was not addressed. This was not necessary since the volatility of the underlying asset was used as a variable. The option values were calculated for a number of different volatilities. The problem of which uncertainty measure to use did not emerge.

As a philosophical approach, the principles of option valuation would seem to apply well to competence valuation. Care should be taken, however, that the option valuation is not used to justify investments too easily. The example demonstrates how otherwise positive option value can under more complex assumptions become less positive. An important factor affecting the valuation is the interaction between the discount rate and the underlying asset volatility. Higher discount rates correspond to higher uncertainties and lower net present values. On the other hand, higher uncertainties correspond to higher option values. The sum of the option value and the net present value is situation-specific and would seem to determine the value creation from an investment. More research should be clearly focused on the interaction between these two and on the situations in which different possibilities for value creation emerge.

A careful analysis and treatment of the underlying uncertainty would seem to provide the key to a more detailed analysis of the option values. Attention should be paid both to the volatility of the underlying asset estimates and the discrete uncertainty inherent in the competence investment projects. A sufficient understanding of these could be achieved only through a detailed analysis of the industry and company-specific drivers affecting the underlying asset volatility and the investment success probabilities. There exists an extensive body of literature on, for example, company acquisition success factors. There are clearly factors that affect the investment success probabilities. More attention should be focused on transforming these factors into discrete success probabilities, asset value volatility estimates, and eventually into input parameters for the valuation.

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4 VALUATION OF ABSORPTIVE CAPACITY AS A COMPOUND OPTION

Tomi Laamanen

ABSTRACT

This paper addresses the development of the real option valuation methodology and the question of how to adapt it to competence building situations. The concept of absorptive capacity has originally been used in the literature to describe the ability of a company to absorb new technologies from the environment. This paper expands the concept of absorptive capacity to include also the time dimension. Due to the apparent path dependency of technological development, the absorptive capacity is seen to provide an important building block that allows companies not only to absorb other existing knowledge, but it provides the option for developing, understanding, and absorbing future technological competencies. Absorptive capacity is modeled in this paper as a compound option. The implications of modelling absorptive capacity as a compound option are discussed. The role of absorptive capacity is analyzed with the aid of an algorithm providing a numerical approximation of Geske's (1979) compound option equation.

1 Introduction

Companies are often in a situation where they have to decide how to develop their existing competencies. Action has to be taken, but committing the company to some specific technology may be a costly mistake. An alternative would be to develop a set of generic competencies that would enable the company to prosper despite some of the uncertainties in the future. A software company could develop generic network software competencies without committing itself into a specific network configuration or network type. A pharmaceutical company could develop basic biotechnology competencies without committing itself into specific chemical entities. Both examples represent competence development named here as absorptive capacity development. Due to its derivative nature, the traditional valuation methods are inadequate in the valuation of absorptive capacity. Ideally, the valuation should be carried out as simple or compound option valuation. Commonly, the absorptive capacity has more of a compound option than simple option nature. For example, the development of basic biotechnology competencies creates a pharmaceutical company options to acquire small biotechnology companies, to start technological collaboration, or to start investing in internal research and development. All these create growth options in the biotechnology field. The entry to the field, however, cannot yet be regarded more than as the first option exercise.

The concept of absorptive capacity has originally been used in the literature to describe the ability of a company to absorb new technologies and new knowledge from the environment. The further development of the concept of absorptive capacity can be seen to provide additional value added for a number of reasons. First, the absorptive capacity is sufficiently formalized to allow for further formalization of the valuation. Second, the concept of absorptive capacity is rooted into the competence-based view of strategic management. It is a useful concept to combine the research on competence building and the research in the modern finance theory. Third, the absorptive capacity can be analyzed in sufficiently small elements. The development and the functioning of absorptive capacity can be analyzed using competence differentials. It is beneficial to analyze how a differential increase in knowledge in a company can lead into differential increases in absorptive capacity and further differential increases in the value provided by the absorptive capacity. Fourth, the absorptive capacity can be seen as a binding element in the technological competence development. The absorptive capacity can be seen as a link from the present technological competence development to the future technological competence development in a path-dependent world.

This paper contributes to the research on technology valuation and the valuation of competence building by expanding the concept of absorptive capacity to include also the time dimension. The absorptive capacity, as defined by Cohen and Levinthal (1989), does not explicitly include the time dimension. The absorptive capacity is seen as the capacity of a company to absorb new technology or knowledge, in general, from other companies. The technology that is to be absorbed is seen from a static point of view. It is seen to exist already in the other companies as extra-industry knowledge. The focus is on simple option rather than compound option nature of the absorptive capacity.

2 Absorptive capacity

Absorptive capacity can be seen as one of the core elements in competence building. The concept of absorptive capacity centers around the concept of the stock of knowledge of a company. Cohen and Levinthal (1989) model absorptive capacity by looking at the additions of a company's stock of knowledge as a result of research and development investments. The additions in a company's stock of knowledge are expected to increase the earnings of the company at a marginally decreasing rate. The additions of the company i's stock of knowledge are represented by z_i

(1) $$z_i = M_i + \gamma_i\left(\theta\sum_{j\neq i} M_j + T\right)$$

where M_i is a company i's investment in research and development, g is the fraction of knowledge in the public domain that the company is able to exploit, θ is the degree of intra-industry spill-overs, and T is the level of extra-industry knowledge. In essence, γ represents the absorptive capacity of the company. Cohen and Levinthal assume that the absorptive capacity is built over time as a result of the company's research and development efforts at a marginally decreasing rate $\gamma_M > 0$, $\gamma_{MM} < 0$. The indexes represent the differential of the absorptive capacity in relation to the cumulative research and development investment. In addition, Cohen and Levinthal point out that the absorptive capacity is also a function of the characteristics of the underlying scientific and technological knowledge β.

(2) $$\gamma_i = \gamma(M_i, \beta)$$

Cohen and Levinthal suggest that the variable β would comprise of the complexity of the knowledge and the degree to which the outside knowledge is targeted to the needs of the absorbing company. Taking the competitive interaction into account, Cohen and Levinthal assume that the increases in a competitor's knowledge diminishes both company i's profits and the marginal benefit from increasing the knowledge level: $\Pi^i_{z_j} < 0$ and $\Pi^i_{z_j z_i} < 0$, where Π represents the earnings of the company i. Further, Cohen and Levinthal define the marginal return from research and development as a differential of P in relation to the research and development investment M_i. Conceptually, the second term represents the effect of the competitors research and development activities in decreasing the marginal return of the research and development carried out at the company i. The first term represents the marginal increase in the return due to the research and development investments and the absorption of the external knowledge.

(3) $$R \equiv \Pi^i_{z_i}\left[1 + \gamma_{M_i}\left(\theta\sum_{j\neq i} M_j + T\right)\right] + \theta\sum_{j\neq i}\gamma_j \Pi^i_{z_j}$$

Where R is the marginal return to own research and development. The other variables are as in equation (1). Differentiating the equation, Cohen and Levinthal show that the increasing complexity of the underlying scientific and technological knowledge β increases the marginal returns from own research and development investments and makes the spillovers of the company more difficult for the competitors to absorb. Cohen and Levinthal also note that the increased levels of extra-industry spillovers may substitute for own research and development, but mainly when the absorptive capacity is not endogenous. In the case of endogenous absorptive capacity, the companies have incentives to carry out research and development to be able to benefit from the spillovers.

The analysis of the absorptive capacity has direct implications for the analysis of competence transfer of external competence acquisition in general. A drawback in the model is the determinism implied. The extra-industry spillovers are assumed to deterministically increase the overall knowledge pool of the organization. No price has been set for the actual knowledge acquisition transaction. In addition, it has not been taken into account whether the company really perceives it important to absorb the knowledge that it could absorb. There may be uncertainty concerning the viability of the competence development route. In contrast to having marginally decreasing returns from additional knowledge, there are resource-based knowledge processing limits that the company may not be able to overcome. A company cannot take all the knowledge that it has an option to absorb. There are a number of different directions to develop the existing competencies. A company has to select the main routes of competence development. Sometimes these are selected on the basis of the existing complementary competencies. The complementary competencies may be linked to the absorptive capacity of the company. Sometimes it may be necessary to develop the absorptive capacity to provide the option to absorb competencies.

3 Model development

The model defining the absorptive capacity does not model the link between the incremental increase in the knowledge pool of a company and the marginally decreasing returns. The link is assumed to exist. From the options perspective, the assumption can be questioned. The marginal increase in the pool of knowledge may increase the gross returns of a company, but the net increase in value may be negative due to required investments. This is acknowledged also in the model of Cohen and Levinthal. The model does not, however, recognize that *the actual gross returns may be not only marginally decreasing but also zero.* Despite the fact that the gross earnings may be zero, the company may still increase its value by investing in increasing its stock of knowledge. The value added comes from the option value provided by the additional competencies, the increases in the stock of a company's knowledge. The options created by the increases in the stock of a company's knowledge may or may not be recognized in the company. The recognition of these options is not necessary for the option value creation. On the other hand, the recognition of the options is necessary for the option exercise. Otherwise the options may remain non-exercised. Decisive option portfolio creation and management can, however, improve the chances of a company to successfully develop, recognize, and exercise valuable options. Equation (4) shows how the option value can be used to expand the model. It combines the marginally decreasing returns and the differential change in the value of the company due to competence option building. In addition to the direct absorption of the external knowledge and the competitors' absorption of knowledge, the increases in the pool of knowledge create option value.

(4) $$\frac{\partial V_{Company\_i}}{\partial z_i} = \Pi^i_{z_i}\left[1+\gamma_{M_i}\left(\theta\sum_{j\neq i} M_j + T\right)\right] + \theta\sum_{j\neq i}\gamma_j\Pi^i_{zj} + \sum_k C^k_{dz_i}\left(V^k_0, X^k, \tau^k, r, v^{V_k}\right)$$

Where the summation over k denotes the identified option values created by the competence building. For simplicity, the option interactions are not taken into account in equation (4). Equation (4) includes now both the deterministic effects of competence development and the option value creation. The absorption of competencies from other companies could also be seen in terms of the option values. If own research and development would create competence leveraging options, the option to absorb from other companies would correspond to a compound call option. Transforming the first term in the equation into a compound call option and leaving the competitor competence absorption into the equation would result into equation (5).

(5) $$\frac{\partial V_{Company\_i}}{\partial z_i} = \sum_k C^k_{dz_i}\left(V^k_0, X^k, \tau^k, r, v^{V_k}\right) + \sum_l CC^l_{dz_i}\left(V^l_0, X^l, \tau^l_0, \tau^l_1, r, v^{V_l}\right) + \theta\sum_{j\neq i}\gamma_j\Pi^i_{zj}$$

Where the summation over l denotes the compound option values created by the options to absorb knowledge from other companies or other sources. The competitors' influence, represented in the third term, could be incorporated into the model also in the option values. Trigeorgis demonstrates in his dissertation how the competitive interactions and the effect of competitors could be taken into account when calculating the growth option values. The principles of Trigeorgis could be used to deduct the third term from equation (5). As a result we would end up into an equation (6) where the marginal increase in the stock of knowledge or competence building would result into k growth options and l compound options to acquire competencies externally.

(6) $$\frac{\partial V_{Company\_i}}{\partial z_i} = \sum_k C^k_{dz_i}\left(V^k_0, X^k, \tau^k, r, v^{V_k}, \theta, \gamma_{1...N}\right) + \sum_l CC^l_{dz_i}\left(V^l_0, X^l, \tau^l_0, \tau^l_1, r, v^{V_l}, \theta, \gamma_{1...N}\right)$$

Where N denotes the number of relevant competitors taken into account in the option valuation. The option value of competencies can be seen as a link between the value of competence development and value creation. In principle, the real options valuation should be applicable for the valuation of all kinds of competence development. The underlying asset uncertainty, the exercise times, the underlying asset development processes, interest rates, and the exercise prices vary. By configuring these parameters according to each situation, all competence development could, in principle, be valued using the option models.

Absorptive capacity building could be seen as option platform creation. This is illustrated in figure 1. The developed absorptive capacity provides a number of competence development options. The more generic the developed absorptive capacity, the more competence development options it provides. In a same way, the further in time the possible consequences of the absorptive capacity are analyzed, the more extensive are the options provided by the absorptive capacity building. In a path-dependent world, the different competence development paths can lead further from the initial state or from each other on a longer time perspective than on a shorter time perspective. In net present valuation, these paths are assumed to be fixed. In option valuation, the value of different platforms can be estimated. The option valuation could be seen in fact as a generalization of the net present valuation. Under simplifying assumptions concerning the volatility of the underlying asset, the model converges into a net present valuation model.

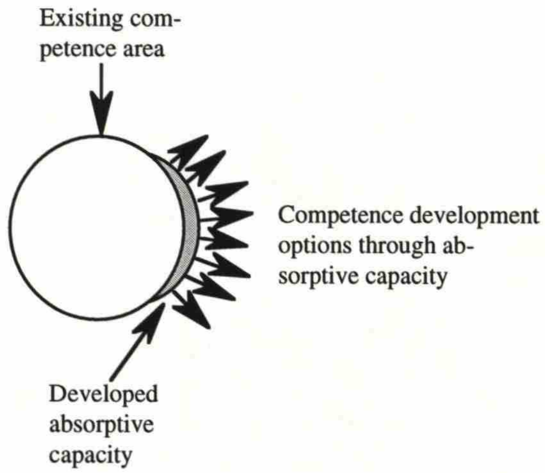

Figure 1 An illustration of competence development options created through absorptive capacity

One of the problems in competence valuation is that the value of competence options is derived from future opportunities. It is derived from future projects that provide the positive cash flows in the case of successful option exercise. Due to the inherent uncertainties in the competence development, the identification and analysis of these future competence opportunities becomes highly relevant. The attempts to identify future competence opportunities coincides with the visionary approach in the strategic management. The visionary or *aspiration based approach* to strategic management is built on the idea that the competitive situation in a two to three-year perspective is difficult to predict due to the different competitive interactions between the different players in a value network. The future on a longer time perspective is somewhat easier to predict. Different drivers of future scenarios can be identified on a longer term. These drivers can then be used in predicting the longer term future scenario (Baghai et alii, 1996). Identification of a desirable future in a company can and should contribute to the actions taken in a company. A company can attempt to optimize its the position in the future vision. Striving this way towards the future vision, the actions of the companies are also shaping the future.

The option valuation of competencies should take place in an analogous manner. The possibilities for competence leverage should be identified on a longer time perspective. Competence building could then be assumed to take place according to the competence leveraging opportunities, according to the competence development path that is identified the most attractive. The envisioned competence leveraging opportunities would determine the upper limits of investments that could be allocated for the competence building. As was pointed out, the competence building can create several different kinds of options. Typically, however, the upper limit value of some of the most important options can be determined to a reasonable level of detail. Identifying the upper limit that a company should invest in competence development motivated by future option creation has been found to be of major importance in the empirical technological competence valuation cases carried out by the author.

