Valuation of Generation Assets
- a Real Option Approach

by

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Kopiering fra denne bok skal kun finne sted på institusjoner som har inngått avtale med Kopi-Nor og kun innenfor de rammer som er oppgitt i avtalen.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

The field of valuation is a comprehensive and difficult discipline in business analysis. Valuation can be called a methodology within finance (Koller, Goedhart, & Wessels, 2005), but it is also a key property of accounting reporting. Both aspects are elaborated on in this thesis in order to study value issues related to the Norwegian generating industry.

Real option valuation represents a relatively new approach to valuing assets and companies. The concept of real options is an extension of financial options applied to real projects and business valuation. During the 1970s more and more research was conducted on derivative securities like options and futures. As a financial instrument with a payoff depending on the value of other securities, these became tools for both hedging and speculation. This lead to the famous milestones of option pricing theory written by Black & Scholes (1973), Merton (1973) and Cox, Ross, & Rubinstein (1979). Their techniques leant on the concept of pricing securities by arbitrage methods.

Even if option pricing techniques were initially viewed as a rather arcane and specialized financial instrument, the researchers behind this development recognized early on the potential for applying the same type of approach to a variety of other valuation problems (Merton, 1998). Myers introduced the term "real options in 1977 (Myers, 1977). During the last thirty years much research has been carried out in the field of applying option pricing theory to valuing real assets (Amram & Kulatilaka, 1999; Antikarov & Copeland, 2003; Dixit & Pindyck, 1994; Mun, 2002; Schwartz & Trigeorgis, 2001; Trigeorgis, 1996; Trigeorgis, 1999).

1.1.1 The Advantages of a Real Option Approach in Valuation

Two crucial aspects in valuation are the estimation of an expected growth of future cash flows (or dividend or residual income) and the estimation of the capital cost. Both aspects significantly influence value estimates.

Estimating the capital cost is not an exact field of business research (Gjesdal & Johnsen, 1999). Normally, the capital cost is calculated by the capital asset pricing model (CAPM). However, controversy does exist as regards implementing this model, as e.g. elaborated by Fama & French (1992). Some real option applications make it possible to use risk neutral approaches (Ronn, 2002; Schwartz & Trigeorgis, 2001). Hence, being able to relate to the risk free rate weights heavily in favour of real option analyses. This point is further commented on concerning the analysis of investment opportunities presented in Chapter 5.

Traditional valuation models normally assume an expected growth in the cash flows/dividends/residual income. Such approaches also normally consist of a terminal value estimate. Conventional value estimates are hence very sensitive to the estimate of the expected growth. A small change in expected growth can lead to a significant change in the value estimate, especially the terminal value estimate. One should also bear in mind that it is extremely difficult to estimate expected growth satisfactorily. It is very hard to interpret the continuous streams of new economic information and transform them into changes in expected growth. Therefore, some researchers do question the hypothesis of full market efficiency (Copeland & Weston, 1992; Kinserdal, 2006; Kothari, 2001).

This severe problem regarding traditional valuation also provides a strong argument in favour of choosing a real option approach when analyzing the value of generating companies. Real option calculations are more transparent and reveal transparent information concerning the value components in a total value estimate -

while not to the same extent depending on expected growth. In a real option valuation it is also easier to discuss the assumptions of the value estimates beyond the value of assets-in-place. Traditional valuation, through which expected growth in cash flows or dividends is hard to estimate, may not necessarily capture the value of future possibilities and may also overestimate them. It is far from obvious that a real option approach yields higher value than traditional net present value calculations, but real option valuation is more transparent and provides better insight into value components.

Real options also describe reality and behaviour concerning economical decisions in a better way than the traditional neo-classical approaches. Chapter 5 is an example of how real option thinking captures the level of investments in Norwegian hydropower beyond what a NPV/DCF approach is able to do. The main analysis in Chapter 4 also shows that real options explain the value of generating companies beyond that captured by earnings within a traditional valuation framework. So, the ability to explain economic behaviour, such as aggregate investments, is a strong aspect of the real option concept that should be documented by further research (Bulan, 2005; Kulatilaka, 1993; Pindyck, 1991).

Nevertheless, some factors do limit the usefulness of real option approaches, both as regards use by firms and also research. These obstacles are not always handled well by advocates of real options. These disadvantages are related to the complexity in the assumptions concerning the underlying asset and replication, the uncertainty in different input parameters in many real option analyses and the need for competence in stochastic calculus for performing and understanding an analysis. These factors, and others, are commented on several times throughout the thesis, and are especially discussed in Chapter 3.

Therefore a kind of trade off also comes into play for users of valuation. On the one hand useful information can be captured by using a real option analysis, but on the other hand a number of complex assumptions are in need of assessment. Hence, real option calculations are both complicated to perform and remain uncertain, due to the difficulty of obtaining input parameters. This also makes it difficult to communicate real option analyses for decision makers. Consequently one can well understand why several people ignore the real option tool, and stick to more traditional valuation approaches - despite their shortcomings. The surveys conducted and reported in Chapter 3 indicate that U.S. firms, to a larger extent than European firms, have regarded the information provided by real option valuation as being too complicated to obtain, compared to the benefits of such calculations.

1.1.2 Real Options and Accounting Disclosure

An interesting upcoming discussion in the field of capital market based accounting research (CMBAR) concerns the relationship of real options and accounting disclosure (Chen, Conover, & Kensinger, 2005). However, to incorporate real option values in accounting standards seem unrealistic. As commented on above, the values of possessing real options are difficult to measure, and in contradiction to traditional accounting principles, such as the principle of conservatism in value estimation.

Nevertheless, valuation is a core property of accounting. The disclosure of the presence of real options is value relevant. One field within CMBAR concerns research regarding the economic consequences of increased disclosure in financial reporting. Some studies support the idea that the increased level of disclosure reduces information asymmetries thereby lowering the firms cost of capital - which is directly relevant for value estimates (Lang & Lundholm, 1996; Leuz & Verrecchia, 2000). This provides an incentive for voluntary disclosure of the relevant real options to a firm, and is an aspect for further studies and investigation concerning future norms for accounting disclosure. The analyses in this thesis represent an argument for disclosure of real options in accounting reporting.

This thesis has investigated real option aspects related to the Norwegian generation industry. Improvements and extensions of existing plants and new investment projects are highly value relevant, and would increase the relevance for users wanting to assess the value of a generation company. As commented on several times in this thesis, such information is more transparent and easier to discuss compared to a less precise estimate on expected growth in cash flows or dividends. However, such information should be qualitative and tentative without including the calculation of option values dependent on too many uncertain factors. These recommendations can be found in Chapter 3.

1.2 THE RESEARCH PROBLEM OF THE THESIS

The purpose of this thesis is, through the myopic perspective of real option theory, to study and value generation assets. This is applied to the context of the Norwegian generation industry, in which companies are mainly hydropower generators. This industry is complex. Hence, it comes as no surprise that little research has been carried out in this field. Nevertheless, by applying the real option concept, this thesis provides deeper insight into valuation aspects of generation assets, generating companies and the Norwegian power system. The thesis also contributes to the literature on real option applications.

Other value relevant factors, such as operational management and financial hedging strategies, are deemed outside the scope of this study.

To summarize, the following overall research question for the thesis can be defined:

> **How can real options explain and provide a better understanding of the value of generation assets and generation companies?**

Chapters 4 - 6 show empirical analyses of hydropower generation. Empirical evidence of the explanatory power of real options remains a rather immature part of real option research (Schwartz & Trigeorgis, 2001). Real options have mainly been recommended based on conceptual and theoretical research. The empirical findings in this thesis are thus of interest far outside the boundaries of this industry in one country. The evidence given in Chapter 4 and 5, confirming real options behaviour, do therefore provide a contribution.

The approaches presented in Chapters 4 - 6 are certainly not the most advanced in the field of real option valuation. Nevertheless, advantages do arise through omitting the most sophisticated models and sticking to simplified approaches that, without being too complicated, capture the value of flexibility. This choice avoids comprehensive discussions as to whether strict assumptions are met or not in the analyses. This aspect is especially elaborated on in Chapter 3, but is also discussed in Chapter 5 and 6.

Some properties of the generation industry meet the requirements for making a real option approach especially useful. The generation industry has dynamic characteristics and is exposed to risk; there is an efficient market for trading electricity (Nord Pool), with both a spot and forward/future market. Electricity makes up then an obvious underlying asset for various real options.

This all resulted in some different perspectives of valuation issues related to this industry, as presented in this thesis. The analyses performed (Chapters 4-6) will provide more insight into the complex topic of valuation in the complex industry of electricity generation.

1.3 THE GENERATION INDUSTRY OF NORWAY

The real option approach for valuation is applied to one specific industry in the Norwegian context; the electricity generation industry. This industry is of great importance in Norway. The value of the assets in the industry was estimated at NOK 400 bn (EUR 50 bn) in 2004 (Sande & Thomson, 2004), and considerably more in 2007. The oil and gas industry alone controls higher values.

Norwegian electricity generation is almost entirely hydro based; 99 % by 2006 (The Ministry of Petroleum and Energy, 2006). Norway is the 6th largest hydroelectric generator in the world[1] (NVE, 2003), and together with Iceland, the country with the relatively largest portion of hydroelectric energy (NVE, 2007). The hydro based system with mainly hydro based operators has some significant implications that are discussed throughout the thesis.

[1] Behind Canada, Brazil, U. S., China and Russia

The main background factor for analyzing the electricity industry in Norway is the Energy Act of 1990[2]. The Norwegian Government implemented this Act in order to make electricity markets more competitive (Al-Sunaidy and Green, 2005). Norway is considered one of the pioneers with regard to the restructuring of the electricity market. The purpose of the new law was to secure that production, transmission, distribution and sale of electricity took place in an economically rational way. This opened up for a profound restructuring of the industry, included the establishment of the Nordic power exchange Nord Pool[3]. This market is organised to satisfy a number of participants with comprehensive trading of futures, forwards and options. Hence, the time frame of all the analyses in this thesis is related to the post deregulation period, 1991 to 2007.

The Norwegian Water Resources and Energy Directorate (NVE) regulates the industry. NVE is subordinated to the Ministry of Petroleum and Energy, and is responsible for the administration of Norway's water and energy resources. The increase in electricity prices (see Chapter 4, 5 and 6) has lead to considerable increase in licence applications to NVE for small scale hydropower plants, as illustrated in Figure 1.1.

[2] The Energy Act (short form) of "Law of production, transformation, transmission, sale, distribution and use etc." of 29th June 1990 No. 50. The Act was implemented 1st January 1991.

[3] An electricity pool was established which in 1996 was extended to incorporate Sweden in what was thereafter called Nord Pool, the world's first multi-national electricity market. Later on, Finland and Denmark have joined Nord Pool.

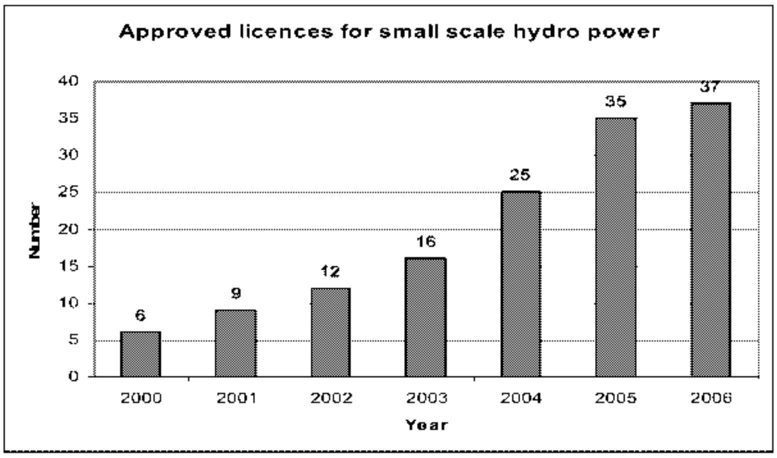

Figure 1.1: Approved licences from NVE concerning small scale hydro power generation.

The deregulation[4] also led to a separation of generation and transmission and opened up for mergers and acquisitions in the industry. Public ownership was no longer required. Electric utilities were prior to restructuring, controlled by public owners such as municipalities, counties and the state. The new situation brought about a market for buying and selling these electric utilities. Since deregulation of the energy sector in 1991, there have been over 430 transactions of the total or considerable parts of electricity producers, vertically integrated companies and transmission enterprises, involving both domestic and foreign private investors. All these transactions have included assessment of the value of the companies in-

[4] Or more precisely *re*regulation, since the transmission and distribution networks continued to be natural monopolies and were, and still are, regulated (Al-Sunaidy and Green, 2005).

volved, creating a need for qualified appraisals of business value. Almost all of these companies were unlisted, limiting the access to value relevant information and complicating business value calculations.

The deregulation of the industry implied an emerging new market for tradable electric utilities. From being publicly owned, the companies became of interest to private investors - as in other industries with competition. While transmission still was, and is, a monopoly, for obvious reasons, real competition in generation and supply came into being. The majority of the production capacity is still publicly owned. The dominant state owned company Statkraft SF owns 35 %, municipalities and counties own approximately 55 % and private investors 10 % according to EBL (2006). By 2003 more than 21 % of the hydro power plants were owned by private investors and of 346 hydro power plants 63 were partially, and 74 fully privately owned.

The deregulation of the hydropower dominated system (Norwegian and Nordic) has made electricity prices extremely volatile. Electricity prices have in this context some special dynamic characteristics that must be discussed in some depth in several of the chapters in this thesis. It is certainly true to say that calculating the value of generating assets and generation companies is a complex and challenging task.

The Energy Act has not so far passed the test of providing the right incentives for investments in more generation capacity. Consensus appears to exist that Norway will need to consider substantial additions to its generating capacity over the next years (The Ministry of Petroleum and Energy, 2006). International connections may play a role, but constraints on transmission and hesitance in long-term commitments by participants, question the viability of such solutions. The government has announced general limits to new large-scale hydropower projects. Gas-fired thermal generation plants are being built, but further thermal generation, (gas-fired, coal-fired or nuclear) seems highly uncertain. Wind generation is also a supply option, but also presents problems associated to profitability and the environment. As a result, electricity prices may rise to narrow the gap between supply and demand. Moreover, if the supply side is constrained as well as random, the result could be increasing price instability or even severely limited in "dry" years. These factors are underlying framework conditions for the analyses in Chapters 4 - 6. Some are further discussed as motivation in these chapters.

As stressed by Førsund (2005) any analysis of hydropower generation should take into consideration the dynamic characteristics of the industry. A key optimalization problem faced by operators will be when to make use of the water in the reservoirs. Any generation can alternatively be performed later when prices may be even higher. Hence, the concept of alternative cost becomes essential. Any realistic modelling of hydropower should therefore take into consideration the stochastic nature of the relevant variables. This is therefore implemented in the key analyses of both Chapters 4, 5 and 6.

The stochastic nature calls for a methodology to handle the uncertainty so prominent in this industry. One approach is stochastic dynamic programming (S-E. Fleten & Wallace, 2002). Another approach is the real option approach (Hlouskova, Kossmeier, Obersteiner, & Schnabl, 2005). Real options, as a technique to capture the value of flexibility in an uncertain environment, become extremely relevant for this industry. Nevertheless, there are few studies of the Norwegian electricity industry in light of real option theory, with some notable exceptions mainly related to plant level studies (Botterud, 2003; Bøckman, Fleten, Juliussen, Langhammer, & Revdal, 2008; S.-E. Fleten, Maribu, & Wangensteen, 2007). Real option analyses of generating *companies* are non-existent, making the analysis performed in Chapter 6 particularly interesting. This chapter presents unique data for a valuation analysis. However, the thesis fits in with the tradition of applying real options in the energy sector (Ronn, 2002; Schwartz & Trigeorgis, 2001).

The complex taxation of the industry is mainly held outside the studies presented. However, in Chapter 4, information and comments are provided concerning taxation, while this aspect is ignored in the analyses conducted in Chapters 5 and 6.

1.4 THESIS STRUCTURE AND OUTLINE

The structure of the thesis and the interaction between the papers or chapters is illustrated in Figure 1.2. A summary of the key references and the key findings of Chapter 5 - 8 are shown in Table 1.1.

Chapter 3 presents a somewhat different type of study to those handled in Chapters 4, 5 and 6. This chapter provides a general discussion and study of the real option tool and looks into why this technique only to a very limited extent has been adopted by firms. It is a qualitative study of the general use of the real option technique in capital budgeting and valuation issues. The chapter also provides some recommendations to practitioners. The three other papers are quantitative analyses of value aspects in the industry. Chapter 4 consists of the main analysis of the thesis, where the pricing of companies, or parts of companies, in the generation industry after the deregulation in 1991, is analysed in the light of real option theory. Chapter 5 and 6 elaborate two types of real options relevant in the industry; growth options and switching options. Chapter 5 is a valuation study of investment opportunities in hydropower and of the optimal trigger price for initiating an investment. Finally, chapter 6, presents an analysis of the switching option values of a mainly hydropower based operator restricted by long term industry contracts when thermal generation is supplemented.

1.4.1 Chapter 2: Theoretical Foundation and Methodology

The chapter provides a brief positioning of real option valuation within the traditions of the comprehensive discipline of business and asset valuation. The chapter also presents a discussion of the methodological aspects of the thesis, the empirical material as well as an assessment of the chosen research designs.

1.4.2 Chapter 3 (paper 1): The Use, Abuse and Lack of Use of Real Options

Real options have for almost three decades existed as a prominent feature of capital budgeting. The technique of incorporating the value of flexibility in project and business evaluation by applying tools from financial option valuation has been widely accepted and applied as an innovation within the academy.

Nevertheless, surveys show that in business practice, the real option approach is only used in a limited way when assessing project and business values. Few firms have followed the academic recommendations to use this technique. How can this paradox be explained? This paper summarizes the current status of real option application and further discusses this issue by taking into consideration institutional theory. Moreover, by illustrating the use of real options in the Norwegian generation industry, the paper suggests when and how real options are relevant, and also when obvious limitations exist regarding the relevance of this valuation technique.

Table 1.1: Selection of key references for the different chapters as well as the main contribution from the studies.

Chapter	Topic / Short title	Key references with key words	Contribution
3	The Use, Abuse and Lack of Use of Real Options	• Graham & Harvey (2001) – Survey of the use of capital budgeting techniques among U.S. firms. • Brounen, de Jong, & Koedijk (2004) – Survey of the use of capital budgeting techniques among European firms.	• Explanations, rooted in different scientific paradigms, concerning the limited use of real options in business practices. • Recommendation about when and how to use real options in valuation and capital budgeting.
4	Explaining the Value of Electric Utilities	• Frankel & Lee (1998) – The use of residual income valuation (Feltham & Ohlson, 1995). • Beaver, Eger, Ryan, & Wolfson (1989) – Incremental explanation of value by additional disclosure.	• Real options contribute to explaining and understanding the value of electric utilities involved in transactions after deregulation.
5	Investment Opportunities – Value and Optimal Timing	• Dixit & Pindyck (1994) – Real option model framework that enables the calculation of the value of investment opportunities as well as optimal trigger price for the timing of an investment	• Demonstration of an alternative approach to calculating the value of hydropower investment opportunities. • Consistency between real option theory and aggregate investment behaviour.
6	The Value of Operational Flexibility – Adding Thermal to Hydro	• Kulatilaka (1988) – Model framework to calculate switching option values.	• Quantification of the switching option value when introducing thermal generation for a mainly hydro based operator restricted by long term industry contracts.

1.4.3 Chapter 4 (paper 2): Explaining the Value of Electric Utilities by Real Options – An Application to Norway

Since deregulation of the energy market in Norway, there have been a number of mergers and acquisitions of electric utilities. (This involves companies operating in the fields of power generation, transmission, distribution and the sale of electricity). In all these transactions the companies have been valued. The value has often significantly exceeded the book value recorded through use of equity and traditional NPV/DCF valuation. This particularly applies to generating companies. How can this premium be explained? Real option theory is in this study applied in order to explain the difference between actual transaction value (market value) and the value based on traditional approach of expected earnings. The residual income model proposed by Feltham & Ohlson (1995) is considered.

The empirical analysis shows that an enhancement in explanatory power of 100 % is brought about through the introduction of independent variables based on real option theory. This supports the use of real options in helping to explain transaction values in this industry during the past decade.

1.4.4 Chapter 5 (paper 3): A Real Option Analysis of Investments in Hydropower – The Case of Norway

This paper presents a valuation study of hydropower investment opportunities in the Norwegian context. According to NVE (Norwegian Water Resources and Energy Directorate, the regulator) an energy potential of 39 TWh has not yet been developed (generation in a normal year is approximately 120 TWh).

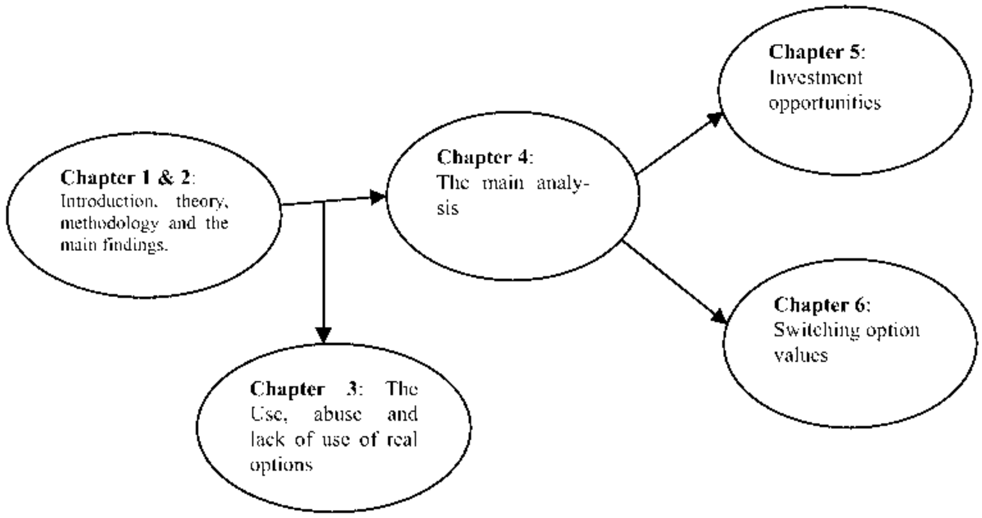

Figure 1.2: Illustration of the structure and interaction of the different parts of the thesis.

By using the conceptual real option framework suggested by Dixit & Pindyck (1994) one can estimate the value of investment opportunities to NOK 11 million/GWh (EUR 1.4 million/GWh). Furthermore, the optimal trigger price for initiating an investment based on electricity forward prices is calculated to NOK 0.32/kWh (EUR 0.04/kWh). The analysis shows consistency between real option theory and aggregate investment behaviour in Norwegian hydropower.

1.4.5 Chapter 6 (paper 4): The Value of Operational Flexibility by Adding Thermal to Hydropower – a Real Option Approach

This paper presents a valuation study of operational flexibility for a hydropower operator restricted by contracts to deliver a steady flow of electricity to the contract counterpart. The hydropower operator has the flexibility to deliver from own production of hydro-electric generation, or deliver by buying option contracts of electricity from thermal electricity producers. The option may be in the form of a call option, or may be an implicit option created by having a separate thermal electricity plant that can be switched on and off. Long term industry contracts can make some operators obligated to always generate at a certain minimum level. Such operators cannot save the water in the reservoirs for peak price periods if this action compromises their ability to deliver the contracted minimum. If thermal generation is added and controlled, flexibility is enhanced and hence more generation can be allowed in peak price periods.

To assess this value of operational flexibility the switching option model of Kulatilaka (1988) is applied. The numerical calculations, introducing nuclear, coal fired or gas fired generation, show an option value for a hydro operator also controlling thermal generation of NOK 65 / NOK 45 / NOK 13, respectively, per MWh yearly generation capacity.

1.5 SUMMARY AND KEY CONTRIBUTIONS

The following list summarizes the key findings and key contribution of this thesis:

- *Chapter 3*: The discussion contributes to the general discussion regarding the seldom use of real option by practitioners. The study offers explanations rooted in different scientific paradigms to explain the limited use of real options in business practices. In addition, the discussion provides recommendations concerning when and how a real option approach may prove beneficial for businesses in their capital budgeting and valuation analyses.

- *Chapter 4*: This chapter addresses the ambitious task of attempting to explain the value of generating companies in this complex industry. The models presented, based on unique data, provide insight into understanding value and value components of electric utilities. Despite some disputable factors, the results do support real options as contributing to value explanation. Hence, this empirical study contributes to the literature on real option applications.

- *Chapter 5*: The analysis demonstrates an approach for calculating the value of hydropower investment opportunities as well as optimal trigger price for initiating such an investment. The chapter provides evidence of consistency between real option theory and aggregate investment behaviour and offers a trustworthy level of the forward electricity price as trigger for an investment.

- *Chapter 6*: This study calculates the switching option values of operational flexibility gained when adding nuclear, coal fired and gas fired power plants to a mainly hydro based operator restricted by long term industry contracts. By switching to thermal in some parts of the year the operator is able to save more water in magazine reservoirs for peak price periods. The switching option value is highest for nuclear and lowest for gas fired thermal generation. If thermal capacity is rented from another operator the option value is depending on the agreed price. Hence, from the viewpoint of flexibility, the least profitable alternative is gas-fired thermal generation – paradoxically the only thermal generation actually implemented in the Norwegian power system. The study shows that option values may in some situations be significant and should be taken into consideration either 1) in assessment of own thermal investments, or 2) in negotiations with thermal operators of option contracts. The results can also to a certain extent be applied for justifying Governmental subsidies at system level.

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CHAPTER 2: THEORETICAL FOUNDATION AND METHODOLOGY

2.1 VALUATION

Valuation of both assets and companies is a difficult business. There are always a number of uncertain assumptions involved. Therefore, a number of different approaches and techniques do exist. These can yield a variety of value estimates based on various input assumptions that can also be of a subjective nature (Dahl, Hansen, Hoff, & Kinserdal, 1996). According to Damodaran (2007) too many valuation models make it hard to find the most suitable one for the case in hand.

In general, one can separate valuation models into *intrinsic*, *relative* and *option based* valuation (Damodaran, 2002; Koller, Goedhart, & Wessels, 2005; Soffer & Soffer, 2003). *Intrinsic valuation* is based on neo-classical net present valuation (NPV). Typical models are the dividend model and cash-flow model (DCF) or the accounting based super-profit model (Penman, 2001), the Economic Value Added model (EVA) (Stern Stewart, 1994) and the residual income model (RI) (Feltham & Ohlson, 1995). These models should in principle yield the same results when applied consistently with the same assumptions (Fernández, 2003; Gjesdal & Johnsen, 1999). The RI model is considered in Chapter 4.

Relative valuation is fairly easy to apply and hence popular among consultants and practitioners (Damodaran, 2002). By using multiplicatives one can make comparisons between companies (Price/Book, Price/Earnings, Price/Sale) (Bhoraj & Lee, 2002; Dyrnes, 2004). However, this approach is not considered in this thesis because of the theoretical shortcomings. Nevertheless, as regards the valuation of generation assets, the industry norm is to measure value per kWh yearly capacity.

Normal value typically ranges from NOK 2.00 to NOK 2.50/kWh average yearly generation capacity. This represents a kind of relative valuation which is commented on and calculated as a part of the main analysis in Chapter 4.

Option based valuation is often considered as the third approach to business valuation (Koller et al., 2005). The value of a company can be considered according to the sum of the following three components (Rødland, 2004):

1. The value of existing operations (with yearly production and cash flow).
2. The value of already decided developments.
3. The value of investment opportunities.

The third component concerns the value of one or several real options. Hence, option pricing can be used for quantifying e.g. future possibilities or the value of possessing operational flexibility. This value of flexibility has been acknowledged by researchers as well as practitioners as an essential part of valuation. Traditional, neo-classical valuation approaches, neglect this important aspect and can therefore fail to incorporate a substantial part of business value.

2.2 REAL OPTIONS

Real options, as a part of business valuation, are legitimate as tools for handling and quantifying *flexibility*. This holds relevance because the future will always remain uncertain. As new information is revealed, management can adjust and respond to this new information. The value of flexibility, in for instance gauging growth opportunities, is incorporated in a real option analysis. A number of scientists have criticized traditional NPV/DCF analysis for ignoring flexibility (Berkovitch & Israel, 2004; Brennan & Schwartz, 1986; Kulatilaka, 1993; Mun, 2002; Myers, 1987). DCF techniques were conventionally developed to value "passive" financial instruments such as bonds and stocks (Trigeorgis, 1996). Some call NPV/DCF a "naive rule" (Milne & Whalley, 2000) when applied to project and business valuation. Ross (1995) even says that "optionality is ubiquitous and unavoidable" concerning valuation issues, and thereby indicates that options should always be included in valuation.

