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Selective Hedging in Hydro-Based Electricity Companies

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Abstract

We analyze risk management trends in electricity commodity markets using the production and transaction data and written hedging policies of 12 Norwegian hydropower companies. The scope of our analysis is the hedging of physical electricity production using the power derivatives available at NASDAQ OMX Commodities. In their hedging policy, these companies either use a Cashflow at Risk (C-FaR) approach or a hedge ratio approach, or follow no explicitly stated approach. We find that the derivative cashflows constitute substantial profits for these companies. Furthermore, hedging contributes to reducing the C-FaR for 10 of the companies. These findings are surprising considering that we expect hedging to yield zero expected profit and to smooth the earnings function. Overall, our findings reveal that a practice of incorporating market views in hedging decisions is widespread in the sample companies, as both sanctioned in their written hedging policy and as indicated by the substantial hedging profits.

1 Introduction

As a rule, the liberalization of electricity markets has transferred risk from consumers to utilities. For example, the risk associated with unfavorable investments was largely borne by customers through the cost-based pricing model before liberalization. With the introduction of wholesale markets for electricity, sector risk is shared differently. At NASDAQ OMX Commodities, risk associated with electricity prices can be hedged through trading of power derivatives. NASDAQ OMX Commodities is currently the largest and most liquid market, relative to the bilateral over-the-counter (OTC) market, for power derivatives in Scandinavia (comprising Norway, Denmark, Sweden and Finland), with an annual turnover of €74.8 billion and a 57 % market share. For an introduction to this market, see Lucia and Schwartz (2002). Lucia and Schwartz (2002) in particular emphasize that Nordic electricity prices are highly volatile, up to an annualized volatility of 189 %. The nonstorability of electricity makes cash-and-carry-based relationships invalid, and this contributes to the high price volatility found in electricity markets. This aspect, combined with the risk premium found in power derivative prices, is described in Longstaff and Wang (2004), Kolos and Ronn (2008) and Botterud et al. (2010).

We find evidence of widespread risk management practice in Norwegian electricity companies. The average annual electricity production in Norway is 123 Terawatt-hours (TWh[1]), of which 99 % is hydroelectricity[2]. Figure 1(a) shows that 90 % of aggregate

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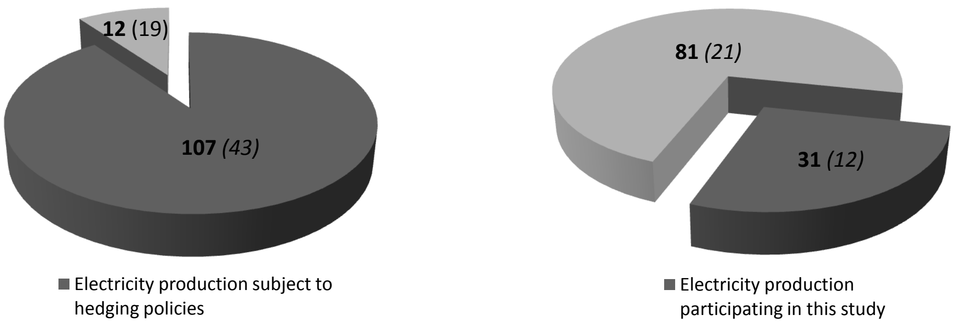
[1] 1 Terawatt-hour (TWh) = 1 billion kilowatt-hours (kWh).
[2] Statistics Norway (SSB), 2003–07.



(a) (b)

Figure 1: Overview of electricity production and hedging in Norway. Values presented are annual energy generation in **TWh** *(number of companies)*. Figure (a) depicts the annual production of electricity subject to hedging policies (107 TWh) in total annual electricity production, comprising companies producing more than 0.1 TWh. Figure (b) depicts the annual production of the companies participating in the present study (31 TWh) relative to the total annual production of all companies contacted during the study.

production is subject to hedging policies[3] when including companies with production of at least 0.1 TWh/a (thereby accounting for 97 % of aggregate production). In other words, companies that undertake hedging account for close to 90 % of the total generated electric energy in Norway.

The literature includes numerous studies of hedging practices in nonfinancial companies. We can divide these studies into three distinct categories: (a) case studies of a particular company, (b) case studies of several companies in the same industry (our chosen approach) and (c) studies of many (100+) companies. While the first two categories draw on data extracted from the firms themselves, the final category relies on data from company financial statements. While the latter has the clear advantage of standardized data collection from a large pool of companies, Judge (2007) highlight several drawbacks in the accuracy of the studies using this data source. First, these studies examine derivative usage generally and not hedging specifically, and therefore ignore hedging methods outside derivative trading. Second, some of the studies may fail to identify that companies may actually aim to increase their risk exposure through derivative trading, unlike hedging. Finally, some studies only use keyword searches to identify hedgers in their samples.

Studies of many companies are performed with data from either financial statements (Allayannis and Weston, 2001; Graham and Rogers, 2002) or surveys (Nance et al., 1993; Bodnar et al., 1998) or a combination of these two methods (Haushalter, 2000). Triki (2005) and Judge (2007) review other (c) category studies. The literature on one-company case studies, which uses data on the same level we have access to, includes Petersen and Thiagarajan (2000) and Brown (2001).

Literature is scarce regarding empirical studies of hedging in nonfinancial companies using firm-level data from more than a few companies, and there are no specific study of hedging practice in the power industry. Accordingly, the purpose of this study is to examine hedging policies in electricity companies. While we follow comparable case studies on nonfinancial companies (Petersen and Thiagarajan, 2000; Brown, 2001; Adam and Fernando, 2006; Brown et al., 2006), and of electricity producers in particular (Fleten et al., 2002, 2010, 2012), our approach is of a more positive than normative character. We attempt to describe and analyze how the hedging of commodity production is actually

[3] A company is assumed to be a hedger when hedging practice or policy is described in its annual report, on its website, or in an interview in public media.

undertaken by highlighting policy, the associated financial transactions, and the results. More specifically, we investigate whether a hedging policy can add value to the firm. Generally, we shed light into the supply side of the financial part of the Nordic electricity market.

For this purpose, we acquire data through direct inquiry to 33 Scandinavian hydroelectricity companies (comprising the 29 largest companies by annual production and 4 others). Twelve Norwegian companies agreed to participate in the study (see Figure 1(b)), together accounting for 25 % of annual Norwegian electricity production. We collected data on the production and financial transactions for these 12 companies over a three-year period (2007–09). The data include some 8,171 unique derivative transactions. This dataset therefore constitutes unique multicompany data not found in the current risk management literature. We contribute to the literature mainly through our empirical analysis of the individual hedging transactions and policies in 12 commodity producers. Analysis of the hedging transactions and statements in the companies' written policies reveals that selective hedging practice (incorporation of a market view in hedging decisions) is widespread among these companies. Most of the companies also have substantial profit contributions from their hedging transactions and are more successful in decreasing the Cashflow at Risk (C-FaR) compared with reducing the cashflow variance. This makes us believe that C-FaR is a more effective metric when evaluating the added value of hedging. We also find that there is seasonal variation in the proportion of production hedged depending on the delivery season. However, there is no clear trend as to which season is hedged more. Together, these findings contradict the neoclassical interpretation of hedging as a pure risk-reducing method with no expected profit.

Our results show that the normalized hedging ratio for the sample of hydroelectric producers is comparable with what is found in studies from other markets and countries. Therefore these results can be applicable to other non-electricity firms. Nevertheless we expect an influence from the fact that the overall majority of electricity-producing companies in Norway are owned by either the state or by municipalities. This should indicate that these companies employ a hedging strategy to produce a consistent dividend level for their owners, who require these funds for public services.

The rest of the paper is organized as follows. The remainder of this section summarizes the literature on hedging practice and corporate risk management. Section 2 describes the dataset. Section 3 provides the characteristics and trends in hedging practice in the sampled companies. Section 4 analyzes how the hedging of commodity prices can add value to the same companies. Section 5 concludes.

1.1 Literature review

Neoclassical economics postulates that hedging cannot add value because markets are efficient and because investors can hedge themselves (Modigliani and Miller, 1958). Nevertheless, the hedging literature provides both theoretical arguments and some empirical evidence that hedging, at least to some extent, can be value-adding for the firm.

A common approach to measure added value is through the increase in firm value. Using a sample of 720 large nonfinancial firms, Allayannis and Weston (2001) conclude that currency hedging firms have 4.9 % higher value than nonhedging firms. Likewise, Lin and Chang (2009) discover that airlines resident in the U.S. that hedge their jet fuel costs increase firm value relative to nonhedgers. Moreover, the results in Lin and Chang (2009) indicate that fuel price hedging is more valuable during periods of high price volatility. In contrast, Jin and Jorion (2006) find no evidence that hedging firms are more valuable than comparable nonhedging firms in a sample of 119 U.S. oil and gas producers. Their explanation is that the commodity risk of oil and gas producers is so simple to identify that investors can hedge on their own.

In another study, 91 % of 350 U.S. nonfinancial firms respond that the most important objective of their hedging policy is to "manage volatility in cashflow (49 %) or earnings (42 %)" (Bodnar et al., 1996, p. 115). However, while there is little or no empirical evidence in the literature on whether managing this form of volatility adds value, Brown (2001), using field study data, does find evidence of income smoothing and reduced cashflow volatility but does not test for significant reductions in volatility. Confirming this approach, Judge (2007) argues that volatility analyses must be based on detailed transaction data, as in Brown (2001), rather than on data gathered from financial reports (which do not report the gains or losses from individual derivative transactions). An example of this approach is found in Hentschel and Kothari (2001), who investigate 425 large U.S. firms and arrive at the conclusion that derivative trading does not result in a significant reduction in stock price volatility[4].

Ederington (1979) argues that companies must balance risk avoidance and the maximization of benefits from informational advantage in their hedging policies. However, belief in one's own advantages may also result in hedging practices that entail speculative motives. For instance, companies are sometimes found to apply an approach called 'selective hedging' where they allow their own market view to influence their hedging practice (Stulz, 1996). This selective hedging concept is supported by Adam and Fernando (2006) in separating hedging into two components: *predictive hedging*, hedging practice attributable to the fundamentals of the firm and its operations, and *selective hedging*, hedging practices related to the firms' views on price and market movements; i.e., speculation within risk management boundaries. After considering hedging in the gold mining sector, Adam and Fernando (2006) find clear evidence of a positive return from predictive hedging while selective hedging has an expected value near zero and a large variance. This corresponds with the assumption in Stulz (1996) that only the hedging of 'real costs' is value-adding for firms, while speculative trading reduces firm value.

Importantly, unformulated policy can contribute to extensive selective hedging. For example, Brown (2001, p. 413) suggests that "... risk management can be a smoke screen for speculative trading". Selective hedging is extensively studied by Brown et al. (2006). They propose three explanations for the widespread extent of this practice. First, risk management staff use selective hedging to identify their value creation potential. Second, historical success from incorporation of one's own market view in hedging decisions can encourage managers to extend the practice. Third, the lack of an overriding theory on optimal hedge ratios effectively allows any hedge ratio to be justified. For instance, a Wharton-CIBC study (Bodnar et al., 1998) of U.S. nonfinancial firms confirmed the tendency among management to 'beat the market', with about 60 % of firms indicating that they alter either the timing and/or size of their hedges based on market views, while 32 % of firms actively take derivative positions based on their market views.

In the worst-case scenario, selective hedging can lead companies to bankruptcy, as amply demonstrated by Stulz (1996) in the examples of Metallgesellschaft and Daimler-Benz. Stulz (1996) further asserts that in many cases, management (by ignoring the efficient market doctrine) will base their trading strategies on a belief that they are able to predict market movements. Stulz (1996) then proposes that transformation of the risk management function into a trading operation is a value-destroying strategy as the firm purposively undertakes large and unfamiliar risks. Accordingly, management must first investigate and understand the source of their information advantage before attempting to act upon it. Reflecting upon their 1994 $100 million derivatives loss, a representative of Procter and Gamble cited that in retrospect "... we don't do a lot of hedging because, if we were smart enough to hedge, there is actually more money to be made in that than

[4]As our study employs detailed data on spot revenues and hedging transactions, as in Brown (2001), we are able to undertake suitable volatility analysis and to avoid the pitfalls presented in Judge (2007).

there is in selling soap"[5].