When valuing the absorptive capacity as a compound option, one of the core questions is which competence investments create the absorptive capacity for the needed future competencies. The answer can be found from an analysis of the competence interrelationships. An analysis of which competencies lead into each other can be used to form a basis for competence platform valuation. The idea of absorptive capacity as a compound option is in harmony with the idea of spawning of investments. The idea in the spawning of investments is that the investments into strategic negative net present value projects create further possibilities to invest into operative positive net present value projects. This is analogous to competence building and competence leveraging. The spawning matrices are typically formed for an infinite number of time periods as the spawning influence of the strategic investments gradually decreases over time. The spawning matrices are typically, however, seen to be deterministic. The uncertainty in the spawning effect is often not taken into account. In addition, the further time periods after the initiation of the operative projects are difficult to value due to the sometimes unclear relation of the spawning matrix and time. A *spawning* option creation matrix can be used to partially solve these problems. The option creation already implicitly takes into account the uncertainty in the relationship. In addition, the model can be seen to work well with a two-period analysis. Expansion into three-period analysis corresponds the expansion of the Black and Scholes (1973) option valuation formula into the Geske's (1979) compound call option valuation formula. Inclusion of further time periods might be ambiguous due to logical complexity and loss of clarity real-life comparison.

A project or an investment into absorptive capacity creation creates competencies that can be used in initiating other projects. This is called spawning (Kasanen, 1986, 1993; Trigeorgis and Kasanen, 1991). A spawning growth option matrix is shown in figure 2. The competencies created by a project can be, however, of different value for the different future projects. For example, project 1 may create competencies that facilitate the initiation of future projects A and B. It may not, however, create the option to initiate project C. The competencies creating the option to initiate project C at some future time may be created by project 3 or project 1 and project 3 together. On the other way round, the value of project 1 may be calculated by calculating the net present value of project 1 and the option values of the project 1 concerning the future projects A, B, and C. In the case both projects 1 and 3 are needed for creating the option to initiate project C, the option creation value concerning future project C should be attributed to both project 1 and project 3 or divided between the projects. Complexity of the problem may increase, if the future projects are interrelated or mutually exclusive. There may even exist switching options between the future projects that would need to be taken into account in the initial project valuation phase.

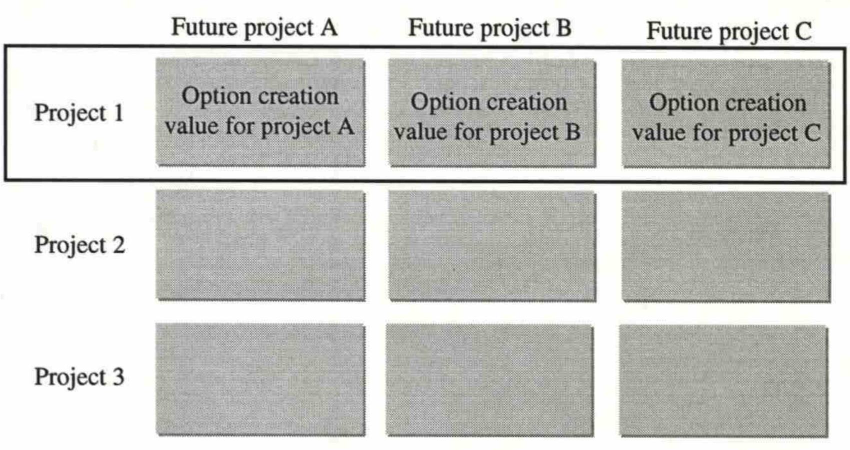

Figure 2 An illustration of a spawning options matrix

The project level analysis can be further expanded to the competence and resource levels. The option values of some of the main competencies or resources created by the project can be valued separately. The competence interconnectedness can be taken into account similarly as with the project level interrelationships. The project level analysis can also be aggregated to the company level of analysis. For example, in company acquisition situations, the list of option creation effects of the acquired company can be crosstabulated across the different future projects where the acquisition is expected to create option value. The competencies and resources of the acquired company can be disaggregated and the option creation value of the different elements can be assessed separately using the spawning matrix.

In a typical company acquisition situation, the leveraging of the competencies acquired through a company acquisition may be linked to the development of some complementary, co-specialized assets. For example, in the acquisition of new, technology-based companies, the competence leveraging is typically influenced by the possibility to connect the competencies to an existing distribution system. In competence leveraging, the complementary resource is often a prerequisite and its influence can be calculated using the net present valuation. The development of complementary resources can also be seen, however, as the development of options to carry out the competence leveraging. For example, both building competence 1 and resource 1 may be needed to create an option for future project B. In the end, the main difference would seem to be that the building of a competence option is inherently uncertain due to the nature of the competence. The development of a complementary leveraging resource is uncertain due to the uncertainty of the competence. The uncertainty is derived from the uncertainty of the competence building.

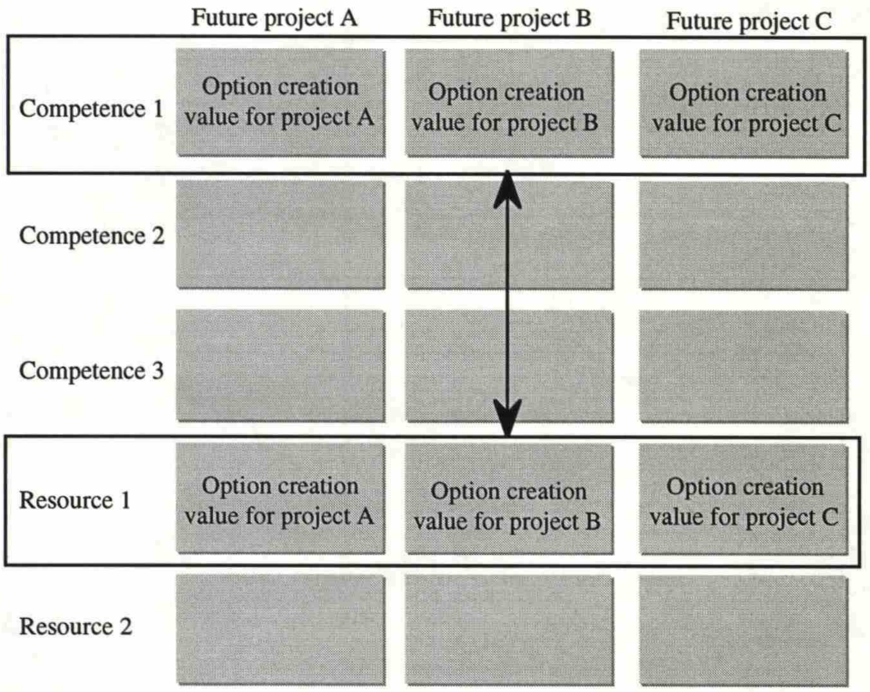

Figure 3 The spawning options matrix on the competence and resource levels

In addition to the competencies used for competence building and resources used for competence leveraging, the competence interactions would also need to be taken into account. The aim should be to develop a complete systemic set of competencies and resources. The competence building, competence leveraging, and the ability to take into account competitive interactions may require investments into several different competencies and resources. All these investments have to be calculated into the option price when assessing the value of the expected future derivative projects.

Sometimes the complete set of competencies and resources to create growth options may not exist. For example, in company acquisition situations, these complementary competencies and resources needed for the development of the acquired company may exist in the acquiring company. Sometimes they may need to be developed internally or acquired from outside through another company acquisition or through collaborative arrangements. The completeness of the competencies and resources can be used as one requirement of the competence and resource elements needed for creating viable options for future projects. Some degree of absorptive capacity is typically required to determine the complete set of competencies and resources needed for the option creation. Absorptive capacity is needed in company acquisition situations to identify the needed competencies, to plan the development of the competencies, and to integrate the competencies to the competencies of the acquiring company.

4 Model analysis

The model of the differential company value change as a result of a differential competence development is restated below. The model expands the idea of absorptive capacity by incorporating the time dimension and the option elements shown below. The model can be seen to consist of three elements. First, it comprises the option provided by the differential competence development. Second, it comprises the option to absorb competencies from other companies and the consequent options created this way. Third, it comprises the competitor interaction represented here with the absorption of competencies by the competitors.

$$\frac{\partial V_{Company\_i}}{\partial z_i} = \sum_k C^k_{dz_i}\left(V^k_0, X^k, \tau^k, r, v^{V_k}\right) + \sum_l CC^l_{dz_i}\left(V^l_0, X^l, \tau^l_0, \tau^l_1, r, v^{V_l}\right) + \theta \sum_{j \neq i} \gamma_j \Pi^i_{z_j} \quad (5)$$

To analyze the implications of the expanded model for the valuation of competence development, a sensitivity analysis of the model is needed. It is interesting to analyze the sensitivity of the model in relation to a number of situational parameters. These parameters include

- the intensity of competition
- the appropriability of the competencies
- the time to the simple option expiration
- the time to the expiration of the first call in the compound option
- the time to the expiration of the second call in the compound option

It could be assumed that under intense competition the simple option value created by differential competence development is lower than under heavy competition. It could be expected that it is beneficial to exercise this kind of option early before other companies can exercise the option making is less valuable. Under intense competition, the competitor's capability to absorb competencies, shown in the third term of the equation, could be expected to be strongly negative. This would make the incremental value-added from incremental competence development lower. The compound option could be assumed to be less valuable under intense competition than under no competition. It can be assumed that the competitors are efficiently utilizing all the competencies that they develop due to intense competition. To sum up, intense competition would seem to make the first term of the equation the most important term contributing to the incremental value of the company. The intense competition would compete away the compound option term. The third term could be assumed to be more negative than under no competition.

The appropriability could be expected to affect almost contrary to the intensity of the competition. The more appropriable the differential competence development, the more appropriable could be expected to be the simple option. The simple option would be optimal to exercise late. The compound option could provide additional value added through the capacity to absorb from the competitors if the competitors would not have appropriable competencies themselves. The competitive interaction through competitors absorption of competencies would be minimal in the case of appropriable competencies. To sum up, the simple option term would be important similarly as under intense competition. The importance of the compound option term would depend on the appropriability of the competitors' related competencies. The third term would be non-existent in the case of high degree of appropriability.

The time to the simple option expiration is dependent on the intensity of the competition and the appropriability of the competencies. Typically, the longer the time to option expiration, the higher the option value. However, when the time to expiration becomes very much longer, the time value of money starts to dominate decreasing gradually the option value increases over time. Same applies to the compound options in general. The longer the time to expiration of the first or second option in the compound option, the higher the value of the compound option. The relationships of the simple and the compound option are explored with a numerical example. In addition to showing the sensitivity of the option values as a function of time, it provides an understanding of the relationships of the simple and the compound option values in absorptive capacity development. The valuation of the compound option is based on Geske (1979), appendix 1.

Table 1 *Numerical sensitivity analyses of out-of-the-money and in-the-money compound call option CC values with the valuation parameters CC(underlying asset value, second option exercise price, first option exercise price, risk-free interest rate, volatility of the underlying asset, time to first option expiration, time to second option expiration)*

	High volatility of the underlying asset		Low volatility of the underlying asset	
Time to second option expiration	Out-of-the-money compound option CC(**100**, **100**, 300, 5%, 120%, 1, **x**)	In-the-money compound option CC(**400**, **300**, 300, 5%, 120%, 1, **x**)	Out-of-the-money compound option CC(**100**, **100**, 300, 5%, 50%, 1, **x**)	In-the-money compound option CC(**400**, **300**, 300, 5%, 50%, 1, **x**)
2	14.4	154	0.13	35.9
3	15.3	167	0.14	40.2
4	16.1	178	0.15	45.0
5	16.7	187	0.16	50.0
6	17.2	194	0.18	54.9
7	17.6	199	0.19	59.7
8	17.9	203	0.20	64.4
9	18.2	206	0.22	68.9
10	18.4	208	0.23	73.2
11	18.5	210	0.25	77.3

Some observations could be made based on the numerical analysis

- The expectations of the underlying asset value would seem to set the magnitude of the compound option. In the case of out-of-the-money compound option, the compound option values are significantly less than in the case of in-the-money compound option.
- Increasing the time to expiration of the second option would not seem to increase the compound option value rapidly. A 5 fold increase in the time to second option expiration would seem to increase the option value ceteris paribus with a multiplier of 1.3 to 2.1.
- The compound option value seems to be very sensitive to changes in the assumed volatility. Decreasing the volatility assumption from 120% to 50% would seem to decrease considerably the ceteris paribus out-of-the money option value. In the case of in-the-money compound option, the change is not as dramatic. The relative change due to the volatility change is higher, the lower the initial values of the compound option.

It is necessary to analyze more the relationship between the compound option value and the volatility of the underlying asset. The volatility and the underlying asset value estimates as parameters are shown jointly in figure 4. The figure illustrates that the higher the uncertainty, the higher the compound option values and the larger the differences also due to the asset value estimates. When valuing the compound option element of absorptive capacity, an analysis of the uncertainty structure is of particular importance. Especially, the changing volatility over time should not be ignored. A decreasing volatility can significantly reduce the compound option value.

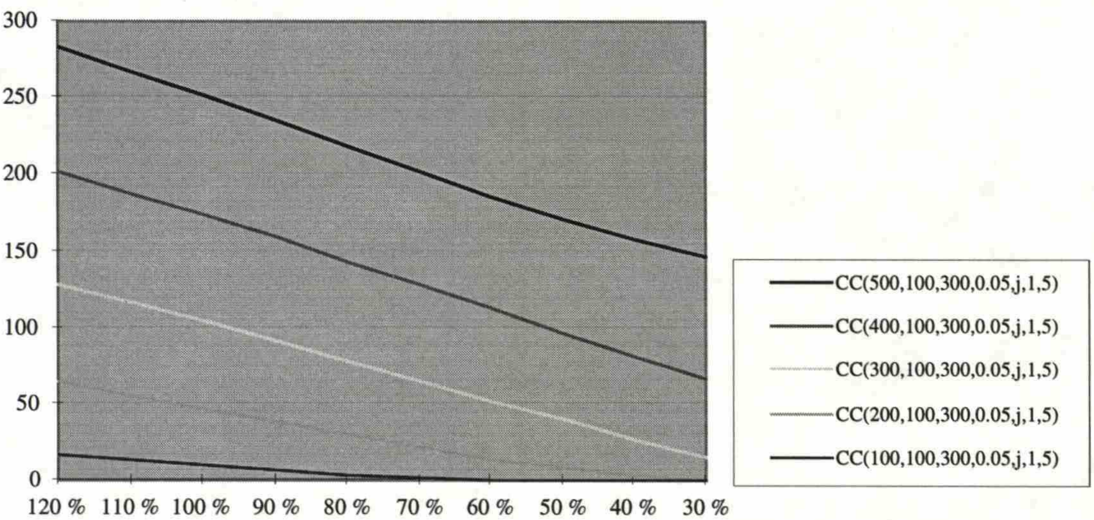

Figure 4 *Five compound option value curves as a function of volatility and the underlying asset value estimate*

The model in equation (5) includes both simple and compound options as elements. They are used as elements to determine the value of a differential knowledge development. In knowledge development, the compound options are typically longer term options than the simple options. Sometimes, a project involving a simple option can be structured to consist of two sequential options. A compound option is more valuable than a simple option ceteris paribus. A compound option provides the added flexibility to decide on the further course of action based on the outcome of the first option investment. It is easier to structure simple long term options as compound options than to structure simple short term options as compound options. On a shorter term, the investment may not be divisible into more flexible option elements.

The division of a simple option into two call options is illustrated in table 2. The difference between the compound call value and the net value of the simple call option is illustrated in figure 5. The difference demonstrates how the structuring of a competence investment can create value-added. The figure also shows how the difference between the simple and the compound option value increases as a function of volatility.