The above factors lead to an extension of the classical NPV rool as proposed by Trigeorgis (1993b):

Expanded (strategic) NPV = static (passive) NPV of expected cash flows
+ value of options from active management

This option component has lead to the elaboration of different types of real options such as (this is by no means a complete list as compared to that found in different textbooks on the topic, but represents the most considered and relevant real options):

Growth options

The value of a company exceeds the market value of the assets currently in place because the firm may have the opportunity to undertake positive NPV projects in the future. Standard capital budgeting techniques involve establishing the present value of these projects based on anticipated implementation dates. However, this implicitly assumes that the firm is committed to going ahead with the projects. Since management does not need to make such a commitment, they retain the option to implement purely those projects appearing profitable at the time of initiation. The value of these options should be considered when valuing the firm (Kester, 1984). The growth potential of investment and expansion opportunities is central in Chapter 4 of this thesis.

Option to expand / option to contract

If an investment turns out positive, this can lead to an upscaling which represents value. An initial investment serves as an entrance to incremental upgrading when more information is revealed. Correspondingly, many projects can be designed in a way that output can be contracted in the future.

Option to defer

To be able to postpone an investment before final commitment also represents value for an investor (Dixit & Pindyck, 1994; Ingesoll & Ross, 1992; McDonald & Siegel, 1986). When the environment is uncertain and prices, in particular, are volatile, this kind of option must be considered. The option to defer, and hence to choose when to start a project is central in the analysis performed in Chapter 5.

Option to switch

Having the ability to switch between different input factors, for instance when prices are volatile (e.g. gas versus oil), provides a switching opportunity which in turn represents genuine value. A switching option enables operating in two or several modes. A considerable amount of literature exists on the subject of elaborating this type of real options (Antikarov & Copeland, 2003; Kogut & Kulatilaka, 1994; Kulatilaka, 1993; Kulatilaka & Trigeorgis, 1994). Switching option values is the main focus of the analysis conducted in Chapter 6.

Option to abandon

A company often has the option to close down a project during its life. This option is known as an abandonment option. Abandonment options, which are the right to sell the cash flows over the remainder of the project's life for some salvage value, resemble American put options. If the market value of the project is lower than the value of the invested assets, this would be a put option with an exercise price equal to the value of the sold assets. This real option variant is elaborated on by Myers & Majd (1990).

This option type is relevant in relation to the establishment of wind mill parks. In contrast to a hydropower plant, a wind mill plant is not an irreversible investment and can be decoupled in the future if, for some reason, this is deemed desirable. The equipment can still be used or sold and hence represents a value. This issue is not though investigated in any depth in this thesis.

Compound options

Compound options refer to an option on options, like sequential growth opportunities. The value of compound options is studied by e.g. Geske (1979).

Multiple interacting options

There is often an interaction of several real options both in project as well as business valuation. This complicates an option based valuation analysis. As profoundly discussed by Trigeorgis, (1993a) different real options are seldom additive. This complicates real option valuation. In this thesis however, no problem exists with interacting option components, as shown and discussed in Chapters 4-6.

All these option variations can be associated with the value of flexibility. The variety of types also illustrates how general option values can be applied, and thus shows the importance in any valuation (Ross, 1995).

2.3 VALUATION OF REAL OPTIONS

There are basically four techniques for valuing real options, which are appropriate mentioning in this introduction (Sick & Gamba, 2007 forthcoming). Each approach has its advantages and disadvantages which are briefly commented on. A feature is that many simple option valuation formulas are designed for European options, whereas most real options are in fact of the American type.

1. Closed form analytical solution includes the famous Black & Scholes formula (1973). But even if it is desirable to generate analytical solutions for real option issues, it is usually hard to meet the requirements and assumptions. Nevertheless, the approach in Chapter 5 includes both a brief discussion and an application of a model yielding an analytical solution (Dixit & Pindyck, 1994).
2. Numerical solutions to partial differential equations (PDEs). This approach is relatively widely used within the academy. Software tools are also available in order to operationalize and value real options. This methodology is not though further mentioned or applied in this thesis.
3. Lattice, binomial tree (Cox, Ross, & Rubinstein, 1979). This is a simple approach, but very useful in communicating real option values. The main limitation is that only one risk driver may be included in order not to make the lattice too complicated. This approach is discussed and used in Chapter 6.
4. Simulation models (e.g. Monte Carlo). This approach is also widely used in academic circles, and is more advanced in coping with several risk drivers (Mun, 2003). However, no simulation is performed in this thesis.

The above shows that there is an abundance of approaches to real option valuation. This is also one of the reasons for there being somewhat of a mismatch between academic circles and practitioners – a subject further discussed in Chapter 3. These techniques can be viewed as compatible, but the choice of valuation approach in any given situation depends on the business concerned, the purpose of valuation etc. As further discussed in Chapter 3, it is not always possible to capture reasonable calculated estimations of real option values. Hence a qualitative approach remains the only fruitful way of applying the real option concept.

2.4 METHODOLOGY

This part of the chapter addresses the methodological foundation for the thesis and accounts for the empirical data used in the analyses. The research design is descriptive, causal and normative. The thesis is mainly based on secondary data with subsequent quantitative analyzing techniques. The exception is Chapter 3 (paper 1) in which use is made of some primary data and a literature review.

This chapter starts with a brief discussion of real options and the philosophy of science. Then the applied statistical and econometric methods are briefly accounted for and assessed. This is followed by a discussion of the primary and secondary data and the unit of the analyses.

2.5 REAL OPTIONS AND PHILOSOPHY OF SCIENCE

A discussion of the real option concept is presented here in the light of the philosophy of science. This clarifies and defines the fundamental assumption concerning this relatively new approach for valuation issues. Real options have been termed a "new paradigm" and "revolution" (Antikarov & Copeland, 2003; Schwartz & Trigeorgis, 2001). Hence, one can ask: is such terminology suitable and appropriate or is it too bombastic?

Research within finance and investments are traditionally mainly positivistic or post-positivistic. No great tradition exists for the discussion of aspects concerning the philosophy of science. The research is often based on rationality, testing hypotheses and searching for causality. However, there has been an emerging trend known as behavioural finance which challenges the traditional approach for research within this discipline. Within accounting and management accounting considerably more research has been done with coming awareness of revealing knowledge based on a phenomenological approach (Burrell & Morgan, 1979; Hopper & Powell, 1985; Husserl, 1946; Miller, 1994).

Valuation has for a long time been dominated by NPV and/or DCF analysis. These techniques have for decades been advocated and recommended within business education and finance research. The introduction of the option approach therefore represented something new and different when introduced in the late 1970's. By including option values, one was able to measure the value of flexibility thereby providing a better foundation for business decisions.

Nevertheless, to use the phrase "new paradigm" or "revolution" is to be too bombastic. The term paradigm of studies refers to the American philosopher Thomas Kuhn (1961). And even if he was not consistent in his use of the concept[1], his main point was that a paradigm is a set of models, techniques and approaches within a research discipline. Through so called "scientific revolutions" one could achieve remarkable breakthroughs and lift a research discipline to another level; another paradigm.

However, these characteristics do not fit in with the introduction of real options. Real options represent an innovation and development of valuation procedures. But one still operates within the frame of NPV valuation as seen by the equation above

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[1] According" to Masterman (1970) Kuhn uses the term "paradigm" in 21 different ways in "The Structure of Scientific Revolutions".

(page 19) conceived by Trigeorgis (1993b). Option values have always existed and have been known intuitively, but the real options approach makes it easier to quantify and measure the value of flexibility. A real option valuation does not therefore replace traditional valuation, but it is a useful supplement and extension in a number of situations (Damodaran, 1999b; Kemna, 1993; MacMillan & van Putten, 2004).

Kuhn also classifies the different disciplines of science to operate in a prenormal versus a normal scientific phase. Research within finance and valuation should be considered to be operating in a normal scientific phase because a set of standards and norms exist about how to perform research in these areas.

The research tradition within quantitative analysis in finance, such as valuation, is therefore more related to the natural sciences and can be termed as operating in a normal scientific phase based on a positivistic heritage. There is no crisis within the research discipline, and therefore the real option approach is just an innovation to deepen and improve the already accumulated knowledge of valuation. Hence, to call real options a "new paradigm" and "revolution" is to be too enthusiastic and bombastic. Real options fit more into the term "revolution in permanence" as used by Popper (Easterby-Smith, Thorpe, & Lowe, 1991). Nevertheless, real options should always be included in valuation analysis (Ross, 1995), and when and how will be further discussed and commented on in Chapter 3.

Except for some aspects discussed in chapter 3, this thesis is therefore mainly founded on and follows the mainstream positivistic or more precisely post-positivistic tradition of finance research. But furthermore, the thesis can also be referred to as instrumental and normative. Real options are recommended as an instrument for calculating better value estimates. The lack of use of this approach is criticised, so by incorporating real option aspects, the thesis gives suggestions in how to improve decisions and valuation procedures.

I do not though abandon the idea that other platforms relating to the philosophy of science can shed light over research questions in finance (Elster, 1989). There is a tendency to operate in only one scientific paradigm. This can limit the possibility of revealing new knowledge as pointed out by e.g. Ittner & Larcker (2001) – in this case concerning management accounting. This thesis represents a modest contribution with regard to including alternative perspectives on the research questions discussed. Nevertheless, the major parts are rooted in a post-positivistic, traditional approach of finance and accounting research.

2.6 RESEARCH DESIGN

The thesis is characterized by causal design with regard to Chapter 4 (paper 2) and considerable parts of Chapter 5 (paper 3) and 6 (paper 4). Chapter 4 aims to explain the value of generating companies. In Chapter 5 there is an explanation of the low level of hydropower investments during the recent decade, while Chapter 6 includes an explanation of the forward-spot spread of some electricity prices on Nord Pool. Chapter 5 and the first part of Chapter 6 also has a descriptive nature in its research approach; Chapter 5 concerning the value of investment opportunities in hydropower, and Chapter 6 regarding switching option values when several generating technologies are involved. Chapter 3 (paper 1) is of a somewhat different nature and can be better considered as an explorative study. It discusses why real options are not more widely used by firms, and how real options should be used to give the most benefit for managers and owners. There is a normative aspect in Chapter 4 in the assessment of the value of generation assets.

Other methodological aspects such as research approach, the data and unit of analysis are summarized in Table 2.1. As the table shows this thesis represents a broader methodological approach compared to traditional finance and valuation research.

The analysis performed in Chapters 4 - 6 are all based on famous models in the valuation and real option literature. In Chapter 4 the residual income valuation model of Feltham & Ohlson (1995) is considered. To use this model in valuation does not present big problems, as there is a considerable tradition of using this model in many applications in the field of financial accounting research (Bernard, 1995; Dechow, Hutton, & Sloan, 1999; Lundholm, O'Keefe, & Feltham, 2001). The models used in Chapter 5 and 6 (Dixit & Pindyck, 1994; Kulatilaka, 1988) are among the most prominent, well-known and respected models within the real option literature. The first one makes use of continuous time whereas the other uses discrete time. These models are also adopted and applied in a variety of settings. Nevertheless, the discussions in these chapters concerning the application of such models to the context of this thesis illustrate the complexity and challenging nature of empirical research on real options. Some strong assumptions have to be made, but not as strong as those applying the Black & Scholes formula in real options settings (Kemna, 1993). Weaknesses and problems in the model applications are discussed in Chapters 5 and 6. However, the findings provide insight and enable capturing the option values of flexibility. But due to their complexity, the results need to be interpreted with caution.

The linear regressions performed in Chapters 4 and 6 are accompanied by standard econometric discussions of basic assumptions and limitations in the interpretations of the results.

Table 2.1: Summarization of some methodological aspects of the thesis.

No.	Research methods	Data source and type	Unit of analysis
Chapter 3 (paper 1)	Literature review Meetings, telephone calls and e-mails with financial managers of generating companies	Primary data (meetings, e-mails, telephone calls) Secondary data from literature review	Firm level (industry level)
Chapter 4 (paper 2)	Linear regression analysis and the residual income valuation model of Feltham & Ohlson (1995)	Secondary data from the database of Europower AS (transactions of companies) and Brønnøysund Register Centre (accounting data)	Firm level
Chapter 5 (paper 3)	The model framework of Dixit & Pindyck (1994) based on stochastic calculus	Secondary data from Nord Pool (electricity spot and forward prices)	Firm level (plant level) (industry level)
Chapter 6 (paper 4)	Linear regression analysis and the model of Kulatilaka (1988) Simulation programming in R	Secondary data from Nord Pool (electricity spot and forward prices) and NVE, the regulator (national water reservoir level statistics)	Firm level (industry level) (system level)

2.6.1 Data

The secondary data used in the analyses of this thesis is collected from Nord Pool, NVE, Europower AS and Brønnøysund Register Centre. In Chapter 3 there is some primary data collected through meetings, telephone calls and interviews.

The Nordic power exchange Nord Pool has offered free access to their FTP server where daily data for spot prices as well as forwards and futures prices are available. The structure of the contracts traded is adapted to the need of the participants (Nord Pool, 2005). The analysis in Chapter 5 relates to the longest forward contracts, while Chapter 6 makes use of the shorter ones. The consideration for making the choices is found within these chapters.

The magazine reservoir level statistics are made publicly available on the NVE web pages. NVE discloses on a weekly basis the levels in percent of maximum national reservoir capacity. The accounting data for the companies analysed in Chapter 4 is obtained from The Brønnøysund Register Centre. The data became available through an agreement.

The data from Nord Pool, NVE and The Brønnøysund Register Centre are easy to relate to and no substantial concern with regard to validity and reliability exists. However, the data from Europower AS should undergo such a discussion. As pointed out in Chapter 4, there is some uncertainty involved in the data that can have caused biases in the analysis. The chapter includes though an appraisal of the validity and reliability of the data set. The data collection for Chapter 4 has represented a major challenge, and has absorbed much time and taken much effort in the preparation of this thesis.

2.6.2 Unit of Analysis

The primary unit of analysis in this thesis is power generation companies, alternatively termed firm level. Companies owning generation assets, involved in a merger or acquisition, are studied and analyzed in Chapter 4. Concerning the study of investment opportunities in Chapter 5, the focus is primarily on the impact on value for companies. And chapter 6, concerning switching opportunities caused by different generation technologies, addresses the value implications for companies restricted in generation by long term industry contracts. The use of real options at firm level is studied in Chapter 3.

Nevertheless, as Table 2.1 shows, there are several comments throughout the thesis concerning both the plant level and the system level (industry level). So even if the firm level is of primary concern in the thesis, there are aspects found in both Chapters 3, 5 and 6 that can give insight into other levels.

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CHAPTER 3 (PAPER 1): THE USE, ABUSE AND LACK OF USE OF REAL OPTIONS[1]

Abstract:

Real options have for almost three decades existed as a prominent feature of capital budgeting. The technique of incorporating the value of flexibility in project and business evaluation by applying tools from financial option valuation has been widely accepted and applied as an innovation within the academy. Nevertheless, surveys show that in business practice the real option approach is only used in a limited way when assessing project and business values. Few firms have followed the academic recommendations to use this technique. How can this paradox be explained? This paper summarizes the current status of real option application and further discusses this issue by taking into consideration institutional theory. Moreover, by illustrating the use of real options in the Norwegian generation industry, the paper suggests when and how real options are relevant, and also when obvious limitations exist regarding the relevance of this valuation technique.

Key words: real options, capital budgeting techniques, institutional theory, generation industry

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[1] This chapter is a major revision and extension of an article published in *Beta* (*Scandinavian Journal of Business Research*) 2/2004 pp 33-45 ("Er realopsjoner oppskrytt?", in Norwegian).

3.1 INTRODUCTION

The real option approach has become a part of most introductory books on capital budgeting and valuation. The idea of incorporating the value of flexibility has profoundly developed and extended value calculations. Traditional net present value calculations have serious shortcomings, as pointed out by a number of researchers; therefore real options have been termed a "revolution" and even a "new paradigm" (Antikarov & Copeland, 2003; Schwartz & Trigeorgis, 2001) in the field of capital budgeting and valuation. Based on claims this technique should be expected to be used in a widespread manner in various businesses. This is not, however, the case. Despite all the recommendations from academic circles, the technique remains infrequently used by firms. Why then has the real option approach been largely ignored by practitioners?

This paradox has received some attention (Copeland & Tufano, 2004; Lander & Pinches, 1998). The discussion has reached far beyond the point whether real options should or should not be a part of project and business valuation, but the main focus has concerned the way of implementing financial option valuation to real projects and firms. There is though an emerging awareness of limitations that make real options unapplicable in many situations. The current task is to find out in what situations this technique should be incorporated and to better understand when and why it is not appropriate to use this tool (Philippe, 2005b).

The following research questions are explored in this paper:

1. **Why is the real option approach not used by many firms with regard to project and business evaluation?**

2. **In which situations should a real option approach be a mandatory part of project and business calculations? (How should the real option approach be used by firms in order to benefit most from this technique?)**

The unit of analysis in this study is firms. The dependant variable is the use of real options in various project and business evaluation situations. The purpose of this paper is to summarize and extend the overall understanding of why real options have so far only to a limited level been used by corporate management, including what institutional theory from an unfamiliar scientific paradigm, from the viewpoint of finance and accounting research, can explain. Furthermore, the purpose is to portray in what situations and in what industries the real option tool is especially relevant in order to recommend how firms better can benefit from the knowledge derived from real option theory.

The paper is mainly based on reflections from literature review, but is supplemented by primary data collected by e-mails, meetings and telephone calls with financial management of especially Norwegian generation companies. Statements from other businesses are also included. The meeting with two representatives of Statkraft SF is central in the empirical material presented.

The paper is organized in the following way: In section 2 an examination of surveys performed concerning capital budgeting and valuation issues, is presented. The results regarding the use of real options are focussed. Section 3 gives an overview of what recent research has revealed about how relevant the application of option theory and option valuation is for real projects and business valuation. The section also discusses some new aspects concerning why real options use is so limited. The next section represents a case study of the use of real options in the Norwegian generation industry. The last section draws some conclusions regarding the above mentioned research questions and offers some recommendations concerning how firms should apply this tool in practice.

3.2 KEY FINDINGS FROM RELEVANT SURVEYS ON THE USE OF CAPITAL BUDGETING TECHNIQUES

This section summarizes the findings from the relevant surveys performed relatively recently concerning the use of capital budgeting techniques in general, and, in particular, the use of real options.

Graham & Harvey's (2001) comprehensive study was performed on 392 U.S. firms. 27 % of the companies in their study always or almost always use real options in project evaluation. The study reveals very little concerning the characteristics of firms that use or do not use real options when using a number of control variables[2]. The only control variable in their study which is significant at a 10 % level is that regulated firms tend to make less use of this tool compared to unregulated firms. This comes as no surprise bearing in mind that real options must be considered a more advanced technique compared to most other capital budgeting tools. The findings of the study stresses that firm size is often strongly related to corporate practices -- included the use of real options.

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[2] The control variables were amongst others: size, price/earnings ratio, leverage, industry, management owned, age of CEO and education of CEO.

Brounen, de Jong, & Koedijk (2004) conducted a similar survey on European firms (UK, the Netherlands, Germany and France). Their sample was 313 firms, at least 50 from each country. Perhaps surprisingly, companies in all four countries seem to make more use of the real option tool than American firms. The findings are shown in Table 3.1.

Table 3.1: Summary of the findings regarding the use of real options from Graham & Harvey (2001) and Brounen et al. (2004).

% of sample that always or almost always incorporates real options in project evaluation[3]	
U.S	27 %
UK	29 %
Netherlands	35 %
Germany	44 %
France	53 %

There are relatively large differences between countries according to these numbers. It is hard to explain why e.g. French firms almost twice as much as U. S. firms systematically use real options in their project value calculations. However,

[3] The question asked in the survey was: "How Frequently Does Your Firm Use the Following Techniques when Deciding which Projects or Acquisitions to Pursue?". The respondents could reply on a scale from 0 (never) to 4 (always). The numbers in table 1 refer to those who answered 3 (almost always) and 4 (always).

the conclusion is that European firms to a larger extent than U. S. firms make use of the real option technique.

Teach (2003) refers to a survey performed by Bain & Co., a consulting firm, in 2000 regarding the use of 25 management tools. Of the sample of 451 U. S. firms, only 9 % used real options. This brought real options next to the bottom of the ranking list. As many as 32 % of the users abandoned the technique after just one year.

Another survey revealing a low profile in practice for the real option tool, is Ryan & Ryan (2002). They obtained a response from 205 CFO's of the "Fortune 1000" companies in the U. S. The findings concerning real options proved disappointing for the advocate of this practice. Only 11.4 % of the firm used this tool, while e.g. 53.9 % used Economic Value Added (EVA).

Other studies, like Geddes (1999) and Pike (1996) (on large U.K. companies) have also been carried out. The results from the different surveys show much variation, when it comes to the use of real options. There seems to be quite low usage amongst American firms, whereas it seems more popular for European firms to include option aspects in their value estimations.

However, there are various aspects to bear in mind. The studies do not consider the type of industry the firm operates in; the only criterion seems to be size. The response rates of the surveys were from 9 % (Graham & Harvey, 2001) to 21 % (Ryan & Ryan, 2002). The studies are performed in 1996 to 2002. Taking into consideration how recent the real option tool is, the investigation may not reflect current use. By 2007 one may argue that this capital budgeting technique has become more refined and is thence more likely to be used properly.

Nevertheless, one can still ask the relevant question: Why has this widely accepted tool not being used more by firms? The paradox remains when this approach has been highly recommended from academic circles for several decades, and yet is not more widely adopted and accepted by the practitioners in corporate firms.

3.3 FOUR ASPECTS REGARDING WHY THERE IS LIMITED USE OF THE REAL OPTION TOOL

The limited use of real options by practitioners has been debated to some extent (Antikarov & Copeland, 2003; Borison, 2003; Copeland & Tufano, 2004; Segelod, 1998; Sick, 2002). To explain the reasons why this technique is not more recognized, this section will comment on *four* aspects which can shed light on this apparent paradox:

1. Real options are too complicated to use properly for many firms. Even if real options have been taught in many courses in business schools for a decade or two, the method is relatively difficult to apply both in the calculation of the option values and in understanding the assumptions. This is the case, even if several computer programmes are provided to assist in the process (Mun, 2003). If firms have adopted the real option tool without the knowledge and ability to apply it properly, it may not work according to expectations leading to miscalculations, disappointment and abandonment.

   This is the reason Copeland & Tufano (2004) recommend a binomial approach rather than involving the Black & Scholes (1973) formula in real option settings. An easier approach can provide sufficient information of the relevant option values involved, without the need to turn to computer programmes or differential equations. By simplifying the methodology one can at least partly overcome the obstacle of real options being too hard to apply in practice.

Their recommendation is close to what is known as scenario analysis – a technique with a longer reputation than real options on valuation issues. A formalized scenario analysis enables to simulate different possible future outcomes that affect value estimates. Such approach can be accompanied by computer tools (Mun, 2003).

2. Real options have been adopted too soon by managers, in order to be perceived as "modern". Real options have been advocated and recommended intensively for the last 20 years. Leading researchers such as Myers, Ross, Trigeorgis, Merton, Schwartz and others have stressed the benefits and the advantages of incorporating the value of flexibility in project and business evaluation. Therefore, firms wishing to be viewed as modern, innovative and on the cutting edge in the field of capital budgeting, adopted this tool. Using real options may provide the desirable image of being an attractive and up-to-date firm.

   This behaviour may be explained by institutional theory (DiMaggio & Powell, 1983, 1991; March, 1994; Meyer & Rowan, 1977; Sahlin-Anderson & Sevón, 2001), a research discipline not usually applied in the field of finance and capital budgeting. Institutional theory has been applied to management accounting tools such as the "Balanced Scorecard", "Total Quality Management" and "Just in Time" (Røvik, 2002). Studies confirm that many management accounting tools are more frequently implemented because of what institutional theory can explain rather than costs and benefits. The aspect of fad is emphasized by e.g. Bjørnenak (1997) and Ax & Bjørnenak (2005). The introduction of real options has similarities.

This may explain why the real option technique has been adopted, without careful considerations as to whether it is suitable and relevant. Hence it could be abandoned when shown to be inappropriate or inadequate for the actual firm. This is easy to understand bearing in mind that several researchers have stressed the complexity and pitfalls in applying real options (Damodaran, 1999b; Fernández, 2001; Howell et al., 2001).

3. Real options suit some businesses better than others. Options are derivatives on underlying assets. The lack of an underlying asset provides a serious obstacle in many businesses. A manager in one of the largest Norwegian firms (Telenor ASA) says of real options: "The method is appealing. The problem is that you depend on estimating a reasonable volatility in order to make it meaningful in application. This is not easy when you operate in an industry not directly exposed to commodity risk with traded options with a relevant time to maturity" (Risstad, 2004). When no obvious underlying asset exists for which the standard deviation of risk can be calculated, problems arise in the application of real options (Alesii, 2003; Copeland & Tufano, 2004). (Antikarov & Copeland (2003) suggest that this can be overcome by letting the project itself be the underlying asset. This remains though a controversial approach).

This point illustrates that real options are more relevant for industries operating in efficient markets including a forward/futures market. This is the case for commodity markets such as oil, gas, electricity, gold, aluminium etc. However, if a firm operates in other industries, such as construction, telecommunication or other service industries, obvious hurdles exist in applying the real option concept. The lack of an easily observable and tradable underlying asset thus renders a real option analysis strange. Therefore it comes as no surprise that both conceptual and empirical studies of real options are often associated with the energy industry (Bergendahl & Olsson, 2006; Bjerksund & Ekern, 1990;

Brennan & Schwartz, 1986; Fleten & Näsäkkälä, 2005; Hlouskova, Kossmeier, Obersteiner, & Schnabl, 2005; Kulatilaka, 1993; Paddock, Siegel, & Smith, 1988).

4. Several complicating factors arise when adapting financial option theory to the real world. One feature concerns the exercising of options. As for American financial options, real options should be exercised at the optimal time (Rhys, Song, & Jindrichowska, 2002). According to Copeland & Tufano (2004), managers (as option holders) fail to do so and thereby act suboptimal. Such a lack of rationality is a major obstacle why real option values disappear. Exercising options at the right time may prove a difficult decision for managers. Missing this will not be reflected in any accounting report, leading to a possible hesitation in exercising a real option at the right time -- because the decision may be unpopular and complicated to carry out.

   A Financial Manager in a large Norwegian company (Veidekke ASA) commented on this aspect: "Timing is the be-all and end-all regarding any investment decision. The problem with regard to real options is the quality of input information. Theoretically real options are excellent, but not so good in practice" (Bjerke, 2004). This aspect therefore provides a solid argument for those opposing and delaying the inclusion of real option calculations of intangibles in accounting standards (Chen, Conover, & Kensinger, 2005; Leadbeater, 2000; Upton Jr., 2001).

   This point is elaborated by Philippe (2005b). According to him a problem exists with corporate governance related to real options, complicating and limiting its applicability. There is a question of ownership to a real option, as well as how exclusively the right to exercise this is for a firm. This aspect may well contribute to the assessment of whether real options are suitable or unsuitable for any one firm in a specific situation.

These factors offer many different explanations as to why the introduction of real options in evaluation issues can so far only be deemed a moderate success, with reference to implementation and use by firms. There are both technical and managerial problems in the application. The above mentioned factors represent both a summarization of current status and some innovative aspects of explanation. Including an analysis based on institutional theory represents a most unusual approach for research questions in finance and capital budgeting. Nevertheless, incorporating an approach using a different scientific paradigm may shed new light on the controversial question of why real options have so far not been more widely taken into use.

3.4 THE USE OF REAL OPTIONS: AN APPLICATION TO THE NORWEGIAN GENERATING INDUSTRY

This section looks more closely at the use of real options in the Norwegian power generating industry. Hydropower generation represents the second most significant industry measured in value[4]. Currently, 99 % of the total average generation of 121 TWh is hydroelectric power. Electricity is traded at the Nordic power Exchange

Nord Pool. Hence there is an obvious underlying asset with efficient spot as well as futures/forward markets. Therefore this is a suitable industry to study concerning the use of real options.

The empirical part of this section consists of two parts, 1) the study of three valuation reports conducted on Statkraft SF, and 2) the results of meetings, telephone calls and e-mails to financial managers in generating companies. I conducted an interview of two analysts in the dominating company Statkraft. In addition there has been more informal contact with several other companies, both larger, medium sized and smaller ones.