Overall, Adam and Fernando (2006) attribute the value from predictive hedging to the risk premium. This risk premium has been thoroughly studied in commodity markets, with Fama and French (1987) identifying a nonzero risk premium in five of 21 commodity markets. The literature defines this commodity risk premium (Longstaff and Wang, 2004; Adam and Fernando, 2006) as:

$$\mathrm{R}(t,T) = \mathrm{F}_t(T) - E_t[\mathrm{S}(T)] \tag{1}$$

where $\mathrm{R}(t,T)$ is the risk premium, $\mathrm{F}_t(T)$ is the forward price at time t with delivery at time T and $E_t[\mathrm{S}(T)]$ is the expected spot price at maturity T. Here, Adam and Fernando (2006) and Botterud et al. (2010) argue that a constant positive (negative) risk premium will result in the biased hedging behavior of producing firms as they can capture the premium by increasing (decreasing) their hedge ratio. However, the risk premium behaves differently for electricity than for other commodities, mainly because its inherent nonstorability invalidates the usual cash-and-carry relationship. These characteristics are further discussed in Fleten and Lemming (2003); Botterud et al. (2010); Huisman and Kilic (2012). In terms of electricity derivative markets, Longstaff and Wang (2004) find that there are significant risk premia in the short-term forward prices in the Pennsylvania, New Jersey, and Maryland electricity market, confirmed by Kolos and Ronn (2008) in the same market for long-term forward prices. Using a sample of 11 years of Nord Pool futures prices[6], Botterud et al. (2010) find significant positive risk premia (ranging from 1.3 % to 4.4 %) with increasing premia for longer holding periods (up to six weeks).

2 Data

The data collected and analyzed in this study are from NASDAQ OMX Commodities, and the participating companies. The price time series consist of hourly spot price data and daily closing prices for related power derivatives. The company data include data from 12 Norwegian electricity companies producing at least 0.1 TWh with a total average production of 30.8 TWh. The period analyzed is January 2007 through December 2009[7]. The data collected include production and revenue data for this period and data on transactions expiring during this period (8,171 transactions in total). The dataset also consists of the written hedging policies of 10 of the 12 companies.

Twenty-one of the 33 companies contacted declined to participate in the study. Their stated reasons for not participating were either a lack of available resources or confidentiality issues. However, a company that has incurred large losses in derivative trading may wish to keep this information from outsiders to avoid any negative attention. This could be one reason for companies refusing to participate in the study and could lead to some sample bias in that only companies that are successful in hedging have participated. However, after communicating with all of the companies, we are confident that this does not apply to the majority of the nonparticipating companies. We perceive that these producers are quite homogenous with regards to transparency and incentives, and companies must anyway disclose the (annual) result of their hedging activity in financial reporting.

Companies that engage in both hedging and speculative ('naked') trading clearly labeled all transactions with the appropriate portfolio, enabling us to separate transactions for hedging purposes from speculative trades. Each transaction contains information on

[5] Scott Miller, Director of National Governmental Relations for Procter and Gamble, quoted from the print version of the Wall Street Journal, April 14$^{\text{th}}$ 2001.

[6] Nord Pool was founded in 1996, though the Norwegian electricity market was liberalized in 1991. Following an acquisition in December 2007, NASDAQ OMX Commodities now owns the subsidiaries of Nord Pool. Appendix A provides a description of the power derivatives.

[7] Owing to data constraints, the period analyzed for two companies is January 2007 through June 2009.

Table 1: Summary statistics of the data collected from the participating companies. The data span 36 (30) months from January 2007 to December (June) 2009). The transaction data are the number of transactions (8,171 transactions in total). The policies comprise a full document (including goals, motivation, procedures, restrictions, and chain of command), hedge ratio boundaries, or no explicit written policy. The exposure forecast method relates to how the company predicts future exposures subject to hedging. If this is by a production plan, the average planning iterations for each delivery period (month) are given (in parentheses).

Company	Months of data	Number of transactions	Extent of policy details	Exposure forecasting method
Company 1	30	46	None written	Production plan (119)
Company 2	36	67	Hedge ratios boundaries	Historical average production
Company 3	36	1 328	Full document	Production plan (21)
Company 4	36	171	Full document	Historical average production
Company 5	36	1 074	Hedge ratios boundaries	Production plan (118)
Company 6	36	1 108	Full document	Production plan (103)
Company 7	36	1 051	Full document	Historical minimum production
Company 8	36	368	Hedge ratios boundaries	Historical average production
Company 9	36	1 163	Full document	Historical average production
Company 10	36	1 555	Full document	Historical average production
Company 11	30	58	None written	Production plan (119)
Company 12	36	182	Full document	Historical average production

the type of power derivative, transaction date, delivery period, price area, contract volume, contract price[8] and whether the volume is hedged in the NASDAQ OMX Commodities market or through some bilateral agreement. The production data describe the time series of generated electric energy along with the resulting revenue[9]. Data on planned production are scenarios of simulated generation, i.e. planned generation for each month in each scenario. As shown in Table 1, for companies not using production planning for exposure forecasts, we use either the historical average or minimum production. The hedging policies for each of the 12 companies are specified in three forms: as a full document (including goals, motivation, procedures, restrictions, and chain of command), as a document specifying hedge ratio boundaries, or no explicit written policy.

We perform the analyses on a monthly basis for the 36 months starting in January 2007 and ending in December 2009. This reflects the architecture of the traded derivatives (power derivatives represents delivery over a time period and therefore can be split and aggregated into month-long derivatives) and the level of resolution of the data obtained from the companies. While some companies apply a rougher resolution (quarterly, yearly, or even across several years) in their hedging policies, a monthly perspective encapsulates all possible resolutions. We treat all data from the companies in confidence. For this reason, we refer to the companies by number. We normalize all absolute values and present the data in such a way that it is not possible to identify individual companies.

2.1 Abnormal values for Company 11

We give some special attention to the data for Company 11 as a preliminary analysis indicates some extraordinary values compared with the other companies. This is the result of three periods where the company unexpectedly shut down a substantial amount of production capacity. The company is committed to deliver license power, about 10 % of the average production level, to neighboring municipalities and counties (described further in Section 3.3). During these periods, the license power commitments exceeded production levels, requiring the company to purchase electricity to fulfill its obligations. This resulted in negative exposure, providing abnormal results, but we retain the data as is to ensure that all analyses are consistent and present actual situations.

3 Description of Hedging Practices

3.1 Policies

All companies consider a hedging portfolio of long positions from expected physical production and short positions through derivatives. This portfolio is subject to hedging practice, for most companies described in explicit written hedging policies. Some companies have policies and restrictions for both hedging and speculative trading practices in the same document, though separately, but only the hedging policies are within the scope of this paper. Based on the characteristics of their policies, we divide the participating companies into four groups (see Table 2).

Groups 3 and 4 differ in terms of the freedom within their hedging policy. For instance, the hedge ratio requirement is set for Group 3 by a combination of the price level of three-years-to-maturity swaps and time to maturity, and without a mandate to apply their own market view in hedging transactions. In contrast, the companies in Group

[8]Transactions on the exchange are denominated in €, while the analyses are conducted in Norwegian kroner (NOK). For currency-hedging companies, we use the hedged currency rate for currency conversions, otherwise the spot currency rate.

[9]Revenue data are either provided directly by the sample companies or calculated from the production data using the appropriate area price and assuming zero variable cost (a reasonable approximation with hydroelectricity production).

Table 2: Policy group characteristics. The groups are formed through a binary classification tree: Explicit written policy (YES/NO), hedge ratio approach (YES/NO), hedge ratio target is a range (YES/NO).

Group	Group characteristics	Number of companies
1	No written hedging policy	2
2	Does not use a hedge ratio approach, Cashflow at Risk requirement	2
3	Uses a hedge ratio approach, time-to-maturity dependent hedge ratio requirement†	1
4	Uses a hedge ratio approach, time-to-maturity dependent hedge ratio range‡	7

† a specific target without mandate to deviate.
‡ a range with lower and upper boundaries.

4 allow the market view to influence their hedging decisions, based on belief in their own market competencies. This is executed through a hedge ratio range defined between an upper and lower boundary (illustrated in Figure 4 in the Appendix) within which risk managers are permitted to decide their preferred hedge ratio based on their own market view. These companies generally consider themselves capable of withstanding higher volatility from fluctuating hedge ratios ("the corporation is robust enough to [...] exploit market opportunities down to zero hedging" states Company 9). This is similar to arguments in Stulz (1996) that a company with a high credit rating (AAA) can afford to incur large derivative losses without risking default. Hence, they are more likely to engage in selective hedging given that they have an informational advantage.

Seven companies explicitly state in their policies the goals of their hedging activity. The more general goals relate to the reduction of the risk associated with physical production. For instance, Company 6 states that "[the goal is to] secure price levels for the physical production", and Company 4 wants to "reduce the risk of the physical production". Conversely, Company 7 and Company 10 have an income smoothing approach as they aim respectively "[to control the risks associated with] periods of lower income and large fluctuations in the result" and "[to] reduce the fluctuations in profit and cashflow on the long term". In this regard, Stulz (1996) asserts that the fundamental goal of hedging should be to eradicate the extreme lower outcomes of a firm's earnings function while the upside is preserved. Company 3 (and Company 12) employ this same argument in their policy when they state that "the goal [of the hedging practice] is to secure an acceptable income and hedge as little as possible to retain as much of the upside potential as possible". Four companies explicitly state that they aim to maximize the value of their hedging portfolio; that is, "hedging [...] shall contribute to maximize the company's revenues within the risk boundaries" (Company 4), "the goal of the hedging activity is to secure a profit or margin" (Company 6), "[we shall] maximize the value of the production portfolio—through active trading management based on market view" (Company 9) and "[hedging shall contribute to] maximize the profit in the long term" (Company 12). Through interviews, the Group 1 companies communicated that their unwritten hedging policies are founded on "ambitions to provide stable cashflows" and a "[desire to build a] slightly long portfolio consisting of physical production and financial transactions". They also express the view that top management in their companies dictate their hedging decisions.

Bodnar et al. (1998) reveals that 32% of nonfinancial firms in their sample actively take positions based on market views. We also find evidence of this practice in our study. For example, Company 6 has "a portfolio for extraordinary hedging transactions based on expectations for future electricity prices", while Company 9 establishes hedging boundaries such that "it is possible to exploit [their] market competence" based on analysis of the available risk capital. Elsewhere, Company 1 and Company 11 communicate that "own market and exposure views" and "the gut feeling of the superior officers" are important in their hedging decisions. In contrast, Company 2 emphasizes that their hedging department "does not have authorization to engage in speculative trading", and Company 10 states that "[speculative] trading is beyond the authority of this [hedging policy]". Overall, the companies all express the view that they now seek more risk in financial markets than previously was the case[10].

Bilateral contracts carry increased counterparty risk, but because they are OTC derivatives, they do not require the buffer margin that is mandatory at NASDAQ OMX Commodities. Four of the companies studied evaluate the possibility of bilateral contracts in their policies, and two actively use bilateral contracts for hedging purposes. In addition, three companies use bilateral contracts without including them in their written policy (Table 3).

The revision cycle of the hedging policies ranges from yearly to not at all during the period studied. Six of the companies maintained the same policy through the entire period, while two revised their policy once, one company revised twice, and one company undertook yearly revisions. Nevertheless, the revisions were of relatively minor scale and did not alter the fundamental hedging policy of any of the companies. Company 5 is the only company employing a benchmark indicator for hedging performance, performed using a theoretical hedge ratio across time. Company 5 modeled this benchmark using factors like spot price simulations, time to maturity and simulations of future physical production, and optimized the result to minimize the company's risk position.