Table 2 *Correspondence between simple and the compound call options. The option investment in the simple option case is calculated by discounting the first call option exercise price from the first call option exercise time with a discount rate of 5%. The compound option values are calculated from the equations in appendix 1 using the algorithm in appendix 2. The parameters of the compound call are CC(underlying asset value, second option exercise price, first option exercise price, risk-free interest rate, volatility of the underlying asset, time to first option expiration, time to second option expiration)*

Black and Scholes call option valuation											
Volatility	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %	110 %	120 %	130 %
Risk-free interest rate	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Underlying asset value V	500	500	500	500	500	500	500	500	500	500	500
Exercise price X	300	300	300	300	300	300	300	300	300	300	300
Time to expiration	5	5	5	5	5	5	5	5	5	5	5
d1	1,47	1,30	1,24	1,24	1,27	1,32	1,38	1,46	1,54	1,63	1,72
d2	0,80	0,40	0,12	-0,10	-0,30	-0,47	-0,63	-0,78	-0,92	-1,06	-1,19
N(d1)	0,93	0,90	0,89	0,89	0,90	0,91	0,92	0,93	0,94	0,95	0,96
N(d2)	0,79	0,66	0,55	0,46	0,38	0,32	0,26	0,22	0,18	0,15	0,12
Option value	281	298	318	339	359	379	397	413	427	440	451
- Option investment	238	238	238	238	238	238	238	238	238	238	238
Net call option value	42	60	80	101	121	141	158	175	189	202	213
Comparative compound call option valuation, Appendix 1, appendix 2											
Volatility	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %	110 %	120 %	130 %
CC(500, 300, 250, 5%, x, 1, 5)	76,5	100,3	125,2	150,3	175,1	199,1	222	243,6	263,9	282,7	300,1

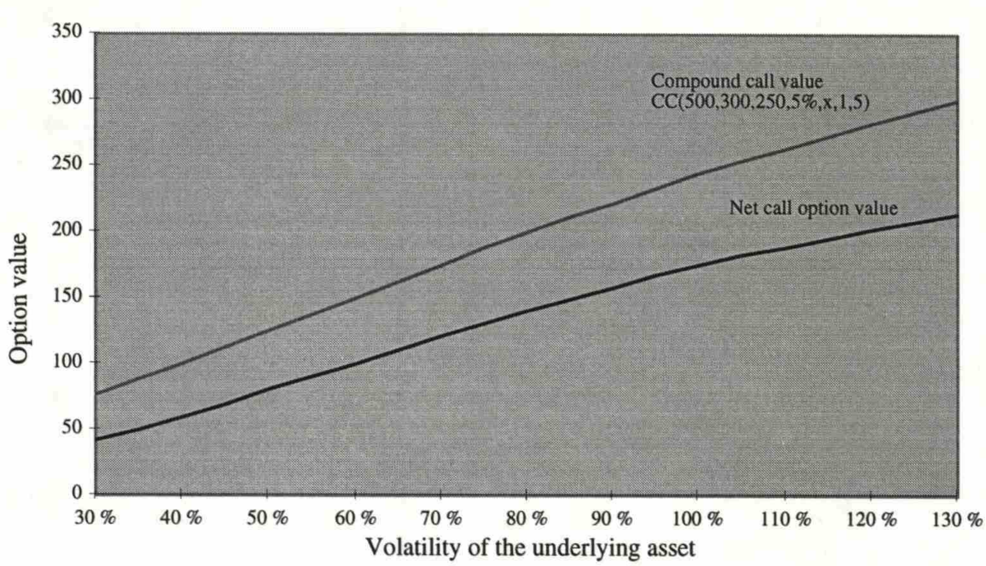

Figure 5 *Compound call option values and simple call option values as a function of volatility*

5 Conclusions

The concept of absorptive capacity as defined by Cohen and Levinthal (1989, 1994) does not take into account the compound option nature of competence investments. Cohen and Levinthal analyze the possibilities to absorb technological competencies from other companies in the present time. They also discuss the importance of the absorptive capacity and the own competence development in relation to possible future competition. This is different than viewing absorptive capacity to provide an option to absorb external technological competencies in the future. The main contribution of this paper is the expansion of the concept of absorptive capacity to apply to the acquisition of knowledge external to the organization in the future. The time dimension is rooted into the option and compound option perspectives. In addition, the option perspective contributes to the valuation of absorptive capacity by providing a tangible way to value the absorptive capacity. This paper is proposing a dynamic view of absorptive capacity as a strategic capability to acquire new competencies. The main contribution of the paper is shown in figure 6.

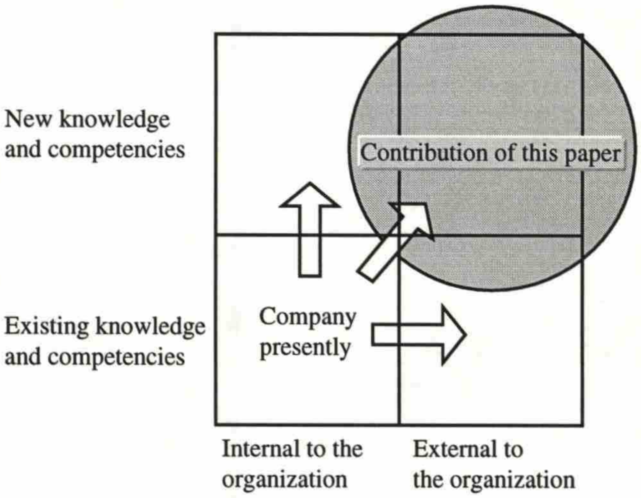

Figure 6 The main contribution of this paper

The expansion of the concept of absorptive capacity is in harmony with the path-dependent nature of technological development. There can be seen to be a path of competence development initiatives or compound options leading from one to another. The earlier investments spawn new investments on the competence development path. The valuation of each individual competence investment initiative is important, but the companies should note that through the investments they are selecting the paths of competence development which they are to pursue in the future. A negative net present value created by some investment on a suitable competence development path may be much better than ending up in a situation where the company has to discontinue the path that it has followed and start investing into a new competence development path. The compound option perspective would seem to be particularly applicable for the valuation of these less deterministic consequences of competence development. On balance, the marginally decreasing value of the multi-option perspective has to be acknowledged. The value-added created in the valuation by the inclusion of several additional higher-order options is marginally decreasing.

The model formalized in equations (5) and (6) provides an expanded model of absorptive capacity as a basis for numerical testing. The valuation of absorptive capacity as a compound option implies that the value of the absorptive capacity increases as a function of the increasing volatility. On the whole, the volatility seems to play an important role in the valuation of absorptive capacity. This is intuitively appealing. A drawback is that the use of compound options in the valuation tends to provide higher values for the competence investment than valuation that centers around simple growth options. This is particularly problematic since even the simple growth options tend to provide higher values for the competence investment than the net present valuation. The role of the simple and compound option valuation is more in showing the value of the opportunities instead of balancing them against the risks. The options thinking directs a company to search for new growth opportunities and to invest in them. More realism in the simple and compound option valuation can be achieved by balancing the option value increases as a function of volatility with the decreases of the underlying asset estimates due to the increased riskiness. Increasing the realism into the valuation in the form of additional constraints decreases the option values and provides more realistic estimates for the value of absorptive capacity.

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Appendix 1 Valuation of compound call options

A compound call option can be valued with an equation (Geske, 1979)

(1) $$CC \equiv C_0\left(C_1(V,K;t_2-t_1),c;t_1\right)$$

or in another form

(2) $$CC=\left[V_0B(d_1^*,d_1;\rho)-Ke^{-rt_2}B(d_2^*,d_1;\rho)\right]-Ee^{-rt_1}N(d_2^*)$$

where V_0 is the initial value of the underlying asset, B is bivariate standard normal distribution (Drezner, 1978) with the density function $f(x,y)=\frac{1}{2\pi\sqrt{1-\rho^2}}e^{\left\{-\frac{1}{2(1-\rho^2)}\right\}\left[x^2-2\rho xy+y^2\right]}$, r is the risk-free interest rate, K is the exercise price of the first option, E is the exercise price of the second option, t_1 is the time to expiration of the first option, t_2 is the time to expiration of the second option, ρ is $\sqrt{\frac{t_1}{t_2}}$. The values of the bivariate standard distribution can be approximated by an algorithm developed by Drezner (Drezner, 1978; see also, Hull 1993). The parameters d_1, d_2, d_1*, and d_2* are calculated as follows:

(3) $$d_1^*=\frac{ln\left(\frac{V}{V^*}\right)+\left(r+\frac{1}{2}v^2\right)(t_1-t)}{v\sqrt{(t_1-t)}}$$

(4) $$d_1=\frac{ln\left(\frac{V}{K}\right)+\left(r+\frac{1}{2}v^2\right)(t_2-t)}{v\sqrt{(t_2-t)}}$$

(5) $$d_2^*=d_1^*-v\sqrt{t_1-t}$$

(6) $$d_2=d_1-v\sqrt{t_2-t}$$

where V* is the value of the underlying asset V at time t_1. V' is the lowest acceptable underlying asset value at time t_1 that is needed in order to exercise the second option. The value of V* can be solved numerically from the normal Black and Scholes equations. It can be solved by solving the value of the underlying asset that produces the exercise price as a call option value. A numerical valuation of the compound option values requires an algorithm to estimate the bivariate standard normal distribution. A useful numerical approximation is the Drezner algorithm that can be used to numerically integrate the bivariate standard normal distribution.

Appendix 2 A Pascal algorithm for calculating compound call option values

```
PROGRAM Compound_Call_Options;
CONST pi=3.14159265358979;

FUNCTION f(a, b, c, d, r : Real) : Real;
VAR aa, bb, tmp : Real;
BEGIN
  aa:=a/sqrt(2*(1-sqr(r)));
  bb:=b/sqrt(2*(1-sqr(r)));
  tmp:=aa*(2*c-aa)+bb*(2*d-bb)+2*r*(c-aa)*(d-bb);
  IF (tmp<-50) THEN BEGIN f:=0.00000; WRITELN('Underflow'); END
    ELSE f:=exp(aa*(2*c-aa)+bb*(2*d-bb)+2*r*(c-aa)*(d-bb));
END;

FUNCTION M(a, b, r : Real) : Real;
VAR i, j : Integer;
    sum  : Real;
    D    : ARRAY [1..4] OF Real;
    C    : ARRAY [1..4] OF Real;
BEGIN
  D[1]:=0.3253030;
  D[2]:=0.4211071;
  D[3]:=0.1334425;
  D[4]:=0.006374323;
  C[1]:=0.1337764;
  C[2]:=0.6243247;
  C[3]:=1.3425378;
  C[4]:=2.2626645;
  i:=1;
  sum:=0.0;
  REPEAT
    j:=1;
    REPEAT
      sum:=sum+D[i]*D[j]*f(a, b, C[i], C[j], r);
      j:=j+1;
    UNTIL j=5;
  i:=i+1;
  UNTIL i=5;
  M:=(sqrt(1-sqr(r))/pi)*sum;
END;

FUNCTION sgn(x : Real) : Integer;
BEGIN
  IF x < 0 THEN sgn:=-1
    ELSE sgn:=+1;
END;

FUNCTION N(x : Real) : Real;
CONST step=0.001;
VAR i, sum : Real;
BEGIN
 IF (x<=-4) THEN N:=0.00001
 ELSE
 IF (x>=4) THEN N:=1.0000
 ELSE
   BEGIN
     sum:=0.00;
     i:=-4;
     IF (x>0) THEN BEGIN sum:=0.5; i:=0.0; END;
     REPEAT
       sum:=sum+step*(1/(sqrt(2*pi)))*exp(-(sqr(i)/2));
       i:=i+step;
     UNTIL i>x;
     N:=sum;
     END;
END;

FUNCTION Bivariate(a, b, r : Real) : Real;
VAR temp, r1, r2, delta : Real;
BEGIN
  IF (a <= 0.0) AND (b <= 0.0) AND (r <= 0.0) THEN
    BEGIN
```

```
      temp:=M(a,b,r);
      Bivariate:=temp;
    END
    ELSE
      IF (a*b*r<0) THEN
        BEGIN
          IF (a<0) THEN Bivariate:=N(a)-Bivariate(a, -b, -r)
            ELSE
            IF (b<0) THEN Bivariate:=N(b)-Bivariate(-a, b, -r)
              ELSE
              Bivariate:=N(a)+N(b)-1+Bivariate(-a, -b, r);
        END
      ELSE
      IF (a*b*r=0) THEN
        BEGIN
        IF (a=0) AND (b>0) AND (r<0) THEN Bivariate:=N(0)+N(b)-1+Bivariate(0,-b,r);
        IF (a=0) AND (b<0) AND (r>0) THEN Bivariate:=N(b)-Bivariate(0,b,-r);
        IF (a=0) AND (b>0) AND (r=0) THEN Bivariate:=N(0)-Bivariate(0,-b,0);
        IF (a=0) AND (b=0) AND (r>0) THEN Bivariate:=N(b)-Bivariate(0,0,-r);
        IF (a=0) AND (b>0) AND (r>0) THEN Bivariate:=N(0)-Bivariate(0,-b,-r);
        IF (a>0) AND (b=0) AND (r<0) THEN Bivariate:=N(a)+N(b)-1+Bivariate(-a,0,r);
        IF (a<0) AND (b=0) AND (r>0) THEN Bivariate:=N(a)-Bivariate(a,0,-r);
        IF (a>0) AND (b=0) AND (r>0) THEN Bivariate:=N(0)-Bivariate(-a,b,-r);
        IF (a>0) AND (b=0) AND (r=0) THEN Bivariate:=N(0)-Bivariate(-a,0,0);
        IF (a>0) AND (b>0) AND (r=0) THEN Bivariate:=N(a)+N(b)-1+Bivariate(-a,-b,0);
        IF (a<0) AND (b>0) AND (r=0) THEN Bivariate:=N(a)-Bivariate(a,-b,0);
        IF (a>0) AND (b<0) AND (r=0) THEN Bivariate:=N(b)-Bivariate(-a,b,0);
        END
      ELSE
        BEGIN
        r1:=((r*a-b)*sgn(a))/(sqrt(sqr(a)-2*r*a*b+sqr(b)));
        r2:=((r*b-a)*sgn(b))/(sqrt(sqr(a)-2*r*a*b+sqr(b)));
        delta:=(1-sgn(a)*sgn(b))/4;
        Bivariate:=Bivariate(a,0,r1)+Bivariate(b,0,r2)-delta;
        END;
END;

FUNCTION SolveVV(X,A,r,sigma,tau : Real) : Real;
VAR V1,V2,d1,d2 : Real;
             i : Integer;
BEGIN
  V2:=A; i:=0;
  REPEAT
    V1:=V2;
    d1:=(ln(V1/A)+(r+sqr(sigma)*0.5)*tau)/(sigma*sqrt(tau));
    d2:=d1-sigma*sqrt(tau);
    V2:=(X+A*exp(-r*tau)*N(d2))/N(d1); i:=i+1;
  UNTIL (V2<=V1+0.0005) AND (V2>=V1-0.0005) OR (i>30);
  IF (i>30) THEN WRITELN('Black and Scholes Iteration Overflow Error');
  SolveVV:=V2;
END;

FUNCTION CC(V,A,X,r,sigma,t1,t2 : Real) : Real;
VAR term1, term2, term3, VV, d1, d2, dd1, dd2, tau1, tau2, rho, t, temp : Real;
    test1, test2 : Real;
BEGIN
  t:=0.0;
  tau1:=t1-t;
  tau2:=t2-t;
  VV:=SolveVV(X,A,r,sigma,t2-t1);
  d1:=(ln(V/VV)+(r+0.5*sqr(sigma))*tau1)/(sigma*sqrt(tau1));
  d2:=d1-sigma*sqrt(tau1);
  dd1:=(ln(V/A)+(r+0.5*sqr(sigma))*tau2)/(sigma*sqrt(tau2));
  dd2:=dd1-sigma*sqrt(tau2);
  rho:=sqrt(tau1/tau2);
  term1:=V*Bivariate(d1,dd1,rho);
  term2:=-A*exp(-r*tau2)*Bivariate(d2,dd2,rho);
  term3:=-X*exp(-r*tau1)*N(d2);
  CC:=term1+term2+term3;
END;

BEGIN
  WRITELN(CC(500,300,50,0.05,0.20,1,5));
END.
```

5 OPTION NATURE OF COMPANY ACQUISITIONS MOTIVATED BY COMPETENCE ACQUISITION

Tomi Laamanen

ABSTRACT

This paper discusses the option nature of collaborative arrangements and company acquisitions motivated by the acquisition of competencies. An analysis of the possibility to apply the real option valuation in the valuation of 111 new, technology-based companies in company acquisition situations is presented. In the studied sample, the collaborative arrangements were not extensively used as options to acquire the collaborative partner. The company acquisitions themselves were used more as options to enter a new technology or business area. The maturity of the acquired competencies, the patentability of the acquired competencies, and the research and development intensity of the acquiring company were found to correlate with the option nature of the acquisition. In the studied sample, the growth option upside realization was found connected to the relatedness of the acquiring and the acquired company, proactive sales motive of the seller, and a favorable industry trend. The findings concerning the performance of the acquisition of related technological competencies seem to be connected to the imperfect markets of new technological competencies.