3.4.1 Valuation reports of Statkraft SF

The 100 % state owned generating company Statkraft SF (35 % of total national generation) has been valued by three consulting companies (Dresdner Kleinwort Benson, 2000; Ernst & Young, 2000; Lehman Brothers, 2006)[5]. In just one of them, (E&Y), an assessment of relevant real options is included. The real options identified are fall rights and new power plants potential and extensions and improvements of existing power plants. The report primarily emphasizes the qualitative sides of real option values because there are many uncertain factors that complicate a quantitative calculation. There is though an attempt to quantify the value

[4] The value of the assets in the industry were estimated at NOK 400 bn (EUR 50 bn) in 2004 (Sande & Thomson, 2004), hence considerably more by 2007. Only the oil and gas industry controls higher assets values.

[5] The Lehman Brothers report (2006) estimated the enterprise value of Statkraft SF to NOK 173-202 bn (EUR 22.1- 25.8) and the equity value to NOK 129-157 bn (EUR 16.5-20.0).

of the new plant potential for the company to approximately NOK 1.5 – 2.5 bn (EUR. 180 – 200 mill). This represents about 4 % of the total equity value estimate.

These reports illustrates that it seems rather random whether real option aspects are included in a value assessment or not. However, this is an industry in which an underlying asset is observable with both spot and forward prices and the presence of several dimensions of uncertainty (precipitation, technological developments, political issues etc.). Two out of three hired consultant companies do not mention any real option aspects, even if they are professionals on business valuation.

3.4.2 Contact with financial managers in generating companies

The lack of use of real options is confirmed by consulting financial managers of generation companies. When smaller companies are contacted, they do not in general incorporate a real option analysis in their calculations with regard to new plants (small scale), extensions of existing plants etc. However, there is an intuitive understanding of the real option concept that is to a certain extent included in evaluations and decisions. The low usage in these companies is explained by lack of competence and scepticism with regard to the relevance and benefits of this approach. This is also the case even if consultants are involved in their analysis (Sande & Thomson, 2004).

Larger companies, such as Statkraft SF and Agder Energi, do though possess a more reflected view with regard to the topic of this paper. They do confirm that real options are regularly involved in qualitative assessments and are "more and more" viewed as a relevant and useful technique in their calculations. The financial manager of Statkraft SF says that "real option aspects are currently more relevant and interesting than ever". Option approaches are relevant in timing of investments and maintenance as well as a possible future abandonment of wind mill plants. There are though clearly difficulties when moving from conceptual ideas to number calculations. As one risk manager of Statkraft SF says: "If the option idea is transferable to a binomial tree, it is easier both to calculate a meaningful option value and communicate the implications to the top management".

The findings presented in this section offer then support to the four aspects presented in the previous section explaining why the use of real options is limited. Here follows a discussion of each of the explanations applied to this industry.

1. The complexity of real option makes firms hesitant to use real option analysis. Many generating companies, especially the smaller ones, do not have skilled people to deal with this concept and are thus neglecting option aspects. Several managers state that real options are too advanced for their financial department. Many of the contacted firms have small financial departments, limited to two or three persons. The above statement made by a risk manager at Statkraft SF confirms the arguments and recommendations given by Copeland & Tufano (2004) that simplification by using the binomial approach both capture the essential point and make communication of option aspects easier.

2. It is more difficult to find empirical support for this aspect, but phrases like "we want to improve our capital budgeting and valuation skills" etc. are made by several people. This can be interpreted in a way that the companies are concerned about their image – also concerning the image of use of financial tools, which can be linked to the abuse and later abandonment of the real option tool. Nobody though, has clearly stated that they have stopped using real options.

3. This aspect is irrelevant since this industry has been selected because electricity is an easily observed underlying asset.

4. The timing of investments and other decisions with regard to generation are carefully considered. Statkraft SF confirms the model framework of Dixit & Pindyck (1994) in which the volatility of the underlying asset affects the timing of implementation of investment decisions.

There are benefits including real options in valuation issues in this industry. Nevertheless, few firms use real options. This implies that there is a lack of use of a capital budgeting technique that could capture the flexibility value in growth potential etc.

It seems that only the larger companies, such as Statkraft SF and Agder Energi, systematically to some extent include real option evaluations. The other companies contacted show little or no use of real options. However, the intuitive part of real option thinking is confirmed by several persons.

3.5 CONCLUSIONS AND IMPLICATIONS

Real options are not a universally applied capital budgeting technique. This tool cannot replace NPV/DCF valuation or compete with IRR or other traditional approaches in business and project evaluation. It seems too bombastic to call real options a "new paradigm" or a "revolution". Option values definitely exist in investments in real assets and should in a number of situations be captured and incorporated in project as well as business valuation. However, real options are en extension of existing approaches and should hence offer a supplement to traditional NPV/DCF valuation (MacMillan & van Putten, 2004; Trigeorgis, 1993b). To include option aspects in valuation is an innovation and improves calculations significantly – when applied properly. There is though a need for considerations of the relevance of option valuation techniques concerning the specific context.

3.5.1 The answer to research question 1:

The use of real options by firms is clearly limited according to the studies summarized in this paper. The reason for this is covered by the four aspects discussed in section 3; the complexity of the technique, the eagerness to have a modern image leading to disappointments and abandonment, the lack of an obvious underlying asset and the complexity in timing the exercising of a real option. These aspects are supported by statements from financial managers.

However, no reporting exists as to whether those using this technique operate in relevant industries or not. Neither is any information available concerning the considerations lying behind the choice of technique when a project or business value is calculated.

The case of Norwegian generation companies shows that even in an industry significantly exposed to risk and where there are efficient spot as well as a forward markets, making the real option tool particularly suitable, there are few examples of actual use. Only the larger companies include real options in their valuation issues. It seems that this is not always the result of some careful consideration, rather that the management in this industry mostly has technical educations and does not have the background and skills required to incorporate real options. Hence there is a lack of use of the real option tool leading to important information concerning project and business evaluation being lost.

3.5.2 The answer to research question 2:

It is often said that the real option technique provides a tool to calculate option values that have always been known intuitively (Antikarov & Copeland, 2003; Mun, 2002). The problems in application though, lead one to suggest that even if real options can provide values, and in a number of situations quite precisely and informative value estimates, there are also a number of situations in which real option thinking should more be applied qualitatively rather than quantitatively (Amram & Kulatilaka, 1999). The real option approach is neither a pure quantitative nor a pure qualitative approach. Real options exist, but to capture their value can, in some cases, be too complex or too uncertain. It would then be more appropriate to incorporate the real option tool as a supplementary qualitative assessment.

The recommendation based on the presentation in this paper is thus that a project or business valuation should *always* include a qualitative real option analysis (Ross, 1995), but not necessarily a quantitative numerical calculation. Any valuation assessment should incorporate real option aspects, but the type of industry and other case specific factors would determine whether these option values should be calculated.

Real options do explain reality better and more precisely than traditional neoclassical finance (Kulatilaka, 1993; Schwartz & Trigeorgis, 2001). Therefore the need arises for competence building in the teaching on this field in business schools. To make apparent specific applications of real options and show how practitioners can benefit from both real options calculation, as well as real options thinking, can also increase the use of real options as part of firms' capital budgeting techniques. By simplifying and illustrating the practical benefits in contrast to stressing stochastical calculus and advanced computer programming, there is a possibility that new surveys in the future will show different results compared to the studies presented in section 2. Wise management should therefore include an overall assessment of relevant real options in project and/or business evaluation.

Real options are used, but by surprisingly few people. Real options are also misused, unsurprisingly since many pitfalls do exist in application. But most apparent is the lack of use by companies which thereby fail to incorporate vital information in their project and business valuations.

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CHAPTER 4 (PAPER 2): EXPLAINING THE VALUE OF ELECTRIC UTILITIES BY REAL OPTIONS – AN APPLICATION TO NORWAY

Abstract

Since deregulation of the energy market in Norway, there have been a number of mergers and acquisitions of electric utilities. (This involves companies operating in the fields of power generation, transmission, distribution and the sale of electricity). In all these transactions the companies have been valued. The value has often significantly exceeded the book value recorded through use of equity and traditional NPV/DCF valuation. This particularly applies to generating companies. How can this premium be explained? Real option theory is in this study applied in order to explain the difference between actual transaction value (market value) and fundamental, intrinsic value. The residual income model proposed by Feltham & Ohlson (1995) is considered.

The empirical analysis shows that an enhancement in explanatory power of 100 % is brought about through the introduction of independent variables based on real option theory. This supports the use of real options in helping to explain transaction values in this industry during the past decade.

Key words: Real options, generating companies, value explanation

4.1 INTRODUCTION

The Norwegian Government implemented the Energy Act in 1991 in order to make electricity markets competitive. Norway is considered a pioneer in deregulation of the electricity market (Al-Sunaidy & Green, 2006). This Act encouraged a profound restructuring of the industry. One consequence was separation of generation, transmission, distribution and wholesale trading. Another feature was the privatization of companies in the industry. Public ownership (municipalities, counties or state) was no longer required.

The deregulation[1] of the industry led on to an emerging new market of tradable electric utilities. The vast majority of generating capacity is as of 2007 still publicly owned. The state owned company Statkraft SF owns 35 %, municipalities and counties own approximately 55 % and private investors 10 % according to EBL (The Electricity Industry Association) (2006). However, in the post deregulation period (1991 to 2006), there have been more than 430 transactions in which electric utilities have been involved in mergers or acquisitions.

All these transactions have included assessment of the value of the companies involved, creating a need for qualified calculation of business value. Almost all of

[1] Transmission and distribution networks continue to be natural monopolies and were, and still are, regulated (Al-Sunaidy & Green, 2006).

these companies were not traded on the stock exchange, limiting the access to value relevant information and complicating business value calculations[2].

Many of the transactions have sparked controversy with several observers (politicians, consultants and others) who claim that the companies have been sold too cheaply. Because of their eagerness to capitalize values for immediate reasons, local and regional authorities have not been sufficiently aware of the real value of their power generating assets and have sold, partly of wholly, their shares in generating companies -- without full compensation.

Traditional valuation is based on NPV/DCF (Net Present Value, Discounted Cash Flow). This industry also tends to base value estimates of generation assets on kWh yearly generation capacity (Econ, 2000). Serious limitations apply to such conventional approaches. They lose out on the value of flexibility, such as growth opportunities, when future information such as higher electricity prices is revealed. Real options have for three decades been studied in corporate finance. Real options, as a part of business valuation, are legitimate as tools for handling and quantifying *flexibility*. The value of flexibility, in for instance gauging growth opportunities, is incorporated in a real option analysis. A number of scientists have criticized traditional NPV/DCF analysis for ignoring flexibility (Berkovitch & Israel, 2004; Brennan & Schwartz, 1986; Kulatilaka, 1993; Mun, 2002; Myers, 1987). Some call

[2] The term *transaction value* refers to the compensation given for the shares of the company. If only a part of the shares of the company is involved in a transaction, the term refers to the value *as if* the whole company was involved.

NPV/DCF a "naive rule" (Milne & Whalley, 2000) when applied to project and business valuation. Ross (1995) even says that "optionality is ubiquitous and unavoidable" concerning valuation issues, and thereby indicates that options should always be included in valuation.

The focus of this paper is to analyze transactions involving Norwegian generating companies during the period 1991 to 2006, and moreover, test a conventional valuation model and an extended model based on real option theory. The purpose is then to test whether introducing option components increases the explanatory power of the valuation model. The purpose is also to deepen the understanding of the value and value components of these enterprises. Hence, the research questions arise:

1. How can the value of Norwegian electricity generating companies be explained?
2. Can real options enhance explanation of value compared to traditional valuation models?

This study makes use of the residual income model developed by Ohlson (1995) and Feltham & Ohlson (1995) as the benchmark model for valuing the companies (see section 3). The residual income model framework is one version of a classical valuation model, and is in a line with several papers published regarding company valuation (Frankel & Lee, 1998). Access to accounting data makes this a convenient approach. The model is used as a benchmark before introducing option-related variables.

The paper is organised as follows: after an elaboration of the real option perspective and the context of this study in section 1, the residual income model and the research design is presented in section 2. The empirical model is presented in section 3. Hypothesized links between dependent and independent variables are derived as well. The sample, data and results are also summarized in this section. Conclusions, implications and limitations are reported in section 4.

4.1.1 Real options, valuation and Norwegian electric utilities

Business value as a sum of present business activities and future growth opportunities can be traced back to Miller & Modigliani (1961) and Myers (1977) (Myers introduced the term "real options" in 1977). Since then there has been a vast development and extension of the understanding of present business value as the sum of the value of existing investments (assets-in-place) and future investment opportunities.

The majority of research, especially in the early stages, was linked to different types of project assessment. Later, the real option framework was extended to business valuation. A firm can be viewed as a portfolio of projects. Companies can possess a portfolio of options of different kinds that obviously affect business value. This has always been known intuitively, but real option theory introduced a framework and a new approach for quantifying and deepening the understanding of this aspect.

Still, there are far more theoretical and conceptual articles than empirical studies in the academic literature on the subject[3]. Although real options have been widely presented in corporate finance literature, academic journals and in financial books, implementations by professionals in business are still limited in numbers. This paradox has been debated (Borison, 2003; Copeland & Tufano, 2004; Philippe, 2005b; Sick, 2002; Teach, 2003). Hence studies that can empirically test the relevance of real option theory may be of considerable interest.

4.1.2 The electricity market in Norway

A consequence of deregulation was the introduction of a Nordic power exchange, Nord Pool. This unification of the Nordic system had great importance and by 1997 most trading products, including derivatives, were established. With this settled an important source of knowledge became available in order to understand better electricity prices and hence the value of companies possessing generation capacity (in appendix 2 there are figures of both spot price and forward price development at Nord Pool). The financial market includes forward contracts up to four years ahead, determining long term prices and hence expected future earnings which in turn affect value calculations. This is of course a relatively short horizon in business valuation; nevertheless, these long-term forward contracts provide the best available input for valuation of generation assets.

[3]The empirical studies like Paddock, Siegel, & Smith (1988), Baily (1991), Quigg (1993; 1995) and Moel & Tufano,(2000) are therefore much quoted within real option literature (Philippe, 2005a; Trigeorgis & Schwartz, 2001).

The companies in this industry have had rather low earnings, but high equity-to-debt ratio compared to other industries in the post deregulation period. A report (Bye, Bergh, & Kroken, 2001) even point out that up to 2001 the profitability in the generation industry was among the lowest of Norwegian industries. The reason remains outside the scope of this study, but it is confirmed by the data utilized in the analysis (see Table 4.1)

Low electricity prices as well as regulatory hurdles (NVE, Norwegian Water Resources and Energy Directorate) have limited the availability of profitable projects and hence caused a low level of investments in generation capacity in the relevant period (post deregulation). On the other hand a new focus has developed on small-scale hydro power and alternative types of generation technologies such as wind and thermal gas or coal-fired generation. There has also been an ever more detailed mapping of both small-scale hydro and wind power potential in different areas of the country.

Option values of investment opportunities in the area in which a company operates have received increased attention when electricity prices have risen and investment costs have dropped. The number of licence applications to the regulator (NVE) has also increased considerably during recent years.

As regards the valuation of generation capacity, the industry norm is to measure value per kWh yearly capacity. Normal value typically ranges from just below NOK 2.00 to NOK 2.50/kWh per average yearly generation capacity. On the other hand, a variety of complicating factors make valuation of electric utilities difficult. Many companies do not just operate as generation companies, there are different tax positions, there can be issues related to contracts of cheap surplus electricity supplied to local municipalities and also differences in financial strength. The age and quality of the generation assets can also influence the value.

4.2 THE RESIDUAL INCOME MODEL AND RESEARCH DESIGN

The market value of firms is defined as the discounted present value of expected net cash flow using an appropriate discount rate reflecting the relevant risk. Forecasts of future revenues, expenses, earnings and cash flow form the crux of the valuation (Kothari, 2001; Miller & Modigliani, 1961). Lee (1999) even concludes that the "essential task in valuation is forecasting. It is the forecast that breathes life into a valuation model". Dominant valuation models are the cash flow model and the dividend model. But there are other alternatives - such as the residual income (RI) model developed by Feltham & Ohlson (1995)[4].

Theoretically, there is equivalence between the various models (Feltham & Christensen, 2003; Fernández, 2003; Penman, 1997). They all yield the same fundamental value of companies' when applied properly and consistently[5]. The residual income valuation model expresses value as the sum of current book value and the discounted present value of expected abnormal earnings, defined as forecasted earnings minus a capital charge equal to the forecasted book value times the discount rate. The advantage of the RI model is the relation to accounting numbers as input parameters, making it a convenient benchmark model[6] in this study. Instead of a complicated estimation of future net cash flow, one can rely on the accounting

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[4] Earlier contributors to the residual income model are Hamilton (1777), Marshall (1890) Edwards & Bell (1961) and Stewart (1991) (Kothari, 2001).

[5] Relative alternativeness in practice is more controversial. (Penman & Sougiannis, 1998; Plenborg, 2002).

book value of equity and an estimation of future net income. One version of the RI model is:

$$V_t = BV_t + \sum_{i=1}^{\infty} \frac{E_t[NI_{t+i} - (r_e \cdot BV_{t+i-1})]}{(1+r_e)^i} = BV_t + \sum_{i=1}^{\infty} \frac{E_t[(ROE_{t+i} - r_e) \cdot BV_{t+i-1}]}{(1+r_e)^i}$$

(4.1)

in which V_t is value at time *t*, BV_t is book value at time *t*, $E_t[\cdot]$ is expectation based on available information at time *t*, NI_{t-i} is the net income for period *t+i*, r_e is the capital charge of equity and ROE_{t+i} is the after-tax return on book equity for period *t+i*.

This residual income approach to valuation divides firm value into two components. First comes the book value of equity to be found in the financial statements at the time of the valuation. The other component is the net present value of future residual income. Residual income is defined as the difference between *ROE* and r_e multiplied by the book value of equity. This implies that a firm which earns *ROE* above the capital charge has a higher value than the book value and vice versa.

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[6] Benchmark model is in this paper related to the traditional valuation model neglecting real option values.

If equation **(4.1)** is divided by BV_t an expression for the price-to-book ratio materializes. The electricity industry, as a mature industry, could be characterized by low residual income. Nevertheless, there are so many uncertain characteristics in the industry, which makes it reasonable to believe that a significant part of the business value in this industry should lie in the second component, i.e. in future growth opportunities (Dixit & Pindyck, 1994). These uncertain aspects are associated with the volatility of electricity prices, the uncertainty of the market due to political and environmental concerns, constraints in transmission capacity and the prices of oil, gas and coal. This remains though unconfirmed by the empirical findings in this study.

Traditional valuation models are normally assuming an expected growth in the cash flows/dividends/residual income. Such approaches do also normally consist of a terminal value estimate. Conventional value estimates are hence very sensitive to the estimate of the expected growth. A small change in expected growth can lead to a significant change in the value estimate, especially the terminal value estimate. One should also bear in mind that it is extremely difficult to adequately estimate expected growth. It is very hard to interpret the continuous stream of new economic information and transform them into changes in expected growth.

This severe problem with traditional valuation is a strong argument in favour of choosing a real option approach when analysing the value of generating companies. Real option calculations are more transparent and reveal open information of the value components in a total value estimate which do not to the same extent depend on expected growth. In a real option valuation it is also easier to discuss the assumptions of the value estimates beyond the value of assets-in-place. Traditional valuation, through which expected growth is hard to estimate, may not necessarily capture the value of future possibilities or may also overestimate them. It is far from obvious that a real option approach yields higher value than traditional net present value calculations, but real option valuation is more transparent and offers better insight into value components.

4.2.1 Research design

The first step in the methodological part of the study is to establish a benchmark model for valuing electric utilities. The purpose of this study is to test the incremental impact of independent "real option" variables enabling use of a simplified basic model as benchmark. The design is inspired by Beaver, Eger, Ryan, & Wolfson (1989) (banking industry), Bowen (1981) (electric utility industry), Bernard & Ruland (1987) and Jennings (1990). The following model for the value at time t can be expressed as follows:

$$V_t = BV_t + RI_t + GO_t + u_t \qquad \textbf{(4.2)}$$

where BV_t is book value at time t, RI_t is the net present value of expected future residual income at time t, ignoring growth options, GO_t is a proxy for the value of growth options at time t and u_t is the error term in the model. The two first terms in the equation make up the benchmark model, estimating the value of assets-in-place and predictable growth. This part includes expected growth as performed in traditional valuation. The third term is supposed to capture the potential value of real options not captured by earnings based on assets-in-place (included predictable growth). This is discussed in more detail later.

The benchmark model gives an estimate of the intrinsic value of assets-in-place based on certain input parameters; 1) current book value, 2) cost of equity capital and 3) estimated future *ROE*. To determine these parameter values the following must be considered:

BOOK VALUE (BV)

Book value of equity is obtained from the most recent annual accounting report before the transaction.

COST OF EQUITY CAPITAL (r_e)

The cost of equity should reflect the premium demanded for investing in projects with comparable risk. It should be firm-specific capturing the relevant operational and financial risk for the actual company involved in a transaction. The cost of equity after tax can be found by using the CAPM model (Norwegian tax rate of 28 %)[7]:

$$r_e = r_f \cdot (1 - 0.28) + \beta_i \cdot ERP$$

where r_f is the risk free rate, β_i is the equity Beta for the actual company *i*, and *ERP* is the equity risk premium after tax.

RISK FREE RATE (r_f)

Concerning the risk-free rate Koller, Goedhart, & Wessels (2005) recommend 10-year state issued bonds, whilst Gjesdal & Johnsen (1999) recommend 3-year bonds. This study is conducted in a Norwegian context making it natural to follow the latter recommendation (obtained from NIBOR (Norges Bank, 2007)).

BETA (β)

Equity betas of energy producers in Europe are about 0.70 (Lehman Brothers, 2006). Financial managers at Statkraft SF have implied an even lower beta for hydropower generators. This is due to the inelasticity in demand for power, which does not vary much over the business cycle.

EQUITY RISK PREMIUM (*ERP*)

The equity risk premium is set to 5 %. This fits in with the discussion and recommendations presented by Gjesdal & Johnsen (1999). This should be the representative premium in the Norwegian context for the 1991-2006 period. With a current risk free rate of 4.5 % (March 2007), this gives the equity cost of capital after tax for a 100 % generation company:

$$r_e = 0.72 \cdot 4.5\% + 0.70 \cdot (5\% + 0.28 \cdot 4.5\%) = 7.62\%$$

EXPECTED FUTURE *ROE*

To forecast future *ROE* is no easy task. According to Frankel & Lee (1998), two alternatives exist for estimating forecasted *ROE*: historical time series of earnings and analysts' forecasts. Because the current study concerns non-listed companies (with two exceptions), there are no analysts' forecasts available. Hence the basis must be historical earnings performance.

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[7] This is the relevant tax rate for an investor. The industry is subjected to a comprehensive tax regime (concession tax, nature resource tax, economic rent and real property tax).

According to Penman (2001) return is "mean reverting", meaning that it tends to move close to the capital cost over time, due to competition and diminishing profitability. On the other hand, studies have shown that current *ROE* is a reasonable estimate for future *ROE* (Fairfield, 1994). The peculiar characteristics of this industry would seem to point to a reliance on historical performance. Nevertheless, several choices need to be made. One is "how many years of data to use in the estimation of future *ROE?*". Forecast horizon and terminal value estimation must also be decided on. The time line follows the illustration in Figure 4.1. Transaction year is set to *t*. The transactions are spread throughout the year, so the year *t-1*, *t-2* and *t-3* are defined as the three fiscal years before the transaction took place. The estimated parameters are for year *t+1*, *t+2* and *t+3*.

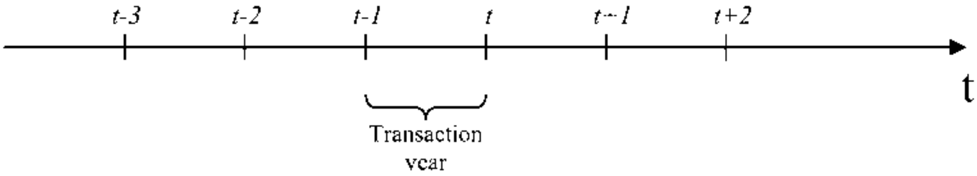

Figure 4.1: Time line for the analysis.

Estimated future *ROE* based on the average historical *ROE* from the past three years is shown as follows:

$$\hat{ROE}_t = \frac{1}{3} \cdot \left[\frac{NI_{t-3}}{0,5 \cdot (BV_{t-4} + BV_{t-3})} + \frac{NI_{t-2}}{0,5 \cdot (BV_{t-3} + BV_{t-2})} + \frac{NI_{t-1}}{0,5 \cdot (BV_{t-2} + BV_{t-1})}\right] \quad (4.3)$$

in which *NI* is net income after tax the relevant year and *BV* refers to book value from the balance sheet (end of year). The same lagged procedure is implemented in the estimates of *ROE* during time period *t+1* and *t+2*:

$$R\hat{O}E_{t+1} = (\frac{1}{3} \cdot (ROE_{t-2} + ROE_{t-1} + R\hat{O}E_t))$$

$$R\hat{O}E_{t+2} = (\frac{1}{3} \cdot (ROE_{t-1} + R\hat{O}E_t + R\hat{O}E_{t+1})).$$

The forecast period must be finite (Frankel & Lee, 1998). This leads to the need for a terminal value estimate. This terminal value at time T becomes:

Terminal value: $\frac{(ROE_{T+1} - r_e)}{(1+r_e)^T \cdot (r_e - g)} \cdot BV_T$ **(4.4)**

in which g denotes the predictable growth for assets-in-place.

ESTIMATED VALUE ACCORDING TO BASIC (BENCHMARK) MODEL

The benchmark model $\hat{V}_t$ is established in three versions, based on different time horizons. The model has a one to three year time horizon (Frankel & Lee, 1998). Using three versions can also serve as a sensitivity check of the benchmark model.

The following forms of $\hat{V}_t$ are calculated:

$$\hat{V}_t^1 = \hat{BV}_t + \frac{(R\hat{O}E_t - r_e)}{(1+r_e)} \cdot \hat{BV}_t + \frac{(R\hat{O}E_t - r_e)}{(1+r_e) \cdot (r_e - g)} \cdot \hat{BV}_t \quad \textbf{(4.5a)}$$

$$\hat{V}_t^2 = \hat{BV}_t + \frac{(R\hat{O}E_t - r_e)}{(1+r_e)} \cdot \hat{BV}_t + \frac{(R\hat{O}E_{t+1} - r_e)}{(1+r_e)^2} \cdot \hat{BV}_{t+1} + \frac{(R\hat{O}E_{t+1} - r_e)}{(1+r_e)^2 \cdot (r_e - g)} \cdot \hat{BV}_{t+1} \quad \textbf{(4.5b)}$$

$$\hat{V}_t^3 = \hat{BV}_t + \frac{(R\hat{O}E_t - r_e)}{(1+r_e)} \cdot \hat{BV}_t + \frac{(R\hat{O}E_{t+1} - r_e)}{(1+r_e)^2} \cdot \hat{BV}_{t+1} + \frac{(R\hat{O}E_{t-2} - r_e)}{(1+r_e)^3} \cdot \hat{BV}_{t+2} + \frac{(R\hat{O}E_{t+2} - r_e)}{(1+r_e)^3 \cdot (r_e - g)} \cdot \hat{BV}_{t-2} \qquad \textbf{(4.5c)}$$

The formulas are in nominal terms. Hence the g (expected growth) denotes growth due to inflation. A reasonable estimate on the average inflation in Norway 1993-2005 is 2.0 % (Jonassen & Nordbø, 2006; SSB (Statistics Norway), 2007). Growth because of increased future profitability if electricity prices become higher is held outside the model.

The introduction of future book values also calls for an estimation of dividend pay-out ratio used in conjunction with the clean surplus relation (CSR). CSR is the fundamental assumption for the Feltham & Ohlson (1995) approach to valuation:

$$BV_{t-1} = BV_t + NI_{t+1} - d_{t-1} \ \textbf{(CSR)} \qquad \textbf{(4.6)}$$

in which d is the dividend. CSR is a constraint on book-keeping (corresponding to "kongruensprinsippet" in the Norwegian Accounting Act of July 17^{th} 1998 no 56 (§4-3)). The dividend payout ratio (k) is assumed to be constant and is obtained as the average of the three previous fiscal years ($\frac{d}{NI}$). This gives:

$$BV_{t-1} = BV_t + NI_{t+1} - d_{t-1} = BV_t + (1-k) \cdot NI_{t-1} = \left[1 + (1-k) \cdot ROE_{t-1}\right] \cdot BV_t \qquad \textbf{(4.7a)}$$

$$BV_{t-2} = \left[1 + (1-k) \cdot ROE_{t-1}\right] \cdot \left[1 + (1-k) \cdot ROE_{t+2}\right] \cdot BV_t \qquad \textbf{(4.7b)}$$

Equations **(4.5)-(4.7)** represent one to three period models for value estimation in the study. This completes the design of the basic benchmark model (traditional valuation) for the value of electricity generation utilities involved in mergers or acquisition after deregulation in 1991. The benchmark model is not expected to explain a lot of the variation in company values. A comprehensive study performed by Dechow, Hutton, & Sloan (1999) on U.S data 1976 – 1995 resulted in a R^2 of 0.40 as mean, and a study by Begley, Chamberlain, Li, & Lundholm (2006) of the U.S. banking industry 1991 – 2000 provided a R^2 of 0.28. An examination of U.K. firms 1990 – 1994 by Stark & Thomas (1998) yielded a R^2 of 0.40. Even so it will be interesting to see how well the model performs in the important electric utility industry of Norway.