3.2 Transactions

The power derivatives available at the exchange include futures, forwards, European-style options and Contracts for Difference (CfDs)[11], and are denominated in € per Megawatt-hour (MWh[12]). One MWh represents the electricity (energy) volume generated from a source with a power of one Megawatt (MW) operating for one hour. Nord Pool Spot organizes the day-ahead market for physical exchange of electricity, and, unlike for e.g. PJM in the eastern U.S. this market is regarded as the spot market. From the day-ahead auction, Nord Pool Spot calculates a so-called system price, which serves as the underlying average spot price over the delivery period (Figure 3 in Appendix A illustrates the underlying price for month swaps). The bilateral OTC market offers equivalent instruments to those listed at NASDAQ OMX Commodities, along with swing contracts[13]. The futures and forwards contracts at the exchange are not in accordance with standard financial terminology. Forward contracts are offered with yearly, quarterly, and monthly delivery, while futures contracts are available with weekly and daily delivery, representing delivery over a period and not an instant in time, as would be the case for a storable commodity. Thus these futures and forwards are equivalent to financial swaps (Benth and Koekebakker, 2008), and for the remainder of this paper, the term swap will be used instead of forwards and futures. All power derivatives have a holding period (the time from transaction to maturity) and a delivery period (all swaps are differentiated by delivery period, with yearly, quarterly, monthly, weekly and daily swaps).

As shown, yearly swaps dominate the traded volume (Table 3), with six of the 12 companies trading more than 50 % in yearly swaps and only two having less than 40 % of

[10] Revealed during conversations with the companies.

[11] The underlying price for power derivatives is the *system* price, while physical generation is sold at *area* prices depending on the price area where production resides. The price difference between the system price and area prices can be hedged with CfDs.

[12] 1 Megawatt-hour (MWh) = 1000 kilowatt-hours (kWh).

[13] The buyer of a swing contract can choose when to purchase the electricity within a set of restrictions, enabling a flexibility option. Swing contracts are further described by Keppo (2004).

Table 3: Descriptive statistics for hedging transactions, based on 8,171 unique transactions. The bilateral contracts are listed as % of the total traded volume [MWh] for each company (the residual volume is traded at the exchange). Swaps (differentiated by length of delivery period), CfDs (Contracts for Difference) and options are listed as % of the total traded volume, adding to 100 %. Company 5, Company 9 and Company 10 only traded swaps. Ex. = volume exercised.

		Counterparty	Allocation of derivatives as % of total derivative volume									
		Bilateral	Swaps (*length of delivery*) *						Call options		Put options	
Group	Company	contracts	*Year*	*Quarter*	*Month*	*Week*	Total**	CfDs	Not ex.	Ex.	Not ex.	Ex.
1	Company 1	26 %	*58 %*	*36 %*	*5 %*	*1 %*	100 %					
	Company 11	29 %	*50 %*	*38 %*	*6 %*	*1 %*	94 %	6 %				
2	Company 3†	3 %	*40 %*	*7 %*	*1 %*	*1 %*	49 %		16 %	4 %	17 %	12 %
	Company 12		*70 %*	*8 %*	*1 %*		79 %	12 %	4 %		4 %	
3	Company 4	36 %	*34 %*	*23 %*	*4 %*		61 %	39 %				
4	Company 2	33 %	*76 %*	*24 %*			100 %					
	Company 5		*59 %*	*32 %*	*9 %*		100 %					
	Company 6		*24 %*	*54 %*	*9 %*	*1 %*	87 %				13 %	
	Company 7	25 %	*54 %*	*21 %*	*24 %*	*1 %*	99 %	1 %‡				
	Company 8	2 %	*36 %*	*23 %*	*21 %*	*2 %*	81 %	19 %				
	Company 9		*57 %*	*32 %*	*9 %*	*2 %*	100 %					
	Company 10		*41 %*	*37 %*	*21 %*	*1 %*	100 %					

* None of the 12 companies in the sample trades day swaps.
** ±1 % deviation from rounding error.
† Plus 2 % of traded volume in swing contracts.
‡ Only one transaction.

Table 4: Cumulative volumes hedged with swaps in % of total swap volume. Volume is the sum of the absolute transaction volumes.

		Holding period [months]				
Group	Company	60	36	24	12	6
1	Company 1	24 %	53 %	54 %	69 %	77 %
	Company 11	0 %	47 %	50 %	66 %	77 %
	Group mean	12 %	50 %	52 %	68 %	77 %
2	Company 3	8 %	11 %	25 %	44 %	67 %
	Company 12	0 %	25 %	60 %	81 %	92 %
	Group mean	4 %	18 %	43 %	63 %	80 %
3	Company 4	49 %	54 %	60 %	77 %	91 %
4	Company 2	0 %	20 %	36 %	72 %	93 %
	Company 5	0 %	6 %	16 %	42 %	61 %
	Company 6	0 %	1 %	11 %	36 %	63 %
	Company 7	3 %	14 %	29 %	54 %	70 %
	Company 8	0 %	8 %	19 %	33 %	52 %
	Company 9	0 %	0 %	3 %	27 %	52 %
	Company 10	0 %	0 %	1 %	31 %	66 %
	Group mean	0 %	7 %	16 %	42 %	65 %

their total volume of trades in yearly swaps. Furthermore, three of the companies trade more than 20 % of their total volume in monthly swaps, while the corresponding value for the remaining companies is 9 % or less. The trade in weekly swaps is only minor. Five companies also use the bilateral market in addition to NASDAQ OMX Commodities, while seven companies utilize instruments other than swaps. For instance, options are most suitable for companies with large uncertainties in expected production as they postpone the decision to trade the underlying swap until the date of expiry. However, only three companies utilize these instruments. Likewise, swing contracts enable a flexible load during the delivery period but are limited to only a handful of trades for Company 3, amounting to just 2 % of the total swap volume. Only Company 3 trades all types of the derivative instruments regularly over the period analyzed.

The mean percentage price deviation between the system price and the area prices (Table 11 in Appendix A) indicates a two-digit percentage difference during Q3 2007, Q2 and Q3 2008, and September 2009. This price difference is the result of a downtime in transmission capacity between the price areas. In our correspondence, the companies expressed the opinion that the CfD market suffers from low liquidity and is therefore not suitable for hedging the basis risk arising from this price difference. This is also found in the relatively low level of utilization of CfD derivatives among the companies (Table 3). Hence, basis risk will influence the accuracy of the hedging policies during periods of high congestion in the transmission grid.

Swaps constitute the greatest part of the traded volume and are the main hedging derivative for the companies. Figures for swap volume depending on holding period as a % of total swap volume are listed in Table 4. Two of the companies, Company 1 and Company 4, initiated more than 25 % of the swaps with five years or more before maturity, while Group 4 stands out with lower hedging activity at longer maturities. In evidence, two years before maturity groups other than Group 4 had entered on average into 52 % of their total hedge volume, while the corresponding figure for Group 4 is just 16 %.

With the exception of Company 6, Company 7 and Company 10, all companies trade yearly swaps to build a hedging foundation at long maturities. As maturity approaches, they then employ quarterly, monthly and weekly swaps to fine-tune their hedging ratio. For instance, Company 1, Company 4 and Company 11 all hedge large parts of their production with yearly swaps until respectively 50, 55 and 35 months before maturity and then only trade shorter swaps for the remaining time.

We should put these findings in the perspective of the financial market. Yearly swaps have a maximum holding period of five years, quarterly swaps two and a half years, monthly swaps half a year, and weekly swaps six weeks. The availability of long maturity swaps is therefore effectively restricted to yearly and some quarterly swaps. In contrast, companies can trade bilateral OTC contracts over far longer maturities.

3.3 Risk Exposure

There are two types of hydroelectric production: run-of-the-river and reservoir. While the production from a run-of-the-river plant depends on the current flow of the river, a reservoir plant is controlled and enables the producer to govern outflow. Reservoir plants therefore have the advantage of scaling down during periods of low prices and scaling up when prices are high (the aggregate production of the participating companies comprises 21 % run-of-the-river and 79 % reservoir production). This has significant consequences for risk management. For instance, with this high degree of flexibility, exposure remains uncertain until actual production begins, mainly because of three phenomena in reservoir electricity production. First, the ability to store water grants an option to defer production until periods of higher prices, a practice known as 'transferring water' (i.e. through time). Second, several of the companies in the study have indicated a practice where, for fiscal periods with lower-than-expected earnings, production is scaled up at the end of the period to meet profit targets. This is referred to as 'channel stuffing' in other industries. Third, in a situation with very low inflow the reservoir level might become very low, and the producer might not be able to produce physically the volume sold financially. In this situation the producer has to revise its hedge ratio according to updated production plans. Together, these practices interfere with the long-term production plan and make it challenging to plan the appropriate size of hedging transactions to comply with the restrictions set in the hedging policy.

Exposure is also subject to the attributes of governmental regulations. First, hydroelectricity producers are obliged to deliver up to 10 % of physical production at low or no fee to the local councils where their production plants reside (license power[14]). Second, the Norwegian tax code enforces a natural resource tax for hydroelectricity production alongside the standard corporate tax. The tax is the result of Norwegian regulation policies to apply additional taxes to the extraction of natural resources. Here, all revenues from physical production attract both the natural resource tax and corporate tax, while revenues from financial contracts are only subject to corporate tax. The following calculation of the change in after-tax profit from an increase in the spot price of one unit illustrates how the natural resource tax affects the hedging decision.

$$\textit{Increase}\text{ after-tax profit physical production} = \textit{Decrease}\text{ after-tax profit financial contracts}$$

$$\underbrace{1}_{\text{Spot revenue}} - \underbrace{0.30}_{\text{Natural resource tax}} - \underbrace{0.28}_{\text{Corporate tax}} = -(\underbrace{x}_{\text{Derivative cashflow}} - \underbrace{0.28 \cdot x}_{\text{Corporate tax}}) \tag{2}$$

$$x = -0.583$$

[14]Electricity companies residing in Norway are required to compensate counties and municipalities affected by regulated electricity production because of permanent environmental damage arising from the production plant and its operation. This compensation consists of a fee and a share (up to 10 %) of the average physical electricity production, called license power, which is delivered at low tariff or for free. However, as these calculations do not include exposure to market uncertainty, they are not subject to hedging considerations. For this reason, we subtract license power from physical production when calculating risk exposure, and so all production values in the analysis exclude license power.

Table 5: Forecast error (the mean absolute percentage error) for each exposure forecast method. The values are averaged over the companies using each method (Table 1).

Method of exposure forecast	Forecast horizon [months]				
(number of companies)	24	12	9	6	3
Production plan (5)	43 %	52 %	50 %	38 %	33 %
Production plan w/o outlier (4)	22 %	26 %	24 %	22 %	18 %
Historical average production (6)	17 %	17 %	17 %	17 %	17 %
Historical minimum production (1)	14 %	14 %	14 %	14 %	14 %

Assume that x is the net *long* position in the financial market as a fraction of expected production that ensures a full hedge; that is, a position where the after-tax profit is unaffected by changes in the spot price. Then the increase (decrease) in after-tax profit from physical production following a spot price increase (decrease) must equal the decrease (increase) in after-tax derivative profit. We also assume that the correlation between the price and production volume is zero[15] (the production level is unaffected by a price change). If the price per unit increases by one, the revenues per unit from physical production also increase by one (variable cost is negligible in hydroelectricity production, while fixed costs are unaffected by a price increase), while the cashflow from a *long* position increases by x. Both sides of the equation are reduced by the corporate tax, but the after-tax profit from the physical production is further reduced by the natural resource tax. Hence, a full hedge for electricity companies differs from the full hedge for other industries; namely, a unitary hedge ratio (a hedge ratio of one).

The natural resource tax is 30 %, and the corporate tax is 28 %[16]. Thus, a fully hedged position implies that the net long position is -58.3 % of expected production. Put differently, 58.3 % of expected production must be sold through power derivatives to reach a fully hedged position. However, only Company 9 explicitly refers to the natural resource tax operating in Norway and its consequences for the hedge ratio in their policies. Nonetheless, interviews with some of the companies reveal that they are also familiar with the consequences of this tax.

Practice among the studied companies is that production planning and hedging operations are performed separately, in accordance with Wallace and Fleten (2002). Three different methods to forecast the exposure from physical production are utilized in the studied companies: historical average production, historical minimum production, and the output from their internal production planning model (used by operators for production scheduling). Each company's method is presented in Table 1. There is a one- to three-year horizon for production planning. Company 7 uses the historical minimum production to avoid situations where unexpected downtime in production results in a net short position in the hedging portfolio (where the volume sold through power derivatives exceeds the production volume).