1 Introduction

One of the main emphases in the research on strategic capital budgeting has been the attempt to better take into account the long term consequences of strategic investments. The traditional discounted cash flow methods have been found deficient (Trigeorgis, 1993). The use of net present valuation in strategic capital budgeting has been increasingly critisized (Shank and Govindajan, 1992). The net present valuation makes implicit assumptions concerning the expected cash flows. It presumes management's passive commitment to a certain fixed strategy. It does not take into account the managerial flexibility and the inherent growth options in the investments.

The growth options have become into a central focus also in the of field of strategic management. From a static competitive analysis approach, the field of strategic management has moved through a resource-based view of strategy to a dynamic capabilities view of strategy. The field of strategic management is largely driven by the question of how companies achieve and sustain distinctive competitive advantage (Teece et alii, 1992). One of the approaches to answer this question is the competitive forces approach (See, for example, Porter, 1980), rooted in the structure-conduct-performance paradigm of industrial organization (Caves, 1980; Porter, 1981; Rasche, 1994). One of the approaches is the entry deterrence approach rooted in the game theoretical methodology of the industrial organization theory. These two approaches attempt to explain the sources of competitive advantage through variables related to industry structure. In contrast, the resource-based strategy approach and the dynamic capabilities approach focus on variables related to the company resources and capabilities (Teece et alii, 1992). Company-specific resources and capabilities are seen as sources of competitive advantage (Penrose, 1959; Rumelt, 1984; Wernerfelt, 1984). The dynamic capabilities view focuses on the strategy development process taking into account the dynamic strategy adjustment and learning during the implementation. The real option valuation, developed in the field of finance, can be used to take into account the managerial flexibility during the implementation of strategic investments. It can also be used to value the learning taking place through the investments. Often in strategic investments, the organizational learning plays an important role. Platform investments can be regarded as investments into future growth opportunities.

The aim of this paper is to contribute to the understanding of growth options provided by collaborative arrangements and company acquisitions. The growth options have been discussed both in the field of strategic management and in the field of finance. Despite the extensive literature, there seems to be a clear lack of empirical studies testing whether the collaborative arrangements and company acquisitions in reality provide growth options for the acquiring companies. There is also lack of knowledge concerning the factors contributing to the option nature of collaborative arrangements and company acquisitions. Furthermore, there is lack of knowledge concerning the factors contributing to the option upside realization in the option-type of company acquisitions. The purpose of this paper is to decrease these gaps in the existing knowledge.

2 Hypotheses

Collaborative arrangements as options to acquire

It has been hypothesized that collaborative arrangements and particularly joint ventures could be used as an option to buy technology (Folta, 1994). Investments in joint ventures and other collaborative arrangements could be regarded as call options. If the joint venture arrangement proves successful, it can be bought by one the partners. In a study of 148 joint ventures, Kogut (1988) found that the industries that were the most active acquirers of joint ventures are chemicals, primary metal industries, communications, machinery, and other manufacturing industries. Altogether 68 joint ventures had been either dissolved or acquired. In a follow-up study of a subsample of 92 manufacturing joint ventures, Kogut (1991) found that 27 joint ventures had been terminated by dissolution, 37 by acquisition, and 28 were still operational. Hypothesizing that joint ventures are options to acquire, Kogut studied factors increasing the likelihood of acquisition. In line with the option hypothesis, the main correlations were found between the unexpected increases in the value of the venture, the degree of concentration of the industry, and the propensity to acquire the joint venture. Similarly in line with the option hypothesis, Kogut found that a market decline did not correlate statistically significantly with the dissolution of a joint venture (Kogut, 1991).

Some studies have taken the hypothesized transition process even further by pointing out that there may be a gradual transition from contractual collaborative arrangements to more integrated equity-based collaborative arrangements. Gulati (1995) discusses the effect of social structure in alliance formation. Harrigan (1988) discusses how the contractual arrangements are being replaced by other ventures of more permanent nature. Contractual collaboration is hypothesized to lead into decreasing uncertainty and, in successful cases, into increasing levels of integration. The increasing levels of integration in a network can typically take place in many different dimensions including institutional integration, integration of decision making, and integration of execution (Herz, 1992).

Hagedoorn and Sadowski (1996) have studied the potential transition from collaborative arrangements to acquisitions on the basis of their databases of collaborative arrangements and acquisitions. More specifically, they studied the transition from contractual research and development agreements, joint development agreements, technology-motivated joint ventures, and technology-motivated minority holdings to acquisitions. In addition, Hagedoorn and Sadowski studied whether contractual technology alliances are transformed into joint ventures. All the results were contrary to the expectations. Out of the total of 6060 alliances only 143 or 2.4 % were found to be transformed into acquisitions. Out of all the contractual alliances only 84 were found to be transformed into joint ventures. Hagedoorn and Sadowski note that if the transition to an acquisition took place, it took place in 64 % of the cases within a period of five years after the establishment of the partnership. Out of the transformed alliances 33 % represented companies of similar size and 68 % represented companies of dissimilar sizes. A total of 64 % of the companies in the transformed alliances were from identical sectors and 36 % were of different sectors. Over 70 % of the companies in the transformed alliances had over 5000 employees. Only 19 % of the companies in the transformed alliances had below 500 employees. The distribution of the transformed companies differs statistically significantly from the distribution of all the companies in the database. In the whole database, nearly 70 % of the companies have below 5000 employees.

Even though the results of Hagedoorn and Sadowski are somewhat contrary to the findings of Kogut, they seem quite logical. It would seem that companies do not use much equity collaboration in the pre-acquisition process when acquiring small companies. In the case of larger companies the importance of the gradual approach is better acknowledged. Also the transition from a joint venture to an acquisition is more natural. A joint venture is a unit established outside the collaborating companies. The natural ways to end up the relationship are the closing down and the acquisition.

Acknowledging the earlier results, it is interesting study the role of the option-type of collaborative arrangements when acquiring small new, technology-based companies. It is hypothesized that

Hypothesis 1

Previous option-type of collaborative arrangements do not play a significant role in the acquisition of small, new, technology-based companies by large companies

Company acquisitions as options

More than regarding collaborative arrangements as options to acquire the collaborative partner, the acquisitions themselves could be regarded as options to acquire a new technology or business area. The collaborative arrangements could be regarded as options on options or compound options. The acquisitions of new, technology-based companies could be regarded as the acquisitions of options to enter a new technology area. This hypothesis is tested in this paper.

The option-nature of new, technology-based company acquisitions could be expected to play a particularly significant role in connection with company acquisitions where the technological competencies are not yet fully developed. The acquiring companies could assume that the technology possessed by a new, technology-based company will develop favorably making the technology option valuable for them. The option role of the acquisitions could be expected to be more important, the smaller the acquired companies are at the time of acquisition. Similarly, the industry trend at the time of the acquisition could be expected to affect the option nature of the acquisition. It could be hypothesized that the more favorable the industry trend at the time of the acquisition, the more important the option-nature in the new, technology-based company acquisitions. Also, the acquirer research and development intensity, the patentability of the technology, and the age of the acquired company could all be expected to contribute to the option-nature of the acquisition.

Hypothesis 2

Small, new, technology-based companies are acquired by large companies as options to enter a new business or technology area. The option-nature of the new, technology-based company acquisitions is particularly important

- *the less mature the acquired technological competencies are*
- *the smaller, in terms of size and personnel, the acquired companies are*
- *the more favorable the industry trend at the time of acquisition*
- *the more research and development intensive the acquiring company*
- *the better the patentability of the acquired technological competencies*
- *the younger the acquired company*

In addition to the option nature and the factors contributing to the option nature of the acquisitions, it is interesting to study the option upside realization in the option acquisitions. The factors related to the option upside realization in company acquisitions could provide a deeper insight into the uncertainty structure of technology-motivated company acquisitions. The option upside realization is related to the research on the company acquisition success factors in general. The performance of company acquisitions has been the topic of a large number of both conceptual and empirical studies. It has attracted the interest of a large number of disciplines. The performance of acquisitions has been studied from the perspectives of financial economics, different schools of strategy, and organizational behavior. The studies in the field of financial economics have focused on the stock market responses to company acquisitions. The focus of the studies has been on relatively large acquiring and acquired companies. In these studies, the companies have been clustered according to several variables. The clustering has been done mainly into related and unrelated companies according to the similarity of the acquired company and the acquiring company. The studies have empirically attempted to find out whether the acquisitions lead into above average cumulative abnormal returns for the shareholders of the companies. A typical finding has been that the announcements of acquisitions have created positive or no changes in the combined wealth. The gains have occurred mainly for the shareholders of the acquired companies while the gains for the shareholders of the acquiring companies have commonly been insignificant, see, for example, Jensen and Ruback (1983). In parallel with the stock market studies, more conceptual work has been carried out in the strategy literature (Kitching, 1967; Rumelt, 1974). The concept of relatedness between the acquired and the acquiring company has played a major role also in the strategy literature where the main focus has been on the relationships between the different acquisition strategies and company performance. The emergence of the resource-based approach to strategy and the dynamic capabilities view of strategy have further strengthened the theoretical basis of the strategy literature on acquisitions. Due to the dissatisfaction in the dominating relatedness versus unrelatedness focus of both the strategy and the financial economics schools of acquisition research, there has been an increasing shift in the focus towards the integration issues. Combining the organizational behavior school approach to acquisition integration with the traditional strategy approach has resulted into a process perspective on acquisitions (Jemison and Sitkin, 1986).

In an earlier study on the success of new, technology-based company acquisitions in general, Laamanen (1997) found a number of variables that correlated with the success of new, technology-based company acquisitions in general. In the study of Laamanen, the success of company acquisitions was divided into four component measures of success. As a result of regression analyses and elimination of variable collinearity, Laamanen found that different variables correlated with different measures of success. The findings of Laamanen are shown in figure 1. In his study, Laamanen points out the importance of complementarities in company acquisition success.

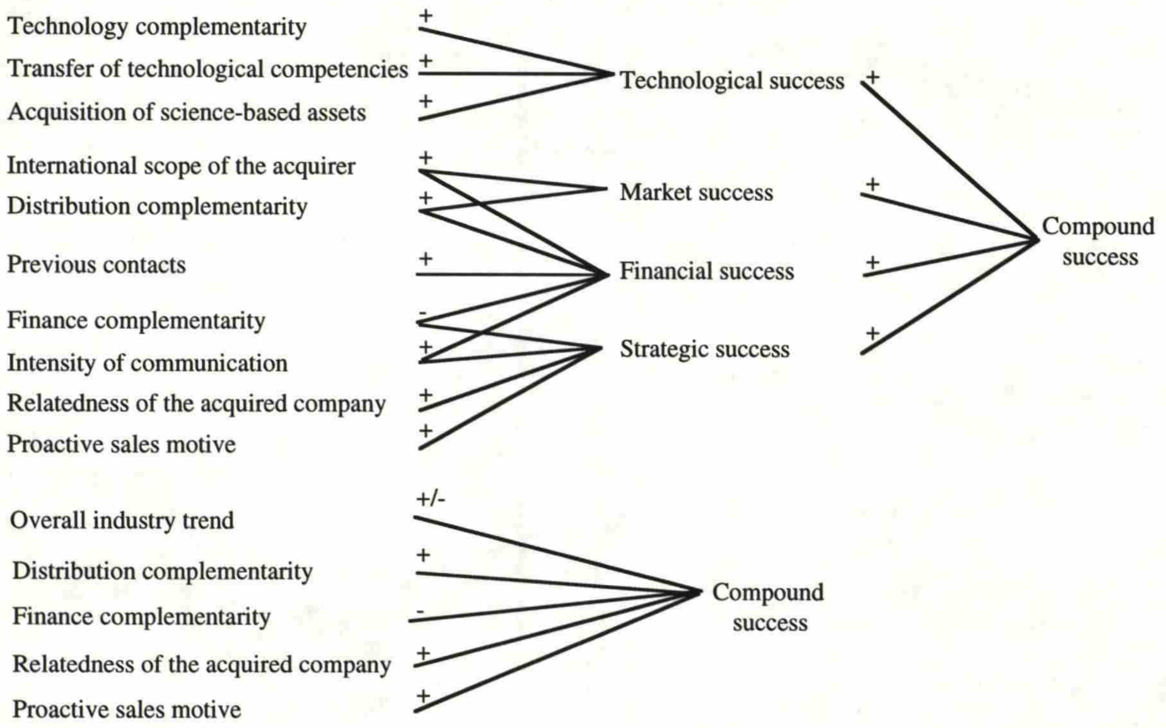


Figure 1 Factors contributing to different component measures of company acquisition success

Based on the existing research on company acquisition success factors, a number of factors can be hypothesized to contribute to the success of option-type of acquisitions. In line with the findings of Laamanen (1997), the technological, distribution, and finance complementarities are hypothesized to correlate with the success of the option-type of new, technology-based company acquisitions. Similarly, the overall industry trend, the relatedness of the acquired company, and the proactive sales motive of the acquired company are hypothesized to correlate with the success of the option-type of new, technology-based company acquisitions. In addition to Laamanen's study, these factors have been found to be linked to the new, technology-based company acquisition success in a number of other studies. For example, Granstrand and Sjölander (1990) and Lindholm (1994) discuss the importance of the proactive sales motive of the seller. Even though the option upside realization has not been studied in previous studies, it can be expected that the more general company acquisition success factors coincide with the factors contributing to option upside realization. It is hypothesized that

Hypothesis 3

In option-type of acquisitions of new, technology-based companies, the option upside is correlated

- *positively with the existence of favorable industry trend*
- *positively with the existence of distribution complementarity*
- *negatively with the existence of finance complementarity*
- *positively with the relatedness of the acquiring and the acquired company*
- *positively with the proactive sales motive of the seller*
- *positively with the existence of technological complementarity*

3 Empirical sample

The empirical part of this paper concentrates on acquisitions where a new, technology-based company was acquired by a larger company. The sample consists of 111 such new, technology-based company acquisition cases. The focus was set intentionally on new, technology-based companies. The new, technology-based companies can be seen to represent a bundle of technological competencies. Consequently, the valuation of these companies in company acquisition situations could be seen to represent the valuation of a complex bundle of competencies. The technological competence component can be seen to dominate in the company acquisitions. Due to the small sizes of the acquired companies, it would seem improbable that many of the companies would have been acquired for other reasons. In the case of large companies, there are also several other assets or resources that could be considered targets of acquisitions. For example, the existing customer base or brand name could be considered as such assets. The valuation of these more diverse assets using the option valuation methodology is beyond the scope of this paper. In a more complex real option valuation situation, particular problems could be expected to be caused by the interrelationships between the option values. The brand name could have some option value. The acquired customer base could have some option value. A problem is that these option values may be interrelated.