4.2.2 "Real option" variables

As stated, the main purpose of this paper is to test whether the introduction of "real option variables" provide an explanation of the residual variance of transaction values of electric utilities. The underlying assumption is then that there are factors beyond earnings that can enhance the explanation of market value. The objective is to include independent variables that can be used as proxies for the level of opportunities (options) for a company involved in a transaction. The following shows an operationalization of two hypotheses derived from real option theory.

IMPROVEMENT AND EXTENSION POTENTIAL

The performance of hydro-electric power plants has improved during recent years. In particular turbine efficiency has significantly improved. Increased knowledge also exists related to expansion of existing plants, including increased inflow to the reservoirs (such projects may require revision of licences (NVE, 2006b)). NVE has surveyed this potential and estimated it to almost 12 TWh (NVE (Norwegian Water Resources and Energy Directorate), 2006). Much of this is so called winter power, making it particularly interesting in the Nordic context. Therefore it would be appropriate to include proxy variables for the possibility of improving and expanding existing plants of the companies involved in this analysis. Favourable developments in electricity prices and regulatory policies would make such investments profitable. Growth options stand forth as a prominent candidate from the real option literature (Kester, 1984).

The average age of existing plants could serve as a proxy for the growth potential concerning improvements and expansions of existing plants. Necessary data is, however, unavailable. Hence existing capacity serves as a proxy for extension and improvement potential. Existing capacity measured in GWh is obtained from the database of Europower AS. The level of GWh therefore serves as a way of measuring the expansion and improvement potential (growth options) not captured by earnings. This discussion suggests the following hypothesis:

> **Hypothesis 1**: Keeping the benchmark value fixed, transaction value increases in production capacity.

SMALL SCALE HYDRO-ELECTRIC POWER PLANT OPPORTUNITIES

Over the last decade a low level of investments in new capacity has been reported. The demand for more electricity generation capacity is widely acknowledged. New large scale hydro power projects are infeasible because of environmental concerns (EBL (The Electricity Industry Association), 2006). However, small scale hydroelectric power potential is being considered. In a report from NVE (Norwegian

Water Resources and Energy Directorate) (2004), the total estimated potential of small scale hydro-electric power plants (below 10 MW capacity) is in total 25 TWh[8] with investment costs less than 3 NOK/kWh. Furthermore, the estimated potential with investment cost between 3 and 5 NOK/kWh amounts to approx 7 TWH. Hence a total of 32 TWh may be available - if prices and regulation are favourable.

NVE has developed a model based on digital maps, hydrological conditions and digital costs of surveying the hydroelectric potential for every municipality (NVE, 2007). The market potential can be estimated as well. A company operating in a region with considerable potential should have a higher option value compared to companies located in flat areas. The survey of NVE (2007) reveals considerable differences in potential between Western and parts of Northern Norway compared to central and Eastern Norway.

Growth potential is set as a variable defined as the potential in GWh in the natural surrounding municipalities of the company with the highest cost limitation as stated in the NVE report. It is difficult to define "natural surrounding" in a simple way. This cannot be the potential in municipalities within some distance, since a number of factors are involved, such as geographical constraints and the number of nearby competitors. Some of the companies in the study also operate in larger re-

[8] Such numbers of the capacity in TWh is based on years with normal precipitation (middle years). Because of the volatility in amount of precipitation there are large differences from "dry" years to "wet" years.

gional areas, not just locally. This also complicates defining what can be termed the "natural surroundings" of an enterprise. A possible way is to make an individual assessment of each transaction and include the potential for the nearby municipalities, sometimes the whole county. But it seems more convenient to use a dummy variable to cover this aspect, denoting whether the company is located in an area with significant potential for new small scale power plants or not. This classification is presented in appendix 1.

This discussion then suggests the following hypothesis:

> **Hypothesis 2:** The transaction value of companies located in areas with more generation development potential will be higher than those located in low development potential localities.

To control the results of the above-mentioned hypotheses for the impact of other factors, the analysis includes the test of some additional explanatory variables. To control a company by owning more than 50 % of the shares is often associated with extra value, a control premium. Therefore an additional test concerning whether the transaction involves the aspect of control is included. The test considers whether there is a higher value when more than 50 % of the shares are involved in the transaction.

The value of generation assets is naturally connected to expectations of future electricity prices. Hence a logical test concerns whether the level of forward prices affects the value. By including the average forward price of the longest contracts traded at Nord Pool (three year ahead yearly contracts and two years ahead tertial (from 2005 quarterly contracts), one can test this aspect. A higher level of forward prices would presumably be linked to higher transaction values.

There has also been a discussion of whether public owners of generation assets have sold shares in generation companies too cheaply compared to private sellers. The data make it possible to test whether the transaction value of companies sold by private investors exceed the value held by public owners.

4.3 DATA, EMPIRICAL RESULTS AND ANALYSIS

Dealing with unlisted companies makes it hard to obtain accurate data. The data of the transactions in this study is obtained from the database of Europower AS (a privately owned consulting firm monitoring the industry). As far as the author knows, no alternative source for information of the relevant transactions exists. The information is obtained during the post deregulation period (1991-2006) based on public disclosures. This concerns the date of transaction, object of transaction, transaction value, and the size of generation capacity at the time of the transaction as well as some supplemental information.

In the post-deregulation period from 1991 to 2006, 431 transactions have taken place involving large blocks of shares of electricity generators, vertically integrated companies and transmission companies, involving both domestic and foreign private investors. The distribution of transactions in the period is shown in Figure 4.2. The activity of mergers and acquisitions peaked around 2000.

The accounting data needed to calculate benchmark values is obtained from the central register of companies, the Brønnøysund Register. This centre is a government body under the Norwegian Ministry of Trade and Industry, and consists of several different national computerised registers.

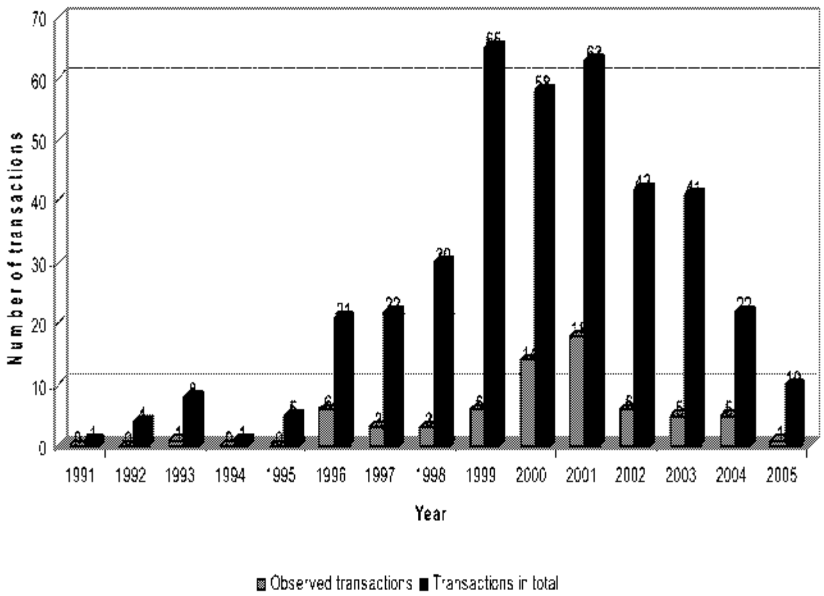

Figure 4.2: The distribution of transactions after deregulation in 1991, both in total and included in the analysis.

THE FILTRATION PROCESS

The database of Europower AS consists of 431 transactions from December 1991 to June 2006. Many of these transactions concerns companies dealing with transmission, distribution and wholesale. Transactions in which no or very small generation assets are involved are omitted (below 40 GWh yearly capacity). Of the remaining transactions some are excluded owing to incomplete data. Some of the plants involved in transactions were not legal entities, making it impossible to obtain relevant accounting information. This leads to a final sample size of 65 transactions (from December 1993 to November 2005), involving 32 different companies (see appendix 1). Descriptive statistics of these transactions are given in Table 4.1.

According to Norwegian standards the figures reveal that the sample consists of enterprises with high average transaction values. This is partly because Hafslund ASA as a large company (and also a company operating in several industries) is included in 11 of the 65 transactions. Because of low income, and high dividend payout (as in Hafslund ASA), the average payout ratio is as high as one on average. The statistics also show that the industry has relatively high book values of equity ratios and low *ROE*. (Bye et al., 2001).

The sample should prove sufficiently representative. Even if a criterion that the firm is involved in a transaction, there should be no particular concern relating to possible bias. According to NVE there was at the end of 2005, a total of 177 companies[9] possessing a licence for electricity generation (NVE, 2006a). The sample consists of all kinds of companies such as the larger ones (Hafslund ASA, Agder Energi AS, Trondheim Energiverk AS) as well as medium-sized and small producers. All parts of the country are represented (14 out of 19 counties).

[9] The corresponding number in 2000 was 160.

Table 4.1: Descriptive statistics of the companies and transactions in the analysis.

Variable	Number of observations[10]	Average	Median	Q3	Q1
Transaction value (mill.)	59	2.225	1.192	2.987	459
k (DIV/NI)	57	0.99	0.64	1.37	0.13
ROE (three years before transaction year)	148	0.03	0.06	0.12	0.01
GWh	65	1211	558	1560	219
Ownership shares traded	61	29.3 %	18.6 %	42,8 %	9.3 %
Equity ratio	59	0.56	0.45	0.70	0.34
Price/kWh (NOK)	54	2.37	2.30	2.77	1.77
Price/Book	59	2.72	2.22	2.96	1.42

The data enable the development of two models explaining the transaction value of the electric utilities (*TV*). The first version is to use one to three factor versions of the residual income model:

MODEL 1

$$TV_i = \hat{V}^1_{it} = \hat{BV}_{it} + \frac{(\hat{ROE}_{it+1} - r_e)}{(1+r_e)} \cdot \hat{BV}_{it} + \frac{(\hat{ROE}_{it-1} - r_e)}{(1+r_e) \cdot (r_e - g)} \cdot \hat{BV}_{it} \quad \textbf{(4.8a)}$$

$$TV_i = \hat{V}^2_{it} = \hat{BV}_{it} + \frac{(\hat{ROE}_{it-1} - r_e)}{(1+r_e)} \cdot \hat{BV}_{it} + \frac{(\hat{ROE}_{it-2} - r_e)}{(1+r_e)^2} \cdot \hat{BV}_{it-1} + \frac{(\hat{ROE}_{it-2} - r_e)}{(1+r_e)^2 \cdot (r_e - g)} \cdot \hat{BV}_{it-1} \quad \textbf{(4.8b)}$$

$$TV_i = \hat{V}^3_{it} = \hat{BV}_{it} + \frac{(\hat{ROE}_{it-1} - r_e)}{(1+r_e)} \cdot \hat{BV}_{it} + \frac{(\hat{ROE}_{it-2} - r_e)}{(1+r_e)^2} \cdot \hat{BV}_{it+1} + \frac{(\hat{ROE}_{t+3} - r_e)}{(1+r_e)^3} \cdot \hat{BV}_{it+2} + \frac{(\hat{ROE}_{it+3} - r_e)}{(1+r_e)^3 \cdot (r_e - g)} \cdot \hat{BV}_{it+2} \quad \textbf{(4.8c)}$$

This represents the basic benchmark model for estimating the value of electric utility companies based on the residual income model with different timing of the terminal value, and recent accounting information. This approach distinguishes between a one-period, a two-period and a three-period model.

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[10] The number of observations differs from 65 because of some incomplete data. The data of *ROE* concerns all available firm years up to three years before the transaction.

MODEL 2

Model 2 introduces additional independent variables derived from real option theory. This is done to test the incremental explanatory power. The regression equations are derived as follows:

$$TV_i = \beta_0 + \beta_1 \hat{V}^1_{it} + \beta_2 GWh_i + \beta_3 PNP_i + \varepsilon_i \qquad \textbf{(4.9a)}$$

$$TV_i = \beta_0 + \beta_1 \hat{V}^2_{it} + \beta_2 GWh_i + \beta_3 PNP_i + \varepsilon_i \qquad \textbf{(4.9b)}$$

$$TV_i = \beta_0 + \beta_1 \hat{V}^3_{it} + \beta_2 GWh_i + \beta_3 PNP_i + \varepsilon_i \qquad \textbf{(4.9c)}$$

in which GWh denotes the existing capacity of generation in GWh (yearly, middle production) and *PNP* denotes the potential of new plants in the area.

A version of this model with the price/book ratio as dependant variable avoids the problems with heteroschedasticy. By dividing equation **(4.9a)** with book value, one derives the following regression equation:

$$\frac{TV}{BV_i} = \beta_0 \cdot BV^{-1} + \beta_1 \frac{\hat{V}^1}{BV_{it}} + \beta_2 \frac{GWh}{BV_i} + \beta_3 \frac{PNP}{BV_i} + \varepsilon_i \qquad \textbf{(4.10a)}$$

which represents a relative version of model 2, though with no constant term. A version with a constant term becomes:

$$\frac{TV}{BV_i} = \chi_0 + \chi_1 \frac{\hat{V}^1}{BV_{it}} + \chi_2 \frac{GWh}{BV_i} + \chi_3 \frac{PNP}{BV_i} + \varepsilon_i \qquad \textbf{(4.10b)}$$

4.3.1 Empirical results and analysis

The results of the empirical test of the three versions of the residual income benchmark model (model 1) are found in Table **4.2** (The regressions estimated are: $TV_i = \beta_0 + \beta_1 \cdot \hat{V}^n$, where n refers to 1, 2 or 3 factor version). The table shows that all three versions of the model essentially yield the same results. The model is well established in the data with significant results at conventional levels. The results are consistent with earlier studies on U.S. and U.K. data (Dechow et al., 1999; Stark & Thomas, 1998). Because the results of the three versions of the model are similar there will be a focus on the model with the shortest time horizon (V1, equation **(4.7a)**) in the following.

Table 4.2: Results of regression analysis of the three benchmark residual income valuation models.

	Number of observations	R^2	Adjusted R^2	F-value	Sig.
Equation **(4.8a)**	58	0.427	0.417	42.405	0.000
Equation **(4.8b)**	58	0.380	0.369	34.964	0.000
Equation **(4.8c)**	58	0.352	0.340	30.932	0.000

The next step is to compare **(4.8a)** with **(4.9a)** and analyze the correlation between the independent variables. The purpose is to include the variables capturing option values and to test whether this has an incremental explanatory effect. This is done by including the generation capacity (*GWh*) and the potential in the surrounding area (*PNP*). Defining the surrounding area for a given company is extremely difficult, hence *PNP* is defined as a dummy variable where the value is 1 if the company operates in an area with substantial potential and 0 elsewhere. The criteria for having a substantial potential is that the company operates in a county with more than 250 GWH potential (according to NVE). The classification is rendered in appendix 1. The counties' potential for small scale plants is shown as well.

The results of the regression analyses are presented in Table 4.3. Several versions are available to examine the data more profoundly, including a version with only GWh as an independent variable. The findings show a significant improvement in explanation of 100 % from **(4.8a)** to **(4.9a)**. The adjusted R squared rises from 0.417 to 0.839 (100 % increase)[11].

While both the V1 and GWh variable remain highly significant, this does not apply to the PNP variable. To test whether there is a significant empirical difference between model 1 (M1) and model 2 (M2) the following F-value was estimated (*m* is number of linear restrictions (Gujarati, 2003)):

$$F = \frac{(RSS_{\text{mod}\,el1} - RSS_{\text{mod}\,el2})/m}{RSS_{\text{mod}\,el2}/(n-k)} = \frac{(2.5\cdot 10^{14} - 6.4\cdot 10^{13})/2}{6.4\cdot 10^{13}/55} = 79.897$$

This value is significant at a 1 % level.

[11] The DW indicator becomes low for the two latter versions. Since the data does not represent a pure time series, it is difficult to interpret what the DW actually measures.

Table 4.3: Regression estimation based on different independent variables:

		Variable						
		Constant	**$\hat{V1}$**	**GWH**	**PNP**	**R^2**	**Adj. R^2**	**DW**
Model 1	**Unstandardized coefficient**	1596678	0.359			0.427	0.417	2.058
	T-value	5.612	6.512					
	Sig.	0.000	0.000					
Model 2	**Unstandardized coefficient**	242450	0.186	1254	259042	0.848	0.839	1.689
	T-value	0.531	5.010	12.175	0.574			
	Sig.	0.598	0.000	0.000	0.568			
	Unstandardized coefficient	505830		1491		0.766	0.762	1.582
	T-value	2.383		13.666				
	Sig.	0.021		0.000				

No multicollinearity was detected ($VIF < 2$ for all independent variables). The null hypothesis of homoschedasticy could be rejected at the 5 % level when using the Breusch-Pagan/Cook-Weisberg test with regard to model 2. The presence of homoschedasticy diverts the focus to the relative version of the model.

Table 4.4: Correlation matrix (Pearson correlation) of the independent variables in model 2 (equation (4.8a)).

Variable	$\hat{V}1$	GWh	PNP
$\hat{V}1$	1		
GWh	0.430*	1	
PNP	-0.502*	-0.466*	1

* Correlation is significant at the 0.01 level (2-tailed).

The result of estimating equation **(4.10)** where the price/book ratio is the dependant variable is rendered in Table 4.5, both with and without a constant term. Also concerning this model no multicollinearity was detected ($VIF < 2$ for all independent variables see footnote 13 and appendix 3b). There is still some heteroschedasticy, but not as much as in model 1. The plot of the standardized residuals against predicted values is shown in appendix 3a.

Table 4.5: The regression estimated (equation (4.10a)) is: $\frac{TV}{BV_i} = \beta_0 \cdot BV^{-1} + \beta_1 \frac{\hat{V}}{BV_{it}} + \beta_2 \frac{GWh}{BV_i} + \beta_3 \frac{PNP}{BV_i} + \varepsilon_i$ and a version with traditional constant term (4.10b)

		Variable						
		Con-stant	$Book^{-1}$	^ V1/ Book	GWH/ Book	PNP/ Book	R^2	Adj. R^2
Equation 4..10a	Unstandardized coefficient		-46725	0.218	1231	229523	0.773	0.755
	T-value		-0.928	4.859	7.124	3.182		
	Sig.		0.358	0.000	0.000	0.003		
Equation 4.10b	Unstandardized coefficient	1.207		0.154	776	144.731	0.415	0.380
	T-value	3.432		3.404	4.358	2.375		
	Sig.	0.001		0.001	0.000	0.021		

The models are well established in the data, even though the adjusted R squares cannot be compared. The results imply that the price/book ratio is explained by the relationship between conventional valuation and the book value of equity, but also significantly by the relationship between generation capacity and the book value of equity. In addition there is a part that is explained by the inverse of book value of equity for companies located in areas with high potential for growth.

Table 4.6: Correlation matrix (Pearson correlation) of the independent variables (equation (4.10)).

Variable	**$\hat{V}1$/Book**	**GWh/Book**	**PNP/Book**
$\hat{V}1$/Book	1		
GWh/Book	-0.766*[12]	1	
PNP/Book	0.119	0.097	1

* Correlation is significant at the 0.01 level (2-tailed).

Hence it is a significant increase in explanation by including the additional variables compared to conventional valuation of the price/book relationship. In this version of the model also the PNP/Book variable is significant at a 2 % level (1-tailed test[13]). The previous discussion of the variables' connection to real option

[12] The strong negative correlation is caused by one extreme observation. See appendix 3b. If that observation is ignored the correlation becomes 0.017 (which is insignificant).
[13] For 1-tailed tests the level of significance shall be divided with 2.

theory and real option thinking, shows, therefore the relevance of real options in order to deepen the understanding of value and value components.

ADDITIONAL CONTROLS AND ANALYSIS

The analysis shows that there is a significant increase in value explanation by including the variables in line with real option theory. In total this yields an incremental explanation of 100 % (from adjusted R squared of 0.417 to 0.839, equation **(4.8a)** compared to equation **(4.9a)**).

There are of course a number of additional factors influencing the value and the price/book ratio that have to be considered when assessing the results. Intangible assets such as human capital and brand equity are not particularly relevant to this study. Electricity is a homogenous product and the industry has, to a large extent, fairly equal access to key expertice for managing power generation. However, there are other factors, including the phenomena of mergers and acquisitions, which should be included in this discussion.

The value of companies being acquired tends to exceed market value. This can have many different causes such as the benefits of control. New owners may possess certain skills or information to make some advantages of the assets compared to previous owners (synergy) and hence be willing to pay a premium (Tirole, 2007). The data for each transaction indicates whether the transaction involves the aspect of control or not, i.e. whether the transaction concerns more than 50 % of the shares of the company. An introduction of such a variable in equation **(4.8)**, **(4.9)** or **(4.10)** does not show any significance.

Other aspects affecting value is associated with various macroeconomic parameters such as interest rate, inflation and the general economic situation (Schleifer & Vishny, 1992). These factors are too complicated to be included in the analysis.

However, the impact of the general forward price of electricity can be tested. The average forward price of the longest contracts traded at Nord Pool can serve as a proxy for the level of expected long term prices. But this independent variable also fails to contribute in explaining the transaction values.

Yet another concern relates to the GWh variable and the potential link to the market power issue. Electricity markets are vulnerable to market power (Borenstein & Bushnell, 1999; Newbery, 1995; Skaar & Sørgard, 2007). This may in one way or another affect the transaction values observed in his study. In the Norwegian context the state-owned company Statkraft SF controls more than 30 % of generation capacity. Only one of the transactions in the sample concerns an acquired company with more the 3 % of total generation (Agder Energi AS with 9.8 TWh generation of a total 120 TWh i.e. approximately 8.3 %). Hence, this aspect should not have any particularly impact on the results.

The age of the plants could be a possible variable that affects value. One should though bear in mind that hydropower plant assets have some different characteristics compared to other generation assets. When hydropower plants are constructed, major parts of the assets, as magazine reservoirs and tunnels, are close to infinite living. The issue of age will hence not have the same impact as would be the case for thermal power plants or wind mill parks.

Finally the results are tested for whether a seller being public affects transaction value. There is, however, no significant impact of this variable.

4.4 CONCLUSIONS, IMPLICATIONS AND LIMITATIONS

It is impossible to comment on all potential factors affecting the transaction values studied in this paper. Nevertheless, the models presented support the theory that independent variables based on real option reasoning seem to be omitted variables in model 1. However, the above discussion offers other possible explanations. It is hard to explain and understand values of complex companies in the generation industry.

Regarding the PNP variable there should also be some additional remarks. As shown in appendix 1, there are only three companies classified as located in flat areas. One of these, Hafslund ASA, is involved in 8 of the transactions. One should bear in mind that this company is characterized by possessing river plants and not reservoirs. River plants do not provide the kind of flexibility that is associated with reservoirs; that is the ability to generate relatively more in peak price periods (in winter). The GWh capacity of a river plant is hence less valuable than reservoir plants. Therefore, it is possible that the PNP variable is capturing this aspect rather than location.

The sample of this study shows that the industry is characterized by high book values and rather low equity profitability. Therefore the three different versions of the RI model do not vary much indeed. The residual income valuation model is suitable for this kind of analysis in which the purpose is to examine and explain the market value of companies. When the unit of analysis is firm level, it is advantageous to make use of accounting figures. In the post-deregulation period a restructuring of ownership occurred in the industry with a peak of transactions in 1999-2001. The activity actually has decreased considerably during recent years. This may be linked to the significant rises in electricity prices from autumn 2002. The uncertainty caused by several aspects such as rising demand without corresponding increase in supply, Co_2 allowances, the possibility of the introduction of green certificates and the unsettled issue of the home fall institute makes owners of hydro-electric power hesitant to sell. This seems easy to understand of course bearing in mind the current period of highly volatile prices. One runs the risk of selling at too low a price (see appendix 2).

The residual income valuation model of Feltham & Ohlson (1995) explains approximately 40 % of the variation in the company values in the generation industry. The results show that secondary data of option components do contribute in explaining transaction values of electric utilities involved in mergers or acquisitions over and above the explanatory power provided by the residual income valuation framework. The incremental explanation is approximately 100 %, as the adjusted R squared rises from 0.417 to 0.839 moving from model 1 to model 2.

Despite shortcomings and limitations, the findings therefore provide some support for the real option approach for understanding business value in this industry. The econometric discussion leads to a focus on the relative versions of the model in which the findings are most convincing. The analysis shows how the price/book ratio can be explained beyond what is captured by conventional valuation techniques.

These findings may be used to argue that option aspects do affect the value beyond that captured by traditional valuation based on earnings (cash flow, dividend, residual income). Therefore, one should take account of option components in valuation of companies. With ever more studies of real option applications, the real option framework enables researchers as well as consultants to assess the business value beyond assets-in-place. This may be performed more transparently than just assuming an expected growth in cash flow/dividend/ residual income without a solid basis for a growth estimate.

Furthermore, this has implications for public and private owners of generation assets as well as advisors involved in negotiating sales of electricity utilities. This analysis enhances the understanding of value of generation assets given encouragement to using the real option tool to quantify the value beyond assets-in-place more accurately. By incorporating option values one can improve the estimation of business value of generating companies. This is important for owners in order to monitor their values. Traditional valuation techniques should be supplemented by real option analysis of the value captured by future opportunities and active management (Trigeorgis, 1993b).

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APPENDIX 1

List of companies involved in the transactions included in the analysis (year of transaction in brackets). Some have been involved in several transactions during the same year.

The classification of being in an area with high (1) or low (0) potential regarding new hydro-electric power plants is also indicated.

Company	County	County potential (GWh)
A/S Oppdal Everk (1996,2004) (1)	Sør-Trøndelag	562
Agder Energi AS (2001) (1)	Vest-Agder	707
Arendals Fossekompani ASA (1996,2003) (1)	Øst-Agder	476
EAB Produksjon AS (Energiselskapet Asker og Bærum) (1999) (0)	Akershus	0
Eastern Norge Svartisen AS (2003) (1)	Nordland	3862
Elkem ASA (2005) (1)		
Finnmark energiverk AS (1993) (1)	Finnmark	542
Firdakraft AS (2000) (1)	Sogn og Fjordane	5285
Hafslund ASA (1996,1997,1998,1999,2000,2001,2002,2003) (0)		
Hedmark Energi AS (2001) (1)	Hedmark	293
Hellefoss Kraft AS (2002) (1)	Buskerud	658
Herlandsfoss Kraftverk AS (2001) (1)	Horda-land	3993
Istad Kraft AS (2000,2001) (1)	Møre og Romsdal	2696
NEAS (Nordmøre Energiverk) (2001) (1)	Møre og Romsdal	2696
Nordkraft AS (2000) (1)	Nordland	3892
Nyset-Steggje kraft AS (2000) (1)	Sogn og Fjordane	5285
Oppland Energi AS (2001) (1)	Oppland	939
Oppland Energiverk AS (2001) (1)	Oppland	939

Company	County	County potential (GWh)
Salten Kraftsamband AS (2004) (1)	Nordland	3862
Sogn og fjordane Energi AS (2001) (1)	Sogn og Fjordane	5285
Sognekraft AS (1998,1999) (1)	Sogn og Fjordane	5285
Sunnfjord Energi AS (1997,1999,2000) (1)	Sogn og Fjordane	5285
Sunnhordland Kraftlag AS (2000) (1)	Horda-land	3693
Tafjord Kraft AS (1999,2001) (1)	Møre og Romsdal	2696
Vittingfoss Kraftstasjon AS (2004) (0)	Vestfold	74
Voss og Omland Energiverk AS (2002) (1)	Horda-land	3693
Østerdalen Kraftproduksjon AS (2003) (1)	Hedmark	293

APPENDIX 2

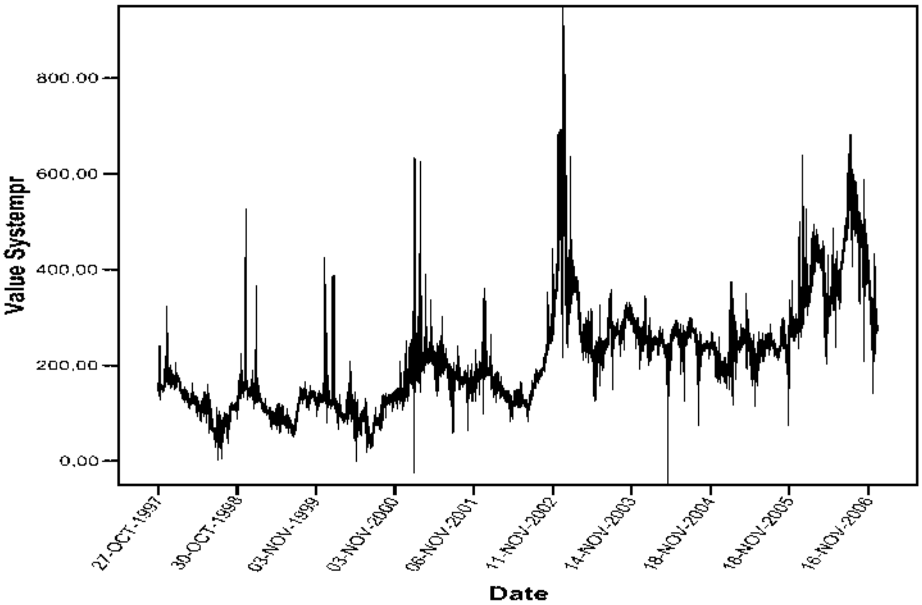

Figure 4.3: System price (spot price) development 27th October 1997 – 29th December 2006.