The companies' success in predicting exposure is measured by the forecast error (the mean absolute percentage error). For the companies utilizing a method based on historic

[15]The zero correlation between price and production volume is subject to some dispute. A negative correlation between volume and electricity prices prices lowers the incentives for hedging as this relationship acts as a natural hedge while the converse is true for a positive correlation (Näsäkkälä and Keppo, 2005). We find that both relationships are plausible. Short-term price increases then give producers the incentive to increase electricity production from reservoirs to exploit high price levels. On the other hand, price increases visible at seasonal or annual granularity can be the result of droughts, which results in reduced production levels. Thus, the long-term relationship between price and the level of production can be negative. For the purpose of (2), the profit horizon is ambiguous, and it is therefore challenging to interpret the correct sign of the correlation. Therefore, we believe that a zero correlation gives a reasonable benchmark for a fully hedged position.

[16]http://www.regjeringen.no/nb/dep/fin/dok/nouer/2000/nou-2000-18/3/8.html?id=359771.

Table 6: Tests for difference in mean absolute percentage error between the production plan and historical average production methods. The test is performed for several different forecast horizons.

Forecast horizon [months]	Kruskal-Wallis test statistic	p-value	p-value w/o outlier
36	0.83	0.361	0.670
24	1.63	0.201	0.394
12	3.33	0.068*	0.136
9	2.70	0.100	0.201
6	1.20	0.273	0.522
3	0.83	0.361	0.670
1	0.83	0.361	0.670

* significant at the 10 % level using a one-tailed test.

production, the forecast error remains the same irrespective of the time to maturity. The minimum production level method has the smallest forecast error, while the companies using production plans have the largest average forecast error (Table 5). To test for a difference in the predictability of the forecasting methods (that is, between the production plan and the historical average production), we apply the Kruskal-Wallis test of the equality of variances to the data[17] for the 11 observations over several different times to maturity (36, 24, 12, 9, 6, and 3 months and 1 month). The p-values are presented in Table 6.

As shown, there is a significant difference between the forecasting methods at the 10 % level 12 months before maturity. Thus, a forecasting method based on historic production levels is better when predicting the exposure level subject to hedging when compared with a dynamic production planning tool approach. However, this is mainly the result of the mean absolute percentage error for Company 11, as caused by the extraordinary months described in Section 2.1 and resulting in extreme forecast errors. Nevertheless, this reveals the pitfalls of using a production plan for exposure forecasts for hedging decisions. In contrast, the design of the historical minimum production method minimizes the effects of such extraordinary periods and thereby avoids net short positions.

We have also tested the sample without Company 11 (referred to as "...w/o outlier"). The results reveal that the forecast errors for companies using production plans are closer to the errors for the methods using time series data. Also, the test for difference between the production plan and historical average production methods shows no significance at the 10 % level. The lowest p-value is 0.136 at 12 months forecast horizon. These results still indicate that the historical average production is more accurate regarding prediction of exposure than the method of production plans.

We conclude that companies should use different methods for estimation of the risk exposure subject to hedging (we find a method based on historic production to be the most accurate) and for maximization of the value of the water in its reservoirs (a dynamic model is appropriate as hydroelectricity production is quite flexible (Wallace and Fleten, 2002)). Generally speaking, the historical forecasting method yields better predictability for hedging operations and less forecasting error when compared with the dynamic approach.

3.4 Hedge Ratio Characteristics

Detailed production and transaction data allow for the calculation of hedge ratios (the fraction of production hedged). The following section describes the hedge ratio both before maturity (as applied by Brown (2001), Adam and Fernando (2006)) and at maturity (following Brown et al. (2006) and Lin and Chang (2009)). The companies in Groups 3

[17] Allowing a nonnormal distribution of the small sample size.

and 4 apply hedge ratio targets in their hedging policies, and it is possible to measure their hedging performance by constructing the hedge ratio h.

$$\mathrm{h}_{t,d,i} = \frac{1}{\mathrm{E}(t,d,i)} \sum_{\tau<t} -\mathrm{C}(\tau,d,i) \tag{3}$$

where

$\mathrm{C}(t,d,i)$	Short position[18]initiated at date t with delivery period d for Company i
$\mathrm{E}(t,d,i)$	Risk exposure forecast for delivery period d updated at date t for Company i
t	Observation date
d	Delivery period for swap: {January 2007, ..., December 2009}
i	Company: {Company 1, Company 2,..., Company 12}

The hedge ratio comprises three dimensions: the time-series dimension t (relative to the time to maturity and not the absolute timeline), the cross-sectional dimension d, and the companies i.

The hedge ratio reflects the NOK increase (decrease) in the hedging portfolio for each NOK decrease (increase) in the underlying price, while the standard deviation of (3) measures the consistency in a company's hedging practice over time. Table 7 presents the hedge ratio and its standard deviation at different times to maturity.

The time series for the hedge ratio portrays the development of hedging activity as transactions are undertaken and exposure forecasts revised. Figure 4 in Appendix B plots the hedge ratios as a function of time to maturity for each company. The detailed values are in Table 7. All the hedge ratios build up gradually as maturity approaches, consistent with the policies described in Section 3.1. This 'staircase formation' results as the companies gradually increase their hedge ratio. The plots fluctuate rapidly because the companies perform hedging transactions as often as several times a month, and even several times a week. For companies with production plans as their forecast method, fluctuations also result with any changes.

Because of the presence of the natural resources tax, the hedge ratios for electricity companies are not directly comparable with the findings in other studies of nonfinancial companies. However, analogous values can be calculated by normalizing the hedge ratios[19]: 1.69 (Group 1), 0.90 (Group 2), 0.82 (Group 3) and 0.91 (Group 4), while the mean for all groups excepting Group 1 is 0.88. This is considerably higher than is found elsewhere in studies of hedging in nonfinancial companies. For example, Brown (2001) identifies an average hedge ratio of 0.74 for the currency exposure of HDG Inc. (pseudonym) 3 months before maturity. Alternatively, Brown et al. (2006) reveals an average hedge ratio of 0.34 among active hedging firms, and Adam and Fernando (2006) calculate hedge ratios of 0.36 two years before maturity and 0.54 one year before maturity for North American gold miners employing positive hedge ratios. Lastly, for non-U.S. airlines, the average hedge ratio for jet fuel hedges lies in the interval 0.73–0.83 (Lin and Chang, 2009).

The average hedge ratios at maturity for Groups 2, 3 and 4 are approximately the same. Group 1 is clearly overhedging their exposure, while the other groups on average are close to a fully hedged position (0.583 as calculated in Section 3.3).

The companies in Group 3 and 4 have upper and lower hedge ratio boundaries at specific times to maturity. As an example, Company 2 states that their hedge ratio two years before maturity should lie between 0.1 and 0.3, while one year before maturity, the corresponding values are 0.2 and 0.4. Figure 4 reveals that the median hedge ratios

[18] C is a short transaction as all hedgers will have a net short financial position. As C is preceded by a negative sign, the hedge ratio h will have a positive sign.

[19] Hedge ratios are normalized by dividing each hedge ratio by the hedge ratio for a fully hedged position (0.583). This yields a normalized hedge ratio where a value of one is equivalent to a unitary hedge ratio for other commodities.

Table 7: Descriptive statistics for the hedge ratio of each company. The hedge ratio is the fraction of (forecast) production hedged. The table includes median values for the hedge ratios based on the 36 monthly values and the standard deviations over this period. The values are plotted in Figure 4 in Appendix B.

			Median				Standard deviation			
Group	Company	Time to maturity	2 years	1 year	6 months	Maturity	2 years	1 year	6 months	Maturity
1	Company 1		0.48	0.73	0.76	0.91	0.35	0.25	0.23	0.21
	Company 11		0.57	0.69	0.76	1.06	1.19	1.16	0.73	1.90
	Group mean		0.53	0.71	0.76	0.99				
2	Company 3		0.07	0.05	0.20	0.53	0.15	0.60	0.59	0.26
	Company 12		0.36	0.48	0.48	0.52	0.08	0.07	0.06	0.08
	Group mean		0.22	0.26	0.34	0.53				
3	Company 4		0.38	0.51	0.51	0.48	0.28	0.27	0.27	0.28
4	Company 2		0.14	0.27	0.34	0.38	0.07	0.09	0.09	0.10
	Company 5		0.18	0.28	0.34	0.36	0.08	0.29	0.24	0.19
	Company 6		0.03	0.29	0.42	0.35	0.07	0.12	0.18	0.21
	Company 7		0.16	0.23	0.24	0.34	0.06	0.09	0.08	0.11
	Company 8		0.08	0.15	0.23	0.49	0.05	0.06	0.12	0.18
	Company 9		0.00	0.18	0.34	0.61	0.06	0.14	0.23	0.23
	Company 10		0.00	0.45	0.52	1.15	0.05	0.39	0.60	0.80
	Group mean		0.09	0.26	0.35	0.53				

of Company 5, Company 6, Company 8 and Company 9 lie within their hedge ratio boundaries, while the median hedge ratios of Company 2, Company 4[20], Company 7 and Company 10 do not. Thus, four of the eight companies manage to stay inside their allowed hedge ratio boundaries. However, the remaining four companies have narrower ranges that are in accordance with their policy boundaries. Hence, it is challenging to accommodate policy targets if the boundaries are set too restrictively.

The lower quartile of Company 3 has negative values (Figure 4(c) in Appendix B). That is, in more than 25 % of months, Company 3 had a negative hedge ratio at this time before maturity, resulting in a long financial position in addition to their long physical position from expected spot production. In 2005, early 2006 and parts of 2008, Company 3 took substantial long positions for all delivery periods, resulting in these negative hedge ratios. There are several possible reasons for this. First, Company 3 has a C-FaR approach to hedging and no specific hedge ratio target. This allows selective hedging. Second, during 2005 and 2006, the company revised its policy to scale down hedging activity. From this perspective, the long positions are transactions aimed at increasing market exposure according to the new policy. However, during Q1 and Q2 2006, all the hedge ratios in the time period analyzed were negative, as low as -2.24 for July 2007 per March 2006. This could be an overreaction to the new policy but is most likely the result of selective hedging. Generally, the result for Company 3 is surprising. On average, it lies close to a full hedge and higher than most of the other companies. However, in their policies, they describe their motivation for hedging as "... [to] secure an acceptable income and hedge as little as possible to retain as much of the upside potential as possible". Possible explanations for its high hedge ratios are then either the belief of positive risk premiums in the financial market (as found for weekly swaps by Botterud et al. (2010)) or a very long transition period toward the revised policies (less likely).

Company 11 has a large variability in its monthly hedging practice, but they succeed in reducing variability six months prior to maturity. We can partly attribute this large variability to the months including production outages, as described in Section 2.1. As also shown, six of the seven companies in Group 4 have maximum standard deviations of less than 0.4.

As shown in Figure 2, the hedge ratios at maturity also appear to follow a seasonal pattern over the cross section of delivery periods. For instance, the hedge ratios at maturity for Company 10 are higher during winter than during summer. Adam and Fernando (2006) identify an equivalent seasonality when analyzing the hedge ratios of gold mining companies. The varying of market conditions across seasons is one possible rationale for such behavior. To investigate this, we apply a one-way ANOVA test for equal means (for normally distributed data) and the Kruskal-Wallis test for equal means (for nonnormally distributed data)[21] to the nine observations for each company. The p-values are included in Table 8.

As shown, at the 5 % significance level, four of the 12 companies display seasonal variation in their hedge ratio at maturity, and eight companies at the 10 % significance level. However, the pattern of the seasonality is somewhat ambiguous in that at the 10 % significance level, five companies have a higher hedge ratio at maturity during winter (Q1 and Q4), while three companies have higher hedge ratios during summer (Q2 and Q3). Only Company 8 indicates in its policy (and successfully achieves) a higher hedge ratio during winter.

In explaining these results, Lucia and Schwartz (2002) find significantly higher spot price volatility in the Nordic area during summer compared with winter. They attribute this to lower prices and more supply shocks during summer. Higher volatilities also require

[20] Even though Company 4 does not have a hedge ratio range, they change their hedge ratio target subject to the market price using targets for different price scenarios.

[21] The data are tested for normality using the Jarque-Bera test.