The sample of new, technology-based company acquisitions was selected from a large number of company acquisitions where a Finnish company was either the acquiring or the acquired company. The company acquisition volumes have varied over the years. The number of closed company acquisition deals has followed the economic cycles. The overall volume of company acquisitions has increased since 1980. Before the 1980s, relatively few company acquisitions took place in Finland. The development of the company acquisition volumes is shown in figure 2. The time focus of this paper is on the most recent economic half-cycle. The half-cycle can be seen to start in 1987 and it would seem to end in 1994. The whole half-cycle has been selected as the total population to be studied. This has been done in order to control, if possible, the effect of systemic economic fluctuations on the company acquisition behavior. The nature of competence acquisition through the acquisition of companies may be influenced by the stage of the economic cycle.

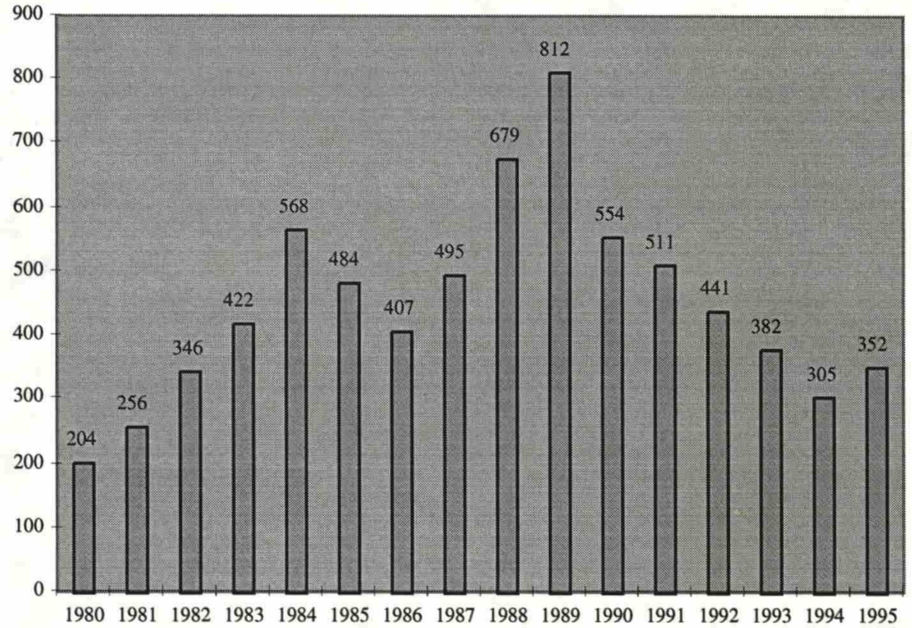


Figure 2 *The development of the company acquisition volumes in Finland during the period of 1980-1995. The data on the acquisition volumes during the period 1980-1986 is based on Talouselämä 1, 1990. The data on the acquisition volumes during the period 1987-1989 is based on the Talouselämä database. Due to different procedures of collecting and reporting the company acquisition data in different periods, the database numbers and the numbers reported in Talouselämä 1, 1990 differ somewhat, but not significantly, (Compare, for example, Virtanen et alii, 1992)*

In the overall population of 4531 company acquisitions, during the period 1987-1995, the dominant acquiring sector has been the wholesales and retail sector, figure 3. The metal and machinery sector has been also an active acquirer followed by the construction and the construction services sector. The construction sector was particularly boosted by the economic growth period at the end of the 1980s. The financial services sector includes all the bank branch acquisitions and bank mergers that have taken place in Finland during the period. The sectoral proportions resemble the structural changes that have taken place in the Finnish economy. The acquisition volumes do not, however, reflect directly the strengths of the corresponding industries in Finland. For example, the pulp and paper industry that is particularly strong in Finland is under the category forestry contributing only 4 % of all the acquisitions. Only 177 acquisitions have taken place in the forestry sector. On the other hand, the acquisitions in the forestry sector are among the largest acquisitions in Finland on average.

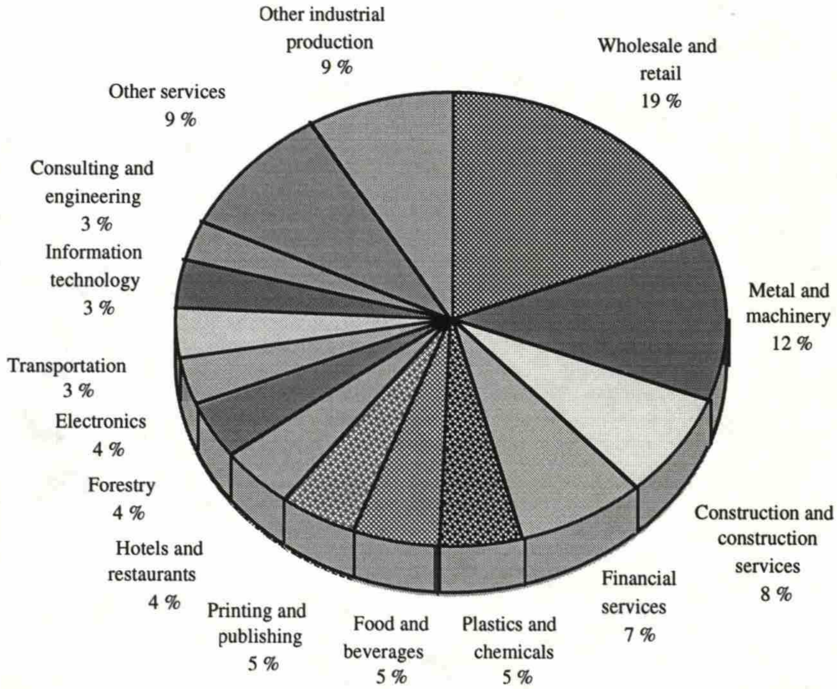


Figure 3 Distribution of the acquisitions according to the industry in Finland during 1987-1995. The total number of acquisitions during the period was 4531

Out of the total of 4531 acquisitions, altogether 109 acquisitions were initially selected for a more detailed study. The initial case selection resulted from a process of examining the information of all the 4531 company acquisitions in the database. The database information was supplemented with more detailed descriptions of the acquisitions in the Finnish press. There were four selection criteria for the selection of the company acquisition cases.

The first selection criterion, in accordance with the definition of the new, technology-based companies, was to select companies that had been sold by entrepreneurs. The companies needed to be majority owned by entrepreneurs before the acquisition transaction. If there was a group of entrepreneurs or entrepreneurs and a venture capitalist or entrepreneurs and a bank as a majority owner, the company was accepted to the sample. In some cases, the companies were sold by entrepreneurs through holding companies, for example, due to tax reasons. These company acquisition cases were included in the sample always when the holding company structure was identified. The applicability of this criterion was cross-checked in the interviews.

The second selection criterion was to select companies that would base their business on the exploitation of *new* technological competencies. This was determined on the basis of the description of the acquired company. If there was uncertainty whether the acquired company based its business on the exploitation of new technological competencies, the company acquisition case was included in the sample. The third selection criterion was to select only companies that were bought by other companies. Companies bought by private persons were excluded.

The fourth selection criterion was to select companies that would not only be capacity expansions for the acquiring company. To be included in the sample, it was required that the acquired companies could have provided some new technological competencies for the acquiring company. The fourth criterion was difficult to determine on the basis of the database. In some cases, the description of the background of the acquisition in the Talouselämä magazine or other press provided more information to decide on the criterion. Otherwise, the fourth criterion was used comparatively loosely in the selection of acquisition cases. All the acquisition cases that fulfilled the other criteria and that *could* have provided new competencies for the acquiring company were included. The accuracy of this criterion was significantly improved by creating an overview of the main motives of *all the acquisitions* carried out by the interviewed acquiring companies. This was done in the first interviews with the presidents, vice presidents, or chief technology officers of the acquiring companies. Carrying out a more detailed screen and a final selection of the acquisition cases in the first interviews can be assumed to have improved the validity of the sample. This was feasible in Finland where there are not many large companies in technology-based industries.

The case selection was adjusted after the first interviews. There were altogether 10 cases that were excluded from the initial sample due to discovered non-conformance of the predetermined criteria. There were 20 cases that were added to the sample after the preliminary discussions in the acquiring companies. There were eight acquisitions that could not be analyzed due to the inability to reach the appropriate persons or due to refusals. There were five refusals and three cases where the companies or the necessary persons could not be located. Four of these eight missing cases can be considered to have been failures as acquisitions. One was continued but it was confidential due to military reasons. Two were so new that they had no history. Concerning the eighth missing case there is no data. For a more detailed description of the case selection process, see Laamanen (1997).

As a result of all the additions and deductions, the total number of cases included in the study increased from the initial selection of 109 companies. The response rate of the study is 111/119 = 93 %. Due to their small proportion, the missing cases are not considered to cause significant bias in the sample. Even though the 111 cases represent only 2.4 % of all the 4531 acquisitions in Finland during period, the study covers well the population where the seller was an entrepreneur, the acquired company based its business idea on technological competencies, the company was acquired by another company, and the company acquisition was not motivated by capacity expansion. The 111 cases were not selected so that they would be as different as possible or as similar as possible. Since the population of company acquisitions that fulfills the predetermined criteria is comparatively small, a survey of the whole population was sensible. Technology-motivated business unit transfers between the companies were not included.

The time-industry distribution of the final case selection is shown in table 1. Many of the selected cases are from time periods during which a large number of acquisitions took place. Due to the technological competence focus of this paper, the industry distribution of the sample does not correspond to the industry distribution of the total population of company acquisitions carried out in Finland during the period. All the acquisitions in all the industries were screened, but in many of the industries, there were no companies that would have fulfilled the predetermined criteria. The acquisitions in the fields of information services, marketing services, transportation services, hotels and restaurants, financial services, wholesale, retail, and construction services did not include any acquisitions that would have fulfilled the criterion of technological competencies. The competencies acquired in these acquisitions could not be regarded technological.

A pie chart representing the industry distribution of the sample is shown figure 4. One third of the acquisition cases, 29 %, took place in the electronics industry. One fourth, 25 %, of the acquisition cases took place in the field of information technology. Around 18 % of the acquisition cases represented the metals and machinery field. The studied industries represent a relatively small proportion of all the acquisitions that have taken place during the chosen time period. On the other hand, in some of the industries included in the study, the studied acquisition cases are relatively representative. For example, the electronics acquisitions studied in this dissertation represent 19 % of all the acquisitions in the electronics industry in Finland during the period. The information technology acquisitions represent 19 % of all the acquisitions in the field of information technology during the whole period. In the metal and machinery industry, the proportion is considerably smaller constituting only 4 % of all the acquisitions in the metal and machinery industry. In the consulting and engineering, the studied acquisitions account for 11 % of all the acquisitions during the period. In the chemicals industry, the acquisitions account for 6 % of all the acquisitions during the period.

Table 1 The selection of the company acquisition cases for the analysis

	Selected acquisition cases	1987	1988	1989	1990	1991	1992	1993	1994	1995	Total
1	Food and beverages										0
2	Printing and publishing		1								1
3	Furniture and wood items production										0
4	Chemicals	1	1		2	1	1			1	7
5	Plastics			1				1			2
6	Metal and machinery	3	6	7	2	1			1		20
7	Forestry										0
8	Construction										0
9	Electronics	4	8	3	3	4		5	1	4	32
10	Textiles and clothing		1								1
11	Conglomerate companies										0
12	Other industrial production		1	1		3			1		6
13	Construction services										0
14	Wholesale										0
15	Retail										0
16	Financial services										0
17	Hotels and restaurants										0
18	Transportation										0
19	Information technology	3	9	6	1	5			2	2	28
20	Consulting and engineering	2	1	7	3	1					14
21	Marketing services										0
22	Information services										0
23	Other services										0
	Total	13	28	25	11	15	1	6	5	7	111

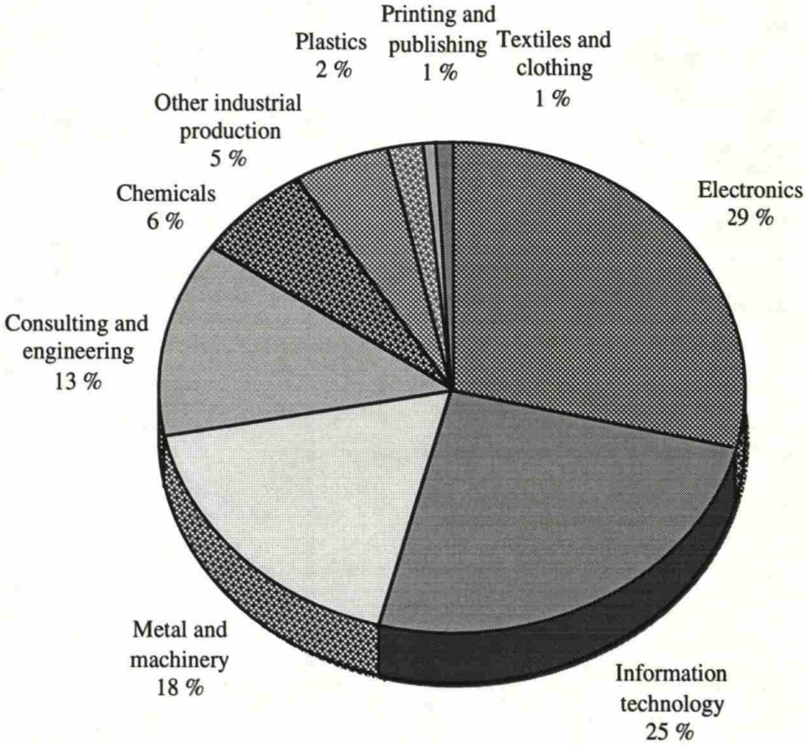
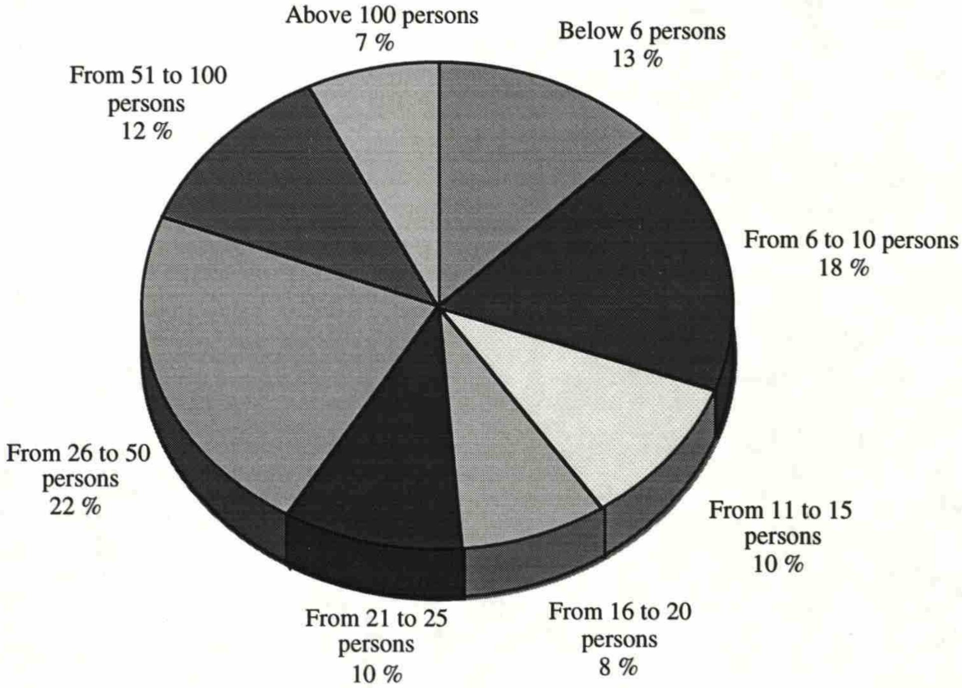