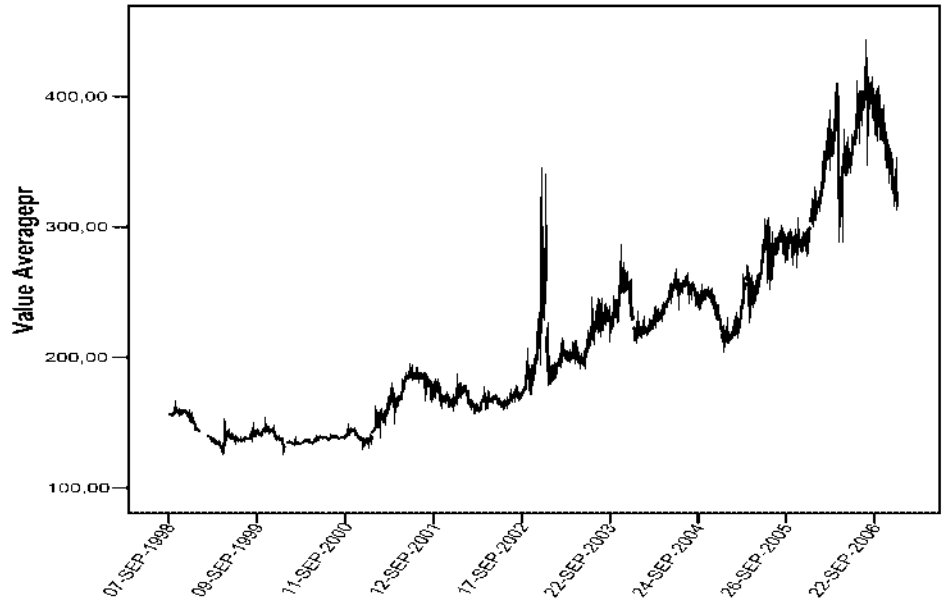

Figure 4.4: Development of average forward price (øre/kWh / NOK/MWh) 7th September 1998 – 27th December 2006. Average forward price is defined as the average of the longest forward contracts traded at Nord Pool. These consist of the three year ahead yearly contracts and the two year ahead tertial contracts (up to 2004, from 2005 quarterly contracts). All together this consists of 9/11 contracts.

APPENDIX 3A

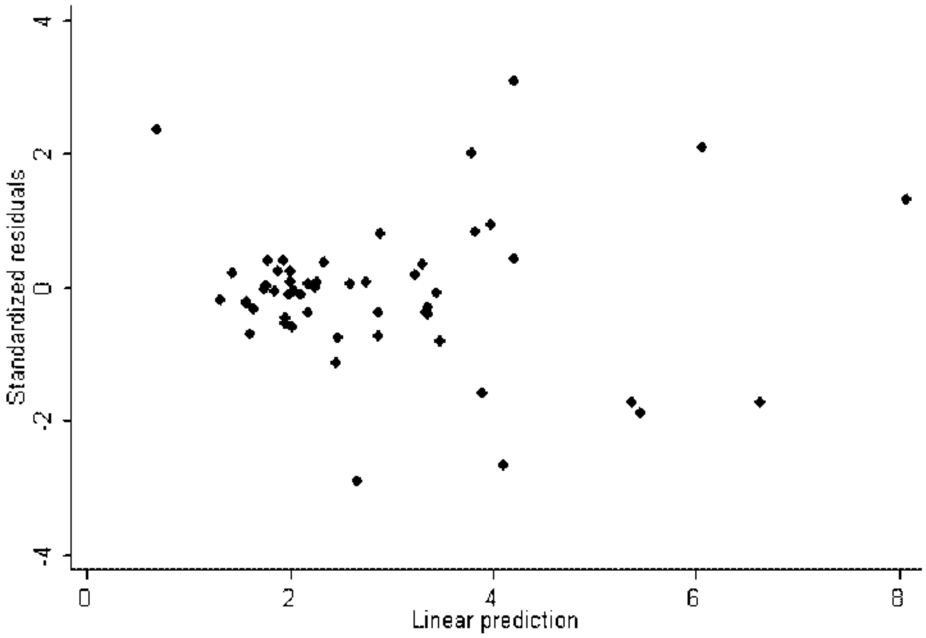

Figure 4.5: Plot of standardized residuals versus predicted value (relative version, model 2, equation (4.10a)).

APPENDIX 3B

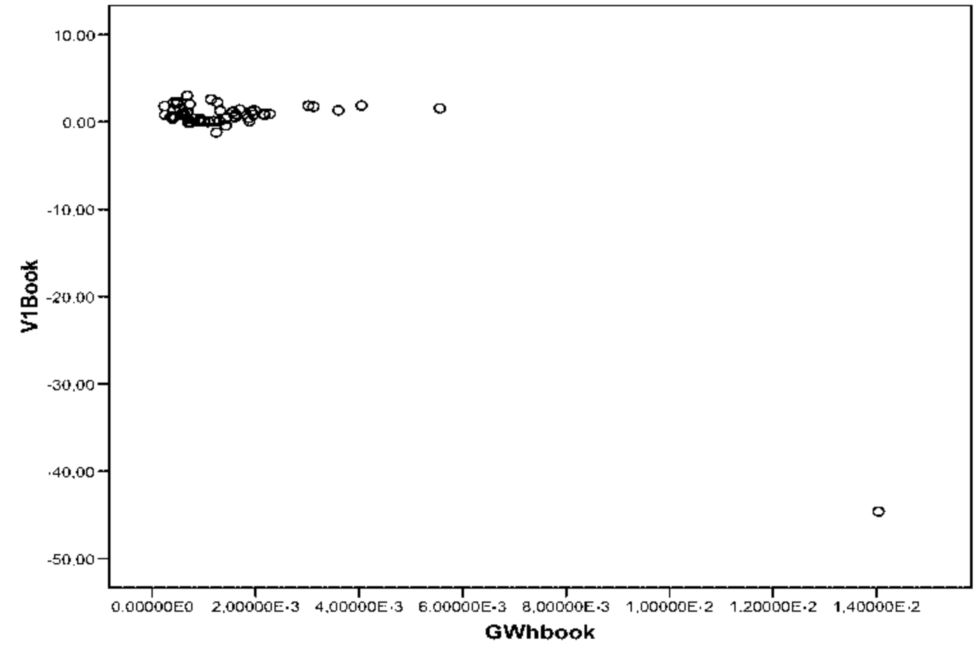

Figure 4.6: Scatterplot of the GWh/Book variable with the V1/book variable in equation (4.10a) and (4.10b).

CHAPTER 5 (PAPER 3): A REAL OPTION ANALYSIS OF INVESTMENTS IN HYDROPOWER – THE CASE OF NORWAY[1]

Abstract

This paper presents a valuation study of hydropower investment opportunities in the Norwegian context. According to NVE (Norwegian Water Resources and Energy Directorate, the regulator) there is an energy potential of 39 TWh has not yet been developed (generation in a normal year is approximately 120 TWh).

By using the conceptual real option framework s Dixit & Pindyck (1994) one can estimate the value of investment opportunities to NOK 11 million/GWh (EUR 1.4 million/GWh). Furthermore the optimal trigger price for initiating an investment based on electricity forward prices is calculated to NOK 0.32/kWh (EUR 0.04/kWh). The analysis shows consistency between real option theory and aggregate investment behaviour in Norwegian hydropower.

Key words: Real Options, Irreversible Investments, Hydropower

[1] A version of this chapter is published in *Energy Policy* (35) 11/2007 pp. 5901-5908.

5.1 INTRODUCTION

Norway is considered as one of the pioneers concerning deregulation of the electricity market by implementing the Energy Act ("Law of production, transformation, transmission, sale, distribution and use etc." of 29th June 1990 No. 50) in 1991, making electricity a competitive commodity (Al-Sunaidy & Green, 2006). This opened up for a profound restructuring of the industry, like separation of generation and transmission and mergers and acquisitions of companies. An implication of this liberalisation was that both prices and investment decisions were set by the market (Nord Pool was established in 1991, but became a fully integrated Nordic power exchange for all the Nordic countries in 2000). There have therefore become considerable challenges in the decisions and timing of new investments in the uncertain environment of the sector, like highly volatile electricity prices.

The investment level in more hydropower capacity has been low in the last decade (Figure 5.1). Due to significant increase in electricity prices, there is a focus on the possibility of introducing more electricity generation capacity in Norway. Large scale hydropower projects is reckoned as passé, but there are an increasingly focus on small scale hydropower plants (99 % of Norwegian electricity generation is at present hydro). In recent reports from the Ministry of Petroleum and Energy (2006) and NVE (Norwegian Water Resources and Energy Directorate, the regulator) (2006), the potential of small scale hydropower plants and improvements and expansion of existing plants is estimated to 39 TWh in total (Figure 5.2). This must be viewed as significant even if only parts of this potential is realistic to develop within the next decade (NVE, 2004). (The numbers of the capacity in TWh is based on years with normal precipitation (middle years). Because of the volatility in amount of precipitation there are large differences from "dry" years to "wet" years. This is referred to as a "theoretical potential (The Ministry of Petroleum and Energy, 2006). The potential is separated in 23.8 TWh concerning new small scale hydropower plants and 15.2 TWh in improvements and extensions of existing plants).

However, there is definitely relevant to ask why not more projects have been initiated earlier. The major explanation is that NVE has limited the availability of profitable projects (Bye, von der Fehr, Riis, & Sørgard, 2003). When prices have been relatively low, there have been few projects with sufficiently low costs to be implemented. But this does not give the overall explanation of the low level of investments (Bye & Hope, 2006). There are a number of factors that influence expectations of electricity prices, making future profitability highly uncertain in this industry and hence hold back investments. This relationship has always been known intuitively, but with the introduction of real option theory one has a tool for calculation and more precisely measure the impact uncertainty have on aggregate investment behaviour. This paper applies real option theory both to assess the value of investment opportunities and to use this powerful tool to find the relation between price level of electricity and optimal timing of investment decisions. The value of flexibility, as for instance growth opportunities, is incorporated in a real option analysis, which by a number of scientists has been pointed out as a weakness of traditional NPV analysis (Berkovitch & Israel, 2004; Brennan & Schwartz, 1986; Myers, 1987; Pindyck, 1991). These techniques were conventionally developed to value "passive" financial instruments as bonds and stocks (Trigeorgis, 1996). Some therefore call NPV a "naive rool" (Milne & Whalley, 2000) when applied to project and business valuation. Ross (1995) even says that "optionality is ubiquitous and unavoidable" concerning valuation issues. Investments in generation assets are irreversible. To understand aggregate investment behaviour one has to consider the opportunity cost that is involved. This aspect contributes to explain the aggregate investment behaviour of hesitance despite an emerging shortage of generation capacity.

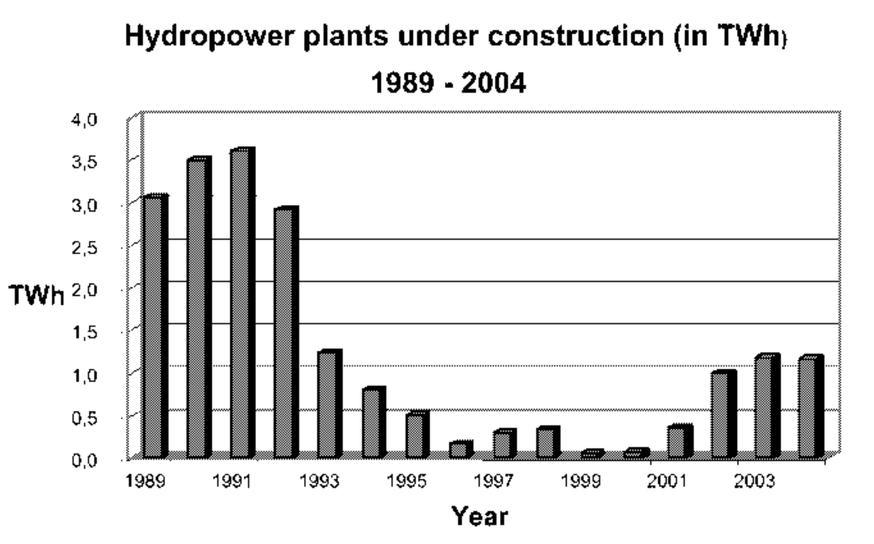

Figure 5.1: Hydropower plants under construction 1989 – 2004 (SSB (Statistics Norway), 2006).

The remainder of the paper is organised as follows: Section 2: An introduction of the theoretical framework of Dixit & Pindyck (1994) and a discussion of the relevance of this model on investment opportunities in Norwegian hydropower. Section 3: The application of this model, including a discussion of the input parameters and the numerical analysis. Section 4 draws the conclusions and implications.

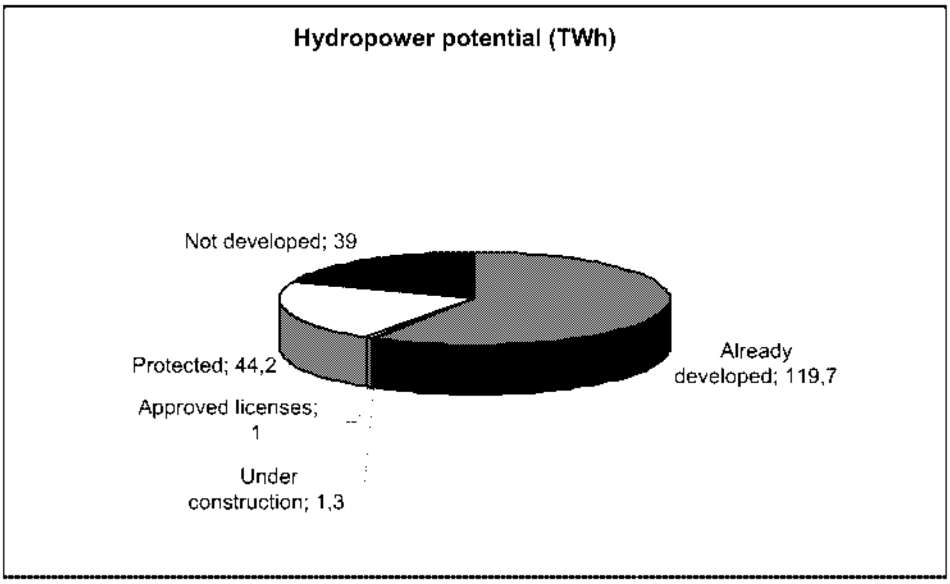

Figure 5.2: Hydropower potential in TWh (NVE, 2006; The Ministry of Petroleum and Energy, 2006).

5.2 METHODOLOGY

The theoretical platform is the model framework of Dixit & Pindyck (1994). When a firm decides to make an irreversible investment, it exercises an option. The lost option value is an opportunity cost that must be included in the assessment of the investment cost which is an essential feature in explaining the lack of consistency between neoclassical investment theory and actual investment behaviour (Pindyck, 1991). Permission from the regulator is not infinite, but in practice many of the potential projects are not applied licence for before they are economically interesting. It is not unrealistic to assume that a company can postpone the licence application process in order to consider timing of the investment and hence can choose to invest immediately or at an optional time in the future. New information can be revealed before commitment (there is of course a time lag from investment decision to a plant can generate, but this is ignored in the analysis).

The basic model of Dixit & Pindyck (1994) is an extension of the model developed by McDonald & Siegel (1986). One version of this framework is to treat the price (P) of the project's output as a geometric random walk. The interesting variable is $V(P)$, the value of the project as a function of P. To obtain this value one can view the project as a set of options (McDonald & Siegel, 1986). In this version of the model it is also a goal to find a critical P^*, where the firm only invests if $P > P^*$.

An important assumption for making such an approach is whether the stochastic changes in P are spanned with existing assets. This assumption means that there has to be possible to construct a dynamic portfolio of assets, which the price perfectly correlates with P. This has been applied on electricity markets by several (Deng, Johnson, & Sogomonian, 2001). This means that the investment opportunity can be solved by the use of contingent claim valuation (Schwartz, 1997). One major advantage is that this excludes the difficult and complex discussion of risk preferences and discount rates. Yet an additional advantage is that this excludes the need of any forecast for long-term electricity prices (Schwartz, 1998).

There are factors making electricity not comparable to most other commodities (Clewlow & Strickland, 2000; Koekebakker & Sødal, 2001). From the physics of electricity one can learn that demand and generation must match each other continuously. If not in balance the transmission network will collapse. Current technology gives no possibility of storing electricity[2]. This non storability aspect implies that electricity cannot be considered a financial asset, eliminating the possibility for the traditional arbitrage approach. The implication of this is that a megawatt hour of power cannot be held as an investment in a portfolio. Electric power can neither be borrowed nor shortened, and then bought back and returned later. This violates the important spanning assumption in the Dixit & Pindyck framework, and the traditional non arbitrage approach for valuation of options. Finance based asset pricing do therefore not apply to power spot price dynamics. But efficient markets do apply to the pricing of derivatives on power. Therefore this study relates to forward contracts which not are under the same restrictions.

Because of these special properties of electricity, there are strong reasons for dealing with forward prices directly, rather than endogenously through spot prices (Koekebakker & Sødal, 2001). If one relate to the observed forward and futures prices one deal with a tradable asset, and do not need to struggle with the complicated area of electricity spot price as a non-asset. While electricity is non-storable, forward contracts are. Hence by relating to forward prices, there should be no violation of the essential spanning assumption in the Dixit & Pindyck framework.

[2] There are some possibilities of storing. Advanced, expensive technologies like pumped/storage hydro, high pressure air facilities and batteries can convert electricity into potential energy in other forms and convert it back. This is though a rare opportunity and involves significant loss in conversion. This is ignored in the analysis.

The model relies on a geometric random walk. This is a convenient assumption because it yields an analytical solution. The modelling of stochastic process is nonetheless controversial. The recommendation of Ronn (2002) is geometric Brownian motion (GBM) for forward priced based models of electricity prices.

This model is in continuous time. In practice however, observed forward prices are restricted to discrete values. Nevertheless, the underlying factors in the industry, like the market mechanisms in an industry with many participants, the sensitivity of national reservoir level information and downpour and temperature forecasts as well as the regulators constant monitoring of the industry, are continuous in nature. Therefore it should not be controversial to apply a continuous time model for the stochastic process of forward electricity prices.

The value of investment opportunities in hydropower generation is of obvious reasons strongly related to future expected prices of electricity. Hydropower plants are normally assumed lasting for several decades. Investors are thus looking way ahead of 3-4 years forward prices that can be observed at Nord Pool. However, there is no efficient market for longer forward prices. The observed prices that are used in this analysis are the longest contracts that can provide reliable data and thus are the best estimates of value of both generation assets-in-place and investment opportunities.

The described modelling implies that the hydro generation basically behaves like a base load producer. This neglects the flexibility characteristics that are associated with hydro generation, and represents a shortcoming.

5.3 THE APPLICATION OF THE DIXIT & PINDYCK MODEL ON NORWEGIAN HYDROPOWER INVESTMENT OPPORTUNITIES

5.3.1 Data for applying the model

Sigma, σ

σ is the standard deviation of the underlying. In this context this implicates that σ is the standard deviation of the observed forward prices. The forward contract structure at Nord Pool has gone through a transition phase. The previous structure was based on the distinction of three seasons: Winter 1 (1st January – 30th April), Summer (1st May – 30th September) and Winter 2 (1st October – 31st December). There were also year forward contracts. The new forward contract structure is based on calendar month, quarter (three calendar months) and year contracts. This was introduced in 2004 (Nord Pool, 2005).

Table 5.1: Average annualised standard deviation of the relevant forward contracts.

Average annualised standard deviation on yearly and tertial/quarterly forward contracts 1999 – 2006

Year	Average annualised standard deviation
1999	15.0%
2000	8.5%
2001	18.7%
2002	25.5%
2003	38.1%
2004	16.9%
2005	21.1%
2006	26.6%

To obtain an overview of the term structure and volatility it should be sufficient to concentrate on the tertial/quarterly and yearly contracts. These are the longest contracts that give the most relevant information when the purpose is to focus on valuation of investment opportunities. The tertial (from 2004 quarterly) contracts are tradable for the two following years after trading, while the yearly contracts are tradable for three years ahead. By analysing these nine/eleven contacts one can obtain a term structure and a long time volatility trend.

From the FTP server of Nord Pool one can obtain a simple descriptive analysis of the tertial, quarterly and yearly contracts. Since the volatility parameter in GBM is an annualized volatility the annualised standard deviations for the price return of the relevant contracts are shown in Table 5.1 (from 2004 the prices are in Euro. The change into the Norwegian currency has been based on the average currency the actual year). These numbers reveal the seasonal pattern and also the term structure of the volatility (Lucia & Schwartz, 2002; Ronn, 2002). The numbers also reveal an increase in volatility after the shock winter of 2002-03.

The results are consistent with earlier studies (Bjerksund, Rasmussen, & Stensland, 2000; Koekebakker & Ollmar, 2005). There is also consistency with the assumption of Ronn (2002). The volatility is high for contracts with short time to maturity and is convex decreasing for contracts with longer time to maturity. An overall analysis of the development of the forward prices (Figure 5.3) shows though an increase in both price level and volatility level after the winter 2002-03. Overall this gives support to let the level of σ be about 20 - 25 % as a base case volatility input parameter in the model. In the analysis later in this paper the starting point for the calculations is set with a σ of 25 %.

Price, P

The sigma is derived from an analysis of the structure of a portfolio of forward contracts. Hence the P for forward prices that has to be the X-axes concerning valuation of the investment opportunities and the trigger for investments in the

Dixit & Pindyck model framework, has to be obtained from the same portfolio of forward contracts.

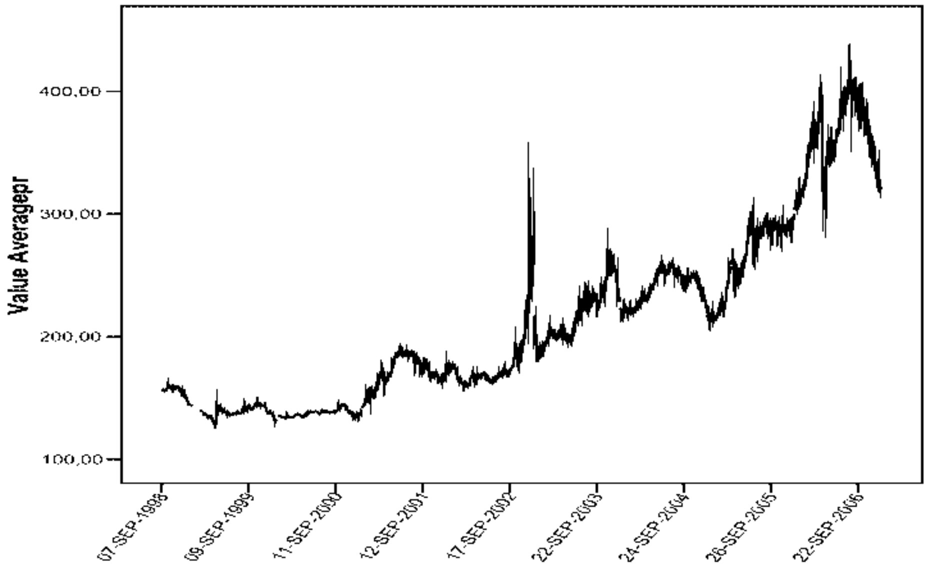

Figure 5.3: Development of average forward price (øre/kWh / NOK/MWh) 7th September 1998 – 27th December 2006.

The P variable should be a measure of the level of forward prices. The choice of this paper is to let P be the average forward price of the six tertial (eight quarterly) and three year ahead forward prices. If one relate to these nine/eleven contracts one can calculate an average forward price at each trading day. The development of this representative forward price is shown in Figure 5.3.

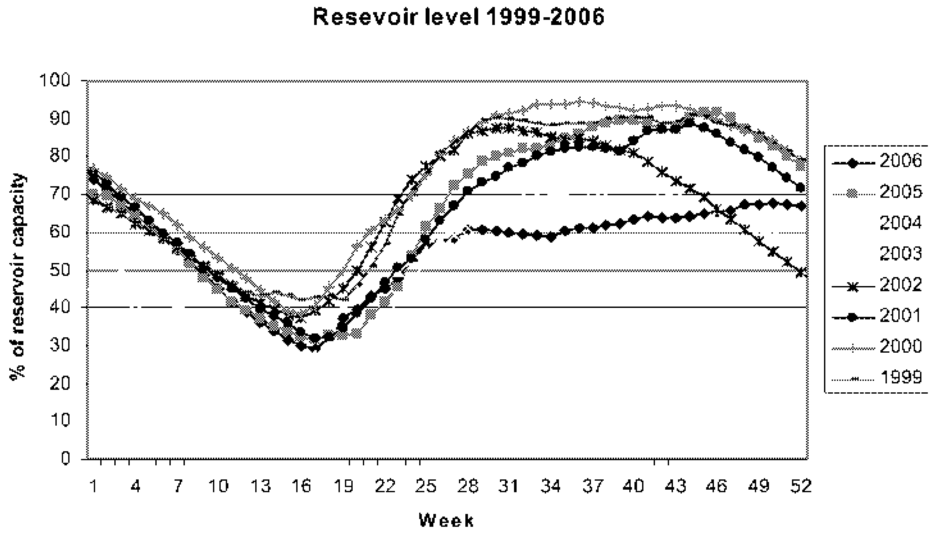

Figure 5.4: Reservoir level statistics 1999-2006 (NVE, 2007).

Delta, δ

In the theoretical introduction of the Dixit & Pindyck model the δ represented the net marginal convenience yield from storage. The assumption was that the output was a storable commodity. As pointed out, this is a complex issue concerning electricity. But in the hydropower dominated system of Norway the water reservoir levels can serve as a kind of inventory, leading to high reservoir levels (inventory) in the summer, and low in the winter (Figure 5.4).

The definition of convenience yield is "the flow of services which accrues to the owner of a physical inventory but not to the owner of a contract for future delivery" (Brennan, 1991). As already pointed out, electricity have some peculiar properties. Because of this there should be made some careful considerations. Botterud, Bhattacharya, & Ilic (2002) points out that there are asymmetry aspects between the supply and demand side of a hydropower based electricity market. Their argument is that there is some flexibility in generation, which can be used for profit purposes at price peaks in the day ahead spot market. But the situation is not the same on the demand side, with limited possibility to adjust demand according to price level. Therefore there are strong incentives for a risk averse demand side to lock in as much as possible of expected future demand in the forward/futures market. This leads to a hypothesis of negative convenience yield consistent with the contango hypothesis.

Another aspect is the seasonal influence on the convenience yield. As with spot and forward prices, also the convenience yield varies throughout the year (Gjølberg & Johnsen, 2001). In the winter time when reservoir levels are low and hence prices are high, the alternative cost of generation is high, yielding a higher δ. In the summer when reservoir levels are high and hence prices lower, the δ is lower and assumable negative (Botterud et al., 2002).

The convenience yield is therefore not a constant as the Dixit & Pindyck model calls for. This is though also the case for most other commodities. It should not be a serious obstacle for the study to assume a constant convenience yield. The δ can be interpreted as an opportunity cost of delaying construction of investment projects. By delaying a project, the firm looses a certain time of production that could have yielded profit. This can be termed an opportunity cost of delaying investment projects for keeping the real option alive. The δ hence represents the level of this opportunity cost. This parameter can be obtained from the *average* convenience yield for the most recent forward contracts that are included in the analysis[3]. However, as shown in table 5, *V(P)* is sensitive even with slightly changes in δ.