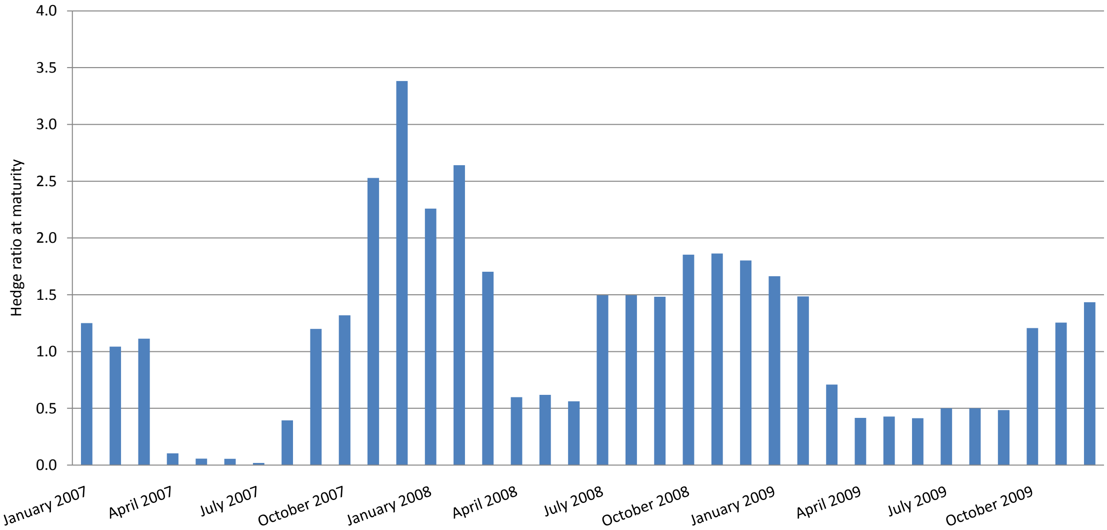


Figure 2: Hedge ratio at maturity (not normalized) plotted over the cross section of maturities d for Company 10. We can observe a seasonality effect as the hedge ratio peaks each winter.

Table 8: Test of seasonality in the achieved hedge ratio. ND = normally distributed. Test statistics are from either the one-way ANOVA test (normally distributed data) or the Kruskal-Wallis test (nonnormally distributed data). High season is where the hedge ratios are significantly higher, either winter (Q1 and Q4) or summer (Q2 and Q3).

Group	Company	ND	Test statistic	p-value	High Season
1	Company 1	Yes	1.76	0.174	
	Company 11	No	6.34	0.096*	Winter
2	Company 3	No	7.71	0.052*	Summer
	Company 12	Yes	1.82	0.164	
3	Company 4	Yes	1.72	0.182	
4	Company 2	No	7.33	0.062*	Summer
	Company 5	Yes	3.71	0.021**	Winter
	Company 6	Yes	1.37	0.271	
	Company 7	Yes	7.02	0.001***	Winter
	Company 8	No	7.49	0.058*	Winter
	Company 9	No	15.71	0.001**	Summer
	Company 10	Yes	12.97	0.000***	Winter

* significant at the 10 % level using a two-tailed test.
** significant at the 5 % level using a two-tailed test.
*** significant at the 1 % level using a two-tailed test.

higher hedge ratios to achieve same level of predictability, and this can help explain higher hedge ratios during summer. Another explanation is that the companies in our sample mainly trade with yearly swaps, which have a fixed power size for all months. As electricity production in Norway is considerably lower during summer, yearly swaps will then generate higher hedge ratios during summer than during winter.

However, higher hedge ratios during winter can also be explained by the high uncertainty of production levels during summer[22]. For instance, Näsäkkälä and Keppo (2005, p. 131) find that producers with "... high load uncertainty postpone their hedging decision in order to get better load estimates". Hence, producers with flexible production will be averse to hedging summer production at long maturities. Considering the low flexibility of run-of-the-river plants, we would expect that producers with more (less) of this type of production show less (more) significance in seasonal variation. This is plausible considering that two of the four companies without significant seasonal variation have 50 % or more of their production from run-of-the-river plants, while the corresponding value for seven of the eight companies with seasonal variation is less than 20 % (without any indication of which season is most hedged). Nonetheless, despite the ambiguity across seasons in both rationale and result, the findings are surprising and interesting. Most interestingly, while seasonal hedging behavior is pervasive across the sample, only one company comments upon the issue in its hedging policy. Selective hedging, of course, also offers a plausible explanation given the ambiguous pattern as to the season in which the hedge ratio is higher.

4 Analyses of Added Value from Hedging

Smith and Stulz (1985) present three nonlinear costs that explain hedging motives: tax convexity, reduced default risk, and stakeholder risk aversion. Several studies already aim at quantifying the addition in value from hedging these costs (Nance et al., 1993; Fok et al., 1997; Graham and Rogers, 2002). However, for Norwegian electricity companies, these costs are less relevant. First, the corporate tax function for Norwegian electricity companies is linear. This is the result of the imposition of a uniform tax rate and allowances to carry forward losses to the next year's budget. Second, because of governmental regulations, virtually all hydroelectricity companies in Norway are under public ownership by municipalities, counties and the state. This, along with relatively low variable costs, results in negligible default risk for hydroelectricity producers. Thus, the only argument left to motivate hedging is stakeholder risk aversion. Here, publicly owned electricity companies pay out a large part of their profits as dividends, making them important sources of finance for public authorities. Large reductions in the dividend, even in the short term, then have large negative effects for owners, translating into high-risk aversion. This level of risk aversion also affects the behavior of both management and employees. For this reason, the hedging motive arising from stakeholder risk aversion is considerably more important than either the convex tax function or default risk motivations. However, it cannot fully explain the rationale for the hedging practice observed in Norwegian electricity companies.

Added value from hedging is usually measured as increased firm value (Allayannis and Weston (2001), Jin and Jorion (2006), Lin and Chang (2009)). However, none of the 12 companies in this study is publicly traded, making it unfeasible to perform reliable

[22]The inflow to hydro reservoirs is fairly stable each year and peaks during the spring season when the snow melts. The companies must optimize their production such that they do not risk having their reservoirs overfilled (the reservoir is unable to contain all the water). On the other hand, they do not want to risk having too little water available for the high winter prices. Given that production capacity during winter is then dependent on water used for summer production, the projections for summer production remain highly uncertain while waiting for the projections for winter demand (in close relationship with the projected temperature level).

calculations as to whether the market values of the companies are correlated with their hedging activities. This paper takes a different approach, inspired by Brown (2001), which focuses on the quantitative information revealed in the companies' written policies. Primary attention is given to the derivative cashflows[23] (as considered by Adam and Fernando (2006) and Brown et al. (2006)), price and cashflow volatility (see Ederington (1979) and Brown (2001)) and C-FaR (see Stein et al. (2001)).

4.1 Derivative cashflows

Company 4, Company 6, Company 9 and Company 10 explicitly state that a goal of their hedging policy is to maximize the value of the hedging portfolio (the portfolio of expected production and derivatives). This is not in accordance with the established theoretical motivations for hedging but can be explained by selective hedging as the companies motivate this by referring to their own market competence. The derivative cashflows are calculated as follows for short positions in (4a) swaps, (4b) Contracts for Difference, (4c) option calls and (4d) option puts (cashflows from swing contracts are calculated as if the contracts were swaps[24]).

$$\pi_s = Q \cdot (f_s(t_1, d) - \bar{p}_{system}) \tag{4a}$$
$$\pi_{CfD} = Q \cdot [f_{CfD}(t_1, d) - (\bar{p}_{system} - \bar{p}_{area})] \tag{4b}$$
$$\pi_c = Q \cdot max\{0, f_s(t_2, d) - k\} \tag{4c}$$
$$\pi_p = Q \cdot max\{0, k - f_s(t_2, d)\} \tag{4d}$$

where

$\bar{p}_{system}$	Monthly average system price [NOK/MWh]
$\bar{p}_{area}$	Monthly average area price [NOK/MWh]
$f_s(t_i, d)$	Swap price traded at date t_i with delivery period d [NOK/MWh]
$f_{CfD}(t_i, d)$	CfD price traded at date t_i with delivery period d [NOK/MWh]
Q	Contract volume [MWh], $Q > 0$: short position, $Q < 0$: long position
k	Strike price of the option [NOK/MWh]
t_1	Date of entering the financial contract
t_2	Date of option expiry
d	Delivery period for swap: {January 2007, ..., December 2009}

In addition, the option contracts entail a (5) premium P due at the time the option is entered into.

$$P = p \cdot Q \tag{5}$$

where

p Option premium per unit [NOK/MWh]

For options, the derivative cashflow is in two parts. The option premium (5) reduces the cashflow for the month in which the option contract is entered into, while the derivative cashflow ((4c) and (4d)) affect the month in which the option is exercised. If exercised, the option transforms into a swap, subject to (4a) at the maturity of the swap.

As shown in Table 9, two of the companies had net negative derivative cashflows from their hedging transactions. Of the remaining 10 companies, five had positive derivative

[23] Termed "hedging gains" by Brown et al. (2006).

[24] This is because we do not have access to information on how the contracts were exercised. We assume a constant load for the whole period of the swing contract, making them equivalent to swaps.

Table 9: Total derivative cashflows; values of monthly derivative cashflows as a % of average monthly spot revenue, averaged over the period analyzed. Cashflows originate from swaps and, for some companies, other derivatives (Table 3). Maximum and minimum values for the yearly average derivative cashflows are provided for the evaluation of robustness.

		Swaps	Other Derivatives	Total		
Group	Company	Mean	Mean	Mean	*Min*	*Max*
1	Company 1	1.4 %		1.4 %	*−9.1 %*	*25.0 %*
	Company 11	−4.9 %	1.9 %	−3.0 %	*−14.8 %*	*30.7 %*
2	Company 3	4.6 %	1.9 %	6.5 %	*−3.3 %*	*27.9 %*
	Company 12	2.9 %	−0.3 %	2.6 %	*−10.0 %*	*16.4 %*
3	Company 4	−8.5 %	−0.1 %	−8.6 %	*−22.1 %*	*11.4 %*
4	Company 2	3.4 %		3.4 %	*−3.2 %*	*9.3 %*
	Company 5	15.2 %		15.2 %	*2.3 %*	*31.2 %*
	Company 6	18.7 %	−0.7 %	18.1 %	*1.3 %*	*41.2 %*
	Company 7	4.0 %	0.1 %	4.1 %	*0.1 %*	*11.3 %*
	Company 8	12.9 %	0.8 %	13.7 %	*4.5 %*	*22.2 %*
	Company 9	14.0 %		14.0 %	*6.3 %*	*19.4 %*
	Company 10	17.8 %		17.8 %	*7.3 %*	*34.8 %*

cashflows of less than 10 % of spot revenue, while the corresponding values for the remaining companies are in the range 10–20 %. However, Table 9 indicates large fluctuations in the payoff from one year to the next. For instance, Company 7 has the smallest gap, ranging between 0.1 % (2008) and 11.3 % (2009) of spot revenue, while the corresponding figures for the company with the largest gap (Company 11) are −14.8 % (2008) and 30.7 % (2009). On a whole, Group 1 companies experience higher variation in yearly average derivative cashflows (the mean difference between the maximum and minimum value is 39.8 % of spot revenue) than companies with written policies (24.6 %). On average, none of the four companies with an explicit motivation for higher derivative payoffs achieved a higher cashflow (6.7 % of spot revenue) than the other eight companies (7.4 % of spot revenue).

Owing to their typically short derivative positions, the derivative cashflows from hedging transactions for the companies are lower in periods of high spot prices. For example, in 2008, the average system price in the Nord Pool Spot was 65 % higher than in 2007 and 21 % higher than in 2009. As a result, six of the 12 sampled companies had negative derivative cashflows from hedging transactions in 2008. Furthermore, three of the four companies with the highest losses in 2008 had either no hedging strategy (Group 1) or a hedging strategy based on a fixed hedge ratio requirement (Group 3). Thus, periods of extraordinarily high spot prices call for a more dynamic strategy that allows the incorporation of a market view in hedging decisions.