Figure 4 Distribution of the studied acquisitions according to the industry ; N=111

The studied population of 111 company acquisition cases is clearly not representative of the whole 4531 population of company acquisitions in the Talouselämä database. In addition to the different industry distributions, there are also other systemic differences. For example, the acquired companies are on average smaller in the studied population than in the whole population. The average sales revenue of the total population of acquired companies was 130 MFIM. The average sales revenue of the companies in the sample was 24.6 MFIM. Similarly, the average personnel of the total population of the acquired companies was 163 persons. The average personnel of the acquired companies in the sample was 47. Both differences in means are statistically significant with the significance level of 0.001. The size and age distributions of the sample are shown below.



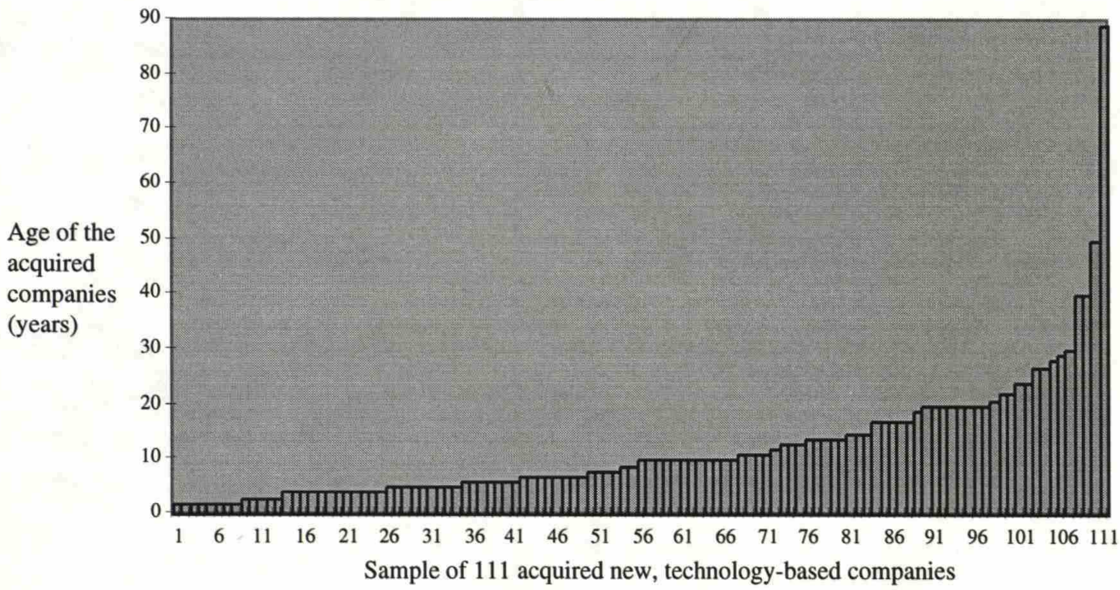


Figure 5 *Size and age distribution of the companies in the 111 company sample*

4 Variable operationalization

To test the hypotheses, it is necessary to operationalize the dependent and independent variables. Both equity or non-equity collaboration can be considered to qualify as previous collaboration. Both can be measured on a binary scale indicating whether there was equity or non-equity collaboration or not. The option nature of the acquisitions can also be determined on a binary scale. Similarly, the option upside realization can be measured on a binary scale. There are a number of other variables that are necessary to operationalize to be able to proceed to testing the hypotheses. The operationalization of these variables is shown in table 2.

Table 2 Operationalization of variables necessary for the hypothesis testing

Name of the variable	Variable operationalization
Equity collaboration before the acquisition	Measured on a binary scale whether one of the companies owned shares of the other company before the acquisition
Non-equity collaboration before the acquisition	Measured on a binary scale whether the companies collaborated before the acquisition in business issues
Dependent variables	
Option nature of the acquisition	Measured on a binary scale whether there was in the acquisition an expectation of long term growth to be realized at a later point in time or whether the acquisition was motivated by short term objectives
Option upside realization	Measured on a binary scale whether the business started growing in terms of sales revenue or whether the growth was not realized
Independent variables	
Maturity of the acquired competencies	Measured on a four-level scale from technological competencies that have not been introduced to mature declining competencies [1..4]
Sales of the acquired company	Measured in absolute terms in Finnish marks as the sales revenue of the acquired company at the time of the acquisition
Personnel of the acquired company	Measured in absolute terms as the number of persons employed by the acquired company at the time of the acquisition
The industry trend at the time of acquisition	Measured on a three-level scale whether the industry was declining, stable, or growing at the time of the acquisition [-1, 0, 1]
Acquirer research and development intensity	Measured on a three-level scale: Acquiring companies or acquiring divisions having no or only insignificant explicit research and development investment are categorized into category 0. Companies or divisions having significant volumes of explicit investment into research and development are categorized into category 2. The remaining companies are categorized into category 1; [0, 1, 2]
Patentability of the acquired competencies	Measured on a binary scale whether the competencies of the acquired company had been patented before the acquisition or whether the competencies could have been patented before the acquisition
Age of the acquired company	Measured in absolute terms in full years as the age of the acquired company at the time of the acquisition
The existence of technological complementarity	Measured on a binary scale whether the acquiring company could support the acquired company technologically after the acquisition
The existence of distribution complementarity	Measured on a binary scale whether the acquiring company could provide the acquired company new customers after the acquisition through its existing distribution system
The existence of finance complementarity	Measured on a binary scale whether the acquiring company could support the acquired company financially after the acquisition
The industry trend after the acquisition	Measured on a three-level scale whether the industry has been in general declining, stable, or growing after the acquisition [-1, 0, 1]
The relatedness of the companies	Measured on a scale of [0 %, 25 %, 50 %, 75 %, 100 %]. The relatedness between the acquiring and the acquired company is rated 100 % if the acquired company can be connected to the core business area of the acquirer. The relatedness is rated 75 % if the acquired company cannot be connected to the core business area of the acquiring company, but there is a direct link between the core business areas. The relatedness is rated 50 % if the acquired company can be connected to a new emerging non-core business area. The relatedness is rated 25 % if the acquired company has some distant links to a new, non-core business area. The relatedness is rated 0 % if there are no pre-existing links between the companies
The proactive sales motive of the seller	Measured on a binary scale whether the seller wanted to sell the company for further growth in contrast to cashing out

The data was collected in interviews with the managers responsible for the acquisitions and with the entrepreneurs that had sold their companies. The persons interviewed in the acquiring companies were typically presidents, vice presidents, or division managers. The persons interviewed in the acquired companies were typically founders or presidents. Altogether 128 interviews were carried out. The interviews were complemented with the existing internal material and the internal audits available in some of the larger companies. All the interviews were carried out by the researcher himself. For a more detailed description of the interview process, see Laamanen (1997).

The numerical values for the variables were assigned based on the interviews. For example, the variable showing the option nature of the acquisition was determined based on the acquisition motivation of the acquiring company, as stated by the interviewed persons. If the acquisition was motivated by long-term growth possibly realizable in the future in contrast to short-term motivations, the acquisition was considered to have the option nature. The option upside realization was determined based on the sales growth of the acquired company. If the sales of the acquired business area started growing, the option upside variable was assigned a value indicating option upside realization. The distributions of the variables used in hypothesis testing are shown in table 3.

Table 3 Distribution of the variables used in the hypothesis testing: all acquisitions: 111 , option acquisitions: 58

Name of the variable	Variable distributions	
Equity collaboration before the acquisition	Equity collaboration	14 (13%) acquisitions
	No equity collaboration	97 (87%) acquisitions
Non-equity collaboration before the acquisition	Non-equity collaboration	25 (23%) acquisitions
	No non-equity collaboration	86 (77%) acquisitions
Dependent variables		
Option nature of the acquisition	Option nature of the acquisition	58 (52%) acquisitions
	No option nature	53 (48%) acquisitions
Option upside realization	Option upside was realized	28 (48%) option acquisitions
	Option upside not realized	30 (52%) option acquisitions
Independent variables		
Maturity of the acquired competencies	1: Competencies not introduced	17 (15%) acquisitions
	2: Introduction to the markets	20 (18%) acquisitions
	3: Growth in the markets	30 (27%) acquisitions
	4: Mature declining competencies	44 (44%) acquisitions
Sales of the acquired company	Sales revenue 0-5 MFIM	41 (37%) acquisitions
	Sales revenue 6-10 MFIM	21 (19%) acquisitions
	Sales revenue 11-20 MFIM	19 (17%) acquisitions
	Sales revenue 21- MFIM	30 (27%) acquisitions
Personnel of the acquired company	Personnel distribution of the acquired companies shown in figure 5	
The industry trend at the time of acquisition	- 1: Industry declining	5 (5%) acquisitions
	0: Industry stable	70 (63%) acquisitions
	+1: Industry growing	36 (32%) acquisitions
Acquirer research and development intensity	0: No or insignificant R&D	30 (27%) acquisitions
	1: Moderate levels of R&D	30 (27%) acquisitions
	2: Significant volumes of R&D	51 (46%) acquisitions
Patentability of the acquired competencies	Patentable competencies	61 (55%) acquisitions
	Non-patentable competencies	50 (45%) acquisitions
Age of the acquired company	Age distribution of the acquired companies shown in figure 5	
The existence of technological complementarity	Technological complementarity	36 (62%) option acquisitions
	No technological complementarity	22 (38%) option acquisitions
The existence of distribution complementarity	Distribution complementarity	25 (43%) option acquisitions
	No distribution complementarity	33 (57%) option acquisitions
The existence of finance complementarity	Finance complementarity	47 (81%) option acquisitions
	No finance complementarity	11 (19%) option acquisitions
The industry trend after the acquisition	- 1: Industry declining	10 (17%) option acquisitions
	0: Industry stable	33 (57%) option acquisitions
	+1: Industry growing	15 (26%) option acquisitions
The relatedness of the companies	No pre-existing relatedness	5 (9%) option acquisitions
	Distant links to new non-core area	8 (14%) option acquisitions
	Related to new non-core area	18 (31%) option acquisitions
	Distant links to core business area	12 (21%) option acquisitions
	Related to core business area	15 (26%) option acquisitions
The proactive sales motive of the seller	Proactive sales motive	25 (43%) option acquisitions
	No proactive sales motive	33 (57%) option acquisitions

5 Data analysis

Collaborative arrangements as options

To study whether the collaborative arrangements played a significant option-role in the acquisition of new, technology-based companies in the sample, it is necessary to analyze in how many cases there were collaborative arrangements. These cases can then be analyzed more in depth. The motives for the establishment of the collaborative arrangements can be examined. Based on the analysis, an evaluation of the option role of collaborative arrangements in new, technology-based companies can be made. The previous collaboration is divided here into previous equity collaboration and previous non-equity collaboration. In the 111 new, technology-based company acquisition sample, there were 14 cases where there was some previous equity collaboration. In addition, there were 25 other acquisition cases where there was previous non-equity collaboration. Altogether, there were 39 instances of previous collaboration.

The previous equity collaboration does not differ in volume in the studied sample and the total sample of acquisitions carried out during the period of 1987-1995 in Finland. Out of the other 4263 company acquisition cases carried out in Finland, there were 430 company acquisition cases where there was previous equity collaboration. The relative proportions, 12.6% and 10.1% respectively, do not differ statistically significantly. The motives for the establishment of the previous collaboration vary. The real motives for the collaboration, according to the representatives of the acquiring companies, are shown in figure 6. The figure illustrates the fact that in only relatively few of the contractual collaboration cases, the option to acquire the collaborative partner played an important role when establishing the collaboration. Fourteen cases represent collaboration in business terms, for example, engineering, marketing, or installation collaboration. Six cases represent subcontracting collaboration. Only two of the contractual collaboration cases can be seen to represent option type of collaboration from the perspective of the larger company. In the previous equity collaboration, the establishment of the collaboration can be seen to be more affected by the options thinking. Eight cases could be considered as investments into the option to acquire. Four cases were pure financial investments without the purpose to get an option to a new business area.

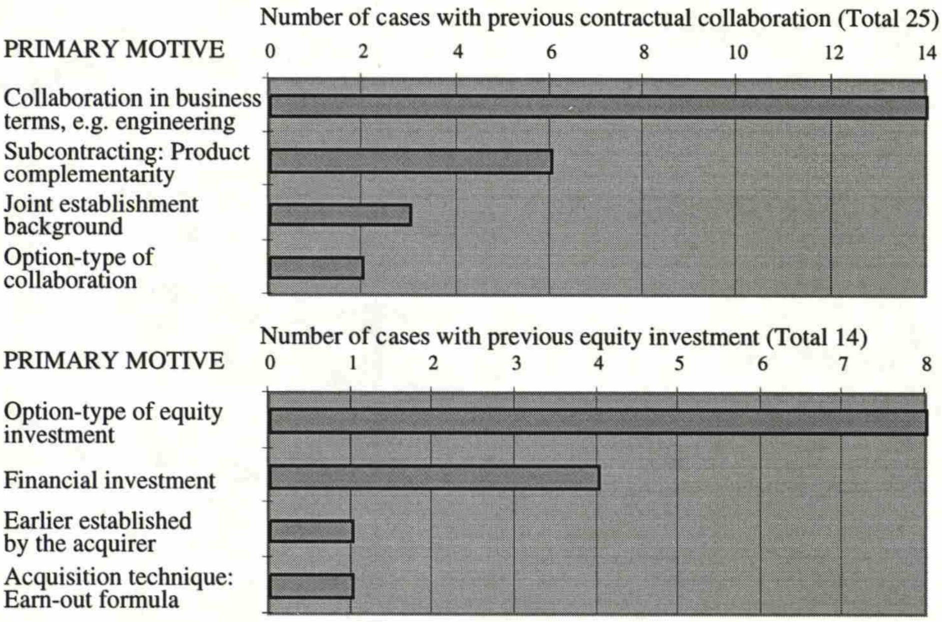


Figure 6 Motives for collaboration in the 39 cases with previous collaboration

In addition to previous equity and non-equity collaboration, the previous contacts between the companies were mentioned in 20 other cases. On the whole, the equity participation, non-equity collaboration, and previous contacts are represented in 59 cases. The previous contacts themselves do not seem to provide much exposure. They would seem to function more as a mechanism to attract attention. Altogether, the option-role would seem to be present in the previous collaboration of 10 of the studied 111 new, technology-based company acquisition cases. This is such a small proportion, 9 %, that it cannot be considered sufficient for rejecting hypothesis 1. The hypothesis 1 would seem to get support from the 111 new, technology-based company acquisition sample.