The formula of measuring the convenience yield, $\psi_{t,T}$, (Pindyck, 2001) over a period t to $t+T$ is:

$$\psi_{t,T} = (1 + r_T) \cdot P_t - F_{t,T} + k_T \qquad \textbf{(5.1)}$$

where P_t is the spot price at time t, $F_{t,T}$ is the future price for delivery at time $t+T$, r_T is the risk free T-period interest rate, and k_T is the per unit cost of physical storage. This equation can be proved by normal non arbitrage reasoning (Pindyck, 2001). Storage cost is assumed like zero in this context (torage costs are vital in a normal discussion of convenience yield, but storage of forward contracts seems reasonable to set as zero). The relative convenience yield becomes:

$$\frac{\psi_{t,T}}{P_t} = \left[(1 + r_T) \cdot P_t\right] - F_{t,T} \qquad \textbf{(5.2)}$$

To obtain a current real option value the focus is on the latest quarterly and yearly contracts, which determines the δ. By using equation **(5.2)** one gets the results shown in Table 5.2.

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[3] This parameter is under GBM related to the expected growth in the current estimate of the forward curve P. If one e. g. calls the growth α, we can set that $\alpha = r - \delta$.

Table 5.2: Relative convenience yield based for the next two years quarterly (CY 1q1 – CY 2q4) 2004 – 2006 and the next three years yearly (CY 1 – CY 3) contracts 2003 – 2006.

Relative convenience yield	Number of observations	Min.	Max.	Mean	Std. Deviation
Cy 1	993	-0.56	0.76	0.0351	0.17191
Cy 2	1001	-0.53	0.78	0.0813	0.18509
Cy 3	1001	-0.50	0.77	0.0894	0.18733
CY 1q1	501	-0.73	0.23	-0.1946	0.15616
CY 1q2	502	-0.53	0.41	0.0190	0.15279
CY 1q3	502	-0.48	0.48	0.0671	0.16094
CY 1q4	502	-0.65	0.40	-0.0529	0.18020
CY 2q1	752	-0.72	0.35	-0.1092	0.16757
CY 2q2	753	-0.48	0.46	0.0768	0.15090
CY 2q3	753	-0.41	0.51	0.1175	0.15044
CY 2q4	753	-0.64	0.42	-0.0149	0.16191

The weighed average of the calculations shown in table 2 gives a parameter of δ about 2.2 %. If one focuses more on the longest contracts, this would give a slightly higher estimate. So for the base case in the analysis it seems appropriate to set δ as 2.5 %. This parameter shows then the advantage of possessing hydropower in reservoirs (as inventory) compared to locked future delivery in forward contracts.

Risk free rate, r

The model does only call for the risk free rate. This can be determined by 10 year Norwegian Government bonds (Norges Bank, 2007). The r used in the model is the monthly average of these bonds as the focus is on long-term investments. But in equation **(5.1)** and **(5.2)** the monthly average 12 months interest rate is used (in early 2007 this is approximately 4.5 %.) (determined by NIBOR, Norwegian Inter-Bank Offered Rate) (2005).

Investment, I

The general picture when examining this sector is the high entry barrier of high investment costs and the relatively low level of variable cost. Concerning investments the reports from NVE seem to level 3 NOK/kWh and 5 NOK/kWh as standard interval concerning classification of the potential new hydropower plants.

According to NVE reports (NVE, 2004) there is an overall estimation that the economically limit for investment is considered 3 NOK/kWh. This limit has been increased since then. A NVE report also show the increased knowledge of small scale hydropower plants leading to a significant upside change in potential (NVE, 2005). In this model framework it therefore seems appropriate to use these numbers as the investment expenditure in the analysis.

Variable cost, c

There is low cost in production in this industry. The level of *c* is dependant of aspects like age, size and complexity (NVE, 2002). An approach for new investments according to the same report is estimating the variable cost as 1 % of the investment (excluded financial cost in building period.). This must be considered as extremely low compared to other commodities and industries. Nevertheless, these estimates can be referred to as maintenance, which would be of no relevance in short term operating decisions. This is an argument for letting this part of the costs be included in the investments cost (which NVE refers to as "conservative") and let the *c* parameter be closer to zero.

5.3.2 Analysis of option value and trigger price

The above discussion of parameter values gives a way of calculating the option value in this sector according to the following equations in the model framework of Dixit & Pindyck (1994):

$$V(P) = A_1 P^{\beta_1} \; if \; P < c \quad \textbf{(5.3a)}$$

$$V(P) = A_2 P^{\beta_2} + P/\delta - c/r \; if \; P \geq c \quad \textbf{(5.3b)}$$

where:

$$\beta_1 = 1/2 - (r-\delta)/\sigma^2 + \left\{ \left[(r-\delta)/\sigma^2 - 1/2 \right]^2 + 2r/\sigma^2 \right\}^{1/2} \quad \textbf{(5.4a)}$$

$$\beta_2 = 1/2 - (r-\delta)/\sigma^2 - \left\{ \left[(r-\delta)/\sigma^2 - 1/2 \right]^2 + 2r/\sigma^2 \right\}^{1/2} \quad \textbf{(5.4b)}$$

The constants A_1 and A_2 are expressed as:

$$A_1 = \frac{r - \beta_2(r-\delta)}{r\delta(\beta_1 - \beta_2)} c^{(1-\beta_1)} \quad \textbf{(5.5a)}$$

$$A_2 = \frac{r - \beta_1(r-\delta)}{r\delta(\beta_1 - \beta_2)} c^{(1-\beta_2)} \quad \textbf{(5.5b)}$$

Figure 5.5 shows the results on the basis of the previous discussed volatility (σ), convenience yield (δ), risk free rate (r) and investment level of 300 (øre/kWh) and hence variable cost 3 (øre/kWh).

P represents the average forward price of the included forward contracts. The value, *V(P)* is the value of an investment opportunity in øre (0.01 NOK) per kWh. The figure shows the significant value this option has depending on forward price level. A change in input parameter *I* and hence *c*, to 500 and 5 as discussed earlier, reveals not a big difference in the results.

The option value of investment opportunities is mainly the intrinsic in-the-money value, close to $\max\{(P/\delta)-(c/r);0)\}$. The option value to stop producing when prices are decreasing ("time value") is low because of the low variable cost (c).

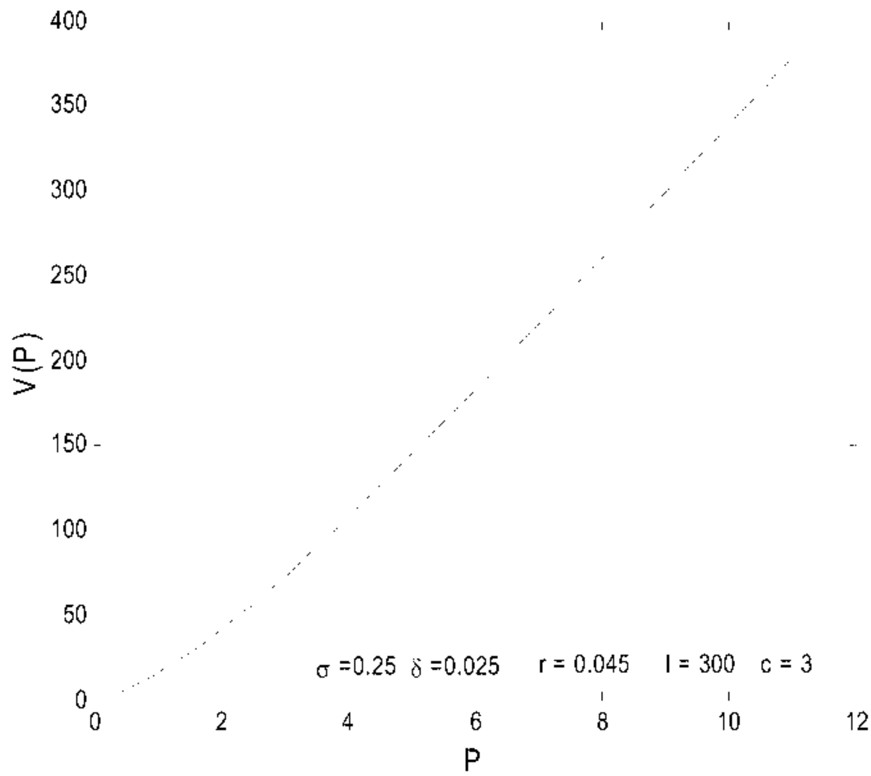

Figure 5.5: Value of investment opportunity as a function of average forward price.

With the first set of parameters, at a present (late 2006) level of forward prices of about 30, this gives an option value of about 11 NOK/kWh (Table 5.3). This option value is though sensitive both to changes in δ (Table 5.4) and σ (Table 5.5). A lower δ would result in a considerable higher option value.

Table 5.3: Option value as a function of average forward price (σ=0.25, δ=0.025, r=0.045, I=300, c=3).

Average forward price (øre/kWh)	**15**	**20**	25	**30**	**35**	**40**
Value of option (øre/kWh)	545	742	940	1139	1338	1538

If a local company then possesses a potential of 100 GWh in its area, this gives a value of NOK 1.1 billion according to this approach. This can be a qualified estimate for the value of the company beyond assets-in-place, and hence be an estimate for a bid premium if such a company is involved in a merger or acquisition[4].

What about the optimal timing of investing? The model framework of Dixit & Pindyck (1994) has developed the following equation that reveals the P^* when solved numerically:

[4] There are a number of other aspects involved in such an assessment as quota regulations, the relationship with private fall rights owners (land owners) and the uncertainty of getting permission from NVE.

$$\frac{A_2(\beta_1-\beta_2)}{\beta_1}(P^*)^{\beta_2}+\frac{(\beta_1-1)}{\delta\beta_1}P^*-\frac{c}{r}-I=0 \qquad \textbf{(5.6)}$$

where A_2, β_1, β_2 are defined as in **(5.5b)**, **(5.4a)** and **(5.4b)**.

Table 5.4: Sensitivity analysis of the option value when the δ parameter is changed.

Average forward price (øre/kWh)	**Value of option (øre/kWh)** (σ=0.25, r=0.045, I=300, c=3)			
	$\delta = 0.01$	$\delta = 0.02$	$\delta = 0.03$	$\delta = 0.04$
20	1937	940	612	454
25	2436	1189	776	575
30	2935	1438	941	698
35	3435	1687	1107	821

With the initial parameters *(σ=0.25, δ=0.025, r=0.045, I=300, c=3)* this gives a P^* according to the equation in the model framework of about 32 øre/kWh. The model suggests that the representative forward price should be at 32 øre/kWh before it is optimal to make an irreversible investment in more hydropower capacity. Table 5.6 shows the effect on P^* when different parameters are changed, one at the time. The results show that the trigging price is sensitive for changes in parameter values. Especially is the trigger price vulnerable for the level of volatility (σ).

One message from a real option approach is that uncertainty reduces investment. The increasing level of volatility in electricity forward prices increases the option value and hence makes investors hesitant due to the high level of the alternative cost in irreversible investments. The model reveals that optimal investment timing is not before the average forward price has exceeded 30 øre/kWh (NOK 30/MWh).

Historically this is a very high level. This level has not been reached before late 2005 (see Figure 5.3). If the volatility was at 20 % (instead of 25 %) the optimal trigger forward price would be about 27 øre/kWh.

Table 5.5: Option value as function of average forward price including different volatilities as input parameters.

Average forward price (øre/kWh)	Value of option (øre/kWh) (δ=0.025, r=0.045, I=300, c=3)			
	$\sigma = 0$	$\sigma = 0.20$	$\sigma = 0.225$	$\sigma = 0.30$
20	733	737	739	749
25	933	936	938	946
30	1133	1135	1137	1145
35	1333	1335	1336	1344

Figure 5.6 shows these results graphically. The tangency point of *F(P)* (option value) with *V(P) – I* gives the optimal trigger price for an investment. If there is no volatility, the traditional NPV rule can be applied. For any positive σ the NPV rule must be modified to include the relevant opportunity cost of the option value. Note that the curves are very close from approximately *P = 25* and upward, leading to possible investment decision at some lower trigger price.

Table 5.6: Optimal trigger price for different input parameters.

I	***c***	***Sigma, σ***	***Delta, δ***	***r***	***P****
300	**3**	**0.25**	**0.025**	**0.045**	**32.22**
400	**4**	0.25	0.025	0.045	42.96
300	3	**0.20**	0.025	0.045	27.43
300	3	**0.225**	0.025	0.045	29.74
300	3	0.25	**0.03**	0.045	33.25
300	3	0.25	**0.02**	0.045	31.24
300	3	0.25	0.025	**0.03**	29.52
300	3	0.30	0.02	**0.06**	35.46

5.4 CONCLUSIONS AND IMPLICATIONS

This paper has applied the real option model framework of Dixit & Pindyck (1994) to potential hydropower investments in Norway to quantify the option value and to understand the timing and aggregate investment behaviour in this industry. The option value is quantified according to the input parameters of the model. Option values are a crucial, but a difficult part of business valuation (Ross, 1995). The existence of option values are beyond debate, but the quantification can be complicated. This study uses option methodology to estimate the value per kWh of potential hydropower investments.

On the basis of reasonable input parameters the value of such investment opportunities is calculated to about 11 NOK/kWh or 11 million NOK/GWh. This makes an adequate estimate concerning valuation of this potential according to relevant input parameters. This framework can thereby contribute to assess a bid premium in connexion with mergers and acquisitions when hydropower potential is involved. This model framework establishes a solid foundation for the valuation beyond assets-in-place.

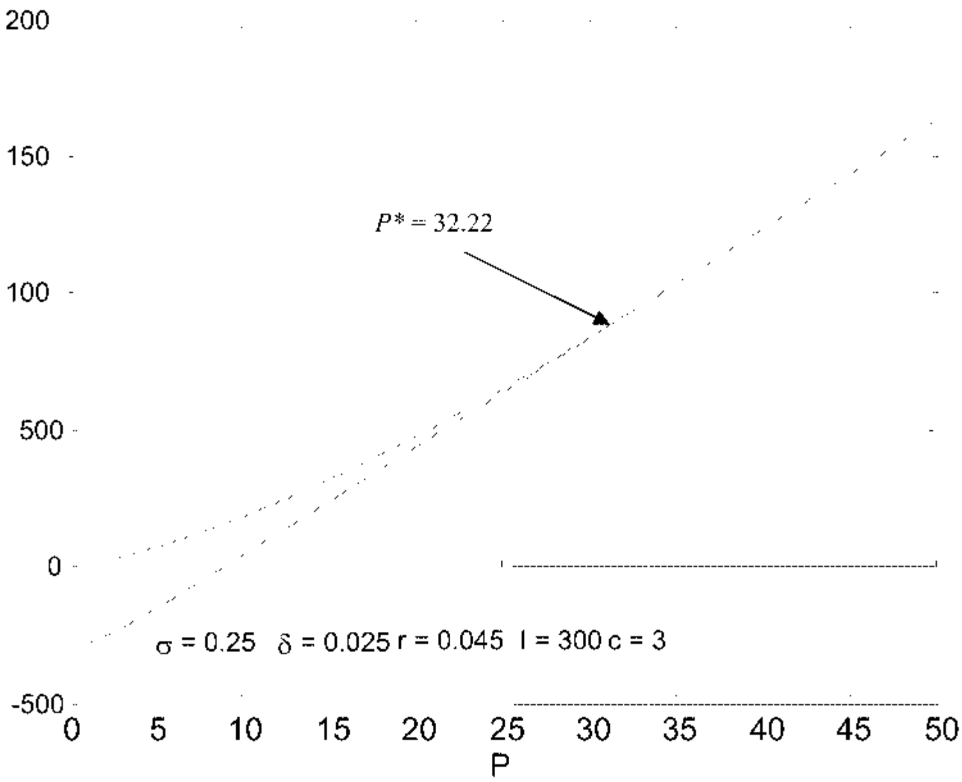

Figure 5.6: Graphical solution of P^* with basic parameters.

The results shown here can also give one explanation to why there has been a low level of new investments in the hydropower sector. The nature of investments in more hydropower capacity is irreversible, making the option component a substantial alternative cost. The analysis shows that the implications are that the price level has to be quite high, way up in the 30ies (øre/kWh), before optimal investment timing is reached, and the value of the investment exceeds the projects full cost. This is a price level that has not been seen before late in 2005 (Figure 5.6). According to SSB (2006) there have in 1994 – 2004 each year been under construction less than 1.2 TWh (Figure 5.2), lower than granted licenses and much lower than applied licenses. This reality gives support to the results of this real option approach.

The analysis also shows that the σ in the model, the volatility of the forward price, has profound impact on the option value and hence the hesitation for making irreversible investments. There have always existed uncertainty factors for investor in this sector. The uncertainty has been linked to aspects like demand, international fuel prices, transmission constraints and climate. But there seems to be an increase in uncertainty and hence volatility in the electricity price development. This significant increase in volatility can possibly be linked to a number of controversial and partly unsettled political issues as the possible introduction of green certificates[5], the introduction of CO_2 allowances, the home fall institute[6], and the emerging awareness of low level of new investments, higher demand and transmission constraints. The increase in oil, gas and coal prices is also interfering. Anyway, the

[5] For several years there were expectations of a common Norwegian Swedish market of green certificates which would make investments in renewable electricity generation like hydropower plants more profitable. This was abandoned by the Norwegian Government in 2006.

[6] The home fall institute is founded in the Norwegian legislation of possessing and operating hydropower plants. Home fall essentially means that private owned plants will without compensation be passed over to the authorities when the licence expires. The length of a licence is 60 years, but will possibly be 75 years. There has been considerable dispute on this issue since 2001, especially whether publicly owned plants also should be under the same legislation.

model shows that by reducing the uncertainty one can lower the option value (alternative cost) and hence trigger the investments at a lower price. More stability and more predictable framework conditions will thus decrease the uncertainty and possibly make electricity prices less volatile. This encourages more investments in small scale hydropower plants and probably other electricity generation facilities.

This real option analysis gives deeper insight into a controversial issue. An option approach explains investment behaviour in a way that is not captured by a neoclassical NPV approach. Even if there is factors in the application of the Dixit & Pindyck framework that are disputable, the analysis shows that real option theory gives insight in the value of investment opportunities and aggregate investment behaviour in this industry.

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APPENDIX 1: MATLAB PROGRAMMING

The following programming has been performed in MATLAB to apply the model framework developed by Dixit and Pindyck (1994) based on an initial model by McDonald and Siegel (1985) (comments are in Norwegian):

- Programming concerning valuation of investment potential:

```
function y = projectvalue(sigma,delta,r,I,c)

beta1=1/2-(r-delta)/sigma^2+(((r-delta)/sigma^2-
1/2)^2+2*r/sigma^2)^(1/2);
beta2=1/2-(r-delta)/sigma^2-(((r-delta)/sigma^2-
1/2)^2+2*r/sigma^2)^(1/2);
A1=(r-beta2*(r-delta))/(r*delta*(beta1-beta2))*c^(1-beta1);
A2=(r-beta1*(r-delta))/(r*delta*(beta1-beta2))*c^(1-beta2);
% a2=3;
P=0:0.1:c;
y=A1*P.^beta1;
plot(P,y);
hold all;
P=c:0.1:11;
z=A2*P.^beta2+P/delta-c/r;
plot(P,z);
hold off;
xlabel('P','FontSize',12);
ylabel('V(P)','Fontsize',12,'Rotation',90);
strsigma=num2str(sigma);
out=['\sigma = ',strsigma];
text(3.5,20,out);
strdelta=num2str(delta);
out=['\delta = ',strdelta];
text(5,20,out);
strr=num2str(r);
out=['r = ',strr];
text(7,20,out);
strI=num2str(I);
out=['I = ',strI];
text(9,20,out);
strc=num2str(c);
out=['c = ',strc];
```

```
text(10.5,20,out);
```

- Programming concerning optimal investment timing (P^*):

```
function y = pstar(sigma,delta,r,I,c,P0)
beta1=1/2-(r-delta)/sigma^2+(((r-delta)/sigma^2-
1/2)^2+2*r/sigma^2)^(1/2);
beta2=1/2-(r-delta)/sigma^2-(((r-delta)/sigma^2-
1/2)^2+2*r/sigma^2)^(1/2);
A1=(r-beta2*(r-delta))/(r*delta*(beta1-beta2))*c^(1-beta1);
A2=(r-beta1*(r-delta))/(r*delta*(beta1-beta2))*c^(1-beta2);
f=@(P)A2*(beta1-beta2)/(beta1)*P.^beta2+(beta1-
1)/(delta*beta1)*P-c/r-I;
z=fzero(f,P0);
P=0:0.03:c;
y1=A1*P.^beta1-I;
plot(P,y1);
hold all;
P=c:0.1:50;
y2=A2*P.^beta2+P/delta-c/r-I;
plot(P,y2);
P=0:0.1:z;
a=beta2*A2/beta1*z^(beta2-beta1)+1/(delta*beta1)*z^(1-beta1);
g=@(P)a*P.^beta1;
h=plot(P,g(P));
%y3=0;
%plot(P,y3);
hold off;
xlabel('P','FontSize',12);
ylabel('F(P), V(P)-I','Fontsize',12,'Rotation',90);
strsigma=num2str(sigma);
out=['\sigma = ',strsigma];
text(5,-270,out);
strdelta=num2str(delta);
out=['\delta = ',strdelta];
text(12,-270,out);
strr=num2str(r);
out=['r = ',strr];
text(19,-270,out);
strI=num2str(I);
out=['I = ',strI];
text(26,-270,out);
strc=num2str(c);
out=['c = ',strc];
text(31,-270,out);
% strc=num2str(P0);
% out=['$P_0 = $ ',strc];
% text(37,-270,out,'Interpreter','latex');
strc=num2str(z);
out=['$\leftarrow\, P^*=$ ',strc];
```

```
text(z,g(z),out,'HorizontalAlignment','left','Fontsize',8,'In
terpreter','latex');
Figpos=get(gcf,'Position'); % Posisjonen til figuren målt i
pixels i forhold til hele dataskjermen
% Posisjonen er en vektor som består av  left bottom  width
height
Axespos=get(gca,'Position'); % Posisjonen til aksene målt i
absolutte koordinater
xticks=get(gca,'XTick');          % xtickene til current axes
(gca) lagres i arrayen xticks
NumberOfXticks=size(xticks);  % size gir formatet til matri-
sen, så
  % NumberOfXticks(2) er lik antallet xticks på current axes.
ticklength=get(gca,'Ticklength'); %  ticklength(1)  er tick-
lengden i 2D målt i absolutte koordinater
% if Axespos(4) > Axespos(3)
%    absticklength=ticklength(1) % *Axespos(4)
% else
%    absticklength ticklength(1) % *Axespos(3)
% end
absticklength=ticklength(1); % tick-lengden lagres i   ab-
sticklength
xlimits=get(gca,'XLim'); % Grensene på X-aksen
ylimits=get(gca,'YLim'); % Grensene på Y-aksen
% lwidth=get(gca,'LineWidth')   Tykkelsen på linjene målt i
pixels
y1=Axespos(2)-Axespos(4)*ylimits(1)/(ylimits(2)-ylimits(1));
% -lwidth/Figpos(4)
 % y1  er y-koordinaten til origo målt i absolutte koordina-
ter
 % siste ledd korrigerer for linjetykkelsen slik at linjen
som lages
 % nedenfor legger seg over ticken for y=0.
x1=Axespos(1); % +lwidth/Figpos(3)   x1 er x-koordinaten til
origo målt i absolutte koordinater.
 % Siste leddet tar hensyn til linjetykkelsen slik at linjen
som lages
 % nedenfor  med annotate ikke begynner til venstre for y-
aksen.
annotation('line',[x1,x1+Axespos(3)],[y1,y1]);
xt=x1;
yt=y1+absticklength;
for i=2:NumberOfXticks(2)
    xt=x1+xticks(i)*Axespos(3)/(xlimits(2)-xlimits(1));     %
+lwidth/Figpos(3)
    annotation('line',[xt,xt],[y1,yt]);
    % strc=num2str(xticks(i));
%
text(xticks(i),0,num2str(xticks(i)),'Margin',5,'HorizontalAli
gnment','center',...
%                                              'VerticalAlign-
ment','top','Edgecolor','red','Position',[xticks(i),
```

```
%           -25]);
text('String',num2str(xticks(i)),'HorizontalAlignment','cente
r',...
         'VerticalAlignment','top','Position',[xticks(i),-25])
end
```

CHAPTER 6 (PAPER 4): THE VALUE OF OPERATIONAL FLEXIBILITY BY ADDING THERMAL TO HYDROPOWER – A REAL OPTION APPROACH

Abstract:

This paper presents a valuation study of operational flexibility for a hydropower operator restricted by contracts to deliver a steady flow of electricity to the contract counterpart. The hydropower operator has the flexibility to deliver from own production of hydro-electric generation, or deliver by buying option contracts of electricity from thermal electricity producers. The option may be in the form of a call option, or may be an implicit option created by having a separate thermal electricity plant that can be switched on and off. Long term industry contracts can make some operators obligated to always generate at a certain minimum level. Such operators cannot save the water in the reservoirs for peak price periods if this action compromises their ability to deliver the contracted minimum. If thermal generation is added and controlled, flexibility is enhanced and hence more generation can be allowed in peak price periods.

To assess this value of operational flexibility the switching option model of Kulatilaka (1988) is applied. The numerical calculations, introducing nuclear, coal fired or gas fired generation, show an option value for a hydro operator also controlling thermal generation of NOK 65 / NOK 45 / NOK 13, respectively, per MWh yearly generation capacity.

Key words: Operational flexibility, Real options, Electricity generation

6.1 INTRODUCTION

The focus of the paper is to assess the value of operational flexibility of a hydro based operator who has the possibility to add thermal power to his production. If a hydropower operator is restricted in minimum generation due to for example long term industry contracts, there is an added operational flexibility when thermal generation could alternatively be used at a cost lower than the current spot price of electricity. The added flexibility would intuitively represent value, if the option is optimally exploited. A key point in understanding the Norwegian (and Nordic) electricity market is the seasonal pattern of prices. Electricity demand is connected to heating requirements (31 % in 2001) (The Ministry of Petroleum and Energy, 2006a), which for obvious climatic reasons is much higher in the winter period compared to other seasons. The integration of thermal generation would therefore provide some obvious benefits for an operator restricted in scheduling planning by industry contracts. By using thermal power instead of hydropower in some parts of the year, in order to produce relatively more in peak price periods, one should yield an extra value, a premium, which must be taken into consideration when buying or renting thermal generation capacity. The research question for this paper is:

- What is the value of operational flexibility in generation when controlling thermal generation in addition to hydro?

The purpose of this paper is to calculate the value of operational flexibility by using the switching option model developed by Kulatilaka (1988). The aim is to calculate the impact on value of being able to switch between alternative sources of generating technologies in order to take advantage of higher electricity prices when national reservoir levels are low. The estimated value of this option is useful in several settings. This value must be taken into account when the rent or investment cost for thermal generation is assessed. The value can also be used to justify governmental subsidies at system level for initiating investments in thermal generation to avoid random fluctuations in supply due to variation in precipitation.

6.1.1 Background and motivation

The Norwegian power system is almost entirely dominated by hydro power. According to NVE (the regulator), hydro power provides more than 98% of electricity generation, whereas the remaining 2% is produced by wind or thermal sources[1]. This makes the Norwegian power system quite unique compared to other countries[2]. Hydropower is renewable, does not emit CO_2 and is in Norway a relatively cheap source of energy.

The generating capacity can be considerably increased by small scale hydro power plants[3]. Projects are also emerging based on alternative technologies, especially

[1] In 2007 the yearly middle production of hydro was 121.8 TWh, wind generation was 0.9 TWh and thermal generation was 1.5 TWh (www.nve.no).

[2] Norway is the 6th largest hydro power generator in the world (NVE, 2003).

[3] In a report from NVE (Norwegian Water Resources and Energy Directorate) (2004), the total estimated potential of small scale hydro power plants is in total 25 TWh with an investment cost below 3 NOK/kWh. Furthermore the estimated potential with investment cost between 3 NOK/kWh and 5 NOK/kWh is about 7 TWH, making a total of 32 TWh with the highest cost limitation. There is also a potential for improvements and expansion of existing hydro power plants. Due to the development of more advanced generating technology there is a potential for enhancing the effect of present plants by almost 12 TWh according to NVE (2006). Correspondingly the latest statistics from SSB (Statistics Norway) have raised the total potential of hydropower capacity in Norway from 186 TWh in 2003 to 205 TWH in 2004.

wind and thermal (gas fired)[4]. The power generation under construction will lead to a slight decrease in the hydro dependence from 98 % to possibly 94 % by 2010 (The Ministry of Petroleum and Energy, 2006a). Thermal power plants are currently, however, a controversial political issue. One gas fired thermal power plant is recently implemented and others are commissioned[5]. In addition, the possible introduction of coal-fired and even nuclear thermal power plants is debated, but none has reached the planning stage. There has also been an increased international interaction along with increased transmission capacity.