The analysis shows that the derivative cashflows from hedging transactions are mainly from swaps. As discussed, other power derivatives (CfDs, options and swing contracts), as described in Table 3, are limited to just six companies[25]. Of these, Company 3 and Company 11 respectively accounted for 30 % and 64 % of the total derivative cashflows from derivatives other than swaps, while the other companies had negligible or no profits from derivatives other than swaps.

Clearly, there is a substantial profit contribution from hedging transactions by these companies, ranging above 10 % of spot revenue for five companies (all from Group 4). While this is a substantial source of profit for these companies, it also indicates extensive se-

[25] In addition, Company 7 has a single negligible CfD transaction.

lective hedging, with the warning by Stulz (1996) that this is potentially a value-destroying strategy if the companies do not fully understand the source of their information advantage and the associated risks. Other work in this area also suggests this sort of behavior. For example, Adam and Fernando (2006) also find large profits from hedging among 92 gold miners, with a mean derivative cashflow of 10 % of spot revenue. However, Adam and Fernando (2006) analyze a 10-year period in their study, including two subperiods of falling prices and one sub-period of rising prices. In contrast, this paper analyzes data over a three-year period with slightly rising (linear trend) prices (see Figure 3 in Appendix A). Accordingly, the positive profits are robust for Group 4, and only Company 2 has a year of negative derivative cashflows.

The mean total derivative cashflows also exhibit some correlation[26] with the annual production levels of the companies (correlation coefficient is 0.33) and the number of transactions (correlation coefficient is 0.72). The strong relationship between derivative cashflows and the number of transactions indicates that larger resources allocated to hedging activities (more transactions require more resources) give a combination of larger capacity to monitor market changes, and more market competence and access to market information. The connection between the latter and selective hedging behavior is strong. That said, the large positive derivative cashflows could relate to the possible sample bias discussed in Section 2. However, while the magnitude of the derivative cashflows does not reject the hypothesis of a biased sample, we find it difficult to believe that more than a handful of the companies refusing to participate in the study did so because of past large derivative losses. Nevertheless, we cannot fully put this concern aside.

4.2 Price and cashflow volatility

Company 1, Company 7, Company 10 and Company 11 identify the reduction of cashflow fluctuations as a motivation for their hedging practice. Here, the reduced volatility of the hedging portfolio increases the predictability of the companies' cashflows and adds value by relaxing stakeholder risk aversion. The volatility in monthly hedging portfolio cashflows has two components: volatility in physical production volume and prices. While cashflow constitutes an essential parameter for these companies[27], derivatives can only hedge prices. Hence, both the volatility expected to be reduced by hedging (price volatility) and that is essential to the companies (cashflow volatility) are analyzed.

The variance of the cashflows and prices with and without hedging[28] are used as measures of volatility. The data (72 observations for each company) are tested for the equality of variances by applying the two-sample variance test to normally distributed data and the Brown-Forsythe test to nonnormally distributed data[29]. The p-values of the tests are in Table 10.

As shown, only Company 1 and Company 12 achieve a significant reduction in their monthly cashflow variance at the 10 % significance level. At the 5 % level, Company 1, Company 2 and Company 3 reduce the variance of monthly average prices, while a 10 % level adds another two companies. Both Group 2 companies are included among these five companies.

These results are surprising for several reasons. First, Company 1 stands out as the only company with a significant variance reduction in both tests at low p-values, though it does have relatively few hedging transactions (similar to Company 2 and Company 12) (Table 1). It is notable that Company 1 achieves this without a written hedging policy,

[26]Correlation is calculated as the correlation coefficient between the total derivative payoff and the number of transactions for each company.

[27]For many companies, the yearly dividend is just as important and cashflow is used as a proxy.

[28]The unhedged cashflow and price are respectively the revenue from spot production and the monthly average spot prices.

[29]The data are tested for normality using Jarque-Bera tests.

Table 10: Tests of monthly cashflow, monthly average price variances and C-FaR. ND = normally distributed. Test statistics are either the two-sample variance test (normally distributed data) or the Brown-Forsythe test (nonnormally distributed data). The C-FaR is the % negative deviation from the average monthly unhedged cashflow (spot revenue).

		Monthly cashflows					Monthly average prices		
		Volatility test			C-FaR test		Volatility test		
Group	Company	ND	Test statistic	p-value	Spot C-FaR	Net C-FaR	ND	Test statistic	p-value
1	Company 1	Yes	2.36	0.012**	79 %	42 %†	Yes	2.12	0.024**
	Company 11	Yes	1.39	0.191	84 %†	91 %	Yes	0.62	0.899
2	Company 3	No	0.18	0.674	92 %	71 %†	Yes	2.14	0.014**
	Company 12	Yes	1.74	0.052*	60 %	50 %†	Yes	1.71	0.059*
3	Company 4	No	0.07	0.799	73 %†	75 %	Yes	1.64	0.075*
4	Company 2	Yes	1.18	0.312	58 %	48 %†	Yes	1.84	0.037**
	Company 5	Yes	1.15	0.337	77 %	65 %†	Yes	1.07	0.423
	Company 6	Yes	0.97	0.531	65 %	53 %†	Yes	0.91	0.607
	Company 7	No	0.04	0.848	59 %	59 %†	Yes	1.22	0.281
	Company 8	Yes	1.11	0.377	65 %	51 %†	Yes	1.16	0.332
	Company 9	Yes	1.30	0.221	62 %	50 %†	Yes	1.26	0.245
	Company 10	Yes	1.15	0.343	76 %	70 %†	Yes	0.61	0.924

* significant at the 10 % level.
** significant at the 5 % level.
† Lowest C-FaR value.

even though they describe cashflow stability as an important motivation for hedging. Second, surprisingly few companies manage to reduce cashflow volatility significantly. This is at odds with most of the extant studies in Section 1.1 in that they suggest that hedging should increase the predictability and smoothing of earnings. However, based on our data, there is little material evidence of any reduction of cashflow variance among electricity companies from hedging, while the reductions in price variance are more extensive though not across the entire sample. This is because power derivatives only hedge price risk, not volume risk, and therefore should (and do) have a greater effect on price variance than cashflow variance. This is emphasized by Company 3 in stating that their "... policy is designed to secure price levels, not necessarily the total profit from production. There is still substantial residual risk associated with uncertainties in production levels".

We can also explain these results from the perspective of the companies themselves. The owners of the companies require stable yearly dividends, such that monthly fluctuations matter less as the yearly results determine the dividend. Several companies also have a quarterly perspective on the hedging portfolio in their policies. For instance, hedging behavior (Section 3.4), the Nord Pool spot price (Lucia and Schwartz, 2002) and the levels of production all exhibit seasonal patterns. This contributes to monthly fluctuations in hedged cashflows, and presumably the variations will smooth out from a yearly perspective. The basis risk from the difference between system price and area price (Section 3.2) will also affect the ability of hedging policies to smooth out cashflows. For example, we identify substantial basis risk during Q3 2007, Q2 and Q3 2008, and September 2009 (Table 11 in Appendix A).

The analysis reveals that only one company, Company 1, of all the companies that focus on a reduction in volatility, achieves its objective. This result is surprising and brings attention to the matter of whether volatility reduction is possible alongside the other goals set in the companies' hedging policies.

4.3 Cashflow at Risk

Cashflow at Risk (C-FaR) was first introduced by Stein et al. (2001) and suggested as an alternative to the Value at Risk approach for assessing the risks of periodic cashflows for nonfinancial companies. In our study, the Group 2 companies employ the C-FaR approach with one of them explicitly stating that securing an acceptable income while preserving upside potential is the main purpose of their hedging practice. Company 7 and Company 10 also use this as motivation for their hedging activity. As discussed in Section 3.1, this corresponds to the proposition in Stulz (1996) that the fundamental goal of hedging is the elimination of the lowest earnings outcomes.

We apply C-FaR empirically. For each company, we measure the deviation of monthly cashflow from the average monthly cashflow. We regard the second most negative deviation as an empirical estimate of the 5.6 % ($^2/_{36}$) C-FaR (6.7 % ($^2/_{30}$) for Company 1 and Company 11.). Table 10 presents the results. All but Company 4 (Group 3) and Company 11 (Group 1) achieve a lower empirical C-FaR with hedging than without. The two companies using the C-FaR approach both manage to achieve a lower empirical C-FaR with hedging.

The companies achieve a reduced C-FaR on a much greater extent than any reduction in volatility. However, these two quantities overlap. While volatility reduction measures the overall income smoothing effect, C-FaR measures the smoothing of lower income levels. C-FaR is then expected to decrease with hedging because the payoffs from the short financial position and the income from physical production are negatively correlated. However, for a majority of the companies, the reduced C-FaR is accompanied by a reduction in the highest income levels, without necessarily significantly reducing the cashflow volatility. Company 3, by aiming to limit downside earnings while retaining the upside, manages to reduce the C-FaR but also reduces the highest income levels. Nevertheless, high stakeholder risk aversion implies that for these companies, the value reduction arising from extreme low outcomes is larger in magnitude in absolute terms than the value benefit arising from the possibility of positive extremes.

In total, the effects of the different strategies on the achieved reduction in cashflow and price volatility are ambiguous. In general, the companies using a C-FaR approach achieve both a significant reduction in price volatility and a reduced C-FaR, but for the other policy characteristic groups, there is no clear trend. For example, one of the two companies that do not have a written hedging strategy (Company 1) achieves a significant reduction in cashflow and price volatility (and C-FaR), while the other no-policy company (Company 11) achieves neither.

5 Conclusion

This paper takes a different approach from the bulk of the empirical risk management literature. We gather unique transaction data from 12 Norwegian electricity companies. The main benefit is precise data on company performance. This provides a solid basis for a fundamental understanding of the characteristics of risk management practices. We identify four specific groups characterized by attributes of their written hedging policies. The largest group, Group 4, applies hedge ratio boundaries defined in their policies and authorizes the use of their own market view in hedging decisions (selective hedging) inside these boundaries. This approach shows strong results for derivative cashflows, especially during periods of higher prices, when compared with the approaches that are more static.

We find extensive evidence of selective hedging practices across the sample, as embedded in many of the companies' written policies and justified by their market competencies and available risk capital. The majority of companies earn a substantial share of their total profit from hedging transactions though they do not manage to reduce cashflow volatility. In theory, we expect hedging to provide the opposite, with zero expected value and income smoothing. Enhanced appetite for risk among the companies and periods of high basis risk are possible explanations for the poor results for reduced volatility. The results indicate that the companies utilize hedging to maximize profit rather than to increase predictability in cashflows. Companies with written hedging policies (10 of the 12 companies sampled) make a clear distinction between hedging and speculation. Nevertheless, hedging in electricity companies appears to embody speculative elements.

Both the theoretical literature and the companies agree that a desired result from hedging is elimination of the extreme lower outcomes of the earnings function. We find support for this practice both in the written hedging policies and by analyzing C-FaR. The results indicate that nearly all of the companies manage to decrease their empirical C-FaR through hedging transactions. Furthermore, compared with the reduction in volatility, C-FaR is widespread among these companies. The two quantities overlap, but because of risk aversion among the companies' stakeholders, we believe that C-FaR is a more appropriate metric as it accounts for the reduction in downside risk.

We also find that eight of the 12 companies have different hedge ratios depending on whether they are hedging summer or winter production. However, the pattern is somewhat ambiguous in that five companies hedge more in winter, and three companies hedge more in summer. Moreover, with a single exception, this seasonal hedging behavior does not appear to have sanction in their written policies. We instead find that the practice is the result of each company's own market expectations and attribute it to selective hedging.

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Appendix A Institutional and Market Characteristics

For the purpose of this paper there are two markets of interest: the physical spot market and the financial market. The physical spot market offers trade for day-ahead physical delivery and prices are determined by daily implicit auctions. The financial market requires no physical delivery and all the derivatives traded are cash settled. NASDAQ OMX Commodities offers four derivatives which use the system price of electricity as underlying price: Futures and Forwards (Swaps), Options and Contracts for Difference.

The Nordic electricity market is divided into several price areas. Within a price area the spot price is uniform, but it differs between areas. This difference is due to congestions and different production capacity between the areas. During the auction at Nord Pool Spot both a system spot price and spot prices for each price area is decided. Producers and consumers must relate to the price of the area they reside in while the system price serves as their underlying price for the financial market. Table 11 reveals that there are periods where the system price deviate substantially from the area prices. This translates into increased basis risk in the financial market at NASDAQ OMX Commodities. The system spot price, as well as its linear trend line and the average monthly spot price (underlying for month swaps) during the analyzed period are plotted in Figure 3.