Company acquisitions as options

In the analysis of whether the acquisitions of new, technology-based companies could be regarded as options to get a new business or technology area, the 111 company acquisition cases were grouped into two categories. The first category consisted of company acquisition cases where there was no explicit option elements in the acquisition. The second category consisted of company acquisition cases where there was seen to be an explicit option element in the acquisition. Since the sample consisted of new, technology-based companies, the option element was present in relatively many of the studied acquisition cases. Altogether 58 companies could clearly be classified as option acquisitions. In contrast to the scarce use of collaborative arrangements as options to acquire new, technology-based companies, the acquisitions of new, technology-based companies would seem to be have an established option role. The first part of hypothesis 2 would seem to get support from the studied sample. To test the second part of hypothesis 2, bivariate correlation analysis is applied. The variables hypothesized to contribute to the option role of the new, technology-based company acquisitions are correlated with the dichotomous variable indicating whether the acquisition was an option acquisition or not. The bivariate Kendall correlation coefficients are shown in table 4.

Table 4 *The correlations of the company acquisition variables and the option nature of the acquisition; N=111. The logarithm of the personnel variable is used in the analysis to avoid bias due to large maximum values*

Correlation coefficients of the variables hypothesized to correlate with the option nature of the acquisition	Expected sign	Kendall correlation coefficient	p-value	Statistical significance
Maturity of the acquired competencies	-	-0.52	0.000	significant
Sales revenue of the acquired company	-	-0.04	0.657	n.s.
Ln(Personnel of the acquired company)	-	-0.07	0.390	n.s.
Industry trend at the time of acquisition	+	0.01	0.953	n.s.
Research and development intensity	+	0.45	0.000	significant
Patentability of the acquired competencies	+	0.48	0.000	significant
Age of the acquired company	-	-0.26	0.001	significant

The bivariate correlation analysis indicates that four of the hypothesized variables correlate statistically significantly with the option nature of the acquisition: the maturity of the acquired competencies, the research and development intensity, the patentability of the acquired competencies, and the age of the acquired company. No statistically significant correlations were found between the option nature of the acquisition with the sales revenue of the acquired company, the personnel of the acquired company, and the industry trend at the time of acquisition.

The maturity of the acquired technological competencies correlates statistically significantly negatively with the option nature of the acquisition. The more mature the technological competencies are the less they typically contain uncertainty and, consequently, the less they contain option elements. The research and development intensity of the acquiring company correlates positively with the option nature of the acquisition. The more research and development intensive the acquiring companies are, the more likely they seem to carry out option type of acquisitions. The patentability correlates positively with the option nature of the acquisition. It would seem that the acquiring companies acquire new, technology-based companies as options when the technology is protectable. One reason for this may be that the large companies are in fact buying the rights for an attractive technology. Similarly to the maturity of the acquired competencies, the age of the acquired company correlates negatively with the option nature of the acquisition.

The variables correlating statistically significantly with the option nature of the acquisition can further be analyzed with the aid of logistic multiple regression analysis. The variables are regressed against the dependent variable indicating the option nature of the acquisition. It is necessary to use the logistic multiple regression instead of the normal multiple regression since the dependent variable is dichotomous. To first determine that there is no collinearity among the four non-dependent variables, a correlation matrix is constructed. The correlation matrix is shown in table 5.

Table 5 *Correlation matrix; N=111*

	Maturity of the acquired competencies	Research and development intensity	Patentability of the acquired competencies
Research and development intensity	-0.31 p=0.00		
Patentability of the acquired competencies	-0.36 p=0.00	-0.36 p=0.00	
Age of the acquired company	0.48 p=0.00	-0.09 p=0.22	-0.18 p=0.02

The correlation matrix presented in table 5 shows that many of the independent variables correlate with each other. This would seem to indicate some degree of collinearity among the variables. Existence of strong collinearity would decrease the usability of the regression analysis for a deeper analysis of the option nature of new, technology-based company acquisitions. Particularly, the age of the acquired company and the maturity of the acquired competencies correlate strongly positively, as expected. The patentability of the acquired competencies and the maturity of the acquired competencies correlate negatively. The patentability correlates also statistically significantly negatively with the research and development intensity. This collinearity is attempted to take into account in the logistic multiple regression analysis by carrying out the regression analysis both normally and by using the standard backward elimination procedure with the likelihood-ratio elimination criterion. The results of the regression analyses are shown in table 6.

Table 6 *Regression equations of two regression analyses: 1 with all the variables that correlated statistically significantly with the option nature of the acquisition, 2 with same variables as in 1 but with a backward elimination procedure that applies the likelihood-ratio (LR) test in eliminating the variables; N=111*

Regression analysis with the option nature of the acquisition as the dependent variable	All variables *B*	Significance	Backward elimination *B*	Significance
Maturity of the acquired competencies	-1.47	p=0.00	-1.32	p=0.00
Research and development intensity	0.90	p=0.01	0.97	p=0.01
Patentability of the acquired competencies	1.18	p=0.03	1.18	p=0.03
Age of the acquired company	0.02	p=0.34	Eliminated	Eliminated
Constant coefficient	2.55	p=0.03	2.30	0.04
Goodness of fit statistic	97.0		93.9	
Chi.-Square test value	63.2	p=0.00	62.3	p=0.00
Level of prediction (prediction table)	75.7%		77.5%	

After the elimination procedures, three variables seem to predict the dependent variable with a high level of prediction. These are the maturity of the acquired competencies, the research and development intensity of the acquiring company, and the patentability of the acquired competencies. The regression results do not show the relative importance of the different variables since the variables represent categorical data that is coded differently in different variables. Coding the maturity of the acquired competencies and the research and development intensity further according to the indicator-variable coding scheme, the relative importance of the variables can be discovered. The results are relatively similar to the ones shown in table 6. The influence of the competence maturity variable is the strongest. The research and development intensity of the acquiring company and the patentability of the acquired competencies are of relatively equal importance.

On the whole, the three explanatory independent variables are as expected. The younger companies comprising the less developed technological competencies are easily perceived and acquired as options. The patentability would seem to indicate that the acquiring companies have carried out the new, technology-based company acquisitions in the higher appropriability regime. Since most of the acquisitions were carried out without any pressure from competition, the acquisitions would predominantly seem to be positioned to the high appropriability - low competition regime.

The hypothesis concerning the option role of new, technology-based company acquisitions would seem to get support. A further important question is the question of value drivers affecting the option upside realization. In real option valuation, these value drivers form the uncertainty structure of the valuation situation. In the company acquisition literature, the value drivers coincide with the company acquisition success factors. To analyze the value drivers in company acquisitions, the 58 option acquisitions are taken as a basis for the analysis. In the sample of these 58 option acquisitions, the six chosen company acquisition variables are correlated against the option upside realization. The option upside was realized in 28 of the 58 acquisitions. The correlation coefficients of the different acquisition variables and the option upside realization are shown in table 7.

Table 7 The correlations of the company acquisition variables and the upside realization of the acquisition; N=58

Correlation coefficients of the variables hypothesized to correlate with the option upside of the acquisition	Expected sign	Kendall correlation coefficient	p-value	Statistical significance
Technological complementarity	+	0.26	0.05	significant
Distribution complementarity	+	0.34	0.01	significant
Finance complementarity	-	-0.15	0.26	n.s.
Industry trend after the acquisition	+	0.41	0.00	significant
Relatedness of the companies	+	0.45	0.00	significant
Proactive sales motive of the seller	+	0.28	0.03	significant

The bivariate Kendall's correlation analysis indicates that five of the hypothesized variables correlate statistically significantly with the upside realization of the acquisition: technological complementarity, distribution complementarity, favorable industry trend after the acquisition, relatedness of the companies, and the proactive sales motive of the seller. The existence of finance for the acquired company does not correlate statistically significantly with the option upside in the acquisitions.

The strongest correlations with the option upside seem to be the correlations with the relatedness of the companies and the industry trend after the acquisition. The closer to the acquiring company's core business area the acquired company is, the more successful the acquisitions seem to be. The importance of the favorable industry trend could mean that the acquiring companies were able to project the industry development and acquire the new, technology-based companies as options at the right time. From the complementarities, the distribution complementarity seems to have the highest statistically significant correlation with the option upside. Technological complementarity rates somewhat lower. Both are elements of fit between the companies. Similarly as in earlier studies, the proactive sales motive of the seller seems to stand out as a success driver in the option acquisitions.

Similarly to the analysis of the option nature of the acquisitions, the variables correlating statistically significantly with the option upside can further be analyzed with the aid of logistic multiple regression analysis. The variables are regressed against the dependent variable indicating the option upside. It is necessary to use the logistic multiple regression instead of the normal multiple regression since the dependent variable, option upside, is dichotomous. To first determine that there is no collinearity among the five non-dependent variables, a correlation matrix is constructed. The correlation matrix is shown in table 8.

Table 8 Correlation matrix; N=58

	Proactive sales motive of the seller	Technological complementarity	Distribution complementarity	Industry trend after the acquisition
Technological complementarity	0.32 p=0.01			
Distribution complementarity	0.12 p=0.35	0.39 p=0.00		
Industry trend after the acquisition	0.28 p=0.04	0.22 p=0.11	0.20 p=0.13	
Relatedness of the companies	0.07 p=0.58	0.20 p=0.09	0.47 p=0.00	0.01 p=0.95

The correlation matrix presented in table 8 shows that some of the independent variables correlate with each other. Again, there would seem to be some degree of collinearity among the variables. Particularly, the distribution complementarity, the technological complementarity, and the relatedness of the acquiring and the acquired company correlate statistically significantly with each other. This is as expected. The technological complementarity correlates also with the proactive sales motive of the seller. There is a clear collinearity among the variables. This collinearity is attempted to take into account in the logistic multiple regression analysis by carrying out the regression analysis both normally and by using the standard backward elimination procedure with the likelihood-ratio elimination criterion. The results of the regression analyses are shown in table 9.

Table 9 *Regression equations of two regression analyses: 1 with all the variables that correlated statistically significantly with the option upside of the acquisition, 2 with same variables as in 1 but with a backward elimination procedure that applies the likelihood-ratio (LR) test in eliminating the variables; N=58. Time from the acquisition time to year 1996 is included to control for the bias of the different acquisition times*

Regression analysis with the option nature of the acquisition as the dependent variable	All variables *B*	Significance	Backward elimination *B*	Significance
Technological complementarity	1.06	p=0.26	Eliminated	Eliminated
Distribution complementarity	-0.35	p=0.72	Eliminated	Eliminated
Industry trend after the acquisition	2.07	p=0.01	1.90	p=0.01
Relatedness of the companies	5.73	p=0.05	5.25	p=0.00
Proactive sales motive of the seller	1.59	p=0.07	1.69	p=0.05
Time from the acquisition to year 1996	-0.16	p=0.48	Eliminated	Eliminated
Constant coefficient	-5.99	p=0.02	-6.22	p=0.00
Goodness of fit statistic	36.6		43.9	
Chi.-Square test value	32.1	p=0.00	30.2	p=0.00
Level of prediction (prediction table)	78.4 %		84.3 %	

After the elimination procedure, three variables seem to stand out. These are the relatedness of the companies, the industry trend, and the seller's proactive sales motive. Again, the regression results do not show the relative importance of the different variables since the variables represent categorical data that is coded differently in different variables. Coding the relatedness and the industry trend further according to the indicator-variable coding scheme, the relative importance of the variables can be assessed. The results are relatively similar to the ones shown in table 9. The influence of the relatedness is the strongest. With the coding scheme, the goodness of fit of the logistic multiple regression model can be increased to 56.1 and the level of prediction up to 90.2 %.

The fact that the acquisitions did not take place at the same time may bias the results of the regression analysis. The more recent option acquisitions have a lower probability of a realized upside since less time has passed after these acquisitions. If the time for each option realization could be determined exactly, the Cox proportional hazard regression model could be used to eliminate the bias. Unfortunately, the exact times of option exercise and option realization are difficult to determine in connection with company acquisitions. It is impossible to determine exactly at which point the option exercise started. The realization of the growth option does not take place instantaneously. The preparations for growth take time. Fortunately, based on the regression analysis in table 9, the different acquisition times do not seem to bias the regression analysis. Time becomes eliminated in the backward analysis. To further analyze the time bias, sensitivity analysis can be carried out. With a reasonable level of confidence, it can be assumed that if the acquisition contains an option element, the option will be exercised within four years of the acquisition. Otherwise, the option will not be realized at all. Taking this as a presumption, the most recent acquisitions are eliminated from the sample. Eliminating the acquisitions that have taken place from 1993 to 1995 would leave into the sample acquisitions where at least four years has passed. In the remaining acquisitions, the time can be seen to play only a marginal role with respect to option upside realization. The elimination removes 11 acquisitions. Replicating the regression analysis with the remaining 47 acquisitions can be used to assess the magnitude of the bias caused by the different acquisition times.

Table 10 Regression equations of two regression analyses: 1 with all the variables that correlated statistically significantly with the option upside of the acquisition, 2 with same variables as in 1 but with a backward elimination procedure that applies the likelihood-ratio (LR) test in eliminating the variables; N=47

Regression analysis with the option nature of the acquisition as the dependent variable	All variables *B*	Significance	Backward elimination *B*	Significance
Technological complementarity	2.06	p=0.09	2.00	p=0.08
Distribution complementarity	-0.15	p=0.88	Eliminated	Eliminated
Industry trend after the acquisition	1.79	p=0.02	1.77	p=0.02
Relatedness of the companies	7.36	p=0.01	7.21	p=0.00
Proactive sales motive of the seller	1.75	p=0.10	1.76	p=0.10
Constant coefficient	-9.06	p=0.01	-8.99	p=0.01
Goodness of fit statistic	31.2		31.4	
Chi.-Square test value	32.9	p=0.00	32.9	p=0.00
Level of prediction (prediction table)	80.9 %		80.9 %	

The results of the regression analyses do not differ much from the results of the regression analyses shown in table 9. The main difference seems to be the role of the technological complementarity. The different acquisition times do not seem to cause much bias. A further analysis by eliminating all the acquisitions that are younger than six years would seem to confirm this. A regression analysis with the remaining 35 acquisition cases shows that the relatedness dominates continuously the analyses. The regression results with the 35 acquisition subset do not differ from tables 9 and 10.