Hydropower generation represents a source of flexibility. The water can be "stored" in reservoirs thus creating an operational flexibility through which operators can adapt to demand and price signals[6]. This is a continuous optimalization problem faced by the generators in their scheduling planning, as studied by several (Fosso, Gjelsvik, Haugstad, Mo & Wangensteen, 1999; Näsäkkälä & Keppo, 2005). According to a recent valuation report on Statkraft SF[7] (Lehman Brothers, 2006) it would be reasonable to assume that this company could achieve a 10 % premium compared to the annual system average price (spot price) due to its ability to generate on demand when prices are high.

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[4] The Government aims to have 3 TWh wind power generation within 2010 (The Ministry of Petroleum and Energy, 2006a). This corresponds to 1000 MW installed capacity and according to NVE (2007) this should be an achievable ambition.
[5] The first plant at Kårstø started up in November 2007. There are under construction gas fired thermal power plants that will provide 5 TWh before 2012 (NVE, 2007).
[6] This flexibility concerns operators with reservoirs and does not refer to those operating river plants.

There are operators that only possess little operational flexibility. Some generators are restricted of long term industry contracts, and thereby obligated to always generate at a certain level[8]. Such operators have limited opportunities for saving water in the reservoirs for peak price periods. In such situations there is a genuine possibility of enhancing flexibility and hence postpone more generation to peak price periods if thermal generation is added and controlled. The following decision alternatives exist for the operator: 1) Use solely own generation restricted by the contracts, reservoir capacity and turbine capacity. 2) Save some of the water in the reservoirs and buy spot in the market in order to meet contract obligations. 3) Save some of the water in the reservoirs and instead use thermal generation, either from own plants or bought from an external plant to an agreed price (V^{Th}), in order to make more benefits of the heavy price fluctuation in the market. The focus in this paper is the value pr kWh thermal generation yearly capacity under the described circumstances of alternative 3.

The hydro dominant Nordic system has some special properties. Much because of the variability and uncertainty in rainfall, short time prices (spot and short forward) tend to be very volatile (see Figure 6.1). Reservoir levels, recent rainfall and weather forecasts have a great impact on short term prices. Therefore, short term electricity prices are often termed as "weather derivatives". The focus of the paper

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[7] Statkraft SF is the state-owned generating company with an average generation of 42 TWh (almost 35 % of total national generation capacity) (Statkraft, 2007)

though, is to estimate the value of enhanced flexibility when a hydro based operator also controls thermal generated supply of gas-fired, coal-fired or nuclear. The results will also briefly be discussed in relation to system level analysis.

The paper is organized as follows: Section 2 examines the relationship between the spot price (system price) and three of the relatively short forward contracts traded at Nord Pool. This enables a thorough analysis of the forward-spot spread as the relevant alternative cost for hydro operation. This is linked to the data of reservoir levels, changes in reservoir levels and deviation from median reservoir level through a regression analysis. The findings enable the explanation of the forward-spot spread and hence the relevant alternative cost.

The results are utilized in Section 3 in a decision model based on the switching option model of Kulatilaka (1988) which implies an option value of a flexible situation per kWh yearly thermal capacity. The pervasive uncertainty in the model lies in the national water reservoir levels, as representing the level for an average producer, and hence the alternative cost of hydro generation. The results will be discussed with the purpose of capturing the impact on value for an operator as well as benefits at system level. Section 4 draws the conclusions and implications.

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[8] This is e.g. the case for several plants in Western and Northern Norway close to energy intensive factories.

6.2 OPERATIONAL FLEXIBILITY, THE ALTERNATIVE COST OF HYDRO GENERATION AND THE OPERATIONAL COST OF THERMAL GENERATION

Operational flexibility is often treated as one of the most paramount real options, termed switching options. The main idea consists of the right to be able to switch between two different modes. This switching option enhances value if the value created by being flexible compared to rigid systems exceeds the extra cost. Switching options is mostly studied in relation to the energy industry, but is also applied to other industries such as shipping (Koekebakker, Ådland, & Sødal, 2006) and manufacturing (He & Pindyck, 1992; Kulatilaka & Trigeorgis, 1994).

A number of studies have focused on the applications of switching options with regard to valuation within the energy industry. This has particularly applied at plant level (Antikarov & Copeland, 2003; Bergendahl & Olsson, 2006; Fleten, Flåøyen, & Kviljo, 2007; Fleten & Näsäkkälä, 2005; Kulatilaka, 1993; Trigeorgis, 1996). Other studies have also been carried out concerning the utilization of the complementary characteristics of hydropower and other energy sources at system level (Bélanger & Gagnon, 2002; de Moraes Marreco & Tapia Carpio, 2006; de Neufville, 2001; Vogstad, 2000). Vogstad (2000) considers hydro versus wind energy in a Nordic context and concludes by estimating an additional value of up to 9 % through incorporating wind power in a hydro based system[9]. Application to

[9] The estimates vary according to different assumptions. The premium for a wind mill project ranges from 3.7 up to 9 %. The approach is though founded on simulation techniques and not option theory.

firm level, though, where an operator controls more than one plant, is virtually non-existing.

The switching option value in the setting of this paper would concern the value of minimizing cost, quite analogue to the option of switching fuels (Kulatilaka, 1993). The idea is that the different cost structure in the different generation technologies can lead to financial benefits in a flexible system. Since the focus is on *operational* flexibility, the investment costs and fixed costs can be ignored. The relevant costs in thermo power generation consist then of operational cost and fuel cost, whereas this is by no means so obvious for hydro power generation. The operational cost for hydro power is close to zero when maintenance is ignored (NVE, 2002). Hence, as corresponding cost, it seems more appropriate to relate to the alternative cost of hydro generation; this is the cost for present generation, thereby sacrificing later generation in peak price periods. This forward-spot spread follows a seasonal pattern and is very volatile and will be further discussed later on this study. The presence of flexibility thus brings advantages with regard to adapting to the uncertainty of the level of the alternative cost of hydro generation.

To meet contract obligations, an operator may trade in the market. However, if thermal generation is available to a lower price than the current spot price, this becomes a better source of generation in order to save water for peak price periods.

There are some assumptions to make before making the calculations. It is hard to neglect that an introduction of thermal generation would influence the electricity price pattern. Nevertheless, the Norwegian (and Nordic) system will remain hydro dominant. Investments in several thermal power plants of e.g. 10 TWh in total would still give a hydro dominance of approximately 93 %. In addition, bearing in mind that there is an increased construction and implementation of small scale hydro power plants as well, this percentage should grow even more. Hydro dominance would seem to continue, and there are arguments for relying on the validity of the presented model of the alternative cost of hydro generation. Therefore, despite being aware of this aspect, it is ignored in the calculations.

Another assumption is regarding the realism of the operator's situation. The approach assumes that there always will be generation due to lock-up in industry contracts, even if the alternative cost is high. At the same time there is thermal generation available. All investments are though undertaken, hence there are short term switching opportunities that are analyzed (Dixit, 1992). These assumptions may be viewed strong. Nevertheless, they are not out of range and do make the calculations viable.

6.2.1 Reservoir level, short term forward prices and the alternative cost of hydro generation

Previous studies of the relationship between the national reservoir level and the spot-forward spread (convenience yield) have been undertaken by Gjølberg & Johnsen (2001) and Botterud, Bhattacharya, & Ilic (2002). However, they stress that Nord Pool represented a young and possibly immature and inefficient market place at that time, and thus futures and forward prices were occasionally outside theoretical arbitrage reasoning. This having possibly been the case in 2001, one can argue that it is of interest to investigate these relationships now - at a time when the Nordic electricity market has matured and become more experienced.

This study intends to link analytical results from more comprehensive data (up to 2006) to the effect on value of a hydro-based power operator adding thermal generation to supply the load. The underlying hypothesis can be stated here: it is value enhancing to possess and control alternative generating technologies so that relatively more power is generated when prices are higher (and aggregate water reservoir levels are low). The aim of this study is to analyze the impact on value of being able to switch between alternative sources of generating technologies in order to take advantage of higher prices when national reservoir levels are running low.

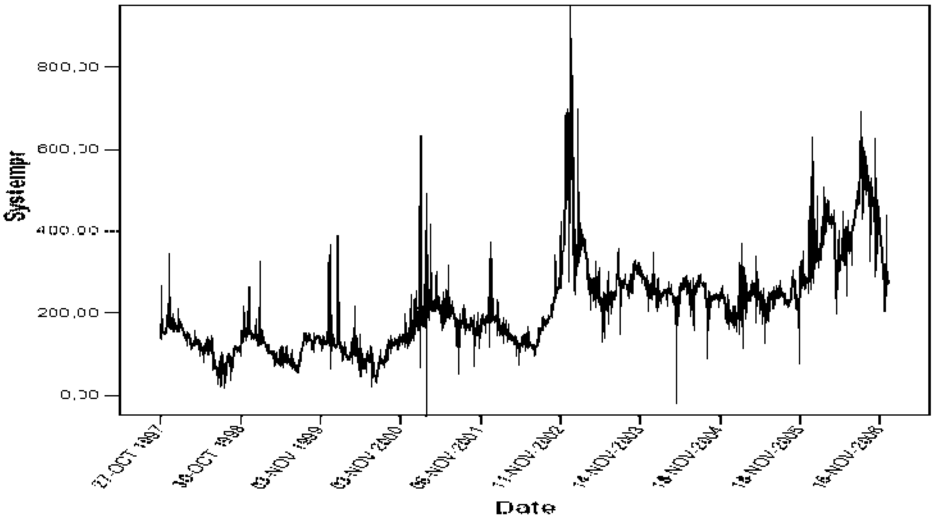

Figure 6.1: System price (spot price) development 27th October 1997 – 29th December 2006 (NOK pr MWh).

A prominent feature of both the Nordic and Norwegian electricity markets is the relatively low correlation between short and long term forward prices[10] (Koekebakker & Ollmar, 2005). Pilipovic (1998) claims that electricity prices exhibit "split personalities" because of the lack of consistency between long term and short

[10] The structure of the forward contracts at Nord Pool is based on calendar month, quarter (three calendar months) and year contracts. Short term forward prices relate to the contracts within one year and long term prices to the contracts maturing more than one year ahead in time.

term prices. Long term price driving factors have little impact on short term price changes and vice versa. Both Koekebakker (2002), Koekebakker & Ollmar (2005) and Lucia & Schwartz (2002) stress the seasonal pattern of electricity prices (see Figure 6.1).

Even if it is the long term prices that are usually of most interest in valuation issues, it is the relationships between reservoir level, spot price and *short* forward contracts that provide the focal point of this part of the study. This is explained by the aim of studying the forward-spot spread representing an alternative cost for hydro electric generation and hence having an impact on value. The relationship between spot and forward prices in general terms has been discussed on several occasions (Brennan, 1991). The classic equation states:

$$F_t(T) = S_t(1+r)^{T-t} + W - CY \qquad \textbf{(6.1)}$$

where $F_t(T)$ is the forward (or futures) price observed at time t for a contract that has maturity at time T, r is the risk free interest rate, W is the storage cost and CY denotes the convenience yield. In the hydro based electricity generation industry it would not seem a controversial assumption to neglect the storage cost and hence set $W = 0$.

According to Pindyck (1990), the convenience yield is highly convex in inventories, becoming large as inventory level is low. This is clearly related to the expectations of availability in the contract period. Electricity does though possess some peculiar properties. Because of the lack of storage possibilities, some careful considerations should be made. Botterud, Bhattacharya, & Ilic (2002) points out that asymmetrical aspect do exist between the supply and demand side of a hydro power based electricity market. They argue that a certain degree of flexibility in generation supply certainly does exist, which can further be used for profit purposes during price peaks in the day ahead spot market. There is, however, no corresponding situation on the demand side, with limited opportunities to adjust demand according to the price level. Strong incentives do exist therefore for a risk averse demand side to lock in as much as possible of expected future demand in the forward/futures market. The consequence is a hypothesis of negative convenience yield and a negative risk premium in keeping with the contango hypothesis. Their empirical findings based on data from 1995 - 2001[11] support the hypothesis.

More flexibility in power generation than implied by Botterud et al. (2002) does, however, exist. In the Norwegian context the water reservoirs are capable of storing water with a low probability of overflow (NVE, 2006). This enables operators to act with a certain degree of flexibility and generate more when prices are high. But when water reservoirs are running low, this flexibility diminishes. In sum this should lead to a theoretical relationship between reservoir level and *CY*. From **(6.1)** one obtains (when *W* is ignored):

$$CY_t = S_t(1+r)^{T-t} - F_t(T) \qquad \textbf{(6.2)}$$

[11] They studied the risk premium for four types of futures contracts, with maturity 1, 4, 26 and 52 weeks ahead. The absolute value of the negative risk premium increased from 1.5 % to 18.3 %.

The definition of convenience yield is "the flow of services accruing to the owner of a physical inventory but not to the owner of contract for future delivery" (Brennan, 1991). Because of the peculiar properties of electricity, this parameter often has a negative value concerning short forward contracts (Kjærland, 2007). The absolute value of the *CY* does then refer to an alternative cost for hydro electric power generation. The relevant alternative cost, C^H, for generation operators is though consequently the forward-spot spread. Formally one gets:

$$C_t^H = \frac{F_t(T)}{(1+r)^{T-t}} - S_t \qquad \textbf{(6.3)}$$

Table 6.1: Descriptive statistics of spot and relevant forward prices (NOK/MWh).

	Number of observations	Min.	Max.	Mean	Standard deviation
System price	108	46.02	610.82	213.36	107.295
Forward one month	108	69.08	591.84	221.60	115.050
Forward two months	108	76.50	624.37	223.23	114.210
Forward three months	108	74.75	664.27	222.96	114.031

in which C^H denotes the alternative cost for hydro generation. This forward-spot spread is an important parameter when analyzing this industry. C^H can be viewed as an alternative cost for the operator because present generation can lead to lost future production in peak price periods. C^H captures the value per kWh of sacrificing generation some months ahead when prices may be higher. This relationship should therefore be examined carefully, to establish what available data reveals concerning this parameter.

This leads to an empirical estimation of C_t^H in equation **(6.3)**. The spot price is the so-called system price[12]. The system price development is shown in Figure 6.1.

Table 6.2: Estimation of the C^H (equation (6.3), NOK/MWh).

	Number of observations	Min.	Max.	Mean	Standard deviation
C^H one month forward contract	108	-59.72	95.28	7.44	25.86
C^H two month forward contract	108	-127.69	126.28	8.27	36.72
C^H three month forward contract	108	-132.30	182.90	7.22	44.84

[12] The system price is the equilibrium price when net congestion is ignored. Due to congestion there are normally different equilibriums in different areas (Norway is divided into three zones), but the system price reflects the general spot price relevant for the analysis performed in this paper.

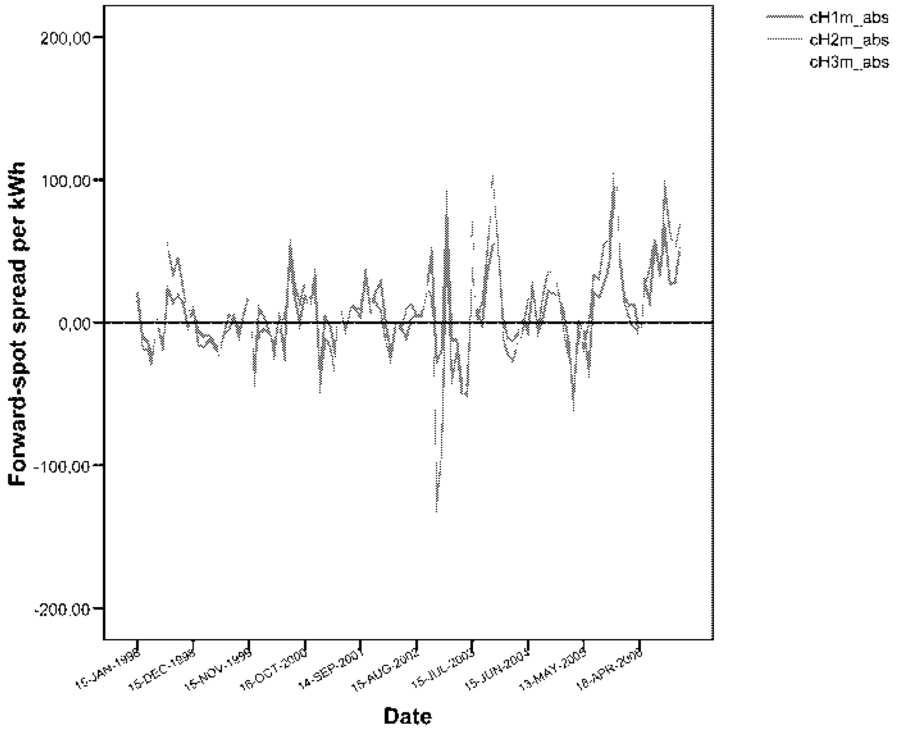

Figure 6.2: C^H (forward-spot spread) for one, two and three month forward contracts 1998 to 2006 (equation (6.3)).

In order to analyze the forward price one needs to choose some of the forward or futures contracts which capture the difference between spot price and near forward price. As pointed out by Lucia & Schwartz (2002) the issue of sufficient liquidity should be taken into consideration. The financial market at Nord Pool has developed and changed since the introduction of financial futures in 1994, since the design of financial instruments considers the needs of the different participants (Nord Pool, 2005). The forward contract structure from 2004 is based on calendar month, quarter (three calendar months) and year contracts. To capture the intended relationship all the three monthly forward contracts are chosen. These are observed from late 2003 to 2006[13]. During the period 1998 to 2002, the weekly block contacts are used. By using the weekly forward contracts one can estimate the corresponding forward prices to the monthly contracts from 2003. Furthermore, the 15th of each month is chosen and with three prices each month being observed. The sample consists then of 108 observations (9 years). Some summary statistics can be found in Table 6.1. As risk free interest rate is used the monthly average of the nominal NIBOR (Norwegian InterBank Offered Rate) rate of respectively one, two and three months, obtained from Norges Bank (2007).

The data is used to calculate the alternative cost, C^{H}. The average results are shown in Table 6.2 and the data is plotted in Figure 6.2[14]. Figure 6.3 shows the average C^{H} for the above-mentioned three contracts together with the national reservoir level development. The figures reveal heavy fluctuations and a seasonal pattern as previously commented on. This relationship is confirmed when making a more systematic approach in a correlation analysis as shown in Table 6.3.

[13] From late 2005 to 2006 the observed price are in Euro and is changed into Norwegian currency (NOK) by using the actual exchange rate the trading date (obtained from Norges Bank (2007)).

Reservoir statistics are provided from the database of NVE (the regulator). NVE collects and publishes reservoir levels on a weekly basis from 1998 – 2006. Figure 6.3 and Figure 6.4 show this for 2001 to 2006. One can recognize the heavy decrease in autumn 2002 causing the extremely high prices in late 2002 and early 2003. This also causes extremely low C^H – as can be seen in both Figure 6.2 and Figure 6.3. Figure 6.4 also reveals the low reservoir level in late summer/early autumn 2006, followed by an unusual increase during the rest of the year, which is due to an extremely mild and wet autumn. This explains the high prices during the late summer/early autumn, whereas there was a significant decrease in price levels for rest of the year. The observations of extremely high C^H in the early autumn of 2006 can be recognized in Figure 6.2 and Figure 6.3.

Table 6.3: Correlation (Pearson) for C^H and the water reservoir levels at national level (*WRL*).

	C^H 1 month	C^H 2 months	C^H 3 months	Average C^H
WRL	0.370	0.457	0.492	0.475

[14] The mean of the convenience yield is negative according to theses data, consistent with the contango hypothesis - the reason being the peculiar properties of electricity as e.g. explained by Botterud et al. (2002) and Koekebakker (2002).

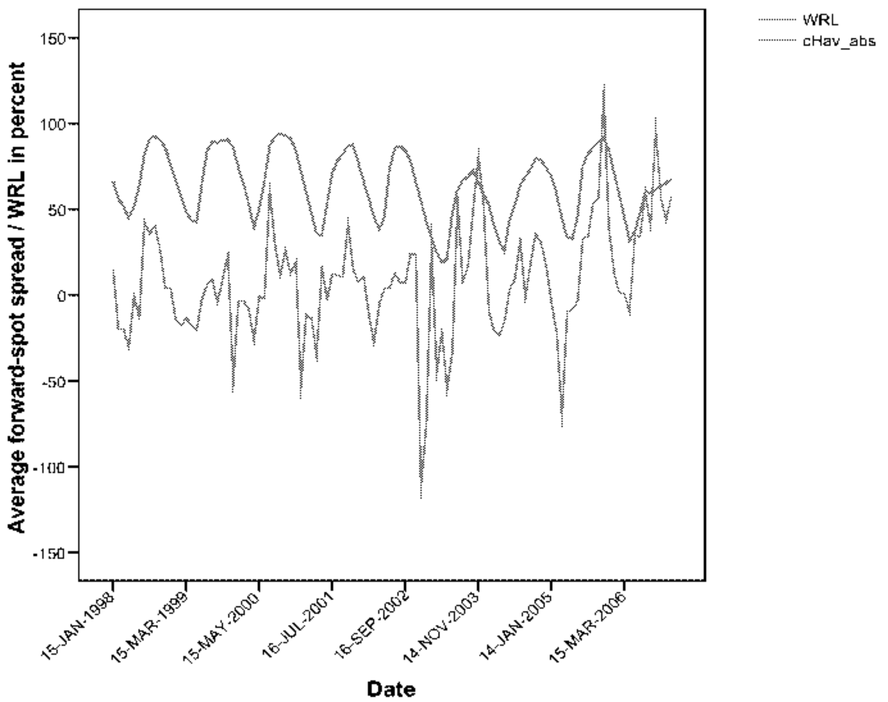

Figure 6.3: Average forward-spot spread (C^H) and national water reservoir level (*WRL*, in percent) 1998 – 2006. The positive correlation can be observed.

6.2.2 Explaining the alternative cost, C^H

The above analysis reveals that spot price, forward price and the forward-spot spread fluctuate greatly and this can be correlated to the reservoir level, published each week by the regulator (NVE). To further test the described relationship between reservoir level and the forward-spot spread, the following regression equation is estimated:

$$C_t^H = \beta_0 + \beta_1 WRL_t + \varepsilon_t \qquad \textbf{(6.4)}$$

in which C^{tl} denotes the average forward-spot spread (as defined in equation **(6.3)**) at time t of one, two and three months forward contracts and WRL denotes the national reservoir level in percent of maximum capacity.

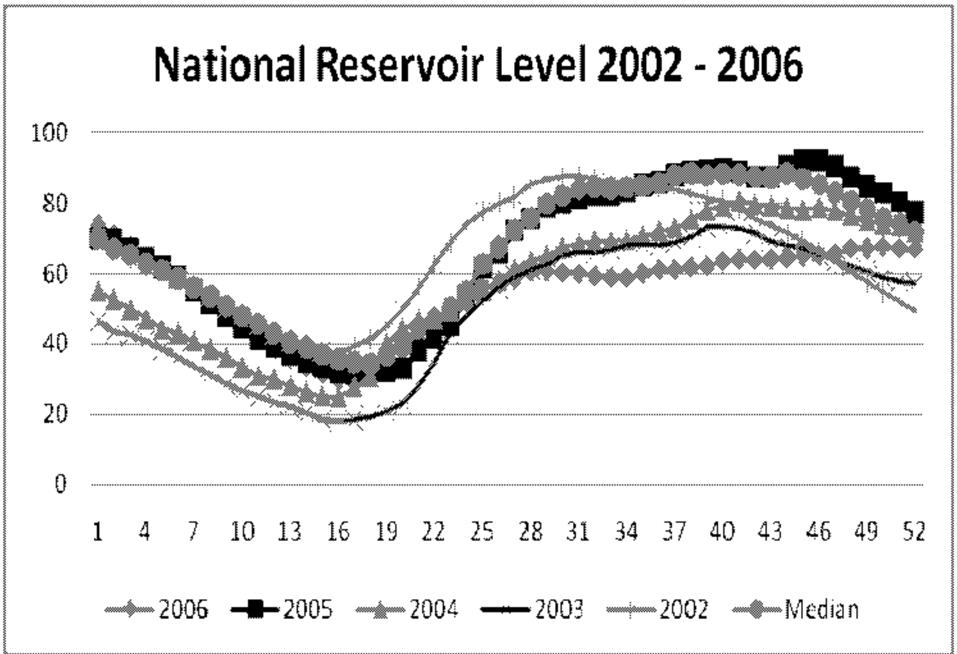

Figure 6.4: Reservoir inventory at national level 2001 – 2006, in per cent of maximal capacity. The X-axis consists of week no. "Median" is for each week the median level of national reservoir levels 1970 – 2006, as disclosed by NVE.

The industry is very much concerned with changes in reservoir levels, leading to include the last week reservoir change observation in the model (Gjølberg & Johnsen, 2001). To also try to capture the hydrological situation, one includes a variable that measures the deviation from the median reservoir level. This variable captures the situation if it is a "wet" or "dry" year. Hence an extension of the model becomes:

$$C_t^{tl} = \beta_0 + \beta_1 WRL_t + \beta_2 \Delta WRL_t + \beta_3 \Delta MED_t + \varepsilon_t \qquad \textbf{(6.5)}$$

in which *ΔWRL* denotes the change in reservoir level during the last week in percentage points ($\Delta WRL_t = WRL_t - WRL_{t-1}$) and *ΔMED* $(= WRL_t - MED_t)$ denotes the difference between median reservoir level the actual week and the reservoir level as disclosed by the NVE. Descriptive statistics and correlations (Pearson) of these independent variables is reported in Table 6.4.

Table 6.4: Descriptive statistics and correlations of the independent variables (*WRL*, *ΔWRL*, *ΔMED*) in the regression equation (6.5).

Variable	Number of observations	Min.	Max.	Mean	*Standard deviation*
WRL	108	18.7	94.1	63.85	*19.49*
ΔWRL	108	-3.5	7.5	-0.11	*2.46*
ΔMED	108	-26.4	19.1	-2.62	*10.28*

	Correlation (Pearson)	
	ΔWRL	*ΔMED*
WRL	0.103	0.331
ΔWRL		0.192

The weekly disclosure of NVE does emphasize both the change in reservoir level and the observation in light of the median level the actual week. Observers and commentators in the industry do the same. Hence, there is a solid foundation for the choice of these independent variables.

Table 6.5: Results of regression analysis of the relation between average forward-spot spread (C^H) and national water reservoir levels 1998 – 2006 (T-values in brackets).

Equation	n	β_0	β_1	β_2	β_3	DW[15]	$\overline{R}^2$
(6.4)	108	-45.192	0.827			1.161	0.218
		(-4.543)	(5.551)				
(6.5)	108	-56.170	0.962	4.496	-1.104	1.371	0.378
		(-5.848)	(6.820)	(4.193)	(-4.072)		

The estimation results of the regression analyses are reported in Table 6.5 and Table 6.6. A plot of the results of equation **(6.5)** is shown in Figure 6.5. The results are consistent with the results of Gjølberg & Johnsen (2001). There is a significant positive relationship between water reservoir level and the forward-spot spread, which may surprise. Nevertheless, this is the empirical findings. At low reservoir levels there is a negative forward-spot spread, as indicated by the negative constant term. At a reservoir level of about 55 percent, the spread becomes positive (equation **(6.4)**). When reservoir levels are high, the spot price is low and hence, the forward-spot spread is high. When reservoir levels are low, the spot price is higher and consequently the spread becomes negative. The spot price seems to dominate

[15]Lower critical value of DW for 100 observation and 3 explanatory variables is 1.61.

the short forward prices. This explains the positive sign of the β_1-coefficient of equation **(6.4)** and **(6.5)**.

The Durbin Watson test shows that autocorrelation does exist in the models. This leads us to perform a robust test of the model (Gujarati, 2003; Wooldridge, 2003). The robust test shows slightly different T-values, but all coefficients remain significant at the 1 % level. No multicollinarity was detected ($VIF < 1.2$ for all three independent variables).

Table 6.6: Results of the regression analysis of equation (6.5) with respectively, one, two and three months C^H as the dependent variable (T-values in brackets).