The derivatives traded on the financial market are either base or peak load contracts. Base load contracts use the system price for all hours Monday through Sunday, while peak load contracts use the system price for Monday through Friday (including national holidays) covering the period 08.00 to 20.00.

A.1 Swaps (Futures and Forwards)

Futures are traded as day and week contracts. Day futures can be traded up to one week prior to maturity, and week futures are listed with six consecutive contracts. These are all base load contracts. In addition futures for peak load are offered. The peak load futures are listed with 5 consecutive week contracts. The settlement of futures consists of both marked-to-market settlement prior to maturity and the final spot reference cash settlement after maturity. The marked-to-market settlement prior to maturity is the change in the market value of the contract (trading profit). Then the final settlement covers the difference between the final closing price of the future and the system price in the delivery period (settlement profit).

Forwards are traded as month, quarter and year contracts. For base load forwards there are six consecutive month contracts, nine consecutive quarter contracts and five consecutive year contracts. For peak load contracts there are month contracts two months ahead, quarter contracts three quarters ahead and year contracts one year ahead. In contrast to futures, the marked-to-market is only accumulated prior to maturity, but not realized until maturity. The settlement after maturity is, as for futures, covering the difference between the forward contract price at time of deal and the system price in the delivery period.

A.2 Contracts for Difference

Due to constraints on transmission capacity within the Nordic grid the price in a specific area can deviate from the system price. This difference in price is a basis risk for market participants and can be hedged by Contracts for Difference (CfD). By combining futures or forwards with CfDs, perfect hedging is possible independent of where the market participant is connected to the grid. The settlement of the CfD is based on the difference between the specific area price and the system price. The market price of a CfD reflects the market's prediction of the price difference during the delivery period.

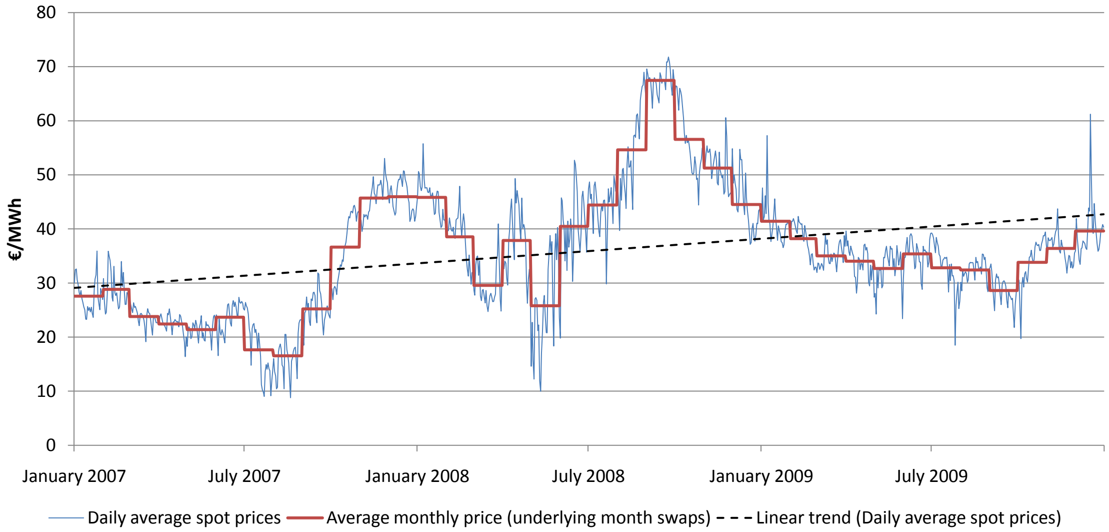


Figure 3: Plot of daily average spot prices, the linear spot price trend and the average monthly spot price over the period analyzed. The latter is the underlying price for month swaps. Year and quarter swaps are cascaded into month swaps and can therefore have the same underlying price. Week and day swaps have average weekly and daily spot price as underlying price. The plot shows a slight positive spot price trend during the analyzing period.

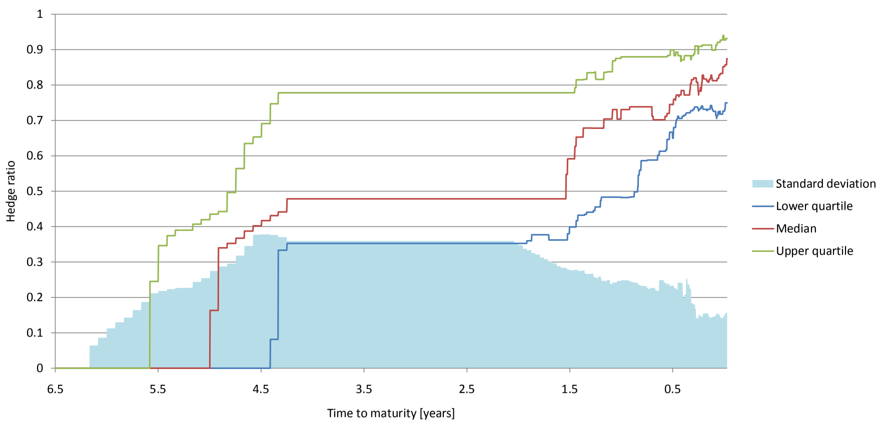
A.3 Option Contracts

All option contracts traded on NASDAQ OMX Commodities are European options. The underlying asset of the options is not the spot price, but the quarter and year forward contracts. The date of exercise for an option is the third Thursday in the month before delivery of the underlying contract.

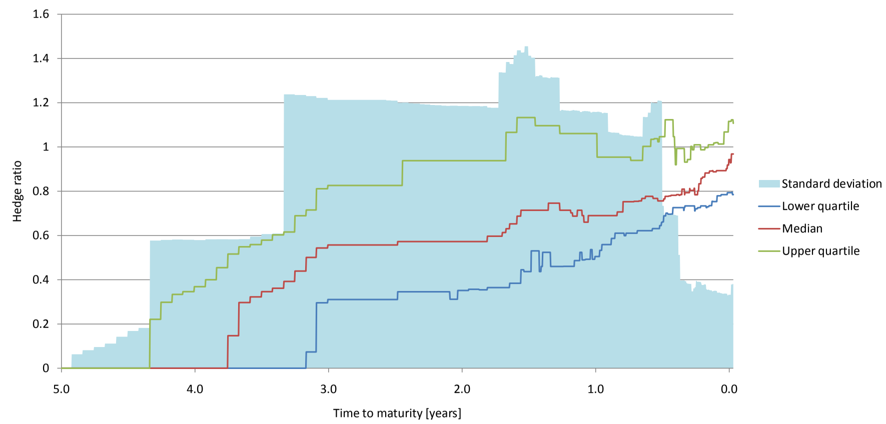
Table 11: Mean percentage deviation between the Nord Pool Spot system price and the respective area prices. The values reveal that there were two-digit percentage difference between the system price and area prices during Q3 2007, Q2 and Q3 2008, and September 2009. This price difference is caused by downtime in transmission capacity between price areas.

	Mean percentage deviation system price and area price		
	Area 1	Area 2	Area 3
January 2007	0 %	−1 %	−1 %
February 2007	3 %	−4 %	−4 %
March 2007	0 %	0 %	0 %
April 2007	0 %	0 %	0 %
May 2007	2 %	−2 %	−2 %
June 2007	7 %	−8 %	−8 %
July 2007	34 %	−35 %	−35 %
August 2007	68 %	−56 %	−55 %
September 2007	27 %	−8 %	−9 %
October 2007	4 %	−4 %	−2 %
November 2007	−1 %	0 %	0 %
December 2007	−2 %	0 %	2 %
January 2008	1 %	−1 %	0 %
February 2008	4 %	−6 %	−1 %
March 2008	9 %	−10 %	−6 %
April 2008	27 %	−19 %	−19 %
May 2008	48 %	−52 %	−86 %
June 2008	38 %	−42 %	−38 %
July 2008	15 %	−29 %	−23 %
August 2008	11 %	−18 %	−6 %
September 2008	5 %	−10 %	−2 %
October 2008	5 %	−8 %	−4 %
November 2008	4 %	−4 %	−3 %
December 2008	4 %	−1 %	−1 %
January 2009	1 %	0 %	0 %
February 2009	0 %	−1 %	−1 %
March 2009	1 %	−1 %	−1 %
April 2009	2 %	−4 %	−4 %
May 2009	2 %	−4 %	−4 %
June 2009	0 %	−2 %	−1 %
July 2009	1 %	0 %	−3 %
August 2009	8 %	2 %	2 %
September 2009	20 %	14 %	14 %
October 2009	5 %	5 %	6 %
November 2009	2 %	−1 %	−1 %
December 2009	4 %	−16 %	−16 %

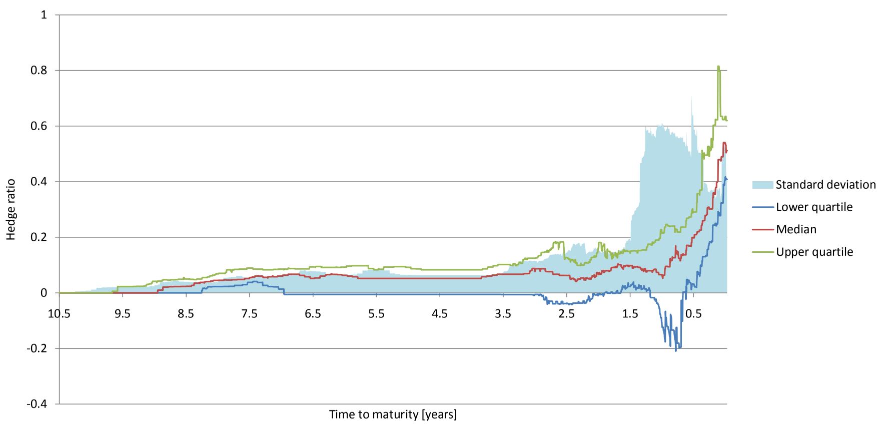
Appendix B Hedge Ratio Plots



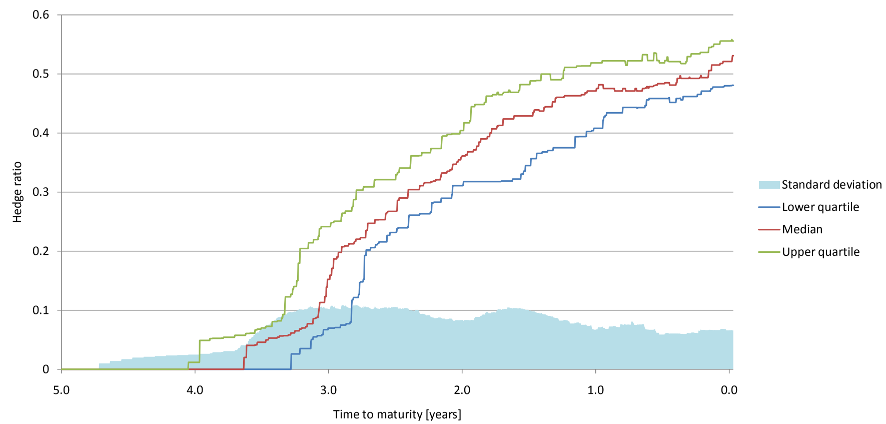
(a) Company 1 (group 1)



(b) Company 11 (group 1)

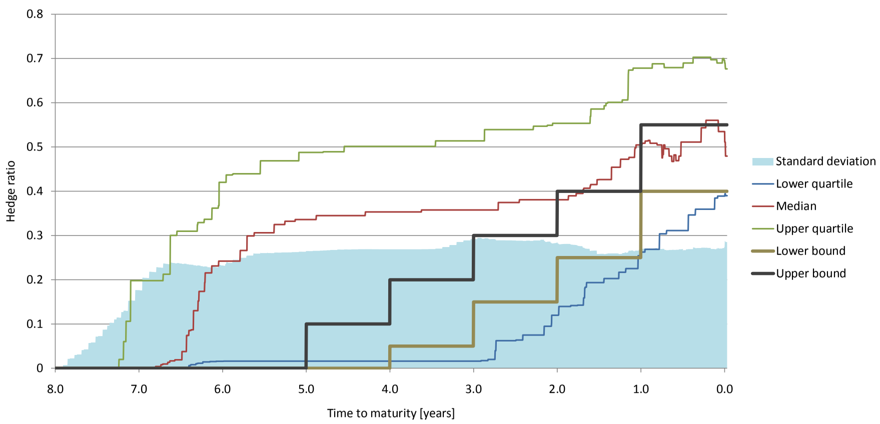


(c) Company 3 (group 2)