A deeper analysis could be carried out by taking the magnitude of option realization into account. Such an analysis could be carried out by applying the tobit analysis. The main problem in the analysis is the measurement of the magnitude of the option realization. The sales revenue growth could be used as one measure. It would be, however, a biased measure since the different companies have different cost structures. Same sales revenue growth could mean different magnitudes of option realization in different companies. Furthermore, it is difficult to estimate the point in time at which to measure the sales revenue growth. The real option realization does not take place instantaneously. A better measure would be the net earnings growth. The problem with the net earnings growth is that it is difficult to determine which net earnings can be attributed to the acquiring company and which net earnings can be attributed to the acquired company. For example, the integration of distribution channels, production, marketing, and management functions makes the measurement difficult. The measurement becomes even more difficult the longer the time from the acquisition.

The relatedness of the acquiring and the acquired company seems to be an important explanatory variable for the option upside realization. This is somewhat in contrast to the thinking that the options are acquired from unrelated business areas to get an option to benefit from a possible upside. One possible explanation for the importance of the relatedness for the option upside is the need for complementary resources. Acquiring a totally unrelated new, technology-based company may provide an option for a new technology area, but it may not necessarily be a realizable option even if the technology area would eventually start to grow. The importance of relatedness would seem to support the hypothesis of the resource-based view. A related use of specialized resources provides the highest rent for the resources. Barney and Turk (1994) contradict this in their study on company acquisitions. They point out that in efficient competitive markets, the acquisition of related resources does not provide any additional value creation potential. The value creation potential is already taken into account in the acquisition price. Barney and Turk hypothesize that the main value creation potential comes from the combination of unrelated resources into the operation of the company. The point made by Barney and Turk does not, however, invalidate the results of this study. The markets for new, technology-based companies and technological competencies in general cannot be regarded as efficient. Higher value creation potential can be achieved in connection with the new, technology-based companies by acquiring related technological competencies. These findings are corroborated by the findings of Capron et alii (1995) and Capron (1996).

6 Conclusions

This paper set out to analyze the option nature of collaborative arrangements and new, technology-based company acquisitions. Based on the analyses, a number of findings can be pointed out

- New, technology-based company acquisitions could be seen more as option acquisition than as option exercise. An analysis of the previous equity and non-equity collaboration shows that in only ten new, technology-based company acquisition cases, the previous collaboration was initiated with the purpose to get an option to acquire the collaborative partner. Most of the cases where the collaboration had the option role were initiated as equity collaboration. Only 2 of the 25 non-equity collaborative arrangements could be regarded to have had the option role.

- Contrasting to collaborative arrangements, the option analogy would seem to be more relevant in the new, technology-based company acquisitions. Altogether 58 of the 111 new, technology-based company acquisitions were found to have explicit option elements. This would seem to favor the use of real option valuation methods in the valuation of technology-motivated acquisitions.

- Using the logistic multiple regression analysis to analyze the variables contributing to the option nature of the acquisitions, four variables stand out. These variables are the age of the acquired company, the maturity of the acquired competencies, the research and development intensity of the acquiring company, and the patentability of the acquired competencies. The achieved level of prediction with these four variables is 75.7 %. Backward elimination procedure is used to remove the age of the acquired company as a variable causing collinearity. This increases the level of prediction to 77.5 %. The correlations of the age of the company and the maturity of the acquired competencies with each other and with the option nature of the acquisition are as expected.

- The patentability of the acquired competencies correlates with the option nature of the new, technology-based company acquisitions. The option nature of the acquisitions seems to coincide with high appropriability and lack of competition. According to Kester's classification of real options (Kester, 1984), it is more optimal to defer the exercise of this kind of options than to exercise them early. The option to defer can be considered to create additional value-added when combined with the growth option.

- From logistic multiple regression analysis, three variables stand out to explain the realization of the option upside in the sample of 58 option acquisitions. These variables are: the relatedness of the acquiring and the acquired company, the industry trend after the acquisition, and the proactive sales motive of the seller. Technology, distribution, and finance complementarity were eliminated due to problems of collinearity. The achieved level of explanation with the three remaining variables is 84.3 %. The level of prediction can further be enhanced to 90.2 % by coding the independent variables of the regression equations according to the variable-indicator coding scheme.

- The relatedness would seem to be the strongest predictor of the acquisition upside in the studied sample. The importance of relatedness would seem to support the resource-based view. According to the resource-based view, a related use of specialized resources provides the highest rent for the resources. The markets for the acquisition of new, technology-based companies and technological competencies in general cannot be regarded efficient and competitive. Even higher value creation potential could be assumed to be achieved in connection with the new, technology-based company acquisitions by acquiring related technological competencies.

On the whole, it is stressed in this paper that an understanding of the real value drivers is required in the valuation of technology-motivated company acquisitions. The real value drivers form a basis for examining the uncertainty structures of the cash flows. The real option valuation would seem to provide a suitable overall framework for valuing the different kinds of uncertainty structures.

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6 Summary

The research problem of this thesis was expressed in terms of the question: *How could the real option valuation be applied for the valuation of technological competencies in general and for the valuation of new, technology-based companies in acquisition situations.* Based on the research problem formulation, four objectives were formulated

1 to create an overview of the real option valuation literature and the methodological state of development of the real option valuation

2 to assess the applicability of the option valuation methods for valuing technological competencies in general and new, technology-based companies in acquisition situations

3 to assess the applicability of the compound option valuation for valuing investments into the development of absorptive capacity

4 to identify value drivers affecting the valuation of new technology-based companies in acquisition situations and, in general, to develop the existing knowledge concerning the use of option valuation in the valuation of technological competencies

The four papers presented in this thesis aim at fulfilling the four objectives. The papers provide four different ways to approach the real option valuation of technological competencies and the valuation of new, technology-based companies in company acquisition situations, figure 6.1.

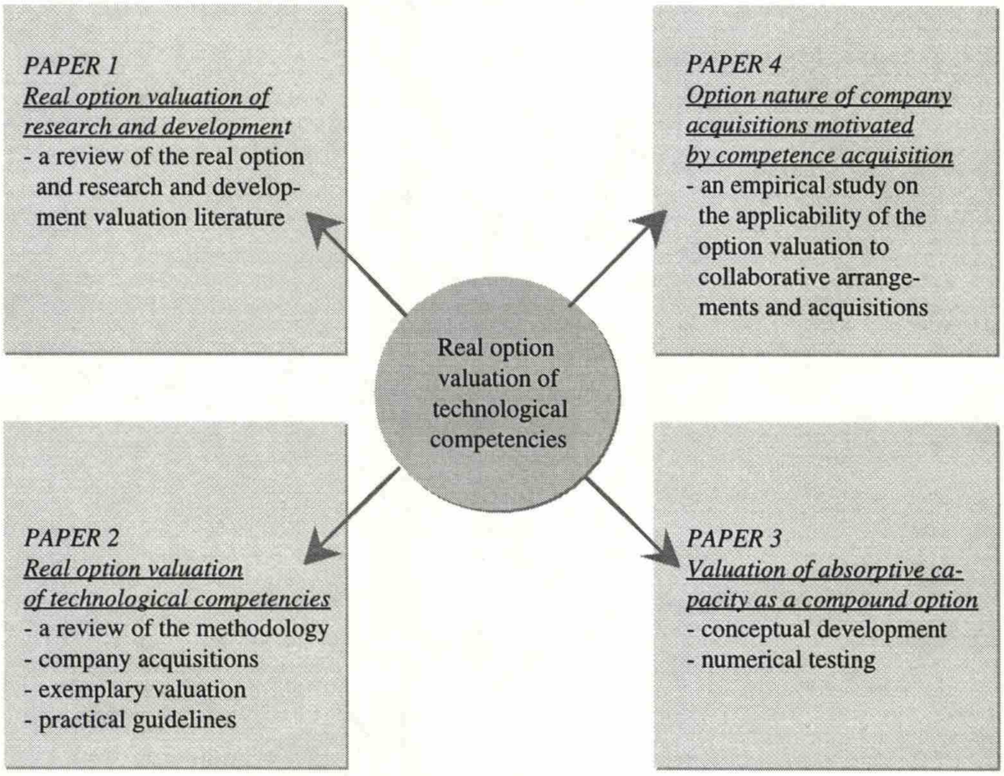

Figure 6.1 Four different ways to approach the use of real options in the valuation of technological competencies

The first paper aims at fulfilling partly the first objective and the second objective by reviewing the literature on real option valuation in general and on valuation of research and development in particular. To summarize, the main findings pointed out in the first paper are

- in contrast to Mitchell and Hamilton, the valuation of competence and knowledge building is proposed to be carried out using the option valuation. With the present focus in the strategic management literature, the competence building is seen to be part of strategic positioning. Competence building can be seen to correspond to compound option valuation
- the increases in uncertainty in the cash inflows and cash outflows both increase and decrease the resulting option values depending on the relative magnitude of the opposite changes
- understanding the uncertainty affecting the underlying asset is crucial for the use of real option valuation in the research and development valuation. For this reason, it is particularly necessary to understand the drivers of uncertainty of the underlying asset
- option valuation can be applied for the valuation of absorptive capacity, competence building, and competence leverage. Absorptive capacity and competence building could best be valued as compound options, competence leverage typically involves less uncertainty and could be valued directly using the discounted cash flow methods
- the differing uncertainties in the costs and revenues could be taken into account with the use of different discount rates. This is necessary also in connection with the real option valuation of research and development. The determination of the initial values for the option valuation requires discounting cash inflows and cash outflows
- the option valuation equations implicitly assume constant volatility in the underlying asset value. This is not a valid assumption in research and development valuation. The decrease in uncertainty over time should be taken into account in the option valuation

The second paper expands the first paper methodologically by looking at the option valuation methodology more in depth. The second paper provides the methodological dimension of the first and the second objective of this thesis. In the second paper, it is concluded that the real option valuation methods can be used to avoid some of the major pitfalls in the traditional valuation of competencies. Both the value drivers and the methodological opportunities provided by the option valuation could be combined in a holistic valuation. For example, in an exemplary competence valuation case, the growth option value, the discrete uncertainties, the differing risks in cash inflows and cash outflows, and the changes in the discount rates according to the changes in the underlying asset volatilities were taken into account. The option values were calculated for different underlying asset volatilities. Both the Black and Scholes model and the binomial model were shown to apply to the exemplary problem. The problem of which uncertainty measure to use did not emerge. It is important to note that when the uncertainty decreases over time, the average uncertainty has to be used as an input in the valuation. It would seem that when using the real option valuation, the valuation framework should always be tailored for the practical valuation problem at hand.

According to the second paper, the principles of option valuation would seem to apply well to competence valuation as a philosophical approach. Care should be taken, however, that the option valuation is not used to justify investments too easily. The example, presented in the second paper, demonstrates how otherwise positive option value can under more complex assumptions become less positive. An important factor affecting the valuation is the interaction between the discount rate and the underlying asset volatility. Higher discount rates correspond to higher uncertainties and lower net present values. On the other hand, higher uncertainties correspond to higher option values. The sum of the option value and the net present value is situation-specific and would seem to determine the value creation from an investment.

A careful analysis and treatment of the underlying uncertainty would seem to provide a key to a more detailed analysis of the option values. Attention should be paid both to the volatility of the underlying asset estimates and the discrete uncertainty inherent in the competence investment projects. A sufficient understanding of these could be achieved only through a detailed analysis of the industry and company-specific drivers affecting the underlying asset volatility and the investment success probabilities. There are clearly factors that affect the investment success probabilities. More attention should be focused on combining the qualitative factors affecting the success into the success probabilities, asset value volatility estimates and eventually to valuation.

According to the third paper, the absorptive capacities of the acquiring companies can be regarded as option platforms. Developing absorptive capacity through competence development makes it possible for the acquiring companies to identify and to successfully utilize external technological competencies possessed by other companies. On the one hand, the absorptive capacity creates and option to acquire companies and new business areas. On the other hand, the absorptive capacity can increase the success probability of the acquisitions and that way affect the valuation directly. In essence, the third paper is proposing a dynamic view of absorptive capacity as a strategic capability to acquire competencies that possibly emerge in the future. The development of this kind of strategic capability could be valued as a compound option.

The expansion of the concept of absorptive capacity is in harmony with the path-dependent nature of technological development. There can be seen to be a path of competence development initiatives or compound options leading from one to another. Earlier investments spawn new investments on a competence development path. Valuation of each individual competence investment is important, but the companies should note that through the investments they are selecting the paths of competence development which they are to pursue in the future. A negative net present value created by some investment on a suitable competence development path may be much better than ending up in a situation where the company has to discontinue the path that it has followed and start investing into a new competence development path. The compound option perspective would seem to be applicable for the valuation of these less deterministic consequences of competence development. The valuation of absorptive capacity as a compound option implies that the value of the absorptive capacity changes as a function of volatility. Volatility and uncertainty seem to play important roles in the valuation of absorptive capacity.

The fourth paper contributes to the second and to the fourth objective. It presents an empirical study on the option nature of new, technology-based company acquisitions. It also contributes to the identification of value drivers of the new, technology-based company acquisitions. The core findings of the fourth paper include

- New, technology-based company acquisitions could be seen more as option acquisition than option exercise. An analysis of the previous equity and non-equity collaboration shows that in only ten new, technology-based company acquisition cases, the previous collaboration was initiated with the purpose to get an option to acquire the collaborative partner.
- Contrasting to collaborative arrangements, the option analogy would seem to be more relevant in the actual new, technology-based company acquisitions. Altogether 58 of the 111 new, technology-based company acquisitions were found to contain explicit option elements. This would seem to favor the use of real option valuation methods in the valuation of technology-motivated acquisitions.
- Using the logistic multiple regression analysis to analyze the variables contributing to the option nature of the acquisitions, four variables stand out. These variables are the age of the acquired company, the maturity of the acquired competencies, the research and development intensity of the acquiring company, and the patentability of the acquired competencies. The achieved level of explanation with these four variables is 75.7 %.
- The patentability of the acquired competencies correlates with the option nature of the acquisitions. The option nature of the acquisitions seems to coincide with high appropriability and lack of competition. According to Kester's classification (Kester, 1984), it is more optimal to defer the exercise of this kind of options than to exercise them early. The option to defer can be seen to create additional value when combined with the growth option.
- From logistic multiple regression analysis, three variables stand out to explain the realization of the option upside in the sample of 58 option acquisitions. These variables are: the relatedness of the acquiring and the acquired company, the industry trend after the acquisition, and the proactive sales motive of the seller. The achieved level of explanation with the three variables is 84.3 %.
- The relatedness would seem to be the strongest predictor of the acquisition upside. The importance of relatedness would seem to support the resource-based view. According to the resource-based view, a related use of specialized resources provides the highest rent for the resources. The markets for the acquisition of new, technology-based companies and technological competencies in general cannot be regarded efficient and competitive. For that reason, even higher value creation potential can be achieved in connection with the new, technology-based companies by acquiring related technological competencies.

Finally, all the four papers jointly contribute to the second part of the fourth objective. The papers develop the existing knowledge concerning the use of real option valuation in the valuation of technological competencies.

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