Equation (6.5)	***n***	β_0	β_1	β_2	β_3	$\overline{R}^2$
1 month	108	-36.603	0.651	1.043	-0.991	0.252
		(-4.565)	(5.532)	(1.166)	(-4.386)	
2 months	108	-58.589	1.007	4.530	-1.173	0.346
		(-5.505)	(6.446)	(3.815)	(-3.909)	
3 months	108	-73.319	1.228	7.917	-1.146	0.439
		(-6.086)	(6.945)	(5.890)	(-3.374)	

The results show that, taking into consideration the last week change in reservoir levels and the deviation from the median value of the reservoir level, hypotheses that these independent variables have impact on the forward-spot spread are supported. This forward-spot spread on the studied contracts is sensitive to inventory information published from the regulator every week. The findings also confirm that the hydrological conditions, depending on the observations are done in a "wet" or "dry" year, also have influence. The observed C^H and predicted C^H (based on equation **(6.5)**) are plotted in Figure 6.5. It is observable that the extreme situations, as winter 2002/03 (very low *WRL* after a "dry" autumn and cold part of the early winter) and late autumn 2006 ("wet" and mild period), are not fully captured by the model.

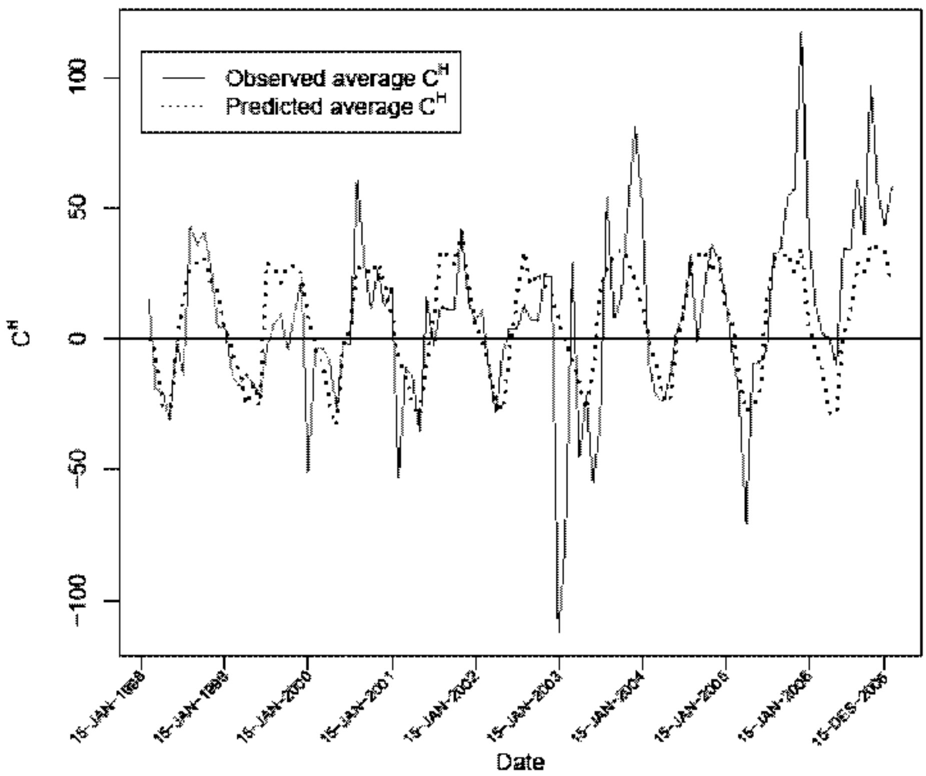

Figure 6.5: Observed average C^H (solid line) versus predicted average C^H (dotted line) (equation (6.5)).

This completes the analysis of the forward-spot spread. When reservoir levels are running low, there is a negative forward-spot spread, making the alternative cost negligible. Hence, there are no benefits involved in including alternatives. However, in times when the forward-spot spread is high, the alternative cost of generating is significant. Thus it becomes economically interesting to have the opportunity to switch to alternative generation in order to generate more in peak price periods, assumed that the cost of using such generation is lower that the spot price.

6.2.3 Operational cost of thermal generation

The relevant cost of thermal generation is operational costs and fuel costs, if the plant is owned by the hydro-operator, or the agreed price, V^{Th}, if there is an option agreement with a thermal operator.

The cost of operating a gas fired thermal power plant is complex, and depends particularly on exogenously determined gas prices. According to Bolland (2006), the operational cost for an average gas fired thermal power plant in the Norwegian context would be NOK 0.0243/kWh and the fuel cost NOK 0.2855/kWh - based on a gas price of NOK 1.73/Sm^3 [16]. Hence, the flexibility value involved in despatching gas fired thermal power to a hydro producer would yield a low switching option value. However, gas prices are highly volatile and have at present (2007) reached a high level compared to for instance 2004 prices which were much lower (average price in e.g. 2004 was NOK 0.97/Sm^3 (SSB (Statistics Norway), 2007).

The operational cost of nuclear and coal fired thermal plants is lower. Concerning the operational cost of nuclear power, a number of country-specific factors do exist. Technological improvements have nevertheless lowered the cost considerably, making nuclear energy the cheapest alternative compared to other non-hydro gen-

[16] According to Statistics Norway this was the average gas price in 2006 (SSB (Statistics Norway), 2007).

eration technologies. According to WNA (World Nuclear Association, 2005), the operating cost, including fuel and maintenance, in Finland and Sweden is currently at a level of NOK 0.08/kWh. This then represents the relevant cost of an input parameter in the model of proposed in this paper.

The operational cost of coal fired thermal power plants is higher than that of nuclear plants, but lower than plants fuelled with gas. According to statistics from the Nuclear Energy Institute (2007), the average cost for U.S. plants is approximately NOK 0.14/kWh. This operating cost can serve as the base case input parameter, even if there are some factors that are complicating transference to a Norwegian setting.

Table 6.7: The operational cost and fuel cost used in the analysis of different types of thermal generation, along with an estimated external renting price. NOK/kWh.

C^{Th} Gas-fired	C^{Th} Coal-fired	C^{Th} nuclear	V^{Th}
0.31	0.14	0.08	0.30

However, if the situation is that thermal generation is rented from another operator, the relevant parameter is the agreed price, termed V^{Th}. The level of V^{Th} would obviously be independent from type of fuel, but be probably somewhere below the general long forward prices traded at Nord Pool. A careful estimate would be NOK 0.30/kWh.

This provides the basis for a further analysis in the next session, aimed at estimating the value of being able to switch between hydro and an alternative of thermal generation. The numbers used in the following analysis is shown in Table 6.7.

6.3 MODEL DESCRIPTION AND NUMERICAL ANALYSIS

6.3.1 The decision model framework

This session describes the model for quantifying the value of the operational flexibility provided by controlling both hydropower and a type of thermal power (de Moraes Marreco & Tapia Carpio, 2006). The model assumes a situation where a generating company can switch and operate in either one of two different modes, *H* (hydro) or *Th* (thermal). If thermal is bought externally, there are two conditions for exercising such an option to become economically interesting; 1) $C^{H} > 0$ and 2) $V^{Th} < S$ (spot price).

The switching aspect relates though only to a portion of the hydropower generation. Because of the contract obligations the operator cannot produce under a certain level. But there is an option value for every kWh below this level that can be replaced by available thermal generation in times when C^{H} is high. The following description relates to this part of the production.

Associated with each mode is a cash flow depending on the uncertainty incorporated in the model. In each period, in this context one week, the operator can choose which mode to operate in. The nature of the situation described in this paper suggests focusing on the cost flows attached to each mode. Hence, in each mode one can compare the alternative cost for hydro energy generation with the operational and fuel cost of thermal generation (respectively gas, coal and nuclear) or V^{Th}. The objective is to minimize the operational cost flow in each period, which in the setting of this paper is each week.

In the model there is a focus on the cost flow generated in week t at either mode hydro (C^{H}) or mode thermal (C^{Th})[17]. Switching costs relating to interchanging between the two modes are assumed to be zero. This could be problematic if thermal generation was owned by the hydropower generator, since switch on/off costs are considerable. However, if the operator possesses an option of renting thermal generation capacity from another entity, this should not cause controversy. The model provides then the net present value of cost saving per kWh yearly available thermal power capacity.

The driving uncertainty in the model is the inflow in the water reservoirs, modelled by a stochastic process. We assume that change in reservoir level (ΔWRL) in each week is truncated normal distributed with expectation the average change in each week 1998-2006 and a standard deviation based on the same time series (see appendix 1). The focus on ΔWRL is justified due to obvious lack of independence between WRL_t and WRL_{t-1}. However, it seems more reasonable to assume independence between ΔWRL and WRL_{t-1}. Hence, one gets:

[17] Alternatively V^{Th}, as described previously.

$$
\begin{aligned}
&WRL_t \equiv WRL_{t-1} + \Delta WRL_t \\
&E(WRL_t \mid WRL_{t-1}) = WRL_{t-1} + E(\Delta WRL_t \mid WRL_{t-1}) \approx \\
&WRL_{t-1} + E(\Delta WRL_t)
\end{aligned}
\qquad \textbf{(6.6)}
$$

This enables to incorporate the uncertainty in downpour, inflow and hence the reservoir level. Change in reservoir level is a variable with a seasonal pattern. But the reservoir level statistics make it possible to calculate for each week the average and standard deviation (see appendix 2). These figures serve as input parameters for simulating the alternative cost of hydro generation according to equation **(6.5)**, which is utilised later in this section. Hence, one incorporates in the model the stochastic and seasonal pattern of inflow and thereby the great differences in alternative cost throughout the fiscal year[18].

When the basis of simulating ΔWRL has been established, one can follow the model framework of Kulatilaka (1988). The purpose is to calculate the option value of possessing both hydro and thermal power when relating to the inflow and hence reservoir level as the stochastic, uncertain factor. This option value is calculated as the difference between the values of the flexible situation compared to the rigid situation without thermal generation. As previously described, the C^H represents an alternative cost for an operator, which can be high in some parts of the year. This means that the option to switch between hydro and thermal generation is worth

[18] The simulated values of *WRL* are programmed to be truncated by the max and min value for each week disclosed by NVE for the period 1970 – 2007 (see the *R* source code in appendix 2).

calculating for those weeks of the year when C^H is at a high level. For the weeks when the negative outcome concerning inflow leads to a higher expected C^H than the operational cost of a thermal power plant, one obtains an option value, due to the opportunity of being able to switch from *H* to *Th*.

The actual model derived from Kulatilaka (1988) provides the following: the flexible situation is studied for a period of one year; $T = 52$. At time *T-1*, when one week remains of the total period, the water reservoir level will be WRL_{T-1} and the operational cost for the last week of the period will either be $C^H{}_{T-1}$ or $C^{Th}{}_{T-1}$ (V^{Th}) depending on which mode one is operating in. When only one period remains, the value can be calculated with certainty given by the minimum cost of the two possible modes, either C^{Th} (V^{Th}) or the estimated C^H. If one denotes the actual cost of the flexible situation C^F one gets:

$$C^F_{T-1} = \min\left[C^H(WRL_{T-1}), C^{Th}{}_{T-1}\right] \qquad \textbf{(6.7)}$$

At time *T-2*, the cost of the flexible system will be the cost of the next period (week) that minimizes this period's operational cost plus the expected value from the last period (*T-1*). This gives:

$$C^F_{T-2} = \min\left[C^H(WRL_{T-2}), C^{Th}{}_{T-2}\right] + \rho^{-1} E_{T-2} C^F_{T-1} \qquad \textbf{(6.8)}$$

where ρ is the risk free discount factor for the week (one period) equal to $(1-r_f)$ (alternatively: $\rho = e^{r_f \Delta t}$).

In each period the operator must contemplate switching to the other node, comparing the expected alternative cost of hydro to the operational cost and fuel cost of thermal generation. To capture the switching option value one relates to a summarization of the cost saving. This is a simplified version of the conceptual model of Kulatilaka (1988), since no switching cost leads to avoiding that the value is depending on modes. The net present value of yearly saved cost in this setting becomes:

$$NPV_{costsavings} = C^{H} - C^{F} = \frac{1}{52}\sum_{t=1}^{52}\left[\rho^{-1} \cdot C^{H}(WRL_t) - \min\left[C^{H}(WRL_t), C_t^{F}\right]\right] \qquad \textbf{(6.9)}$$

where; $t = 1,....52$; and $\rho = e^{r_t \Delta t}$. The optimalization problem is each week to choose the mode minimizing the cost for that week. No switching costs simplify the calculations. The equation gives the net present value of the yearly cost saved per kWh through the accessibility of thermal generation in the flexible situation. This calculation makes it possible to estimate the net present value of saved cost by having a flexible situation compared to a rigid situation of purely hydropower.

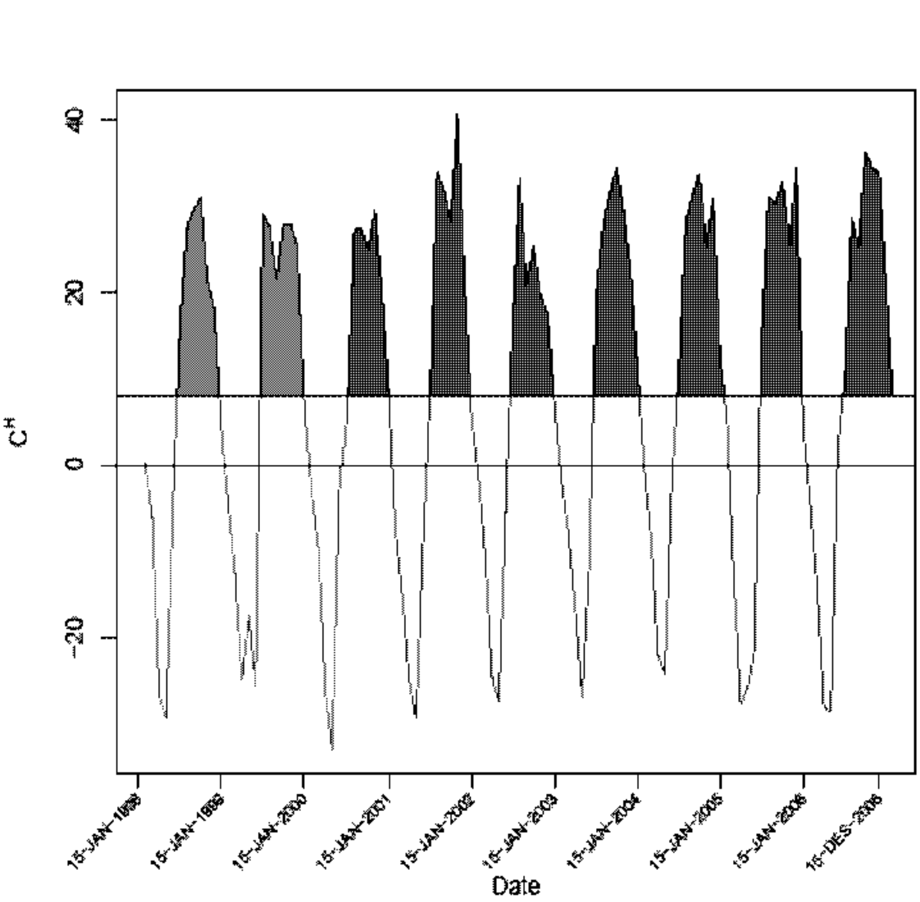

Figure 6.6: The shaded area represents the costsavings calculated in equation (6.9) per kWh yearly nuclear generation that is used instead of hydro when $C^H > C^{Th}$. The areas are limited of the line of estimated C^H (equation (6.5)) and the operational and fuel cost of nuclear of NOK 0.08/kWh.

6.3.2 Numerical analysis

The numerical calculations give the results shown in Table 6.8. The option values based on equation (6.5) and equation (6.9) can be interpreted as the flexible value of introducing thermal power generation for a hydro-based operator in order to generate 1 kWh in a year. The option values are highest for nuclear due to the low operational cost, and lowest for thermal power plants fuelled by gas. The value in the case of nuclear is illustrated as the shaded area in Figure 6.6.

This option value is the net present value of cost savings due to being able to switch to thermal generation in times when the alternative cost of hydro generation as a stochastic variable exceeds the operational cost of a thermal power plant or renting price [19]. The value is a result of high C^H during some parts of the year.

Following these results, one can comment on some implication for an operator implementing thermal power generation in addition to hydropower generation. The rent of some thermal generation in order to have the opportunity to switch from hydro to thermal in some parts of the year for some of the production give some benefits, if not V^{Th} is too high. If thermal generation is controlled by the operator, the value of flexibility becomes higher. If e.g. a producer controls 100 GWh yearly from a thermal nuclear producer (constant through the year) which all can be used for saving water to peak price periods, the value of the enhanced flexibility would be NOK 6.5 million.

[19] The risk free rate is set to 5.2 % p.a. which yields a weekly discount factor of 0.10 %. This is close to the current risk free rate in Norway (October 2007), however this parameter has little impact on the switching option value.

Table 6.8: The option value based on different types of thermal generation (per kWh yearly generation capacity) based on equation (6.9). The value represents a premium for a hydro based operator of being able to switch to thermal generation in times when the alternative cost for hydro is high.

Type of thermal generation	*Input parameters*	*Equation **(6.9)** Value[20], yearly generation 1kWh*	*Standard deviation (equation **(6.9)**)*
Gas fired	$C(C_t^m, m, t)/52$ $C^{Th} = NOK\,0.31/kWh$ ($r = 0.052$)	NOK 0.0128	0.0223
Coal fired	$C(C_t^m, m, t)/52$ $C^{Th} = NOK\,0.14/kWh$ ($r = 0.052$)	NOK 0.0453	0.0525
Nuclear	$C(C_t^m, m, t)/52$ $C^{Th} = NOK\,0.08/kWh$ ($r = 0.052$)	NOK 0.0652	0.0660
Externally bought	$C(C_t^m, m, t)/52$ $V^{Th} = NOK\,0.30/kWh$ ($r = 0.052$)	NOK 0.0219	0.0264

[20] The numbers are a result of 10000 simulations; see the *R* source code in appendix 2.

The numbers calculated in this subsection give reasonable input regarding the flexibility value which is relevant in the negotiations of the rent in order to have access to thermal generation or in the assessment of an investment in a thermal power plant. The numbers show a possible significant value and should be considered in the described situation.

6.3.3 Discussion

Hydro operators face constantly the optimalization problem of use now or later of the water in their reservoirs. No obligation exists for constant output. However, a large part of the production for a significant number of generating companies is locked up in long term industry contracts, limiting the possibility of scheduling the production to peak price periods. By having an option to control thermal power in addition to hydro, there is realism in the calculations presented which should be considered in renting issues or investment decisions.

Another aspect to comment is the uncertainty of fuel prices. The development of the cost of nuclear power as fuel seems quite stable and not particularly volatile. The cost of coal as fuel depends on the location, but seems far less volatile than petroleum. Nevertheless, stochastic elements do exist in the cost of thermal generation that are ignored in this analysis, and hence this represents a shortcoming. However, the value of operational flexibility has intuitively represented a value and has been taken into account as a qualitative aspect in such assessments. But by using the approach presented in this paper, there is a solid foundation for measuring the impact the switching option aspects has for the value at both firm and system level.

This approach may also hold valid at system level. There would always be a demand to be met, and thereby the presented approach yields trustworthy results. The possibility of import could question this point. Nevertheless, the congestion in the net capacity can partly meet this argument. The calculations can hence be discussed in view of the governmental subsidies (The Ministry of Petroleum and Energy, 2006b). If the alternative cost for hydro generation can also be interpreted as a deficit cost in a macro perspective, the findings can justify and legitimate a part of possible subsidies, as done by de Moraes Marreco & Tapia Carpio (2006). Even if uncertain factors do exist in this approach, the results show that the switching option aspect represents a value that should not be ignored. This should definitely be incorporated in the valuation of the alternatives to hydropower.

The findings show that the complementary argument is valid and that the switching option aspect should be included in the economical assessments of adding alternative generation technologies. The values in Table 6.8 provide e.g. the willingness of paying for the option of renting thermal generation capacity.

6.4 CONCLUSIONS AND IMPLICATIONS

This paper represents a real option approach to the value of operating flexibility in the Norwegian generating industry when adding thermal generation to hydropower. The key assumption is the operator's restriction in scheduling due to long term industry contracts. By applying the real option model framework of Kulatilaka (1988), one has been able to estimate the option value per kWh available thermal generation that can be used for saving water to peak price periods. Moreover, estimates have been presented of the net present value of minimizing costs between the alternative cost of hydro and operational cost and the fuel cost of different types of thermal generation in the described situation where large parts of the hydropower generation are locked up in industry contracts.

The alternative cost for hydropower operators has been developed and modelled based on data from Nord Pool and the regulator (NVE). This result in two versions of a model explaining the forward-spot spread (C^H) based on water reservoir level and the hydrological situation. The adjusted R squared for the three-factor model reaches 0.44 at the highest (three month forward contracts, equation **(6.5)**).

The numerical calculations of the switching option value show that there are significant option values when thermal power plants are controlled by a hydro operator. However, if thermal capacity is rented externally, the option value depends on the agreed price. If this price is sufficiently low, an option value emerges. The calculations are useful in order to either 1) assessment of own thermal investments, or 2) in negotiations with thermal operators of option contracts. In both situations, the switching option aspect would provide relevant information in valuation assessments.

Another implication is that ignoring the option value aspect can lead to underinvestment in nuclear and coal fired thermal generation compared to gas fired plants. In other words, from the viewpoint of flexibility, the least profitable alternative is gas-fired thermal generation. Nevertheless, this is the only thermal generation actually implemented in the Norwegian power system.

The value of a flexible system can justify and legitimate governmental subsidies. This assumes that the alternative cost of hydro generation can be linked to a kind of deficit cost at system level. If the estimations of C^H are interpreted in this way, the calculations suggested in this paper partly provide a valid argument for subsidies of alternative power generation, which in turn depends on such support being profitable.

The stochastic nature of this industry makes it challenging to analyze valuation issues. The uncertainty of this paper is related to the uncertainty in reservoir levels throughout the year. The regression equations of C^{H} are also disputable since they only partially explain the forward-spot spread. Nevertheless, the estimations of switching option values are relevant and provide insight into the value of operating a situation with flexibility.

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APPENDIX 1: NATIONAL WATER RESERVOIR LEVEL (WRL) STATISTICS:

(On the following three pages):

Week no. (t)	Average WRL (percent) (1998-2006)	Standard deviation (WRL)	Median (WRL, in percent)
1	67.12	10.05	69.8
2	64.86	10.18	66.8
3	62.61	9.75	65.1
4	59.96	9.51	62.6
5	57.53	9.49	60.6
6	55.09	9.16	58.3
7	52.51	9.05	56.0
8	50.02	9.09	53.5
9	47.44	9.25	50.8
10	44.76	9.16	48.0
11	42.06	8.83	45.5
12	39.78	8.35	42.8
13	37.67	8.14	40.5
14	36.20	8.40	38.8
15	34.53	8.46	37.1
16	33.29	8.17	35.4
17	33.81	8.14	34.6
18	35.78	8.63	34.2
19	38.86	8.84	36.8
20	42.50	10.22	39.2
21	46.76	10.05	44.4
22	50.59	9.79	47.2
23	55.00	9.66	50.1
24	59.78	9.83	54.9
25	64.34	9.89	62.6
26	68.44	10.54	67.5
27	71.87	10.68	72.3
28	74.67	11.02	75.7
29	76.66	11.58	79.8
30	78.21	11.72	82.2
31	78.92	11.64	83.9
32	79.29	11.88	84.5
33	79.71	12.07	84.2
34	80.17	12.18	84.4
35	80.69	11.76	84.8
36	81.06	11.39	85.6
37	81.38	11.31	87.6
38	81.96	10.92	88.3
39	82.44	10.31	87.6

Week no. (t)	Average WRL (percent) (1998-2006)	Standard deviation (WRL)	Median (WRL, in percent)
41	82.81	9.59	87.9
42	81.87	9.79	87.2
43	81.41	10.38	87.1
44	81.59	11.21	88.2
45	80.97	11.23	86.7
46	79.74	11.19	85.2
47	78.30	11.11	82.8
48	76.78	10.87	80.5
49	75.12	10.87	78.1
50	73.33	10.70	75.8
51	71.53	10.52	74.0
52	69.49	10.10	71.6

Week no. (t)	Average ΔWRL (1998-2006)	Standard deviation ΔWRL	Max WRL (1970-2007)	Min WRL (1970-2007)
1	-2,81	0,82	46,4	76,8
2	-2,27	0,81	43,5	74,6
3	-2,24	0,86	42,5	71,7
4	-2,66	0,41	40,7	68,9
5	-2,42	0,67	38,5	66,9
6	-2,44	0,74	36,2	65,0
7	-2,58	0,64	33,7	62,0
8	-2,49	1,20	31,1	61,8
9	-2,58	1,14	28,6	60,1
10	-2,69	0,50	26,5	58,0
11	-2,70	0,52	24,9	57,6
12	-2,28	0,69	23,4	58,0
13	-2,11	0,66	22,1	56,8
14	-1,47	1,11	20,5	55,4
15	-1,67	0,60	18,7	53,8
16	-1,24	0,69	17,3	52,4
17	0,52	1,51	18,7	52,7
18	1,97	1,59	19,4	57,8
19	3,08	3,13	20,9	62,1
20	3,64	1,75	23,0	64,1

Week no. (t)	Average ΔWRL (1998-2006)	Standard deviation ΔWRL	Max WRL (1970-2007)	Min WRL (1970-2007)
21	4,26	1,19	27,1	65,1
22	3,83	2,20	29,5	67,8
23	4,41	2,32	35,7	74,3
24	4,78	1,75	40,6	79,1
25	4,57	1,55	44,5	84,8
26	4,10	1,68	46,6	88,4
27	3,42	1,53	50,0	91,3
28	2,80	0,69	52,4	93,2
29	1,99	1,06	53,8	94,7
30	1,56	1,05	55,2	95,4
31	0,71	0,76	56,4	96,3
32	0,37	0,99	57,0	95,6
33	0,42	0,94	57,2	97,3
34	0,46	0,92	58,3	97,1
35	0,52	0,75	59,5	97,2
36	0,37	0,87	59,7	97,2
37	0,32	0,85	58,9	96,5
38	0,58	1,10	58,1	96,6
39	0,49	1,46	57,8	96,5
40	0,27	1,29	60,0	95,9
41	0,10	1,50	62,2	96,7
42	-0,94	1,09	63,1	97,1
43	-0,46	1,04	63,4	96,5
44	0,18	1,68	64,3	95,1
45	-0,62	1,31	65,1	93,0
46	-1,22	1,16	65,3	91,9
47	-1,44	1,03	63,5	90,2
48	-1,52	1,34	60,6	87,7
49	-1,66	0,93	57,7	86,1
50	-1,79	1,09	54,9	84,6
51	-1,80	1,02	52,1	81,7
52	-2,04	0,98	49,6	78,8

APPENDIX 2: THE R SOURCE CODE

The R source code made for the simulations of equation **(6.9)**:

```
library(foreign)
library(msm)
pdf(file="CH_simulering-WRL%003d.pdf", onefile=FALSE)
N=10000
value=numeric(N)
SimWRL=numeric(52)
SimWRLchange1=numeric(52)
xx =read.spss('H:/PhD/Endringer WRL.sav',
          to.data.frame=TRUE)
WRLchange1.mean=xx[1:52,1]
# WRLchange1.mean
WRLchange1.sd=xx[1:52,2]
# WRLchange1.sd
MedianWRL=xx[1:52,3]
# MedianWRL
MinWRL=xx[1:52,4]
MaxWRL=xx[1:52,5]
WRLuke1.mean=67.1
WRLuke1.sd=10
cTH=8    #atom
# cTH=14   #kull
# cTH=31   #gass
plot(MinWRL,col="red",pch=20,ylim=c(15,100))
points(MaxWRL,col="blue",pch=20)
for (i in 1:N) {

SimWRL[1]=rtnorm(1,mean=WRLuke1.mean,sd=WRLuke1.sd,lower=Min
WRL[1],
       upper=MaxWRL[1])

SimWRLchange1[1]=rnorm(1,mean=WRLchange1.mean,sd=WRLchange1.
sd) #ikke trunkert
   for (j in 2:52) {
```

```
SimWRLchange1[j]=rtnorm(1,mean=WRLchange1.mean[j],sd=WRLchang
e1.sd[j],
          lower=MinWRL[j]-SimWRL[j-1],upper=MaxWRL[j]-SimWRL[j-
1])
      SimWRL[j]=SimWRL[j-1]+SimWRLchange1[j]
    }
   points(SimWRL)

   EstCH=-56.170+0.962*SimWRL+4.496*SimWRLchange1-
1.104*(MedianWRL-SimWRL)
#   EstCH
   CF=pmin(EstCH,cTH)
#   CF
   Diff=EstCH-CF
#   Diff
   value[i]=0
   for (j in seq(52,1,-1)) value[i]=value[i]/1.001+Diff[j]
   value[i]=value[i]/52
#   value[i]
}
hist(value)
mean(value)
sd(value)
dev.off(which = dev.cur())
```

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