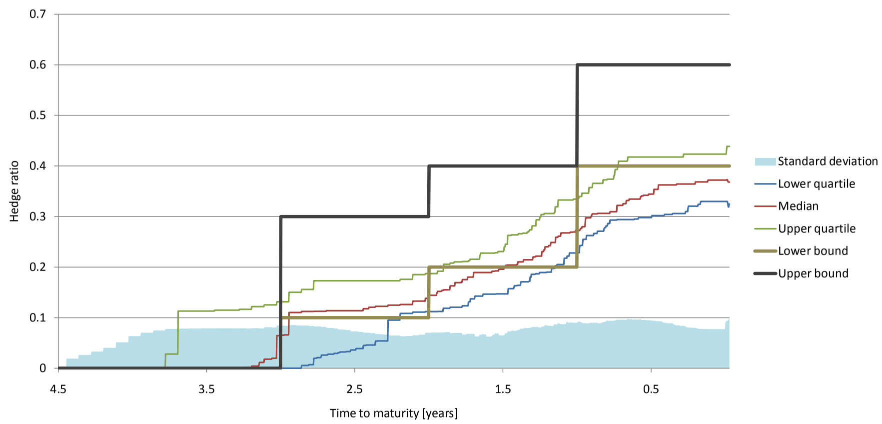


(d) Company 12 (group 2)

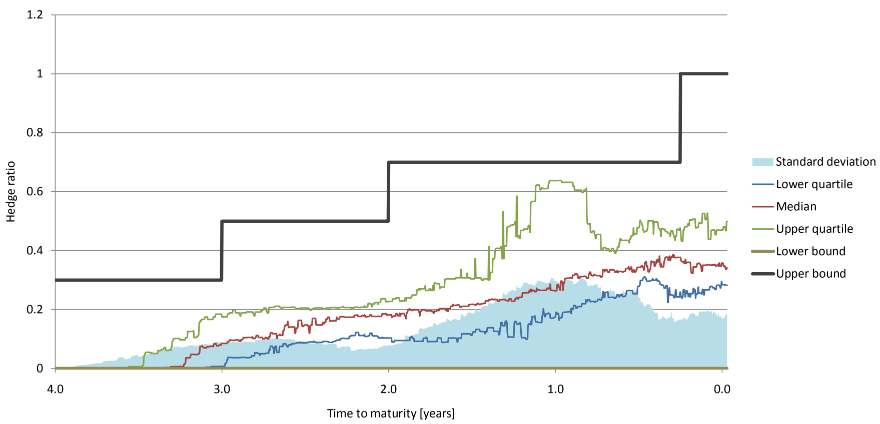
Figure 4: These figures plots expression (3) aggregated along the time series dimension. The vertical axis—hedge ratio—is the fraction of (forecasted) production that is hedged. The horizontal axis—time to maturity—is the residual time [years] before the delivery period starts. Since the plot is aggregated—36 (30 for Company 1 and Company 11) monthly plots—the horizontal axis is relative to the maturity, not the absolute timeline. The three lines are respectively the lower quartile (25% quantile), median (50% quantile) and upper quartile (75% quantile) of the monthly plots while the area is the standard deviation between the monthly plots. The purpose of the quantiles is to give a general illustration of the hedging positions of each company during the period analyzed while the standard deviation illustrates the consistency of the hedging practice. The rapid fluctuations in the plots are due to the frequency of initiated transactions and—for some companies—updates of the simulated future production. Upper and lower bounds for the hedge ratio range are also provided for companies in group 3 and 4. These boundaries are given in the companies' hedging policies.



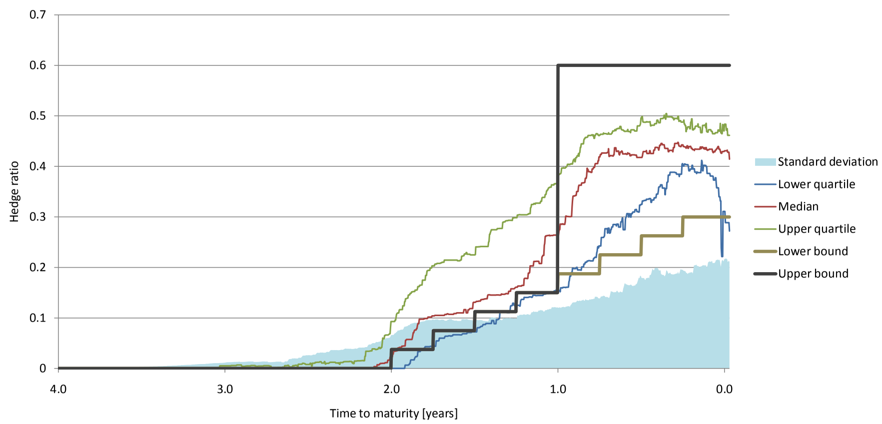
(e) Company 4 (group 3)



(f) Company 2 (group 4)

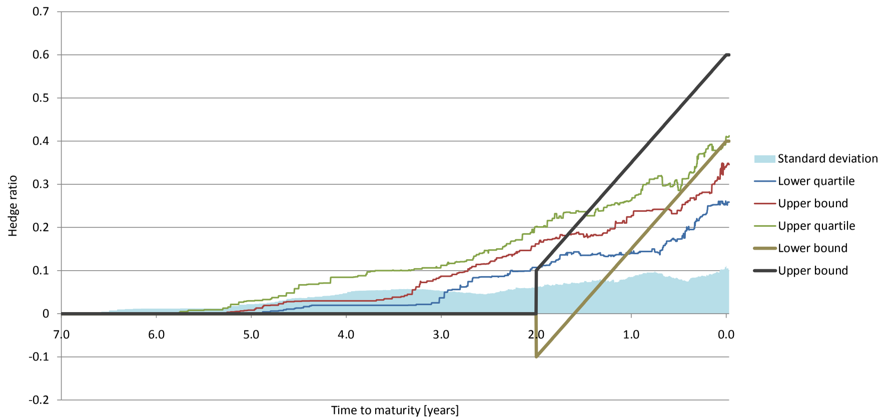


(g) Company 5 (group 4)

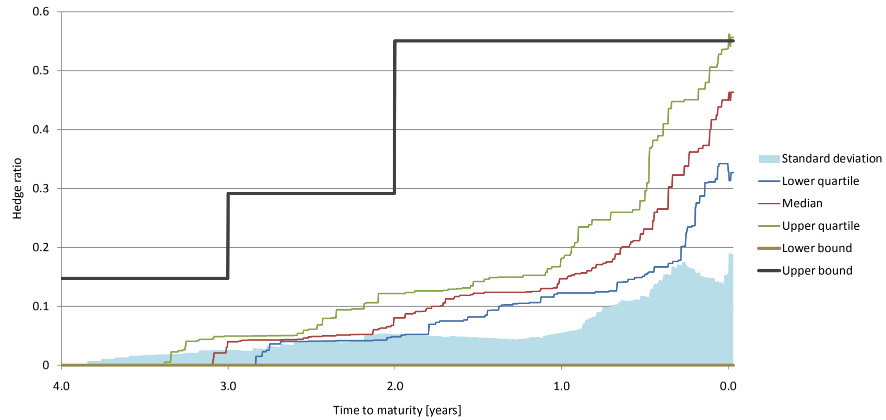


(h) Company 6 (group 4)

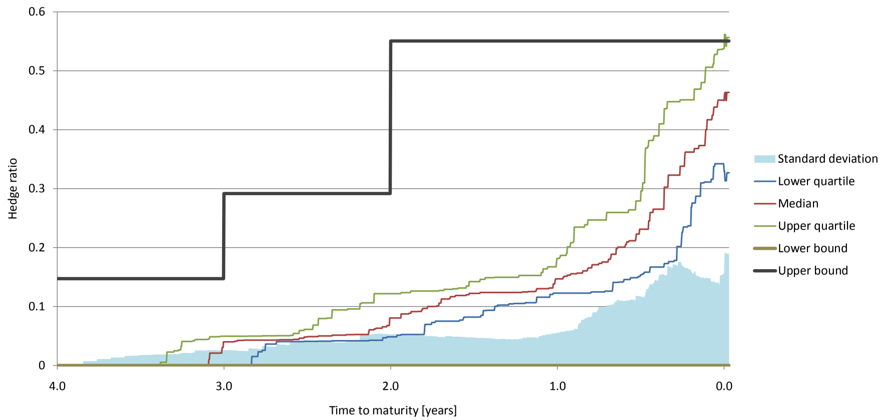
Figure 4: These figures plots expression (3) aggregated along the time series dimension. The vertical axis—hedge ratio—is the fraction of (forecasted) production that is hedged. The horizontal axis—time to maturity—is the residual time [years] before the delivery period starts. Since the plot is aggregated—36 (30 for Company 1 and Company 11) monthly plots—the horizontal axis is relative to the maturity, not the absolute timeline. The three lines are respectively the lower quartile (25% quantile), median (50% quantile) and upper quartile (75% quantile) of the monthly plots while the area is the standard deviation between the monthly plots. The purpose of the quantiles is to give a general illustration of the hedging positions of each company during the period analyzed while the standard deviation illustrates the consistency of the hedging practice. The rapid fluctuations in the plots are due to the frequency of initiated transactions and—for some companies—updates of the simulated future production. Upper and lower bounds for the hedge ratio range are also provided for companies in group 3 and 4. These boundaries are given in the companies' hedging policies.



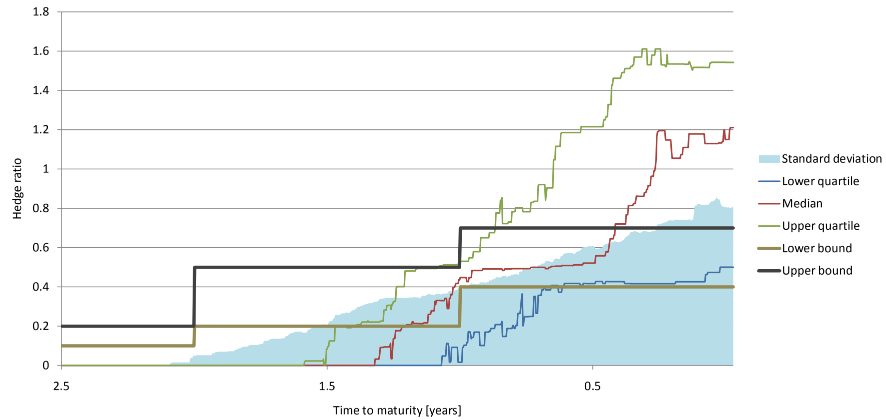
(i) Company 7 (group 4)



(j) Company 8 (group 4)



(k) Company 9 (group 4)



(l) Company 10 (group 4)

Figure 4: These figures plots expression (3) aggregated along the time series dimension. The vertical axis—hedge ratio—is the fraction of (forecasted) production that is hedged. The horizontal axis—time to maturity—is the residual time [years] before the delivery period starts. Since the plot is aggregated—36 (30 for Company 1 and Company 11) monthly plots—the horizontal axis is relative to the maturity, not the absolute timeline. The three lines are respectively the lower quartile (25% quantile), median (50% quantile) and upper quartile (75% quantile) of the monthly plots while the area is the standard deviation between the monthly plots. The purpose of the quantiles is to give a general illustration of the hedging positions of each company during the period analyzed while the standard deviation illustrates the consistency of the hedging practice. The rapid fluctuations in the plots are due to the frequency of initiated transactions and—for some companies—updates of the simulated future production. Upper and lower bounds for the hedge ratio range are also provided for companies in group 3 and 4. These boundaries are given in the companies' hedging policies.